TOWARDS AN INTERPLANETARY INTERNET:
A PROPOSED STRATEGY FOR STANDARDIZATION

Adrian J. Hooke
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, California, USA.

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What is CFDP?

- The **CCSDS File Delivery Protocol** is an internationally standardized mechanism to deliver files of space mission data end-to-end through a space network via a series of store-and-forward hops, using custody transfer techniques.
- The **current CFDP** ("Build 1") provides non-routed, non-custodial delivery through a single hop.

*It supports:*
- the user application

*And consists of:*
- file handling mechanisms
  +
- point-to-point reliability mechanisms

*It draws upon:*
- underlying space link unit data transfer services

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**APPLICATION**

CFDP File operations

<table>
<thead>
<tr>
<th>CFDP point-to-point reliability (PDU ack &amp; retransmit)</th>
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<td>(Core has no routing or custody transfer)</td>
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CCSDS Space Link
International space standards are developed within the Consultative Committee for Space Data Systems (CCSDS)
Current Space/Ground Communications Protocol Architecture

Spacecraft Instruments and Subsystems

Exposed Application Services

Space Packet Protocol
TM Space Data Link Protocol
AOS Space Data Link Protocol
Lossless Data Compression

TC Space Data Link Protocol
Link ARQ
Communication Operation Procedure 1

Convolutional Coding
Reed-Solomon Coding
Turbo Coding
TLM Frame Sync.
CLTU and PLOPs
BCH Coding

Modulation
Radio Frequency

1 Physical
2 Link
3 Network
4 Transport
7 Application Services
Space Applications
219 Missions now using
CCSDS Space Link Protocols
http://ccsds.gst.com/implementations

Consultative Committee for Space Data Systems

Space Domain
Spacecraft Platforms
On-Board Systems
Space Qualified ASICs

CCSDS:
The Fleet

Ground Domain
Commercial Ground Networks
Command & Telemetry Data Processing

~ 20 spacecraft vendors
~ 25 space component vendors

International Space Station (ISS)
Hubble Space Telescope (HST)
Mars Global Surveyor
Mars Express
Rosetta
International Infrared Laboratory

2 commercial networks
50 vendors

Expansion Forward and Return Services
The Next Few Years

• In the next few years (2002-2005) we will evolve and migrate to add:

1. A new flavor of CCSDS space link protocol for communicating at short range, e.g., between spacecraft in a constellation or between orbiters and surface assets
   • “Proximity 1” protocol

2. A more networked set of upper layer standards:
   • **CCSDS File Delivery Protocol** (CFDP) for disconnected environments
     - Long delays, episodic connectivity
     - Custodial store-and-forward mode
     - Most missions will use this for routine space/ground data hauling
   • **Internet suite** for richly connected in-situ environments
     - Short delays, stable connectivity
     - Instantaneous end-end dialog
     - Onboard a spacecraft; near-Earth; on and around another planet

3. Standardized **onboard networking**
Emerging Space/Ground Communications Protocol Stack

- Space Applications
  - Space File Transfer
- Space End-to-End Reliability
- Space End-to-End Security
- Space Networking
- Space Link
  - Prox-1
- Space Channel Coding
- Space Wireless Frequency and Modulation
Emerging 2002-2005 Space Communications Protocol Architecture

Spacecraft Instruments and Subsystems

Exposed Application Services

DELAY TOLERANT

IN-SITU/SHORT DELAY

SCPS-SP Security Protocol

SCPS-NP Space Network Protocol

Proximity 1 Space Data Link Protocol

TC Space Data Link Protocol

Space Data Link Security Mechanisms

TCP/UDP SCPS-TP

IPSec

RSVP

FTP, SCPS-FP

Network

Link ARQ

Communication Operation Procedure 1

Physical

Modulation

Radio Frequency

1

Onboard PHY

Onboard LLC

Onboard IntraNet

Intranet

Space Packet Protocol

Space Data Link Protocol

AOS Space Data Link Protocol

TM Space Data Link Protocol

Lossless Data Compression

Convolutional Coding

Reed-Solomon Coding

Turbo Coding

TLM Frame Sync.

CLTU and PLOPs

BCH Coding

Transport

7

Application Services

3

2

Delay Tolerant In-Situ/In-Tunnel Link Protocol
CFDP Build 2

- Will support Scenario 3 (multi-hop, serial transfer) using either - or both - of two mechanisms:
  - A Store-and-Forward Overlay (SFO) that uses unmodified Build 1 and is not part of CFDP. This application code provides multi-hop routing and custody transfer services.
  - Additional "Extended Procedures" that are part of CFDP and which provide multi-hop routing and custody transfer services. These can optionally also be augmented by the SFO for added flexibility.

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As an interim measure to support “Mars Network” operations, Scenario 4 (multi-hop, parallel transfer) can also be supported by an additional “Data Product Manager” application overlay. The DPM segments user products into pieces that are small enough to transfer as independent CFDP files during a single contact, and passes state to the receiving end to enable their reconstitution.

**User Application**

- **Data Product Manager (DPM) Overlay**
  - (SFO routing & custody transfer)
- **CFDP File operations**
- **CFDP point-to-point reliability**
  - (PDU ack & retransmit)
  - **CFDP Extended Procedures:**
    - routing & custody transfer
- **CCSDS Space Link**
CFDP Operations Scenarios

1. point-to-point, unacknowledged
2. point-to-point, acknowledged
3. multi-hop, in series
4. multi-hop, in parallel - without cross-links
The 5 year Scenario:
fully automated end to end
space mission data transfer
Interplanetary Internet: a "network of internets"
We need a general way to communicate in a disconnected, long-delay environment.
The Internet: a Network of Connected Sub-Networks
Bundles: A Store and Forward Application Overlay

The "Thin Waist" of the Interplanetary Internet

A "network of internets" spanning dissimilar environments
Emerging Space/Ground Communications Protocol Stack

IPN Applications

BUNDLING

Local Space Reliability

Local Space Security

Local Space Networking

Local Space Link

Local Space Channel Coding

Local Space Wireless Frequency and Modulation
Bundle Service Layering

e2e Applications
(e.g., Bundle FTP, CFDP, Bundle NTP)

Bundle APT

Bundle Segmentation & Reassembly

"Bundling"

Bundle
Custody Transfer

Bundle
end-end Reliability

Authentication

Encryption

Bundle

TBD Services

Bundle Routing

Convergence Layer (specific adapters that map Bundles to underlying transmission services)

LTP  TCP  UDP

IP

CCSDS
Long-haul Link

CCSDS
Proximity Link

SONET  Ethernet
CFDP

- Store and forward mode
- Transfers files
- Currently point-point:
  - Static Routing
  - Implicit notion of Custody
- Monolithic
- Fairly complex; adding routing + custody transfer will make it more so
- Only of current interest to the ‘space’ community

Bundling

- Store and forward mode
- Transfers all forms of data
- Inherently networked:
  - Dynamic Routing
  - Full DTN Custody protocol
- Will be internally layered
- Quite complex, but layering will make complexity manageable
- Of wide potential interest to other communities

Proposed Strategy

- Get CFDP into widespread use as a waypoint to Bundling
  - Avoid increasing the complexity of the core protocol
- Mobilize other DTN users to develop Bundling as a community effort
  - Broader base of users and applications = faster development and more robustness
- Infuse Bundling to handle needed complexity and simply move a stable CFDP to become an application running over Bundling
CFDP can become an Application running over Bundling: the user interface remains stable.

CFDP File operations

CFDP end-to-end reliability
(no routing or custody transfer)

e2e Applications
(e.g., Bundle FTP, CFDP, Bundle LTP)

Bundle Segmentation & Reassembly

Bundle Routing

Protocol Migration:
CFDP ➔ Bundling
IPN Architecture (Internet Draft 1) May 2001

DTN Architecture (Internet Draft 2) July 2002

First Draft Bundle Protocol Specification September 2002

Bundle Specification

Specifications
Code base

Bundle Prototyping

1st. Rough Code August 2000

2nd. Prototype Code May 2002

3rd. Prototype Code July 2002

CFDP-over-Bundles Experiment.
Current View:
The IPN is a member of a family of emerging "Delay Tolerant Networks"

Delay can be introduced by, e.g.,
Propagation at c
Lack of connectivity
Lack of resources (power, buffers)
Simplex or asymmetric channels
DTN User Communities

Sensor Webs  Tactical Military  IPN - Public Outreach  IPN - Implementation

DTN Standardization
- DTNRG
- CCSDS

DTN Core Engineering
- DTN Architecture
- DTN Design Documents

DTN Open Source
- Reference Implementation
- Configuration Control

Technical Volunteers

DTN Technical Outreach