

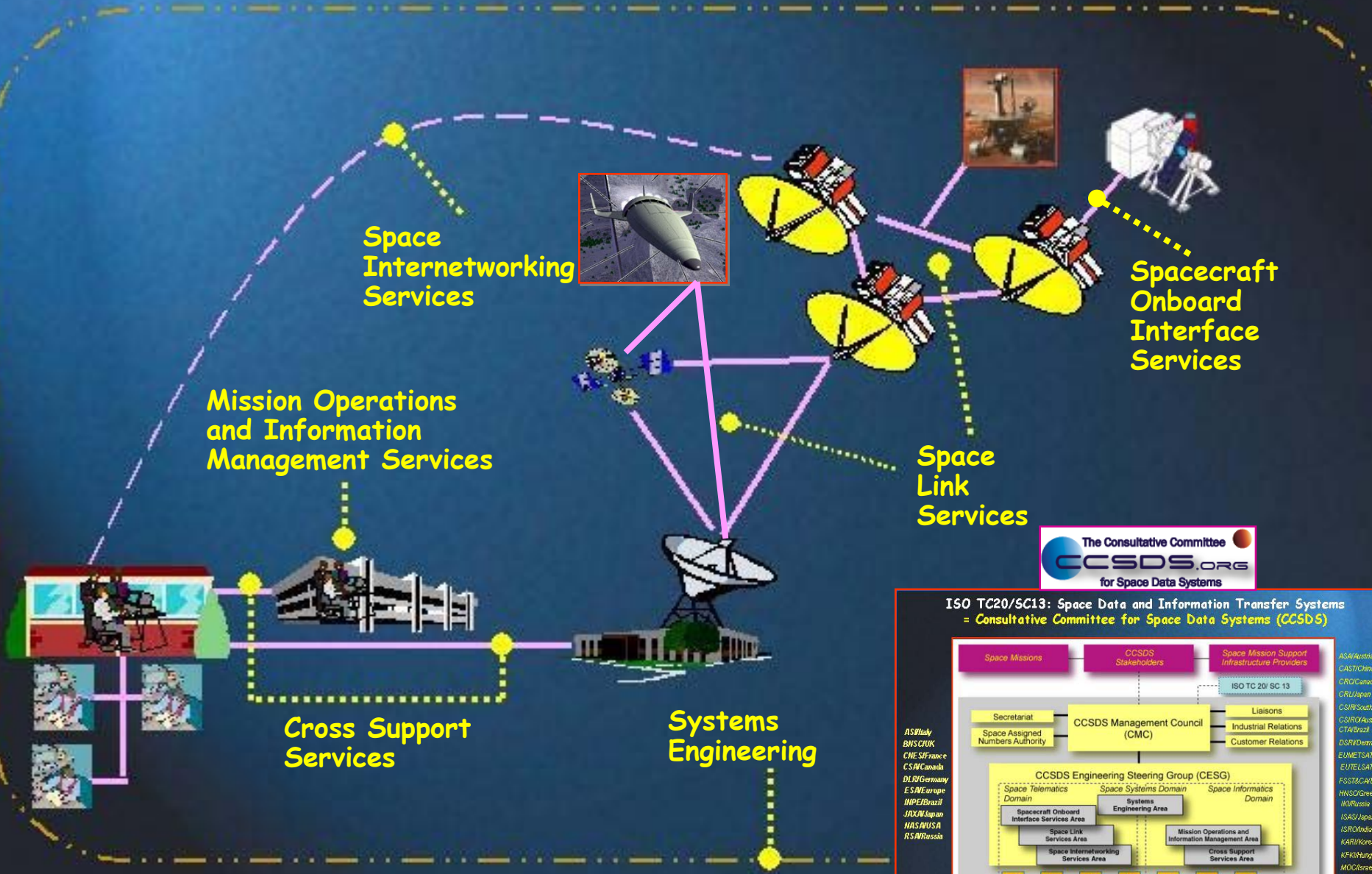


First Deep Space Node on the Interplanetary Internet: the Deep Impact Networking Experiment (DINET)

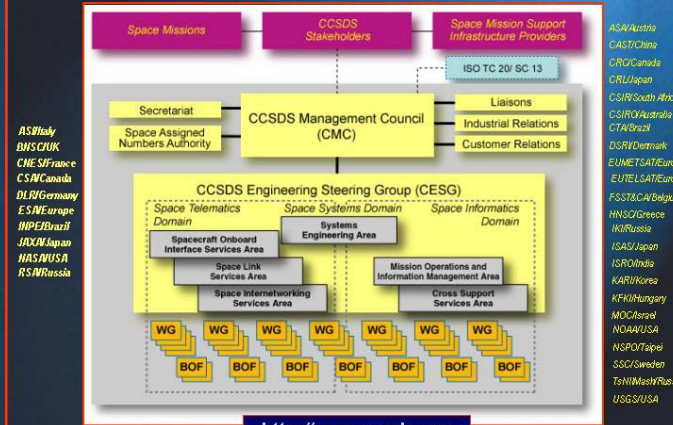
Vint Cerf, Scott Burleigh, Ross Jones, Jay Wyatt, Adrian J. Hooke
Jet Propulsion Laboratory
California Institute of Technology
24 March 2009

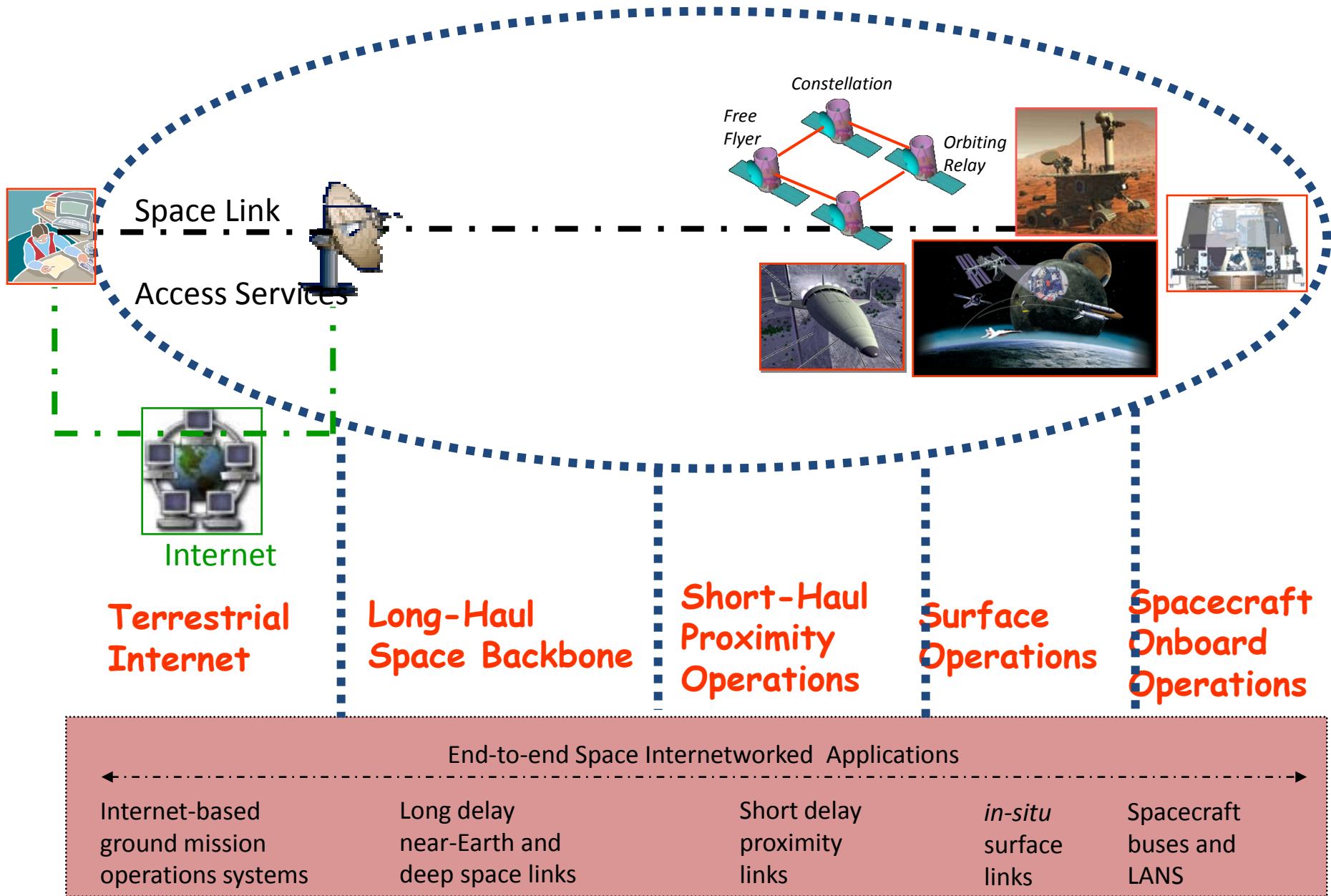
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Technical Areas of International Space Data Standardization



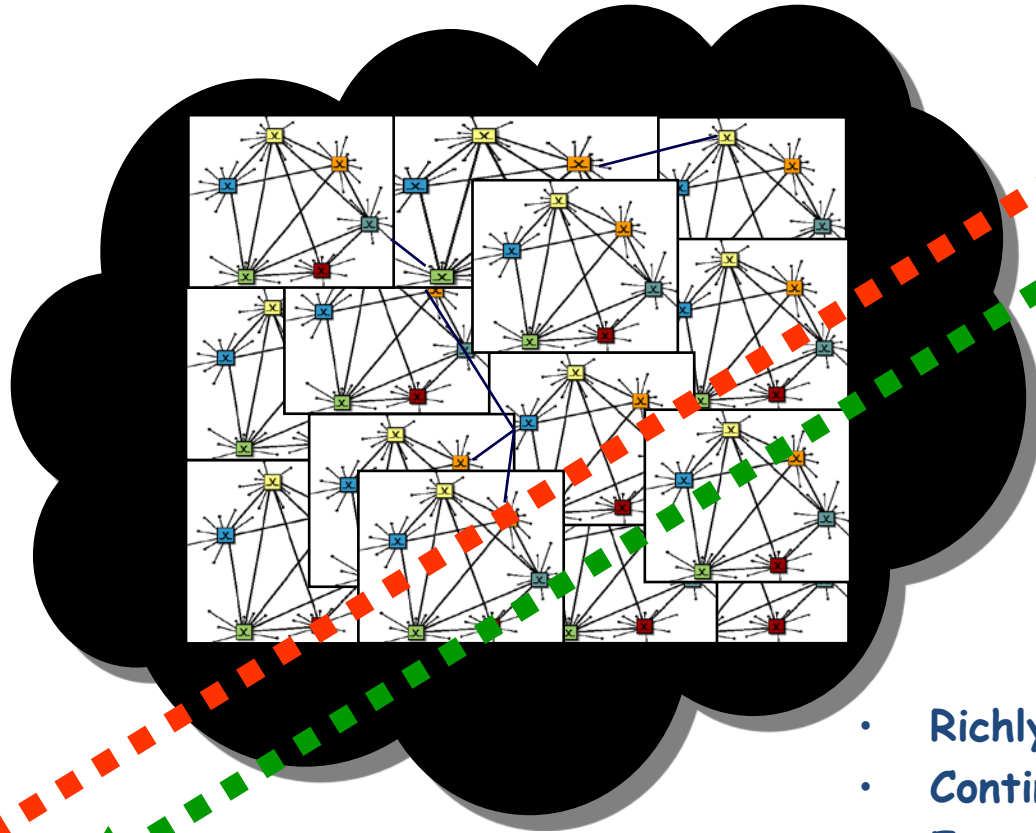
ISO TC20/SC13: Space Data and Information Transfer Systems
= Consultative Committee for Space Data Systems (CCSDS)





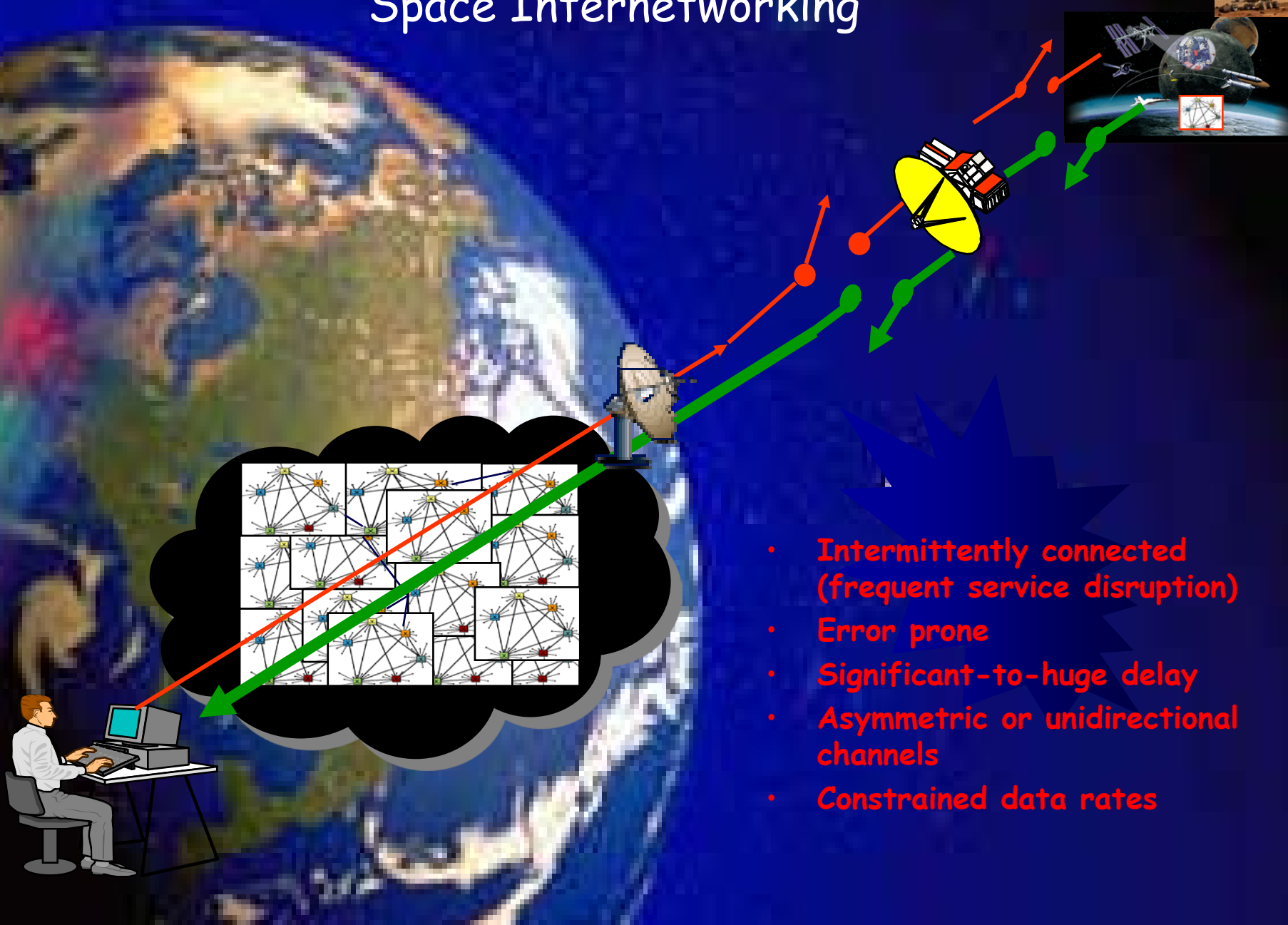
SPACE COMMUNICATIONS PROTOCOLS

Conventional Terrestrial Internetworking



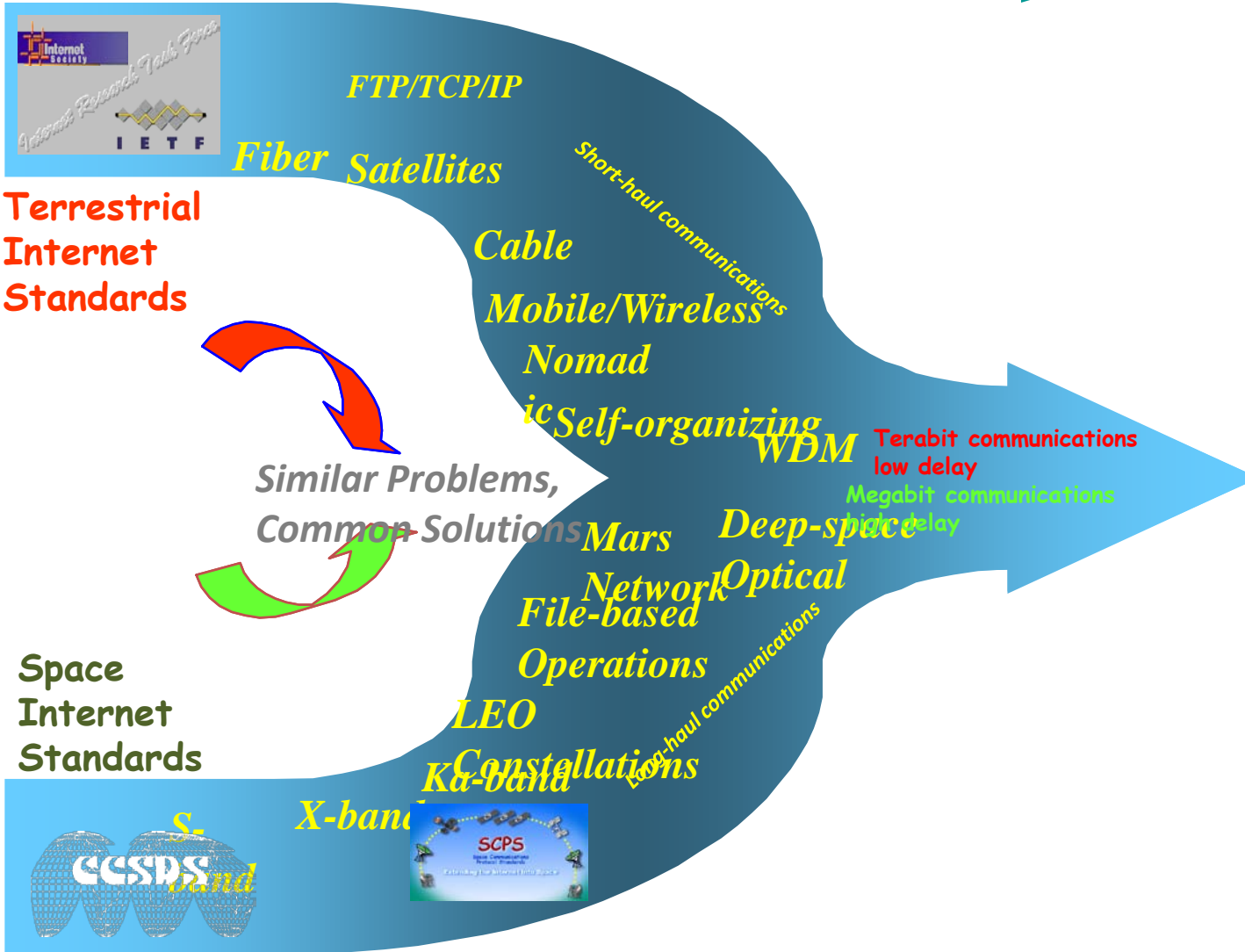
- Richly connected
- Continuous availability
- Error free
- Negligible delay
- Symmetric channels
- Very high data rates

Space Internetworking



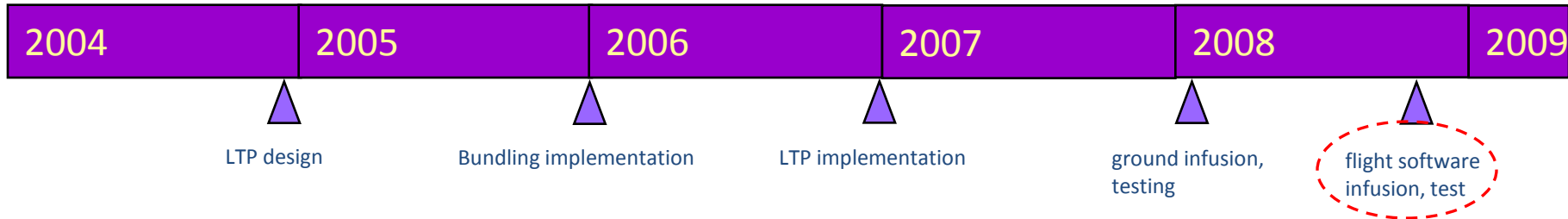
- Intermittently connected (frequent service disruption)
- Error prone
- Significant-to-huge delay
- Asymmetric or unidirectional channels
- Constrained data rates

Opportunity for leverage



InterPlaNetary Internet Architecture

DTN Roadmap for future NASA Exploration



RESEARCH

IRTF-DTNRG projects

PROTOTYPES

JPL/UCLA DTN Sensor Webs

DoD-DFRC/JPL iNET

Next Generation Protocol Suite for Mars

STANDARDIZATION

CCSDS DTN-BOF

CCSDS DTN-WG

CCSDS Standards

Reference implementations

Protoflight Software

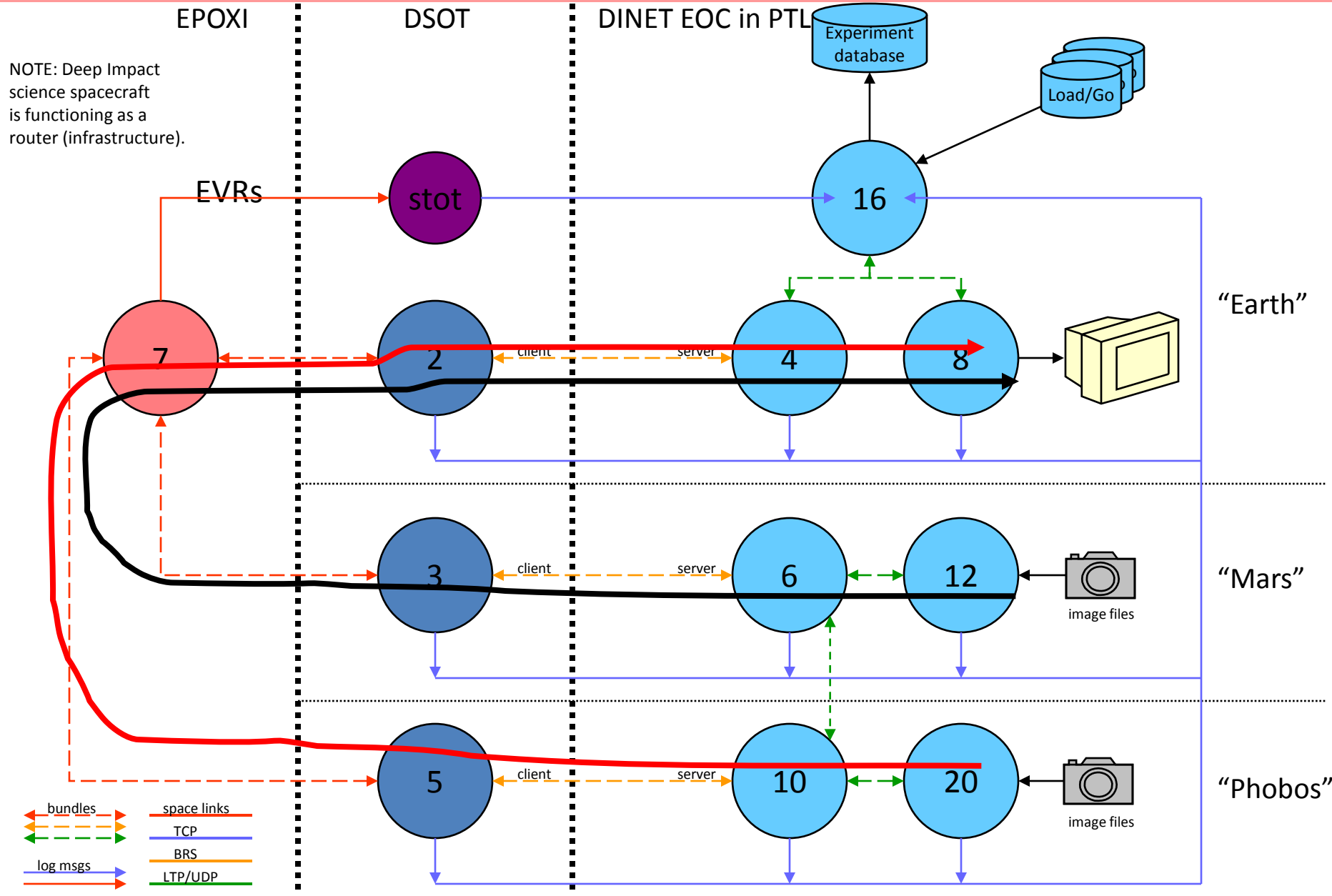
Ready for upload



DINET Overview

- The Deep Impact Network (DINET) project was an experimental validation of “ION” (Interplanetary Overlay Network), JPL’s implementation of the Delay-Tolerant Networking protocols.
- The intent of the experiment was to raise the Technology Readiness Level of ION to 7 or 8, to enable its adoption at low risk by future flight projects.
- The ION software was uploaded to the backup flight computer of the EPOXI (formerly Deep Impact) spacecraft on 18 October 2008 and was operated continuously from that date until 13 November 2008.
 - EPOXI was in inactive cruise period while en route to encounter comet Hartley 2 (November 2010).
 - Spacecraft functioned as a DTN router in an 11-node network (see next slide).
 - 8 Deep Space Network tracking passes of 4 hours each, separated by intervals of 2 to 5 days.
 - One-way signal propagation delay was initially 81 seconds, dropped to 49 seconds by the end of the four-week exercise. (EPOXI was approaching an Earth fly-by in December.)
 - Transmission to spacecraft at 250 bytes/second.
 - Transmission from spacecraft at either 110 or 20000 bytes/second.

Sent images, in bundles, from node 12 to node 8 via nodes 6, 3, 7 (the EPOXI spacecraft), 2, 4. Also sent images from node 20 to node 8 via nodes 10, 5, 7, 2, 4.



Configuration Parameters

- Convergence-layer protocols:
 - “Bundle Relay Service” (TCP) through firewall between DSOT and EOC nodes.
 - LTP (“red”) on all other links, over CCSDS TM/TC (flight) or UDP/IP (ground).
- Images sent at priorities 0, 1. Network mgt traffic, custody signals, critical images sent at priority 2.
- Custody transfer on all application bundles.
- All bundles were CBHE-compressed.
- Bundle status reports were sent only on destruction of custodial bundles.
- Time-to-live was 10 days for all image bundles.
- Max bundle size was 64 KB. Max LTP segment size was 739 bytes.
- Contact Graph Routing used to compute routes dynamically.
 - Intermittent cross-link between nodes 6 and 10 enabled alternative paths.

Results

- Moved 292 images (about 14.5 MB) through the network.
- DTN prioritization assured that all high-priority images were successfully delivered by DINET.
 - Several low-priority images were destroyed upon time-to-live expiration prior to delivery, due to insufficient contact opportunity (unplanned DSN link service outages).
- No data loss.
- No data corruption anywhere in the network.
- Operator intervention was limited to loading and booting the software (including a reboot of all EOC ground nodes necessitated by a Lab-wide power failure) and uploading corrections to the spacecraft clock.

Key Findings

- The protocols work well.
 - Signal propagation delays of 49 to 81 seconds were tolerated.
 - End-to-end latencies on the order of days were tolerated.
 - Station handovers and transient failures in DSN uplink service were handled automatically and invisibly.
 - Protocol overhead was minimal.
 - Dynamic route computation was generally successful.
- The software is highly stable.
 - No software failures in four weeks of continuous operation on VxWorks, Solaris, and Linux platforms.
 - No effect on the operation of other flight software.
 - No leakage of memory or non-volatile storage space.
- Clock synchronization and OWLT estimation errors of several seconds had no noticeable effect on network operation.

Problems

- Several bugs in Contact Graph Routing resulted in some under-utilization of network capacity. Revisions in progress.
- Spacecraft clock drifted more rapidly than expected – over 1 second per day. Revised clock correction deltas had to be uploaded to ION for each tracking pass.
- Various other minor bugs, plus one DSN hardware problem revealed when processing high volume of uplink traffic.

Milestones and Conclusion

- First deep-space node on the Interplanetary Internet.
 - Automatic, contact-sensitive relay operations (store-and-forward Bundle Protocol)
 - Automatic rate control
 - Delay-tolerant retransmission (Licklider Transmission Protocol)
 - Prioritization of merged traffic flows
 - Custody transfer
- Longest digital communication network link ever.
- First use of dynamic routing over deep space links.
- First use of messaging middleware (CCSDS Asynchronous Message Service publish/subscribe) over deep space links.
- **Fully automatic** operation of a delay-tolerant network over deep space links is feasible.