DTN: Technical Overview and the NASA Space DTN Project

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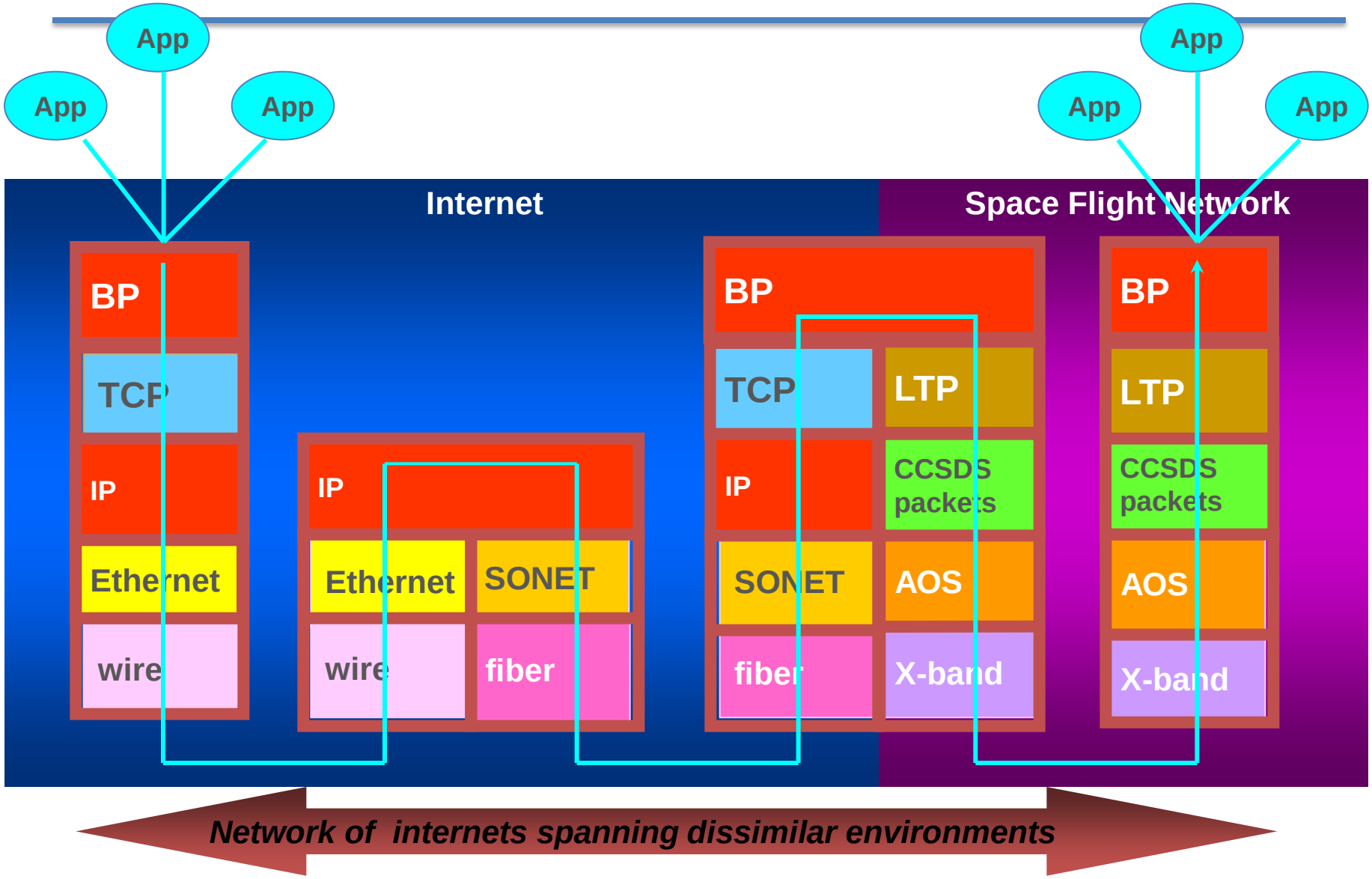
Motivation

- Parameters of Internet communication:
  - All nodes are on Earth and are continuously interconnected. Network partitioning is anomalous.
  - So end-to-end round trip times are always relatively short.
  - This enables TCP, BGP, telnet, HTTP, IKE, etc.
- Parameters of space flight communication:
  - Nodes are generally not continuously interconnected. Network partitioning is routine.
  - End-to-end round trip times are highly variable and may be very long.
  - So different protocols are needed.

DTN End-to-End Path



Routing and Forwarding

- 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.

Recovery from Data Loss

- In the Internet:
  - TCP computes retransmission timeout interval (RTO) based on end-to-end round-trip acknowledgment history.
  - If the RTO lapses prior to reception of acknowledgment:
    - Data loss is inferred and data are retransmitted.
    - Network congestion is inferred from data loss; transmission rate is reduced.
- In DTN:
  - End-to-end RTO cannot be estimated with precision. So:
    - RTO estimation is delegated to convergence-layer protocol.
    - Lapse of RTO prior to acknowledgment implies data loss, but data loss on a space link does not imply congestion; transmission rate over the affected link is not reduced.

Security and Key Exchange

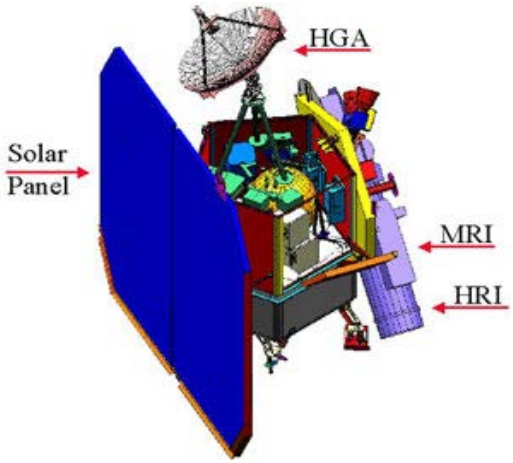
- In the Internet:
  - Security is provided in additional IPSEC protocol layer.
  - Security keys are established by mutual verification conversation, e.g., Internet Key Exchange (IKE).
- In DTN:
  - Security is provided by extension blocks integrated into Bundle Protocol.
  - Security keys are asserted by a key authority; no negotiation of key material.
    - Still a research topic, no standard yet.

Congestion Control

- In the Internet:
  - Congestion is a major problem.
  - Immediate congestion detection and automatic reactive congestion control are built into TCP.
- In DTN:
  - Congestion is not yet a major problem in space flight communication; efficient link utilization is more important.
  - Congestion is forecast from expectations of future network topology.
  - Congestion control is proactive, performed by management.

DTN on the EPOXI Spacecraft

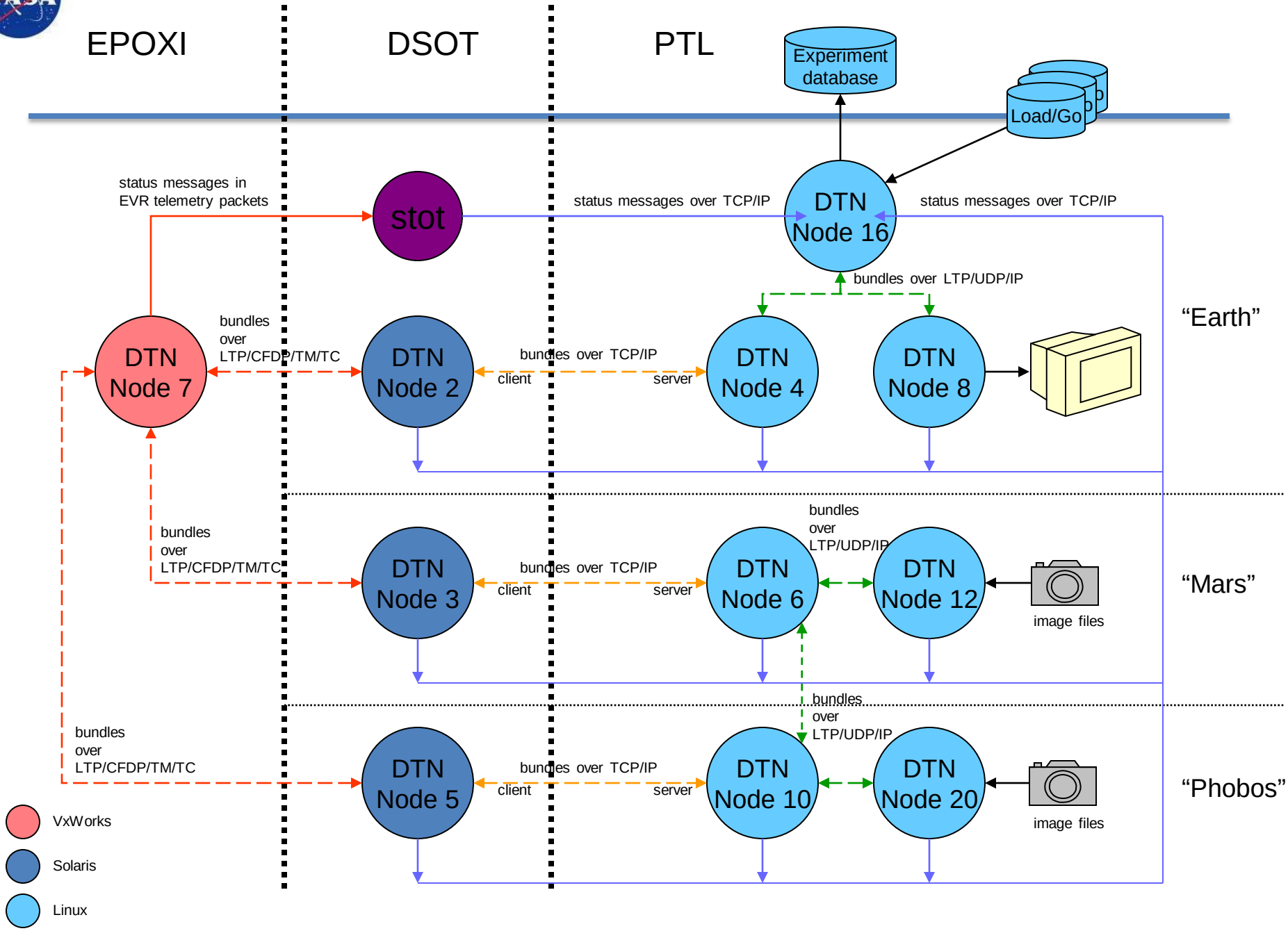
- First deep-space node on the Solar System Internet (2008).
  - Automatic, contact-sensitive relay operations
  - Automatic rate control, delay-tolerant retransmission
  - Prioritization of merged traffic flows
- First use of dynamic routing over deep space links.
- Moved 292 images (about 14.5 MB) through the network.
  - All high-priority images were successfully delivered. No data loss.



One-way signal propagation delay from Earth to EPOXI was 49-81 seconds.

8 Deep Space Network tracking passes of 4 hours each, separated by intervals of 2 to 5 days.

Transmission to spacecraft at 250 bytes/second, transmission from spacecraft at either 110 or 20000 bytes/second.


EPOXI
DSOT
PTL
Experiment database
Load/Go
status messages in EVR telemetry packets
stot
status messages over TCP/IP
DTN Node 16
status messages over TCP/IP
bundles over LTP/UDP/IP
"Earth"
DTN Node 7
bundles over LTP/CFDP/TM/TC
DTN Node 2
bundles over TCP/IP
client
server
DTN Node 4
DTN Node 8
bundles over LTP/CFDP/TM/TC
DTN Node 3
bundles over TCP/IP
client
server
bundles over LTP/UDP/IP
DTN Node 6
DTN Node 12
image files
"Mars"
bundles over LTP/UDP/IP
bundles over LTP/CFDP/TM/TC
DTN Node 5
bundles over TCP/IP
client
server
DTN Node 10
DTN Node 20
image files
"Phobos"
VxWorks
Solaris
Linux

Other Deployments of DTN in Space

- NASA Glenn Research Center:
  - United Kingdom Disaster Monitoring Constellation (UK-DMC) satellite in low-Earth orbit: BP/Saratoga/UDP/IP from UK-DMC to ground station, BP/TCP/IP from ground station to NASA Glenn Research Center.
  - Successful on-orbit experiments 2006 through 2009.
- NASA Marshall Space Flight Center and University of Colorado:
  - DTN has been operational in science data download on the International Space Station (ISS) since 2009.
- NASA Goddard Space Flight Center:
  - DTN functionality was demonstrated on EO-1 in Earth Orbit in December 2010 and February 2011.
  - Additional experiments flowed data through Cisco's Internet Relay in Space (IRIS) satellite and through the TDRSS system.

NASA Project Roadmap

- FY08 to FY13: use DTN to automate NASA mission systems.
  - Development and infusion on ISS.
- FY14 to FY16: begin deployment of Solar System Internet.
  - Use ISS as flight testbed.
  - International partners at ISS: JAXA, ESA.
  - Exploration missions.
- Near-term technology focus:
  - Network management, compatible with SNMP.
  - Security, especially “bptables” traffic management, analogous to iptables.
- Standardization:
  - CCSDS “Blue Books” for Bundle Protocol, LTP, Bundle Security Protocol.
  - Standards for Routing, Network Mgt, Key Mgt are in work.