The Benefits of Delay/Disruption Tolerant Networking (DTN) for Future NASA Science Missions

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Study Background

- The National Aeronautics and Space Administration (NASA) Science Mission Directorate (SMD) has undertaken a study to identify the benefits of a Delay/Disruption Tolerant Networking (DTN) communications architecture and recommend strategies to implement DTN for SMD missions.
- The study will be executed via three primary phases:
  1. Evaluate proposed benefits of a DTN architecture with mission implementers and operators
  2. Identify implementation strategy options
  3. Produce final recommendations on technical implementation

Definition of DTN

- **DTN:** DTN is a suite of *standard protocols* that use information within the data stream (headers attached to data units) to accomplish end-to-end data delivery through network nodes. DTN enables data delivery in situations that involve
  - Disconnections (e.g., end-to-end link unavailability)
  - Delays (e.g., Deep Space missions)
  - Data rate mismatches (e.g., high data rate Science downlinks but lower rate terrestrial connections)
- **DTN Architecture:** A DTN architecture is a store-and-forward communications architecture in which source nodes send DTN bundles through a network to destination nodes

DTN Myths

DELAY/DISRUPTION TOLERANT NETWORKING

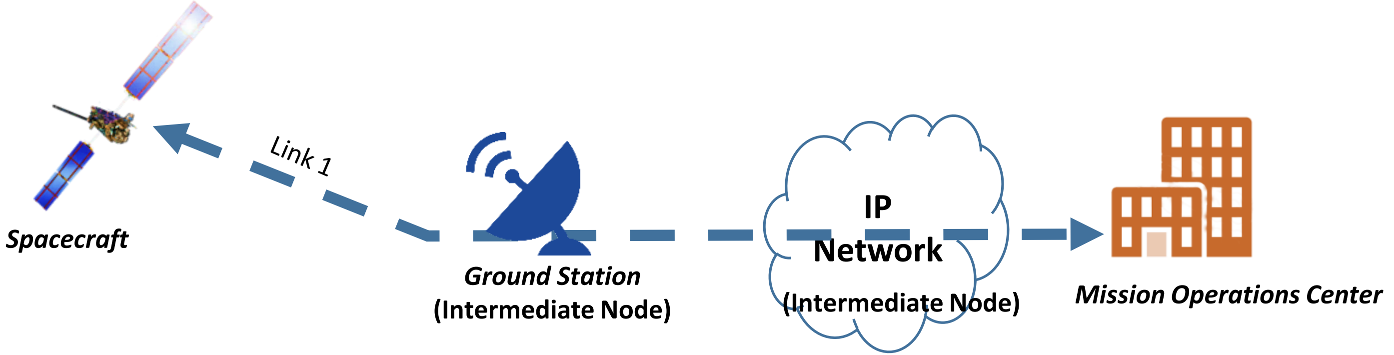
- Myth: DTN increases the speed of data delivery on an individual link
  - ***Fact: DTN may reduce end-to-end latency by allowing more efficient use of available links***
- Myth: DTN requires additional link hardware because all missions will be required to be relay nodes
  - ***Fact: DTN does not require all missions to be relay nodes***
- Myth: DTN changes how radio frequency (RF) links are scheduled
  - ***Fact: Links still need to be pre-established***
- Myth: DTN is only of value for Deep Space missions
  - ***Fact: Many mission types benefit from reuse, standardization, and networking provided by DTN***
- Myth: DTN requires the addition of intermediate nodes to a mission’s data delivery architecture
  - ***Fact: DTN does not mandate the use of intermediate nodes***
- Myth: All missions have the same data delivery requirements
  - ***Fact: Mission science is not always severely impacted by loss of data***
  - ***Fact: Onboard storage is becoming less of a cost driver***

Study Phase 1 Approach

- Dialogue with missions
  - Missions acquired basic understanding of DTN
  - DTN Study Team obtained understanding of current end-to-end data delivery for SMD missions
  - Verified/validated potential DTN benefits

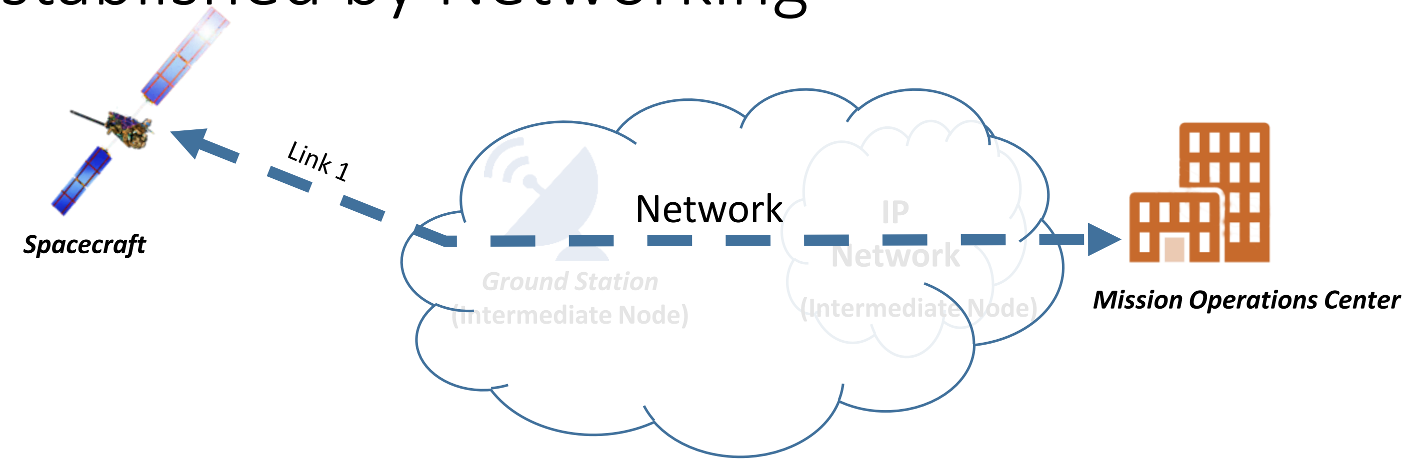
Mission Scenario	Missions Consulted
Low Earth Orbit (LEO)	• IXPE • NISAR • PACE
Planetary Relay and Deep Space	• Kepler/K2 • Mars Missions • Parker Solar Probe
Instrument-only	• ECOSTRESS • MAIA
Cis-Lunar	• LRO
Sun-Earth Lagrange	• WFIRST
Sub-orbital	• Balloons
Other	• Explorers Program

How a Virtual Single Link Is Currently Established



- Current standards allow missions to operate as if they have a direct link between spacecraft and Mission Operations Center (MOC) – a virtual single hop
- Limitations of this approach
  - Does not work when there are data rate mismatches or disconnections
  - Data do not contain the address of the destination, therefore intermediate nodes have to know *a priori* where to send the data
- Missions have been implementing non-standard ways to deal with data rate mismatches

How a Virtual Single Link Is Established by Networking



- Networking allows the virtual single link to happen in a standard, data-driven way like terrestrial use of Internet Protocol (IP)
- IP does not work for scenarios that include delays, disconnections, or data rate mismatches
- The DTN protocols have been developed to provide the benefits of networking in any mission scenario, including scenarios where the terrestrial IP suite cannot be used.

Verified/Validated DTN Benefits

- DTN drives Standardization
  - Reuse
  - Interoperability
- DTN enables networked communications
  - Scalability
  - Autonomy
  - Independent Application and Link Evolution
- DTN's "store-and-forward" communications approach
  - Networking with Delays, Disconnections, and Data Rate Mismatches
  - More Efficient Use of Bandwidth and Contact Time
  - Simplified Flight and Ground System Implementations and Operations

DTN Infusion Challenges

#	Title	Key Question(s)
1	Security	▪ What is needed to ensure DTN meets security requirements? ▪ What impact does DTN have on the security posture of future missions?
2	Navigation	▪ Does the use of DTN impact navigation performance and if so, how are those impacts mitigated?
3	Overhead	▪ How much additional data overhead occurs through the use of DTN?
4	Incentives	▪ What types of incentives would encourage mission adoption of DTN?
5	Provider Availability	▪ Will there be a DTN network provider to support DTN missions?
6	Adherence to Standards	▪ How can standardization be enforced? ▪ How will customization be discouraged?
7	TRL Advancement	▪ What technologies require TRL advancement? ▪ What is needed to make those advancements?
8	Network Management	▪ How will the DTN network be managed?

Conclusions

- Representatives across the NASA science mission community validated numerous DTN benefits
- DTN can benefit any mission type, including
  - missions in low Earth orbit
  - complex future missions that could include multiple landers and relay orbiters, human exploration efforts involving numerous assets on the Moon and Mars, swarms of spacecraft
  - scenarios where every spacecraft may communicate with every other spacecraft.

DTN ***is of value and desirable*** to flight projects

However, there are issues that must be addressed to implement DTN in science missions

Backup

Verified/Validated DTN Benefits: Standardization

Benefit	Description	Mission-provided example

Reuse	Proven DTN hardware, software, and operations procedures could be used by all mission types, reducing or eliminating the frequent implementation of different methods to achieve common mission communications functions	• Nearly every mission representative acknowledged some effort expended to meet end-to-end data delivery requirements including:
		  • Trade studies to determine the best method for meeting requirements
		  • Development of new interfaces between flight segment, ground station, MOCs, and Science Data Systems (SDSs), including accompanying documentation
		  • Development of new implementation and operations procedures
		  • Identification of additional risks and implementation of risk mitigation plans
		  • Additional integration and testing

Interoperability	DTN would provide a standard network layer interface to allow data to be communicated among different systems employing it, including systems belonging to NASA, other government and international agencies, and industry	• A standard capability between WS1 and DSN would have allowed LRO to use both networks • Interoperability between NASA's Near Earth Network (NEN) and Italian Space Agency's Malindi station would allow IXPE to use a consistent interface

Verified/Validated DTN Benefits: Networked Communications

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Benefit	Description	Mission-provided example
Scalability	DTN can reduce the difficulty of adding a new node, link, or path to a communications network	• Mission representatives acknowledged that a standard protocol is necessary to support future mission scenarios where data generated by systems on Mars could be destined for other surface systems, for the relay spacecraft itself, or for Earth
Autonomy	Information embedded in the DTN bundle enables data-driven end-to-end data delivery across multiple hops	• One asset could send information related to detection of a gamma-ray burst to another asset to enable measurement of that event. Though the links may still need to be scheduled, the detecting asset can autonomously determine the data destination and the network will deliver the data
Independent Application and Link Evolution	DTN allows the applications used to transport data to be decoupled from the underlying link infrastructure, facilitating upgrades to both elements	• Balloons could use the same bundle-generating application to return data via TDRSS and Iridium despite differences between the two systems • Enables network upgrades to optical communications

Verified/Validated DTN Benefits: "Store-and-Forward" Communications Approach

Benefit	Description	Mission-provided example
Networking with Delays	DTN enables data delivery across an end-to-end path based on destination address, even when the end-to-end path between source and destination includes extreme communication delays	• Enables reliable communications over planetary distances, such as Mars landers through Mars Relays
Networking with Disconnections	DTN enables data delivery across an end-to-end path based on destination address, even when a full bandwidth end-to-end path between source and destination does not always exist for the duration of a communication session	• LLCD used DTN to automatically retransmit optical communications data that was disrupted by clouds • ECOSTRESS experienced automated delivery of data via DTN that would have been lost during data disconnections along the path between the ISS and their Ground Data System
Networking with Data Rate Mismatches	DTN enables data delivery across an end-to-end path based on destination address, even when sequential nodes on the path transmit data at different rates	• Provides rate buffering to allow delivery of data when the links to Earth are higher data rates than the terrestrial links from the ground station to the MOC

Verified/Validated DTN Benefits: "Store-and-Forward" Communications Approach

Benefit	Description	Mission-provided example
More Efficient Use of Bandwidth and Contact Time	DTN's ability to provide data delivery across an end-to-end path even when the full bandwidth end-to-end path between source and destination does not always exist enables efficient use of bandwidth and contact time	• For missions like Kepler/K2 that have to halt data collection while transmitting, DTN may reduce the amount of time spent transmitting, thereby maximizing data collection • DTN could reduce data retransmission
Simplified Flight and Ground System Implementations and Operations	DTN enables simpler solutions to meet mission requirements	• Could eliminate the need for flight hardware and software systems to maintain lists of all files and the states of all pieces of files in transit (like LRO) • For balloon platforms where data transport happens via multiple processes, DTN could provide a more efficient and standardized approach for instrument data handling and delivery