National Aeronautics and Space Administration

Disruption Tolerant Networking (DTN)

An Architecture for Challenged Communications

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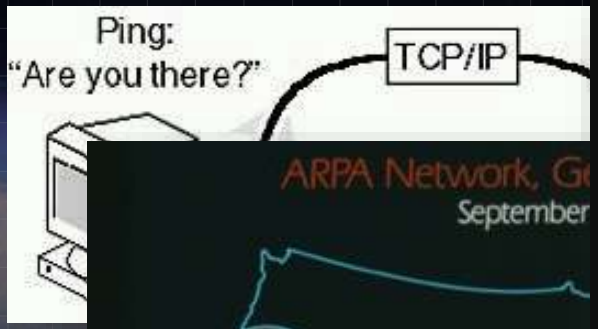
Topics for Discussion:

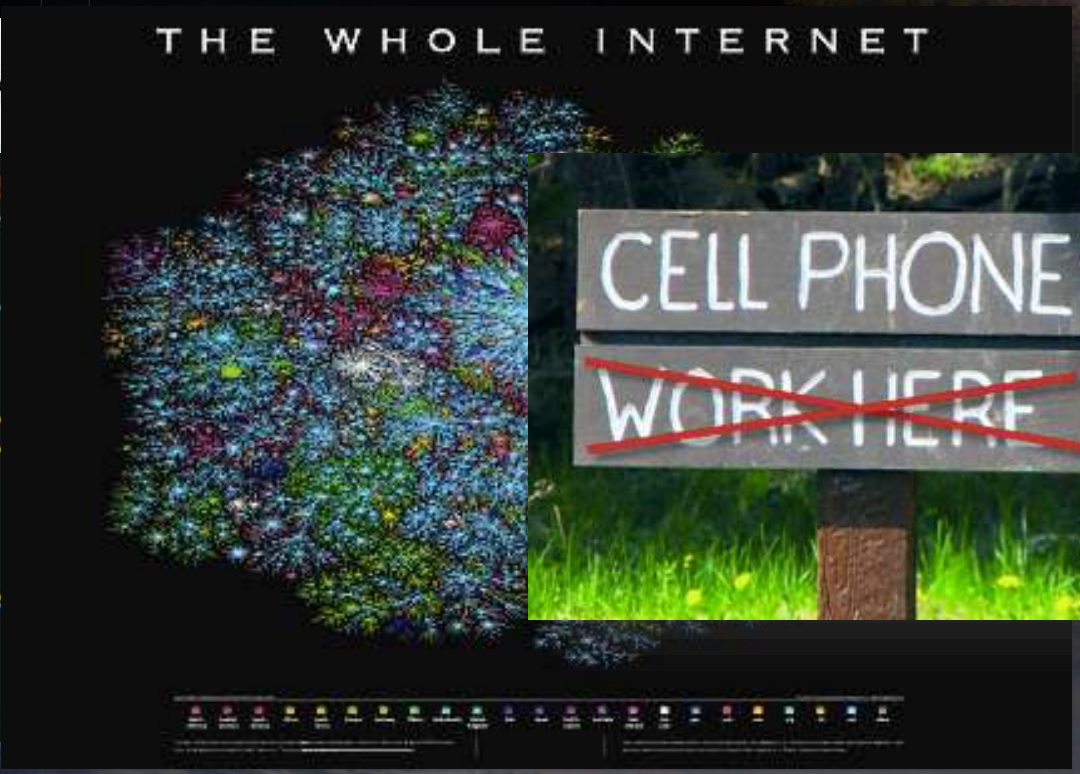
- Motivation
- Technical and Concept Overview (DTN 101)
- Research Areas of Interest
- Planting Seeds…
- Open Discussion

Motivation for Disruption Tolerant Networking

Or, how to ~~succeed~~ in networking without really trying…

1. Invent networked communications…
2. Build a closed research network built on networked communications…
3. Build a world that depends on networked communications…
4. Realize the networked communications you built don't always work...





Five Key Assumptions of the Internet Protocol

1. ***Networks are Richly Connected***

   IP Networks assume that there are many link paths between routers and that those links are consistent with high availability.

   – "If I can reach you, you can reach me" *(reachability is symmetric)*

   – "If I can reach you, and you can reach her, I can reach her." *(reachability is transitive)*

2. ***Networks have Short Delay***

   IP networks assume that the time to propagate a packet across an IP network is small – on the order of ms to second

3. ***Data Links are Symmetric and Bidirectional***

   IP networks assume that forward and return bandwidths are approximately the same and that forward and return connections will only exist in pairs.

4. ***Links have Low Error Rates***

   The likelihood of a packet not making it from end to end due to errors in transmission is fairly low (typically << 1e-8)

5. ***Network Nodes are Trustworthy***

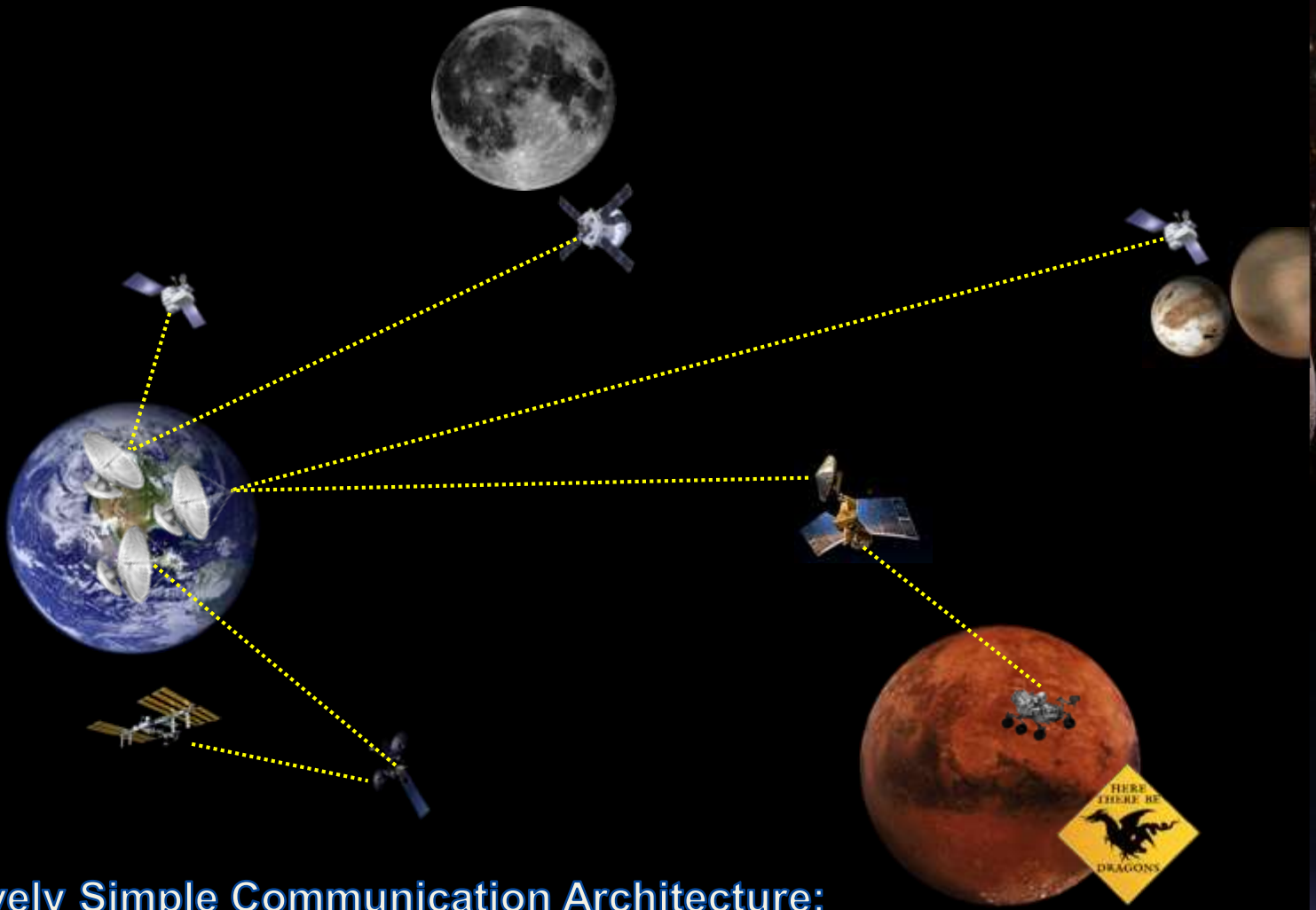
   IP assumes that if a node (router or computer/device) is ON the network it is trustworthy. Additional protocols (eg. IPSEC) provide security enhancements, but core protocols assume a trusted environment.

A More Capable Architecture – Disruption Tolerant Networking

DTN is… an internetworking protocol suite suitable for disrupted, mobile, airborne, near-Earth and deep-space communications:

- An internetworking layer that functions efficiently in environments with time-disjoint and/or simplex links
- A reliable data link layer that improves efficiency of end-to-end delivery by leveraging local link information and tighter local control loops
- Disruption Tolerant Routing services that can take advantage of scheduled and expected future connectivity in addition to current connectivity and that can interoperate with or without a terrestrial routing infrastructure
- Quality of Service mechanisms to provide user control over the order in which traffic is served by the overlay internetworking layer and is independent of the underlying network segments
- Security features that protect the infrastructure from unauthorized traffic and provide standard end-to-end security capabilities (e.g. integrity, confidentiality) and 'over-the-air' key management
- A network management system to configure, monitor, and provide accounting for traffic passing through the system
- International standards (IETF & CCSDS)

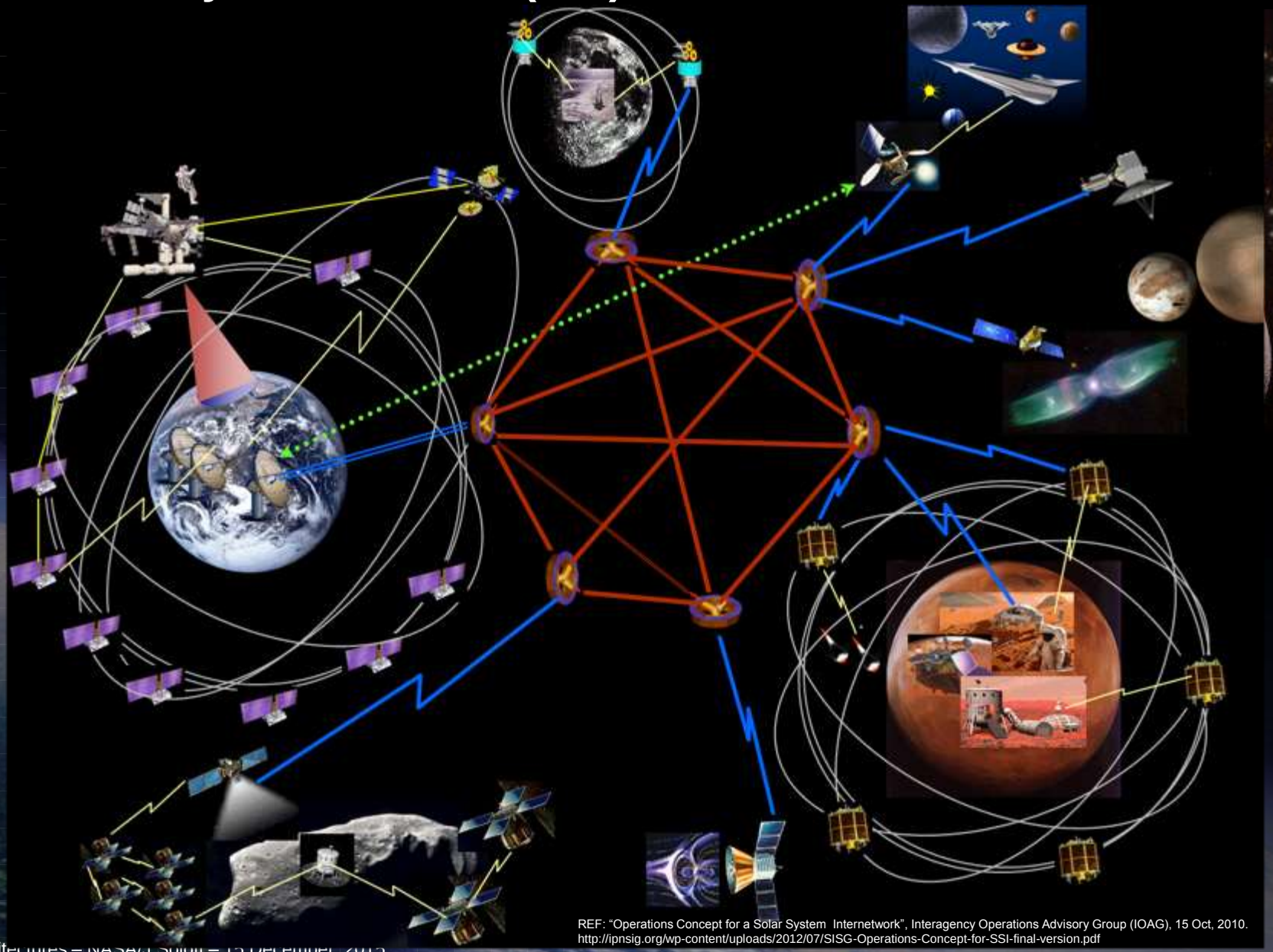
Why NASA?
Current NASA Communication Links



Relatively Simple Communication Architecture:

- Point-to-Point
- Single-hop Relay
- Well served by “traditional” wireless comms

Why NASA?
The Solar System Internet (SSI)



REF: "Operations Concept for a Solar System Internetwork", Interagency Operations Advisory Group (IOAG), 15 Oct, 2010.
http://ipnsig.org/wp-content/uploads/2012/07/SISG-Operations-Concept-for-SSI-final-version.pdf

Delays in Perspective

- Distance to ISS (through TDRS): ~71322 km
  - On-Way Light Time (OWLT) Delay: 0.24 s
- Distance to the Moon: ~384400 km
  - OWLT Delay: 1.28 s
- Minimum Distance to Mars: ~54.6 Million km
  - OWLT Delay: 182.13 sec or 3.04 min
- Average Distance to Mars: ~225 Million km
  - OWLT Delay: 750.52 sec or 12.51 min
- Farthest Distance to Mars: ~401 Million km
  - OWLT Delay: 1337.59 sec or 22.29 min

Notes:

- TCP requires a three-way handshake to establish a connection that consumes 1.5 round-trip times and has a 2 minute timeout.
- TCP also assumes continuous end-to-end connectivity.

Overview of DTN

- Disruption Tolerant Networking (DTN) is a protocol suite that extends the terrestrial Internet capabilities into highly stressed data communication environments where the conventional Internet does not work well.
- These environments are typically subject to frequent disruptions, unidirectional links, possibly long delays and high error rates.
- The DTN protocol suite can run over the existing Internet Protocol (IP) suite or it can operate by itself as a full Internetworking protocol.
- DTN provides assured delivery of data using an automatic store-and-forward mechanism, while IP generally does not.

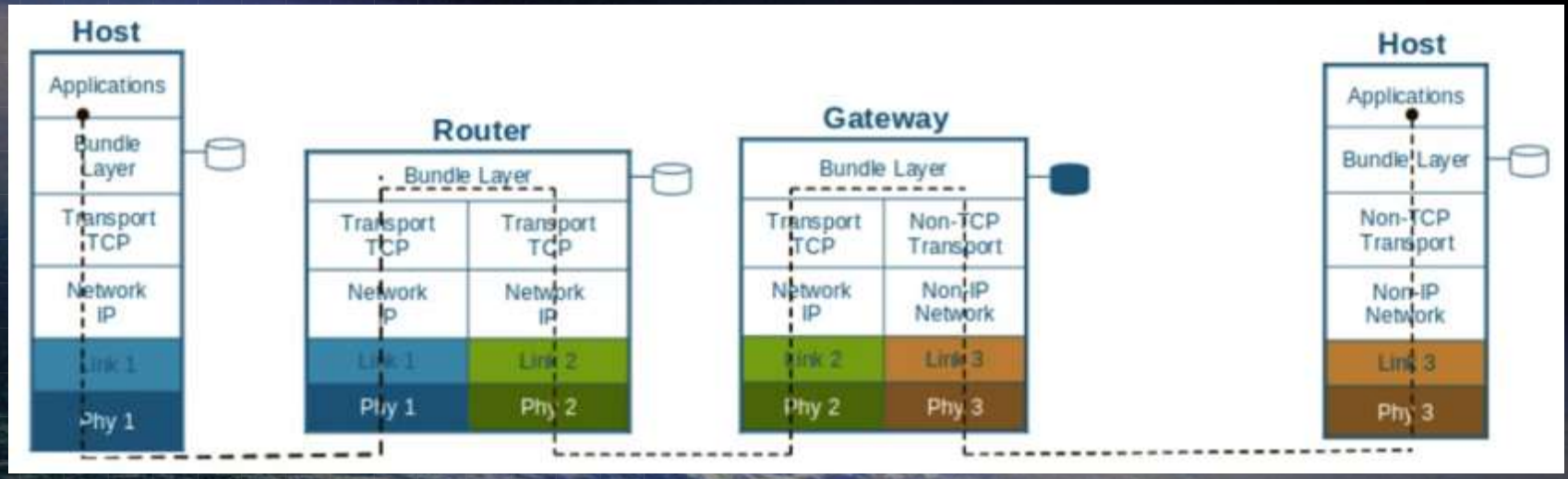


Figure from "Opportunistic Networking: Extending Internet Communication Through Spontaneous Networks", W.Moreira, IEEE Latincom 2011, Oct 26, 2011.

Traditional Internet Transfers vs. DTN Transfers

In the Internet:

- Each received packet is forwarded immediately if possible, deleted if immediate forwarding is not possible.
- Next-hop destination is computed based on known current network topology.

In DTN:

- Each received packet is forwarded immediately if possible, stored for future transmission if forwarding is not currently possible but is expected to be possible in the future.
- Next-hop destination is computed based on expectations of future network topology.

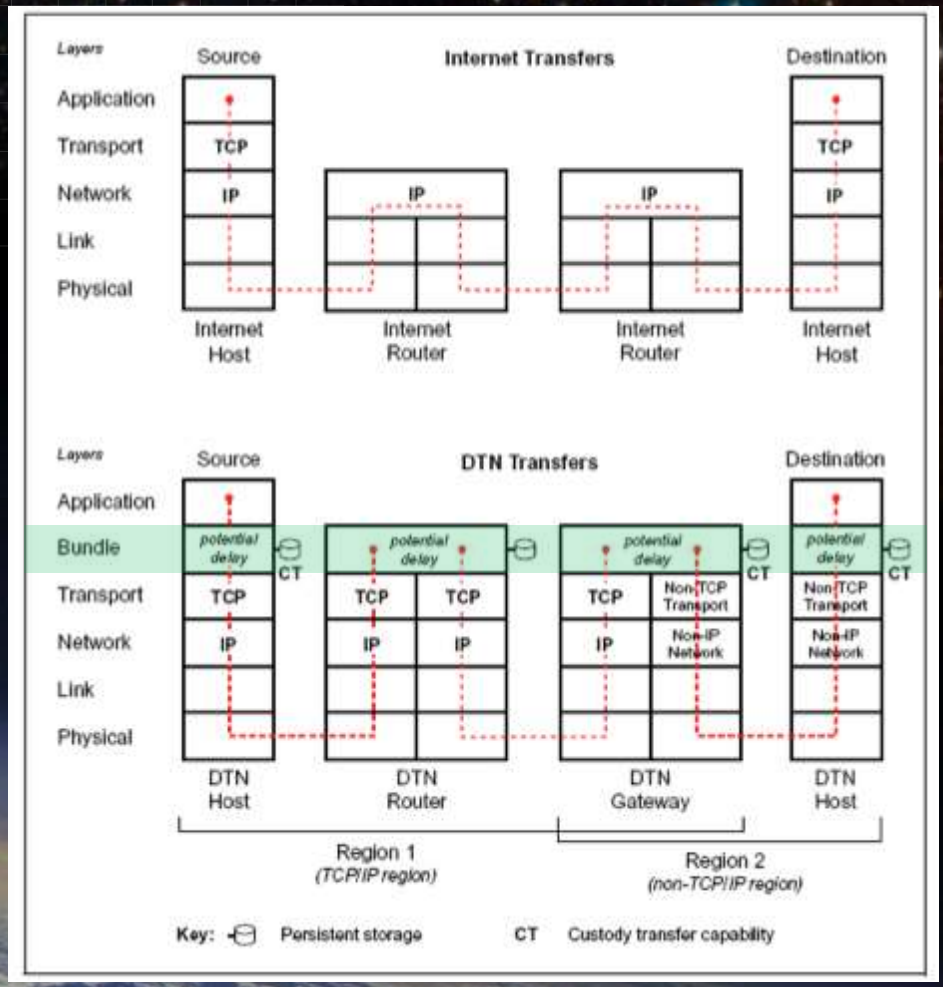
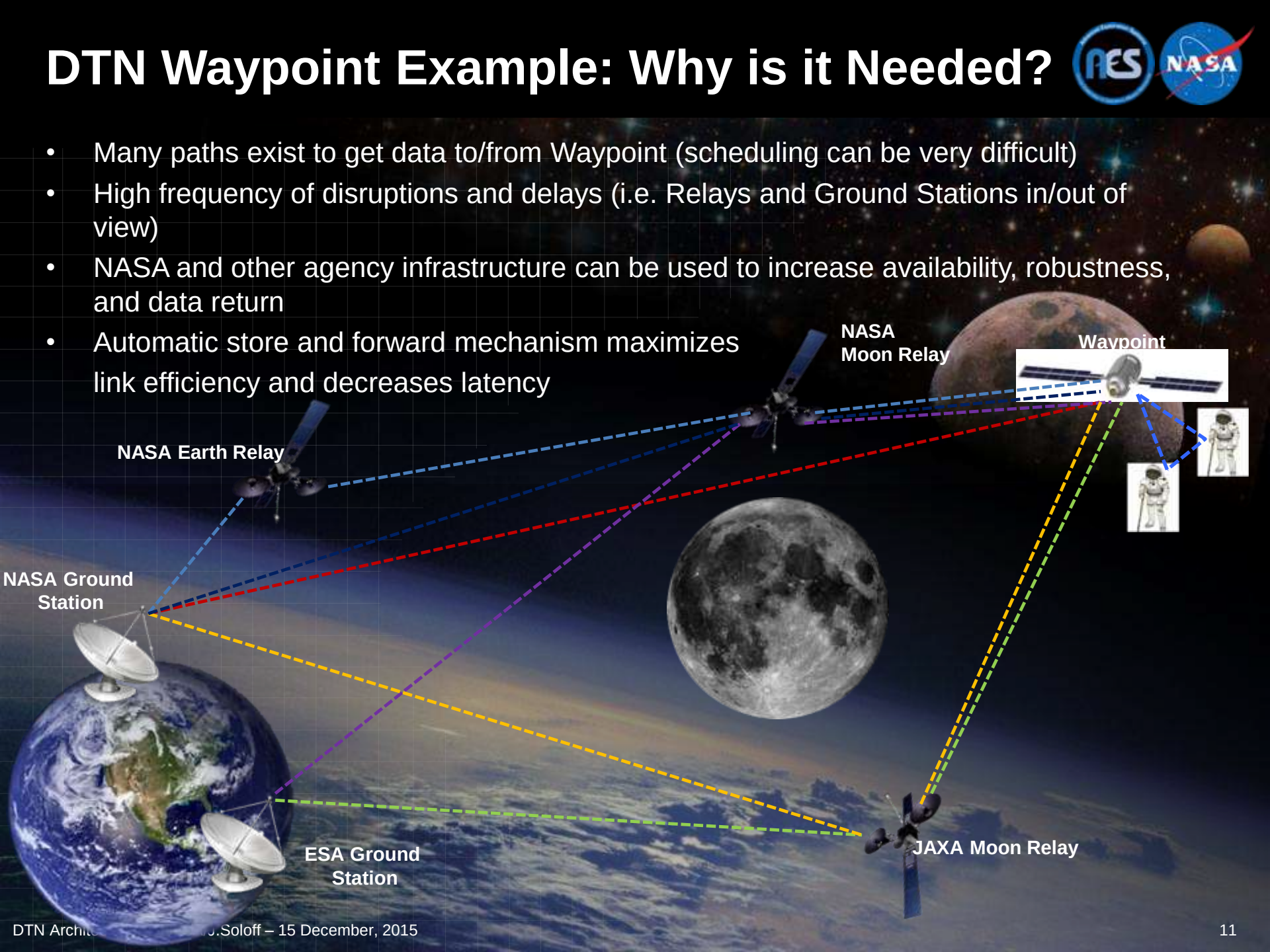


Figure taken from "Delay and Disruption Tolerant Networks: A Primer", F. Warthman
http://ipnsig.org/wp-content/uploads/2012/07/DTN_Primer_v1.02.pdf

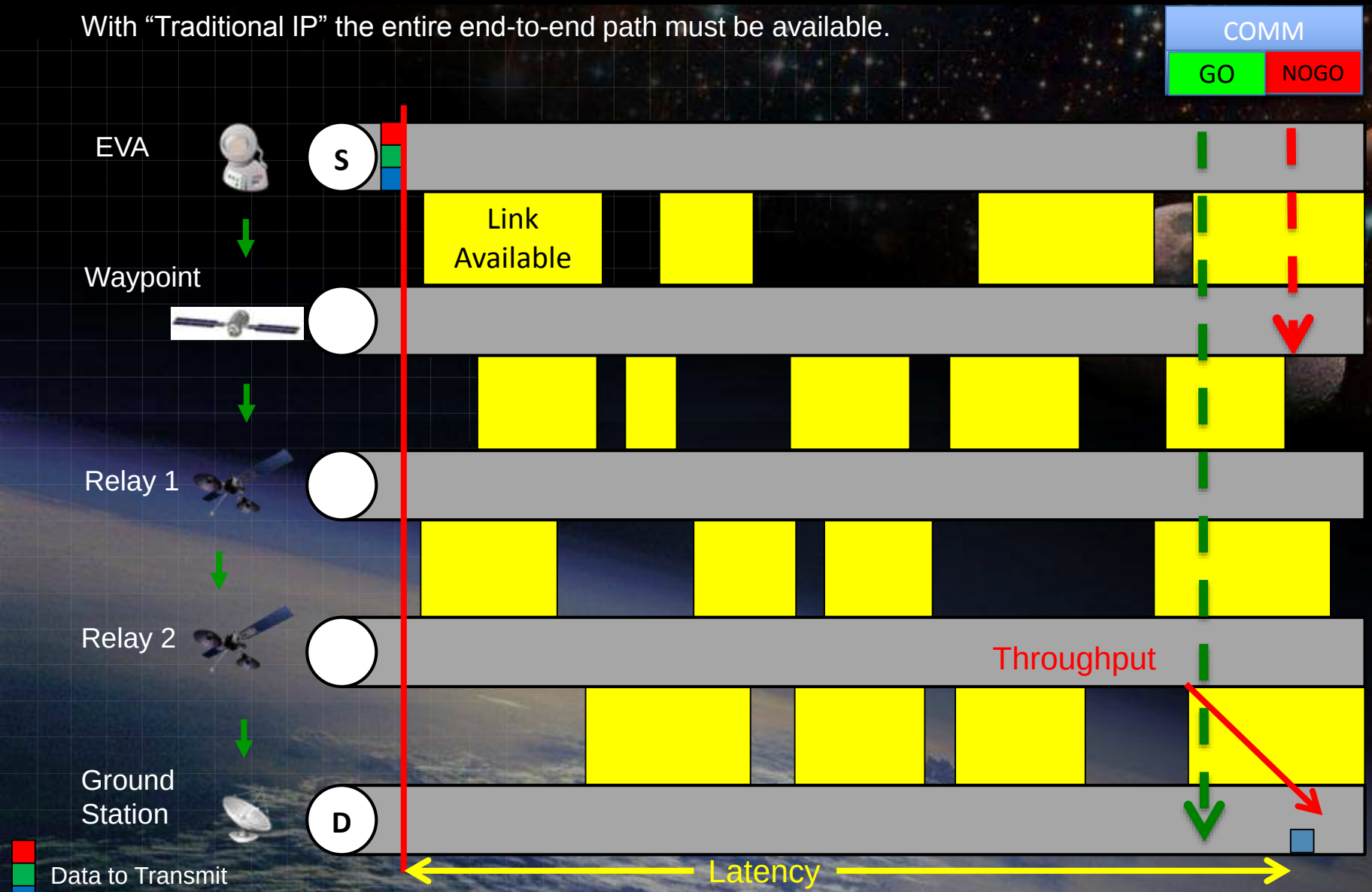
DTN Waypoint Example: Why is it Needed?

- Many paths exist to get data to/from Waypoint (scheduling can be very difficult)
- High frequency of disruptions and delays (i.e. Relays and Ground Stations in/out of view)
- NASA and other agency infrastructure can be used to increase availability, robustness, and data return
- Automatic store and forward mechanism maximizes link efficiency and decreases latency



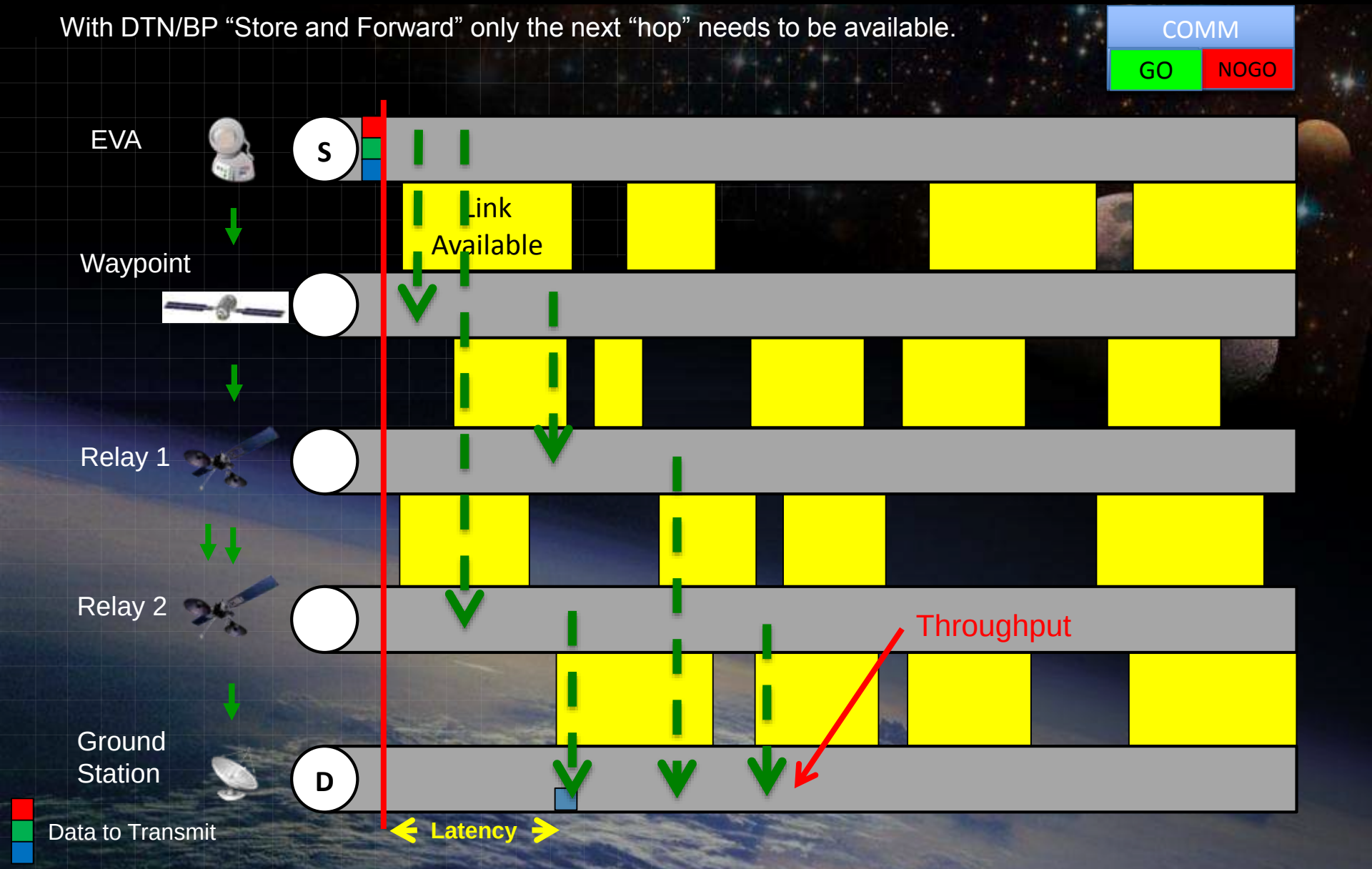
Sample Waypoint Scenario Using Traditional IP

With “Traditional IP” the entire end-to-end path must be available.



Sample Waypoint Scenario Using DTN

With DTN/BP “Store and Forward” only the next “hop” needs to be available.



One Architecture, Many Missions

Orbiting SATCOM

UAV

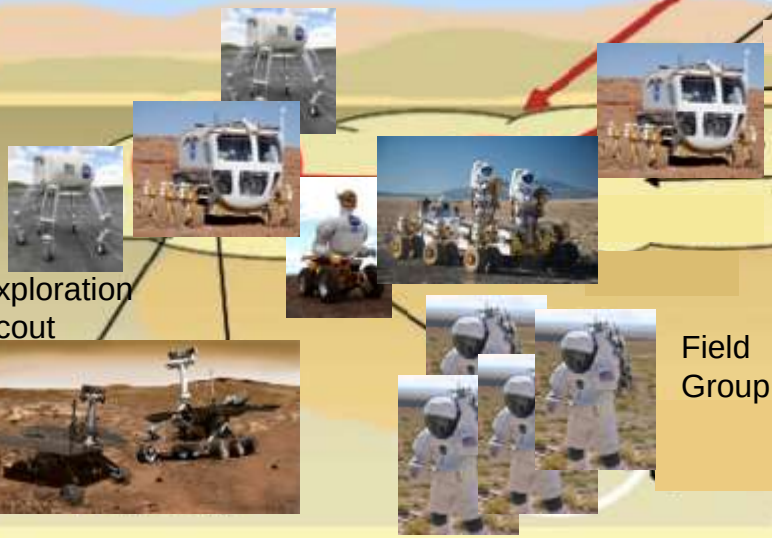
Deployed Exploration Site

UHF

Rover

Beyond Line of Sight

Remote Base



Exploration Scout

Field Group

Image from “Disruption Tolerant Networking for CONDOR” by R.Durst, et. al
https://www.ietf.org/proceedings/65/slides/DTNRG-2.pdf

Scenarios Enabled

- Space Exploration
- Military unit mobility
- First Responder / Crisis Response
- Harsh Environment Robotics / Industry
- Highly Mobile Civilian Applications

Benefits of DTN

- **Improved Operations and Situational Awareness:** The DTN store-and-forward mechanism along with automatic retransmission provides more insight into events during communication outages and significantly reduces the need for ground-based scheduling.
- **Interoperability and Reuse:** A standardized DTN protocol suite enables interoperability of multi-agency communication assets and also allows NASA to use the same communication stack for future missions (LEO, NEO or Deep Space).
- **Space Link Efficiency, Utilization and Robustness:** DTN enables more reliable and efficient data transmissions resulting in more usable bandwidth. DTN also improves link reliability by having multiple network paths and assets for potential communication hops.
- **Security:** The DTN Bundle Security Protocol (BSP) allows for integrity checks, authentication and encryption, even on links where not previously used.
- **Quality of Service:** The DTN protocol suite allows for many priority levels to be set for different data types, ensuring that the most important data is received ahead of less important data.

Additional DTN Services (1/2)

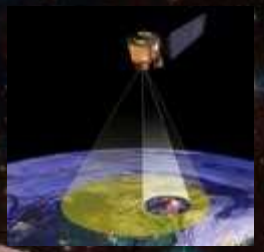
- Bundle Streaming Service (BSS)
  - A framework that supports the delivery of streaming data in DTN bundles, by placing priority on “real-time” data and backfilling any stored data when link bandwidth permits.
- Aggregate Custody Signals (ACS)
  - Makes more efficient use of narrow command path by compressing many custody signals into one.
- Compressed Bundle Header Encoding (CBHE)
  - A convention by which BP convergence-layer adapters may represent endpoint identifiers in a compressed form within the primary blocks of bundles.
- Delay-Tolerant Payload Conditioning (DTPC)
  - A DTN service that guarantees in-order delivery and suppression of duplicate data.

Additional DTN Services (2/2)

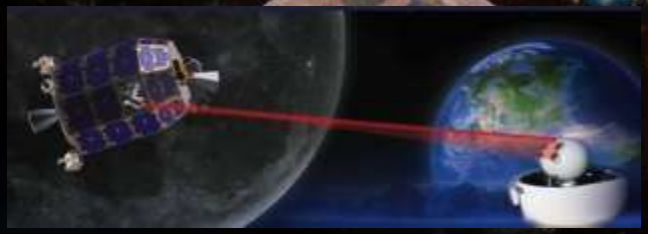
- Delay-Tolerant Key Authority (DTKA)
  - A key exchange framework that is based on distributed KA nodes that provide bulletin services to DTN clients
- DTN IP Neighbor Discovery (IPND)
  - IPND is a method for otherwise oblivious nodes to learn of the existence, availability, and addresses of other DTN participants
    - IPND sends and listens for small IP UDP announcement beacons that are addressed to an IP unicast, multicast, or broadcast address to discover specified remote neighbors, or unspecified local neighbors in the network topology
- Asynchronous Management Protocol (AMP)
  - AMP provides monitoring and configuration services between managing devices (Managers) and managed devices (Agents), some of which may operate on the far side of high-delay or high-disruption links.
- Streamlined Bundle Security Protocol (SBSP)
  - SBSP is an improved security specification to the previous RFC 6257 (BSP) that decouples routing/security functions, minimizes the number of security blocks and operations, adds common block processing and order, and simplifies rules for fragmentation.

Major Agency DTN Progress to Date (1/2)

- Conducted real flight tests of the basic core DTN protocols in Deep Space on the Deep-Impact probe carrier spacecraft (EPOXI) and in Low Earth Orbit on the Earth Observing One (EO-1) mission.



- Tested DTN across optical links as part of the Lunar Laser Communication Demonstration (LLCD) on the Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft.



- Installed two payload nodes (Commercial Generic Bioprocessing Apparatus (CGBA)) on the ISS that have been continuously returning operational science data using DTN, with greatly improved performance over the prior system.

- Began widespread deployment of DTN across various other ISS experimental systems, including gateways on ISS and in MCC to support the Synchronize Position, Hold, Engage, Reorient, Experimental Satellites (SPHERES) Smartphone experiments, and started examining DTN's application to ISS core systems.

Major Agency DTN Progress to Date (2/2)

- Initiated DTN flight experiments on the ISS with two of NASA's major international partners, the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA).

- Established a DTN Engineering Network (DEN) of computers across the NASA Centers and supporting Universities to support DTN protocol development and long-term operational network stress testing.

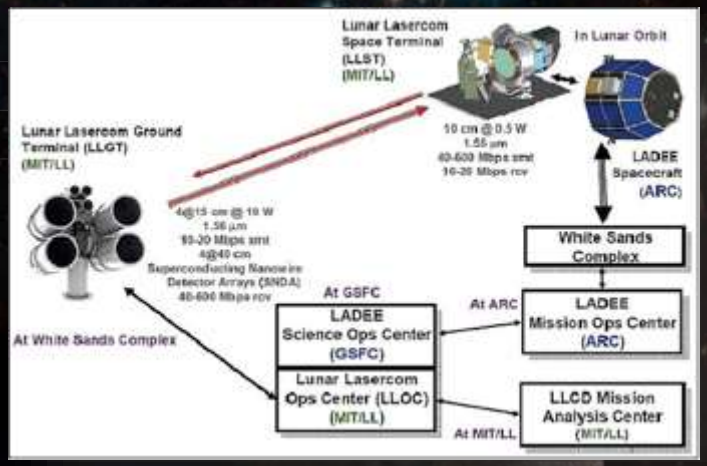
- Tested DTN running over IP via the commercial (Cisco) Internet Router In Space (IRIS).

- Launched the core DTN protocols into the international standardization process through the CCSDS and the IETF.

The Consultative Committee for Space Data Systems

Lunar Lasercom Communication Demonstration

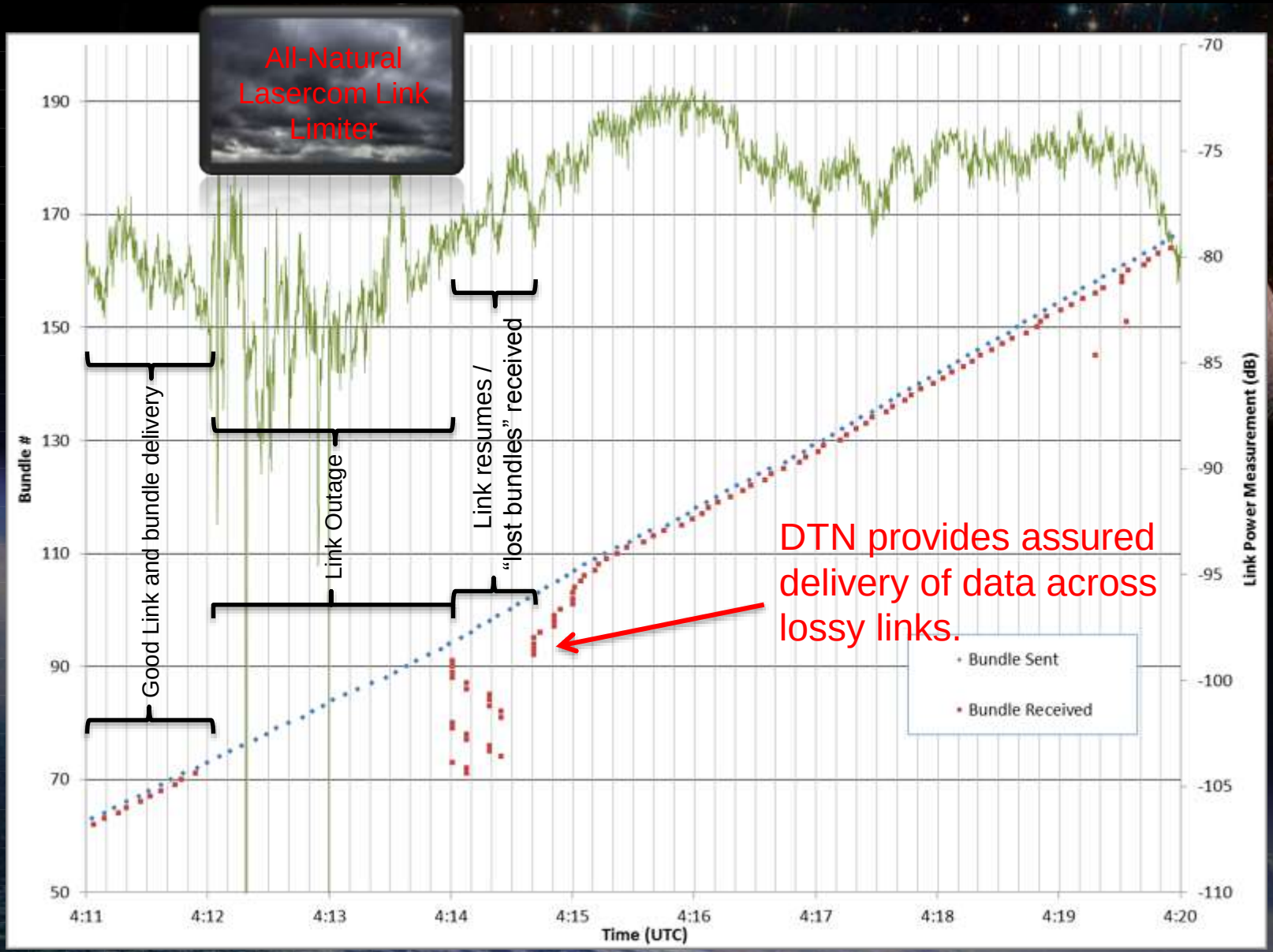
- A DTN demonstration was performed across the LLCD optical links in November 2013
  - Lunar Relay scenario with BP/LTP over optical links
  - Included CFDP over BP file transfers and other multi-hop bundle flows
  - DTN was not onboard the spacecraft itself
  - DTN traffic was limited to 1 – 3 Mbps due to terrestrial bottlenecks and other LLCD requirements
- Successfully demonstrated DTN protocols providing complete automated multi-hop data transfers with a real optical link segment subjected to both scheduled (passes) and random (clouds) link disruptions
- Provided experience and better understanding of requirements for future relay payload, ground station, and network control center systems



Success of LLCD DTN Demo validated the need for DTN capabilities to support LaserCom systems. **This result caused NASA's Space Communications & Navigation Division to determine that DTN is essential to optical communications.**

What did they see? DTN solves the "Cloud Problem"

Bundle Delivery Across LLCD Optical Links (18 Nov 2013)



RESEARCH AREAS OF INTEREST

Where Should DTN Reside on the Spacecraft?

- Key Considerations:
  - Size, Weight and Power
  - Processor Utilization
  - Storage Capacity
  - Device Real Estate
  - Data Rates Required

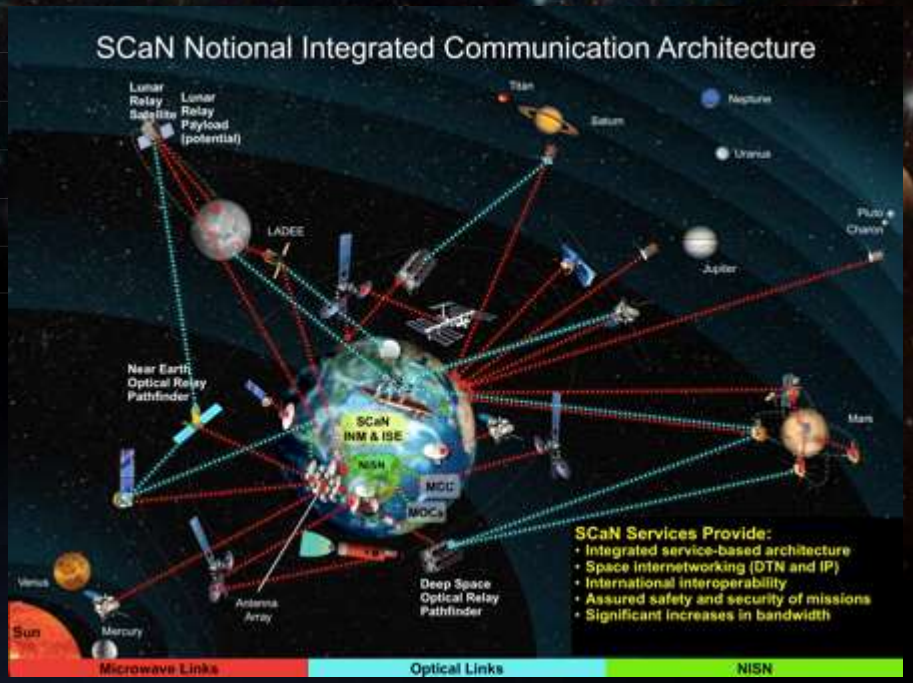
Flight Computer

Intermediate DTN Gateway

Radio

Where Should DTN Reside within the Communication Infrastructure?

- Network Reliability
- Implementation Costs
- International Interoperability
- Multi-Modal
  - RF
  - Optical
  - Terrestrial
- Operations supportability
- End-User Flexibility



End-User Operations Center

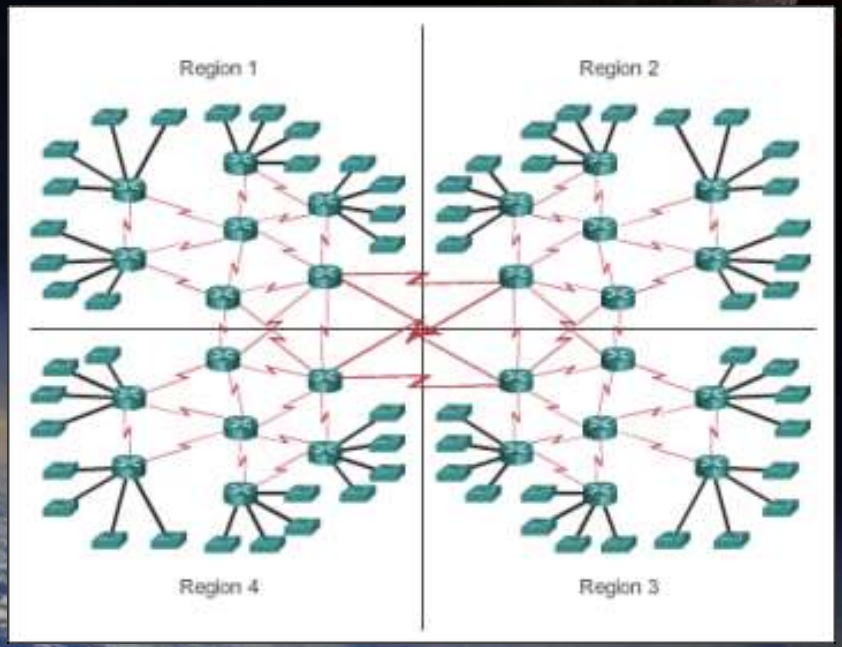
Mission Control Center

Ground Stations

Relay Satellites

Fundamental Research Topics

- Dynamic Routing Protocols
- Predictive / Probabilistic Routing
- “Last Hop” Node Detection and Bundle Delivery
- Disrupted / Disconnected Security Models
- Multi-Domain Routing
- Global Namespace / Node Registration
- “Novel” Uses for DTN Properties
  - Information storage
  - Secure transmission
  - Network-layer error correction
- DTN Management and Operations



IETF DTN Working Group

- NASA helped establish the IETF DTN working group, with the first active meeting at IETF 91 in November 2014.

- Published the Bundle Protocol, Asynchronous Management Architecture, Asynchronous Management Protocol, and Agent Application Data Model documents as internet drafts to the IETF DTN WG.
  - draft-ietf-dtn-bpbis-00
  - draft-birrane-dtn-ama-00
  - draft-birrane-dtn-amp-00
  - draft-birrane-dtn-agent-adm-00
  - draft-birrane-dtn-bp-adm-00
  - draft-birrane-dtn-manager-sql-schema-00

- https://datatracker.ietf.org/wg/dtn/documents/

PLANTING SEEDS…

NASA High Altitude Research Program (WB-57)

- WB-57 provides scientists with high-altitude (>65k ft) access for payloads
  - Users include NASA, NSF, NPS, NOAA, Universities
- Payload / Mission communications currently provided by INMARSAT and /or ViaSat IP services – requires either accommodating outages due to IP or reliance on proprietary "IP enhancement protocols"
- Comms is often disrupted due to A/C maneuvering, obstruction, satellite handoff, etc.
- **NASA WB-57 Program working with AES DTN Project to implement ION DTN and a BP-based network architecture from flight to ground as a standard service to experimenters.**

- Host ION DTN on existing science comms. computer
- Enable both IP and BP traffic (per experimenter choice)
- Provide support (as a program) for TREK science console

WB-57 DTN HSF Capability Validation Mission Concept

Goal:
Q1 / FY2017

VSAT Ka

VSAT SGL

VSAT Ka

TDRSS Ka

TDRS SGL

DYNAMITE Payload

VSAT NOC

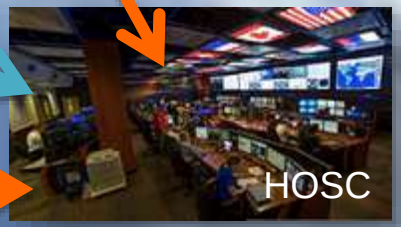
White Sands

EFD

Commercial

Commercial

IONET



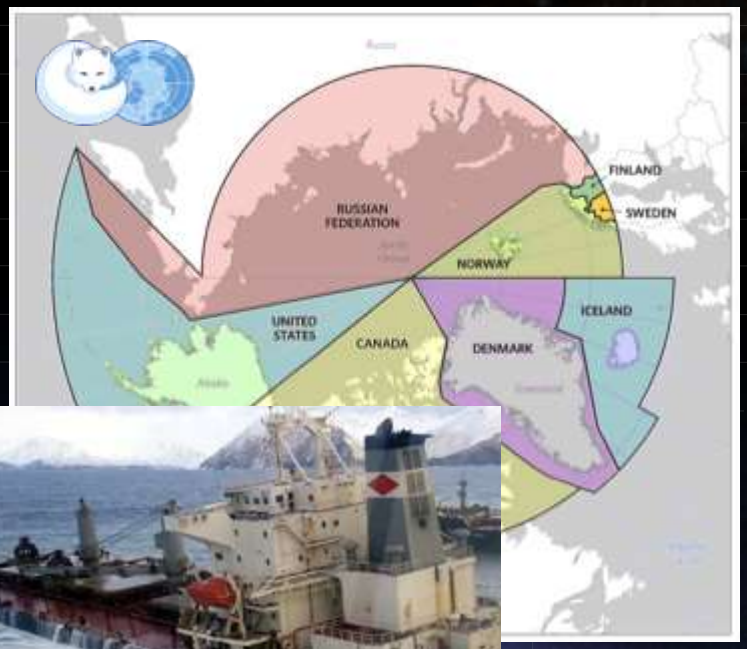
HOSC

IONET

DHS / USCG / CBP

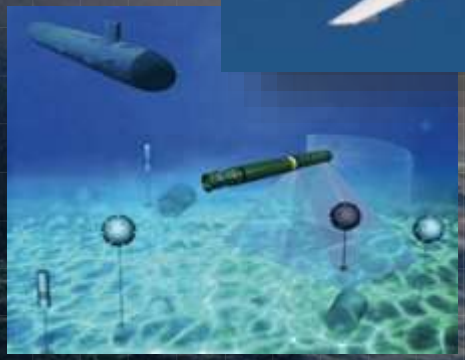
- Maritime AIS
- Cargo / Person Tracking
- Vessel Identification
- Harbor security
- Border security
  - SensorWeb monitoring
  - UAV/UAS comm “mules”
- Customs processing
  - “Gold Lanes”
  - Traffic monitoring

Arctic / Combat Search & Rescue

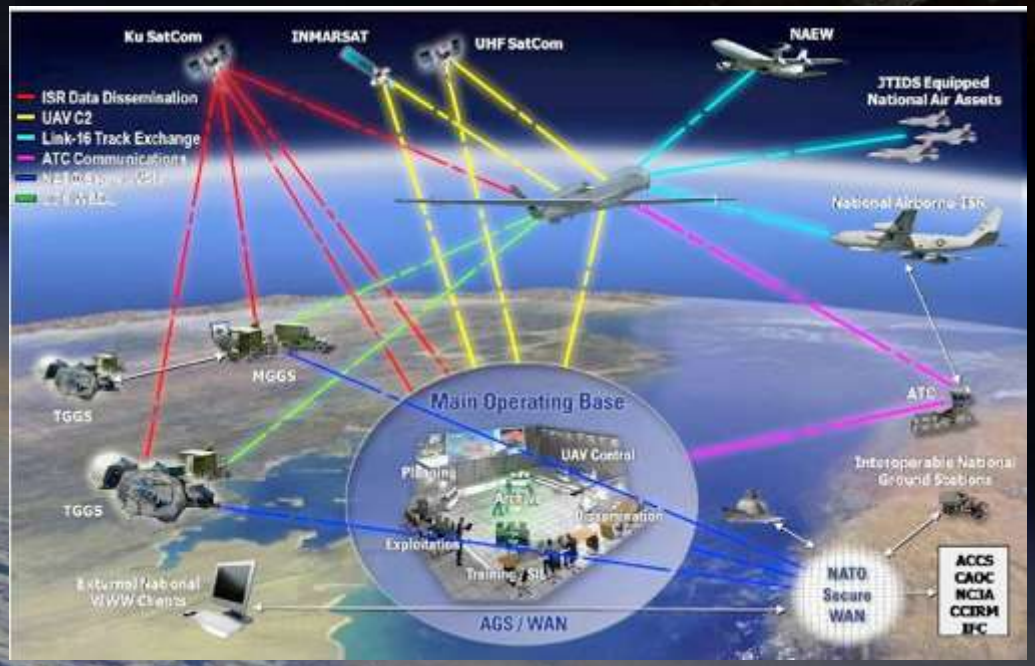


- Integrated communications is a severe challenge
  - Victims may not be able to remain exposed for communication… contact is expected to be spotty
  - (CSAR) Comms on a schedule may not be possible / practical
  - Recovery not necessarily immediate
- DTN useful for comm relay, message store & forward, opportunistic comms

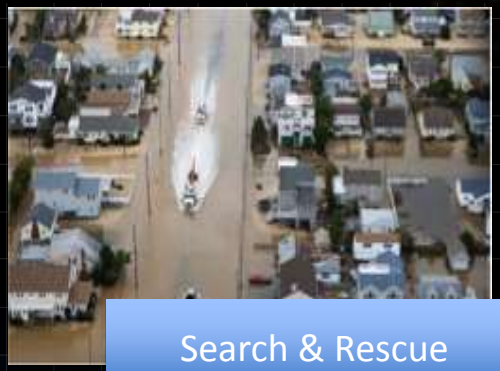
UAV / UUV / C3 Communications



- Civil / Commercial “UAV Operation
- Earth Science
- Maritime Domain Awareness
- Joint Information Networks

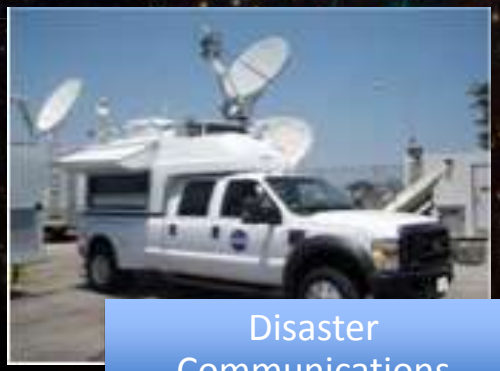


First Responder / Crisis Response



Search & Rescue

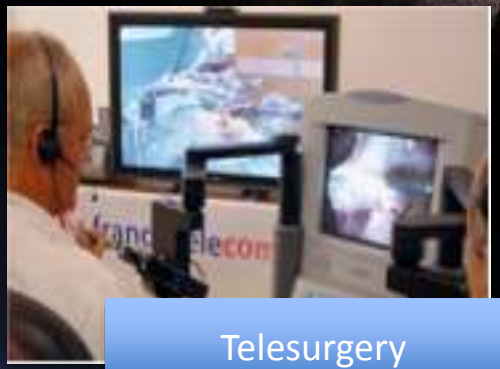
Response Coordination



Disaster Communications

First Responder Telemedicine

Combat Medicine

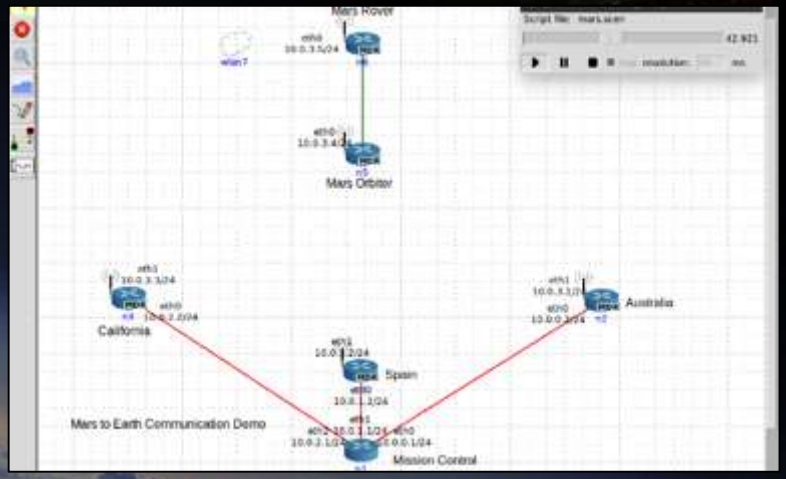


Telesurgery

DTN enables critical communications in harsh, contested and constrained environments.

NASA DTN Deployment Kit

- The NASA DTN deployment kit includes installers, configurators, emulators and pre-built scenarios with sample DTN applications.
- The deployment kit is available as both a virtual machine and a bootable image, and will significantly lower the barrier-to-entry of interested users, allowing them to quickly setup and better understand DTN technology and how it can be applied to various scenarios.
- The deployment kit is built with the Common Open Research Emulator (CORE).
  - CORE is an open-source emulator with a GUI that supports link delays, loss, rate restrictions, simple node mobility, and displays connectivity and runs ION code
  - http://www.nrl.navy.mil/itd/ncs/products/core
- Deployment kit components:
  - ION, DTN2 Installer for Ubuntu
  - ION Installer for Windows
  - JPL ION Configurator and Documentation
  - Sample CORE Scenarios:
    - Simple connect / disconnect (Ground Station Handover)
    - Rate mismatch (Satellite-to-Ground, Ground-to-MOC)
    - Orbiter with multiple ground stations with mixed capabilities
    - Mars (Rover, Relay, DSN Stations)
    - Various Other Topologies: Diamond, 3x3 Mesh, Square
  - Sample Applications
    - ION Utility Applications, CCSDS File Delivery Protocol (CFDP), Line-by-line Image Transfer Application, etc.



DISCUSSION?

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BACKUP

DTN Implementations

- Interplanetary Overlay Network (ION):
  - http://sourceforge.net/projects/ion-dtn
  - NASA's primary DTN implementation (developed by JPL)
  - Includes implementations of BP and LTP as well as implementations of CFDP, BSS and AMS
  - Supported by multiple Operating Systems

- DTN2:
  - http://sourceforge.net/projects/dtn/
  - Includes an implementation of BP and BSP
  - Used at the MSFC HOSC

- Other DTN Implementations:
  - IBR-DTN: http://www.ibr.cs.tu-bs.de/trac/ibr-dtn
    - Available on the Google Play store and as an OpenWRT package
  - JDTN: http://sourceforge.net/projects/jdtn/
    - Java implementation developed by Cisco
  - Postellation: http://postellation.viagenie.ca/

Standardization

- Internet RFCs:
  - RFC 4838 – Delay Tolerant Networking Architecture
  - RFC 5050 – Bundle Protocol Specification
  - RFC 5326 – Licklider Transmission Protocol
  - RFC 6257 – Bundle Security Protocol Specification
  - RFC 6260 – Compressed Bundle Header Encoding (CBHE)

- CCSDS:
  - CCSDS 734.0-G-1 – Rationale, Scenarios, and Requirements for DTN in Space
  - CCSDS 730.1-G-1 – Solar System Internetworking Architecture Informational Report
  - CCSDS 734.2-B-1 (Approved 2015) – CCSDS Bundle Protocol Specification
  - CCSDS 734.1-B-1 (Approved 2015) – Licklider Transmission Protocol (LTP) for CCSDS
  - DTN Network Management Informational Report (Draft)