"The InterPlaNetary Internet
a new way of thinking about
depth space communications"

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In the beginning...
Model of Space/Ground Communications

- Onboard Networks
  - Weight, power, volume:
    - CPU
    - Storage
    - Reliability
    - Cost to qualify
  - Weight, power, volume:
    - CPU
    - Storage
    - Reliability
    - Cost to qualify
- Constrained Networking
  - Delay
  - Noise
  - Asymmetry
- Constrained Applications
  - CPU
  - Storage
- Terrestrial Internet
  - Your Father’s Internet
- Radio Links
  - CPU
  - Storage
  - Reliability
  - Cost to qualify
- Constrained Links
  - Delay
  - Noise
  - Asymmetry
The Consultative Committee for Space Data Systems (CCSDS) is an international voluntary consensus organization of space agencies and industrial associates interested in mutually developing standard data handling techniques to support space research, including space science and applications.

**Member Agencies**
- Agenzia Spaziale Italiana (ASI)/Italy.
- British National Space Centre (BNSC)/United Kingdom.
- Canadian Space Agency (CSA)/Canada.
- Central Research Institute of Machine Building (TsNII Mash)/Russian Federation.
- Centre National d'Etudes Spatiales (CNES)/France.
- Deutsche Forschungsanstalt für Luft- und Raumfahrt e.V. (DLR)/Germany.
- European Space Agency (ESA)/Europe.
- Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
- National Aeronautics and Space Administration (NASA HQ)/USA.
- National Space Development Agency of Japan (NASDA)/Japan.

**Observer Agencies**
- Australian Space Office (ASO)/Australia.
- Austrian Space Agency (ASA)/Austria.
- Belgian Science Policy Office (SPO)/Belgium.
- Centro Tecnico Aeroespacial (CTA)/Brazil.
- Chinese Academy of Space Technology (CAST)/China.
- Communications Research Laboratory (CRL)/Japan.
- Danish Space Research Institute (DSRI)/Denmark.
- European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
- European Telecommunications Satellite Organization (EUTELSAT)/Europe.
- Hellenic National Space Committee (HNSC)/Greece.
- Indian Space Research Organization (ISRO)/India.
- Industry Canada/Communications Research Centre (CRC)/Canada.
- Institute of Space and Astronautical Science (ISAS)/Japan.
- Institute of Space Research (IKI)/Russian Federation.
- KFKI Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
- MIKOMTEK: CSIR (CSIR)/Republic of South Africa.
- Ministry of Communications (MOC)/Israel.
- National Oceanic & Atmospheric Administration (NOAA)/USA.
- National Space Program Office (NSPO)/Taiwan.
- Swedish Space Corporation (SSC)/Sweden.
- United States Geological Survey (USGS)/USA.

http://www.ccsds.org

**Initial focus:**
space/ground data link protocols

http://www.scps.org

**Recent focus:**
space networking

*Clay Frost, MSNBC*
CCSDS Frames and Coding

CCSDS Classic

“Application Over Link”
~200 missions, and counting
Emerging CCSDS

“Application Over Network”

Onboard Network

Link Terminus

Ground Network

App.

App.

App.

App.

App.

App.
The IESG is responsible for technical management of IETF activities and the Internet standards process. The IESG is directly responsible for the actions associated with entry into and movement along the Internet "standards track," including final approval of specifications as Internet Standards.

The IETF is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. It is open to any interested individual.

The IAB responsibilities include:
1. IESG Selection,
2. Oversight of the architecture for the protocols and procedures used by the Internet.
3. Oversight of the process used to create Internet Standards.
5. External Liaison with other organizations concerned with standards and other issues relevant to the world-wide Internet.
6. Technical, architectural, procedural, and (where appropriate) policy advice to the Internet Society.

ICANN is the non-profit corporation that was formed to assume responsibility for the IP address space allocation, protocol parameter assignment, domain name system management, and root server system management functions.

IRTF Research Groups work on topics related to Internet protocols, applications, architecture and technology. Participation is by individual contributors, rather than by representatives of organizations. The Internet Research Steering Group (IRSG) may from time to time hold topical workshops focusing on research areas of importance to the evolution of the Internet.
IPNSIG

Public

IPNRG

Interplanetary Internet Architecture

NASA

Communications requirements

Open Architecture
Open Specifications
Open Implementations

Internet Society

IETF

ISO

International Space Communications Infrastructure
Standardization Options
Basics of the IPN Architecture

Space exploration becomes fully Internet-based

Missions log-on to the "Interplanetary Internet Service Provider" to communicate

Remote internets are deployed in space

An interplanetary backbone network is deployed
I Wired

I Tetherless

Deployed Internets

Stable Backbone

In-situ Internets

Interplanetary Gateways

Security

Interplanetary Backbone

IPN Technology Thrust Areas
What is a “deployed internet” in the IPN?

- The IPN architecture differentiates between the “long-haul backbone” with round-trip times measured in minutes and deployed networks that have round-trip time characteristics closer to those for which the Internet was designed.

- Any deployed network that has the following attributes is considered a deployed internet:
  - Has an environment that does not inherently preclude the use of (possibly enhanced) Internet protocols.
  - It is possible to route to all nodes in the network without resorting to use of long-haul infrastructure (or protocols).
Deployed Internets: A Broad Range of Possible Configurations

- A single lander with an IPN gateway to a (real or virtual) internal network
- Small number of cooperating robots on planetary surface (e.g. Single lander, single rover)
- Orbiter-to-surface communication and coordination (e.g. sample return recovery)
- Multiple beyond-line-of-sight missions connected by low-orbit communication satellites
- Planet-stationary satellites for relay and gateway functions
- Spacecraft on-board LANs
- The Earth’s Internet
Deployed In-Situ Internets

Untethered
Mobile
Mass constrained
Location-Location-Location
Power-Power-Power
Even “Simple” Configurations Aren’t Simple
What's a Backbone?

- A set of high-capacity, high-availability links between network traffic hubs
  - Terrestrial backbone links are between hubs like Houston and Chicago.
  - Interplanetary backbone links are between hubs like Earth and Mars.
# Differences Between Terrestrial and Interplanetary Backbones

<table>
<thead>
<tr>
<th></th>
<th><strong>Terrestrial</strong></th>
<th><strong>Interplanetary</strong></th>
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<tbody>
<tr>
<td><em>Delay (sec)</em></td>
<td>&lt; .1</td>
<td>10 to 10,000</td>
</tr>
<tr>
<td><em>Connectivity</em></td>
<td>Wired; structural, continuous</td>
<td>Radiant; operational, intermittent</td>
</tr>
<tr>
<td><em>Medium</em></td>
<td>Copper, glass</td>
<td>Space; high BER</td>
</tr>
<tr>
<td><em>Deployment $</em></td>
<td>“low”</td>
<td>Very high</td>
</tr>
<tr>
<td><em>Operations $</em></td>
<td>“low”</td>
<td>High (power is costly)</td>
</tr>
<tr>
<td><em>Repair, upgrade $</em></td>
<td>“low”</td>
<td>Very high</td>
</tr>
</tbody>
</table>
What These Differences Imply

• Cost per second of transmission is very high, so…
  – Don’t waste transmission opportunities.
• Intra-backbone connectivity might never be end-to-end, so…
  – Don’t rely on end-to-end connectivity for protocol operations. Use store-and-forward techniques.
• End-to-end round trip time may vary from minutes to weeks, so…
  – Don’t rely on negotiation or other conversational protocol mechanisms; by the time a conversation converges, the reason for it may have passed. Make protocol decisions autonomously, locally.
What Won’t Work

• Absence of automated protocol (the status quo).
  – It doesn’t scale up. Network operations cost would be too high.

• Internet protocols (TCP, UDP, IP) or other protocols designed for terrestrial networks.
  – They rely on conversational protocol mechanisms and/or continuous end-to-end connectivity.
What To Do Instead

• **New application protocols** that don’t rely on in-order delivery of byte streams.

• **New bundle-oriented protocols** at the transport and network layers.
  – “Custodial” store-and-forward operation.
  – Concurrent transmission, out-of-order delivery.

• **New reliable link layer protocol.**
  – Point-to-point retransmission over interplanetary distances.
  – Sub-layer of underlying CCSDS protocols for coding and forward error correction, to minimize the need for retransmission.
Interplanetary Dialogs: communicating in a fundamentally disconnected environment
Interplanetary Dialogs: Design Principles

• Intermittent connectivity suggests an Email-like architecture
  – Common “Handling Instructions” for a data collection
  – Network must accommodate the persistence and transfer of state

• Late-Binding
  – We seek functional independence of remote Internets - a single address space across the entire IPN would couple all parts of the system to evolve at the same rate.
  – Therefore: separate addressing domains for each internet. Administrative names converted to local addresses only at the destination IPN region

• Names (not addresses) are the means of reference
  – Names have two parts: a routing handle (specifies the IPN region) and an administrative part (specifies the DNS name)
  – Routing between IPN regions based upon routing handle

• Indirection
  – Inherent dependence on intermediate relay agents

• Custodial transfer
  – Intermediate nodes assume possibly-long-term responsibility for data forwarding
  – “Bundles” as a common end-to-end transfer mechanism
The Interplanetary Internet:

An overlay network for interconnection of regional internets

- A *region* is an area where the relevant characteristics of communication are homogeneous
- One can define *regions* that are based upon:
  - Communications capability
  - Quality of Service Peerings
  - Security (levels of trust)
  - Degree of resource management
  - Etc.
- Traversal of two or more regions will affect the nature of communications
IP: the “Thin Waist” of the Earth’s Internet

Internet: a Network of Connected Sub-Networks
Bundles: A Store and Forward Overlay
The "Thin Waist" of the Interplanetary Internet

Network of internets spanning dissimilar environments
“Persistence of Vision” provides the illusion of end-to-end connectivity
Names: New Requirements

• Names are **tuples**
  { icesation_zebra.hudsonbay.com, europa.jupiter.sol }

**Administrative Name**
• Opaque outside associated routing domain
• Bound to address only upon entry into its routing domain

**Routing Domain**
• Specifies an IPN region where the administrative name has significance
• Used as a label for routing through "bundlespace"

*Name tuples must be carried end-to-end within each "bundle"*

*Names may refer to persistent objects rather than physical entities*
Single Name Space,
Late Name-to-Address Binding(s)

Name Space - Common Across All Internets

Name-to-Address Binding Space A
Name-to-Address Binding Space B
Name-to-Address Binding Space C

Internet

Interplanetary Backbone

Internet

IPN region: .earth.sol
IPN region: .ipn.sol
IPN region: .mars.sol

Name: {admin part: www.bughunter.org, routing part: earth.sol}
Local Address: 137.79.10.232

Name: {admin part: www.rockshop.com, routing part: mars.sol}
Local Address: 137.79.10.232
IPN Security

Security of user data flowing through the IPN

Security of the IPN backbone
**IPN Security Requirements**

**access control** to the IPN will be required because space-based assets will have limited available resources.

**authentication** will be required to perform access controls.

**data integrity** will be required to assure that what was sent is received.

**data privacy** will be required to assure that unauthorized users cannot obtain information.
Email Key/Encryption Model for IPN

Payload Data → Payload Data

Payload Data

Symmetric key

Payload is encrypted using a symmetric key

Symmetric Key encrypted in destination’s public key (assumes some means of obtaining public keys)

Payload Data

Symmetric key

Bundle Header

Transport + Net Headers

IPN encapsulates in Bundle protocol
“Bundlespace” Service Layering

* Security, if desired, lives in the purple stuff
Bundling and CFDP

- CFDP File Transfer, File Store
- CFDP End-End
- CFDP Extended
- CFDP Reliability

- Bundles
- CFDP

- File Transfer
- Email
- CORBA events
- Streaming Video, <etc>
- Reg Mail
- 4th Class Mail
- <etc>

- Bundle Routing
- LTP
- TCP/TP
- UDP
- IP
- NP

CCSDS Space Link
Current CCSDS Strategy: move CFDP Core + “informative” Extended procedures to a Blue Book.................

...............and defer the Extended evolution to Bundles

“CFDP Build 1”

CFDP Core

CFDP File Transfer, File Store

CFDP Reliability

“CFDP Build 2”

CFDP File Transfer

Reg Mail

LTP

TCP/IP

“Bundles Build 1”

CFDP File Transfer

email

4th Class Mail

Bundle Routing

TCP/TP

UDP

IP

NP

Current CCSDS Space Link

The IPN rollout has begun!
Progressive, planned deployment of reusable communications infrastructure

Earth Science

Deep Space Science

Human Exploration

In-depth Planetary Exploration
For more information......

... http://www/ipnsg.org