Deep Space Network Design

Disruption Tolerant Networking (DTN)

An Architecture for Evolving Communications

History and Use in Space Missions

Leigh Torgerson

ISOC Interplanetary Networking Special Interest Group

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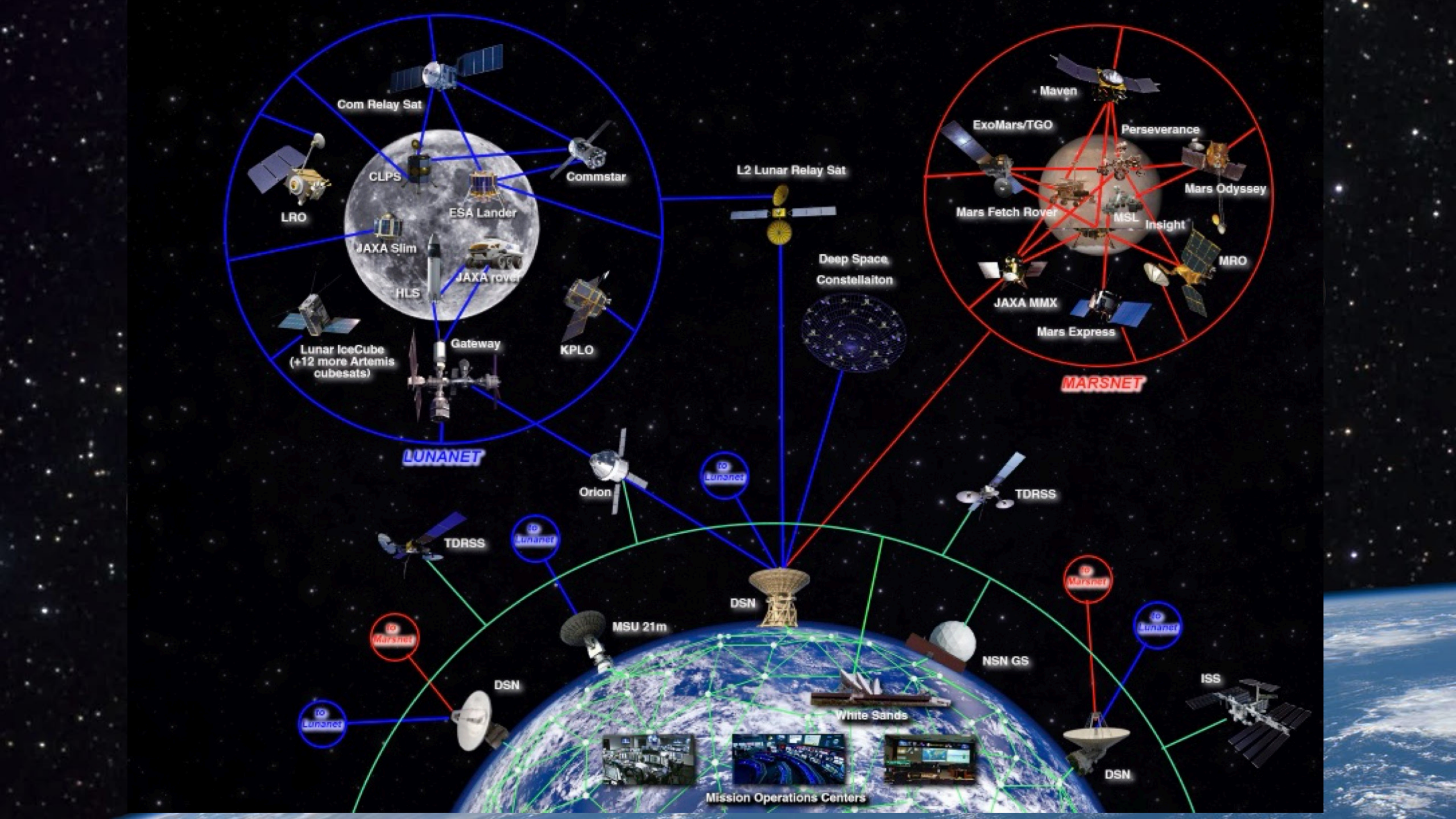
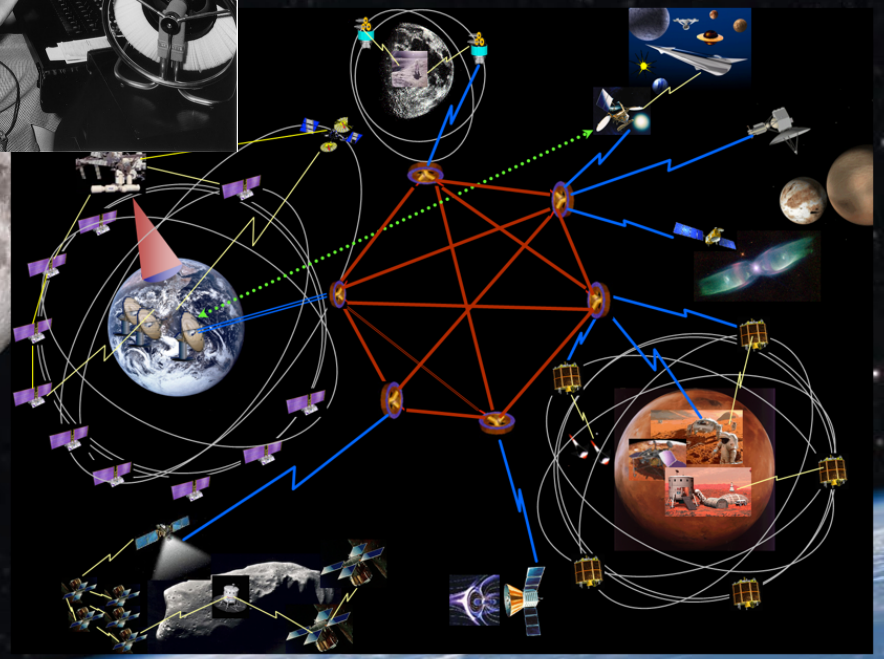
Presentation Topics:

- Why a Space Networking Architecture?
- DTN History and Technical Overview
- Standardization
- Questions

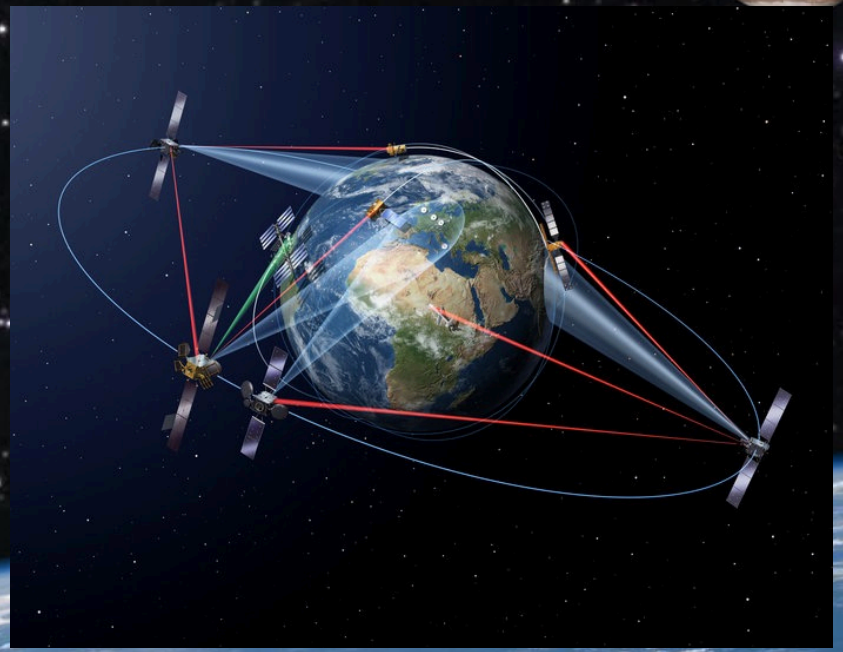

Com Relay Sat
LRO
CLPS
Commstar
ESA Lander
JAXA Slim
JAXA rover
HLS
Lunar IceCube
(+12 more Artemis
cubesats)
Gateway
KPLO
LUNANET
L2 Lunar Relay Sat
Deep Space
Constellaiton
Maven
ExoMars/TGO
Perseverance
Mars Odyssey
Mars Fetch Rover
MSL
Insight
MRO
JAXA MMX
Mars Express
MARSNET
Orion
TDRSS
TDRSS
DSN
MSU 21m
NSN GS
DSN
White Sands
DSN
ISS
Mission Operations Centers

Why Networking?

- Primarily because ops team management of point-to-point links doesn't scale to the future Solar System Internetworking envisioned by NASA / CCSDS!



REF: "Operations Concept for a Solar System Internetwork", Interagency Operations Advisory Group (IOAG), 15 Oct, 2010.



https://www.esa.int/Our_Activities/Preparing_for_the_Future/Discovery_and_Preparation/Space_internet_to_enhance_Earth_observation
(15 Jan 2019)

Why Not Just Use Terrestrial Internet Protocols?

Six Key Assumptions Internet Protocol Design:

- ***Networks are Richly Connected***
- ***Networks have Short Delay***
- ***Data Links are Symmetric and Bidirectional***
- ***Links have Low Error Rates, and that loss is due to Congestion***
- ***Network Nodes are Trustworthy***
- ***Connections are END-TO-END***

Network Characteristics We Face

- ***Sparse network***
- ***Asymmetric; half-duplex or unidirectional links***
- ***Loss due to corruption, not congestion***
- ***Loss due to orbital geometry, antenna pointing errors, etc.***
- ***Inordinately long propagation times between nodes***
- ***Insecure – the threat: you don't need a 34m dish to hack lunar comm links for instance***

Quick DTN Intro Video

Please see YouTube version

https://youtu.be/c_tcC51PIuM

Key DTN Design Elements

- Don’t replace terrestrial networking or legacy comm link technology
  - OVERLAY NETWORK!
- Deal with loss and delay since *contiguous end-to-end paths may be rare*
  - Provide a store-and-forward mechanism at each node in the network
- Don’t reinvent reliable link technology
  - TCP/IP on land, Prox-1 for orbiter-to-surface
  - Deep Space Links needed a reliable link – so Licklider Transmission Protocol (LTP) was developed
- Fix what the IP design missed 40+ years ago
  - Build in security and integrity
  - Provide for Quality of Service
- Deal with different routing needs of underlying networks
  - Pre-planned contact plans for space networks, opportunistic routing for ad-hoc situations, IP routing on the ground.
- Design in provisions for network management, security key management, reliable multicast, projected data transfer types, etc.
  - Asynchronous Management Protocol (DTN-AMP), Delay-Tolerant Key Administration (DTKA), reliable multicast, special protocols for streaming video and applications that need in-order delivery

ION DTN Software Design Philosophy

- **Hard Memory Allocation Limits**:
  - ION operates within a host-specified memory allocation, managing dynamic allocation internally via a private memory management system; dynamic system memory allocation could cause critical flight software to fail.
- **Modular and Robust Operation**:
  - ION's modular structure is implemented through separate daemons and libraries, enhancing system resilience. In a process crash, data in the process's queues/buffers can be preserved in the non-volatile SDR, preventing data loss.
- **Efficient Resource Utilization**:
  - ION is optimized for environments with limited memory, storage, and processing resources. BP and CLA services operate as background daemons to minimize competition with critical spacecraft functions during nominal, high-stress, and off-nominal events.
- **Independence from Native IP Socket Support**:
  - ION employs software abstraction to decouple socket-based programming from its core functionalities. This allows ION to interface the Bundle Protocol and CLAs with various underlying communication systems, such as CCSDS space links, radio communications systems, or customized processing chains that are not IP-based.
- **Portability and Minimal Footprint for Static Linking**
  - ION prioritizes portability and minimal resource footprint in its function libraries. This approach supports static linking through the ION-core package for a specific set of modules.

https://ion-dtn.readthedocs.io/

Brief Historical Outline

- The Beginning:

1998 – A few members of JPL Space Mission Operations Standardization Program met with Dr. Vint Cerf to explain our work on enabling FTP/TCP/IP/IPSEC to adequately perform over geostationary satellites hops.

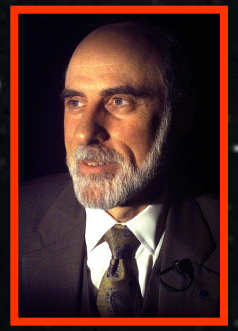
We knew that wouldn’t scale to interplanetary distances, and that more research was needed to really expand the internet into space.

Dr. Cerf arranged DARPA funding and became a member of the team to study how to extend the internet into the solar system.

1999: the IPN Architecture Core Team

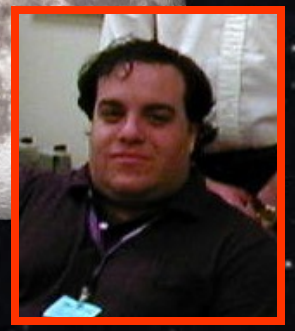

Bob Durst

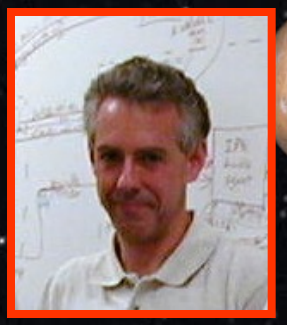

Keith Scott


Vint Cerf


Adrian Hooke


Howie Weiss


Eric Travis


Scott Burleigh


Leigh Torgerson

DARPA

Next Generation Internet (NGI) Initiative

- **JPL:**
  - Vint Cerf, Sr. Vice President of Internet Architecture, Worldcom Inc. and JPL Distinguished Visiting Scientist
  - Adrian Hooke, Scott Burleigh, Leigh Torgerson
- **MITRE:**
  - Bob Durst, Keith Scott
- **Industry:**
  - Eric Travis, Global Science and Technology
  - Howard Weiss, Sparta
- ***Advisors:***
  - ***Bob Braden (USC); Len Kleinrock (UCLA); Dave Mills (UDEL); Deborah Estrin (UCLA); Joe Touch (USC); John Wroclawski (MIT); Jon Crowcroft (UCL); John Klensin (ATT); and others***

Beginnings: The Interplanetary Internet

1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008

DARPA

NASA

RFC-5050 BUNDLE PROTOCOL

Disruption Tolerant Networking: STORE, ROUTE, FLOOD, FORWARD

DARPA

NASA

Jet Propulsion Laboratory **Universe**

Pasadena, California Vol. 28, No. 16 August 7, 199

Lab to develop interplanetary Intern

'Father of the Internet' Dr. Vinton Cerf named JPL Distinguished Visiting Sci

By MARK WHALEN

Internet pioneer Dr. Vinton Cerf has been named a Distinguished Visiting Scientist at JPL to help develop an interplanetary Internet.

Cerf will serve a two-year post that will be in addition to his regular duties as senior vice president of Internet Architecture and Engineering at MCI Communications Corp.

"It took 20 years for the Internet to take off here on Earth," said Cerf, widely known as the "Father of the Internet" for co-developing the TCP/IP protocol, the computer language that gave birth to the communications medium. "It's my guess that in the next 20 years, we will want to interact with systems and people visiting the moon, Mars and possibly other celestial bodies."

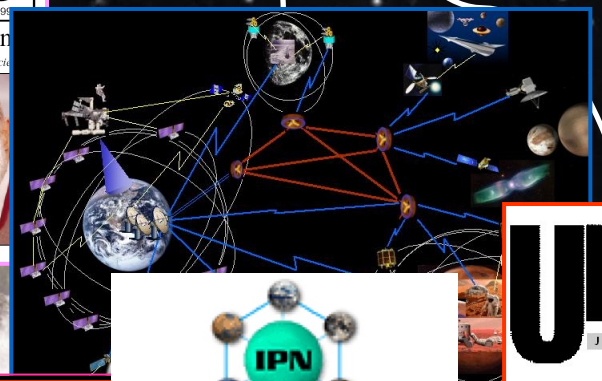
Cerf will work in concert with Adrian Hooke, manager of NASA's Space Mission Operations Standardization Program and a member of Giuf Sujilbi's staff in the Telecommunications and Mission Operations Directorate. Cerf and Hooke will be supported by a small team of technical experts drawn from the Internet community, other NASA centers, universities and the private sector to explore ways to merge the work of the Internet and space communications communities.

The first job of the team will develop a new interplanetary Internet architecture that can cope with the long transmission delays and noisy, intermittent data links inherent today in deep space communications. The traditional framework of TCP/IP will have to be radically adapted for interplanetary communications. Other challenges include the construction of interplanetary gateways and perhaps methods to provide for local caching of content—much in the same manner as many World Wide Web sites are mirrored in different geographic areas to optimize performance.

Cerf's work with JPL will also address how space missions can be made more openly accessible and exciting to the public by engaging individuals via the interplanetary Internet in voyages of interplanetary exploration and discovery. Together, Cerf and Hooke hope to enhance scientific research by allowing scien-

See Internet, page 4

Dr. Vinton Cerf



Title	Interplanetary Internet Architectural Definition
Author(s)	V. Cerf et al.
Filename	draft-irtf-ipnrg-arch-00.txt
Pages	58
Date	18-May-01

This document describes the Interplanetary Internet - a communication system to provide Internet-like services acr interplanetary distances in support of deep space

SPAWAR

EPOXI MISSION

JPL, Ball Aerospace, University of Maryland

Comet Hartley 2

National Aeronautics and Space Administration

DEEP IMPACT EXTENDED INVESTIGATION

Universe

Jet Propulsion Laboratory

May 4, 2001 Volume 31 Number 10

SPECIAL ISSUE

Charles Elachi takes the helm at JPL

ON MAY 2, JPL'S NEW DIRECTOR, DR. CHARLES ELACHI, PRESENTED THE VISION THAT WILL TAKE THE LAB INTO THE NEXT GENERATION OF SPACE EXPLORATION.

Elachi's vision incorporates the comments and ideas voiced during his three months of meetings with JPL employees, and builds on a course set by Elachi's predecessors.

Elachi told a standing-room only crowd in von Karman Auditorium that where once system, the chall in our solar syst discover and und To maintain the stressed sharing with the most im In the next 10 some 25 payload announced a roo stated five reaso to promote prog for technology a

will be responsible for the projects and programs as well as for the associated science and technology.

Thomas Gavin has been appointed to the new position of JPL Associate Director for Flight Projects and Mission Success. This position was

Director Elachi's 2020 vision

Internet Society GENEVA

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BACK

TOPICS

SECTION

- Internet Society Geneva et ORBITAL lancent un site de streaming medias!
- Internet

Internet Research Task Force ready for the new

ISOC-GVA Home : Press : Internet Research Task Force ready for the new Mil

FOR IMMEDIATE RELEASE
7 December 1999
RESTON, VA USA
INTERNET SOCIETY

Summary

With next generation Internet research programs now occurring all over the world, the Internet Research Task Force (IRTF) is more than ever the primary vehicle for coordinating these activities. The Internet Architecture Board (IAB) has therefore appointed Erik Huizer as the new chair of the IRTF. New Research Groups are being introduced that are working on diverse research issues, including a particularly challenging study of the problems that have to be solved as the Internet moves off the Earth - the "Interplanetary Internet".

IPN

InterPlaNet

InterPlanNet iSIG

Discusses issues related to the application of the Internet in outer space.

Interplanetary Internet and Information Systems

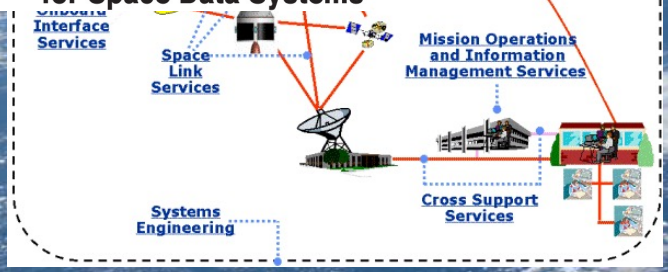
Besides listening to all of you, I also spoke to people outside of JPL who shared their advice with me. I often asked: "What is the most unique thing about JPL? What capabilities, what assets do we have that can be found nowhere else?"

I heard many answers. But one that kept coming up was the Deep Space Network. We now need to create the next generation of the Deep Space Network. And that requires creating the interplanetary Internet of the next 20 years. This is a very exciting challenge. The DSN will be the backbone for this network, and the spacecraft we will have across the solar system and around Earth are information nodes that will interconnect to our network across the Lab and to the World Wide Web.

Consultative Committee

CCSDS

for Space Data Systems

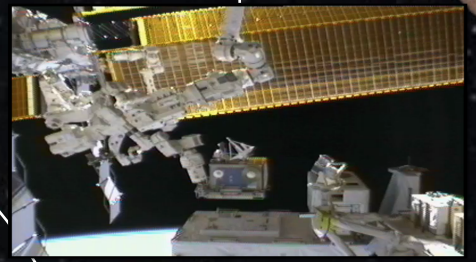


Development Phase

Delay/Disruption-Tolerant Networking

2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

JAXA DRTS



ISS – SCaN TESTBED

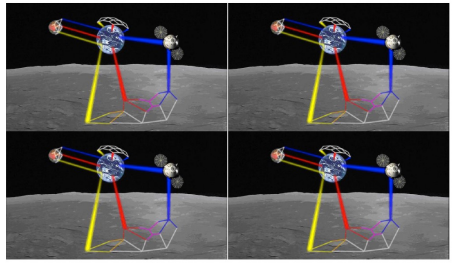
ECOSTRESS

ISS Missions
ECOSTRESS
CAL
+ ~38 others

Interagency Operations Advisory Group
Space Internetworking Strategy Group

Operations Concept for a
Solar System Internetwork (SSI)

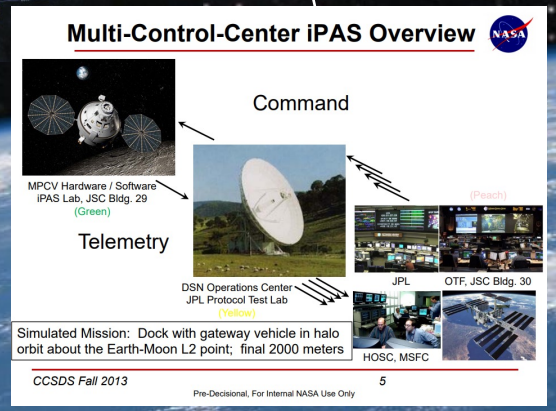
15 October 2010

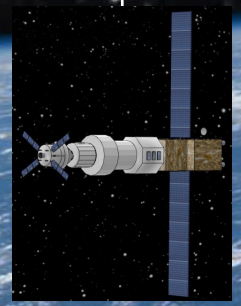


Cover art background: SELENE HDTV image provided by JAXA/NHK

Infusion Phase

LADEE/LLCD





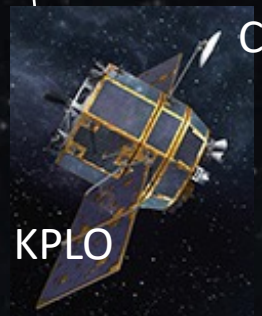
(planned) DTN on
Lunar Gateway

Delay/Disruption-Tolerant Networking

2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030

Deep Space Network

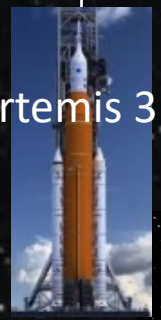
Cubesats



KPLO

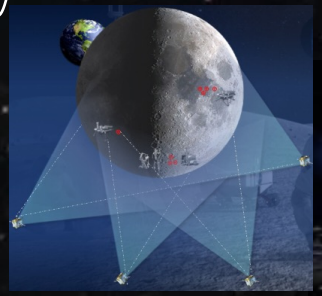
DSS-17 – 21m Morehead

PACE



Artemis 3

Lunar Gateway

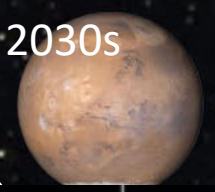


LCRNS

HLS

Artemis 4

Artemis 5



MarsNet 2030s

Moonlight (ESA)
CLPS?
Firefly Orbiter?
KLL?
Other International?

Operational Phase

DTN Standardization

The Primary Standardization Organization

RFC Number	Title / Function	Year
RFC 4838	DTN / Disruption-Tolerant Networking Architecture	2007 /2026
RFC 5050	Bundle Protocol Specification (BPv6)	2007
RFC 6258	BP Metadata Extension Block	2011
RFC 6259	BP Previous-Hop Insertion Block	2011
RFC 7122	Datagram Convergence Layers (UDP, DCCP)	2014
RFC 7242	TCP Convergence-Layer (TCPCL v3)	2014
RFC 9171	Bundle Protocol Version 7 (BPv7)	2022
RFC 9172	Bundle Protocol Security (BPSec)	2022
RFC 9173	Default Security Contexts for BPSec	2022
RFC 9174	TCPCL v4 (for BPv7 with CBOR, security, etc.)	2022
RFC 9675	DTN Management Architecture (DTNMA)	2024
RFC 9713	BPv7 Administrative Record Types Registry	2025

Standardization Organization for Space Applications

CCSDS No.	Title / Purpose	Type & Status
730.1-G-1	SSI Architecture overview / top-level architecture	Green Book (Informational)
734.0-G-1	DTN rationale, scenarios, and requirements in space	Green Book (Informational)
730.2-G-1	Concepts and Rationale for Streaming Services over Bundle Protocol	Green Book (Informational)
734.2-B-1	Bundle Protocol (DTN core protocol) specification (BPv6)	Blue Book (Recommended Standard)
734.2-P-1.1	Bundle Protocol (DTN core protocol) specification (BPv7)	Pink Book (Recommended Standard -- in test to become Blue)
734.20-O-1	Bundle Protocol (DTN core protocol) specification (BPv7)	Orange Book (Experimental)
734.3-B-1	Schedule-Aware Bundle Routing	Blue Book (Recommended Standard)
734.1-B.1	Licklider Transmission Protocol (LTP)	Blue Book (Recommended Standard)
734.5-R-2	Bundle Protocol Security	Red Book (Draft Recommended Standard)
(OTHER)	Several drafts for specs for BIBE, IMC, plus links, coding, modulation, etc.	Drafts or other Bluebook Specs


Questions?