

The Interplanetary Network

*a strategy for
building re-usable international
space communications infrastructure*

International Conference on
Space Mission Challenges for Information Technology
(SMC-IT)

Pasadena, California, USA

15 July 2003

Adrian J. Hooke

Jet Propulsion Laboratory

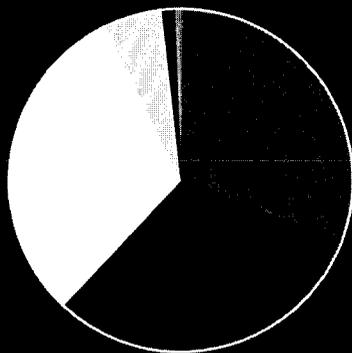
California Institute of Technology

- ***Re-usable***
 - **Standardized**
- ***International space communications infrastructure***
 - **An international “Interplanetary Internet”, with components on Earth and in space contributed by multiple space organizations, that accretes and becomes increasingly capable as a function of time.**

Users on the Internet: September 2002

- CAN/US - 182.67M
- Europe - 190.92M
- Asia/Pac - 187.24M
- Latin Am - 33.35M
- Africa - 6.31M
- Mid-east - 5.12M

• Total - 605.6 M



□ CAN/US

□ Europe

■ Asia/Pac

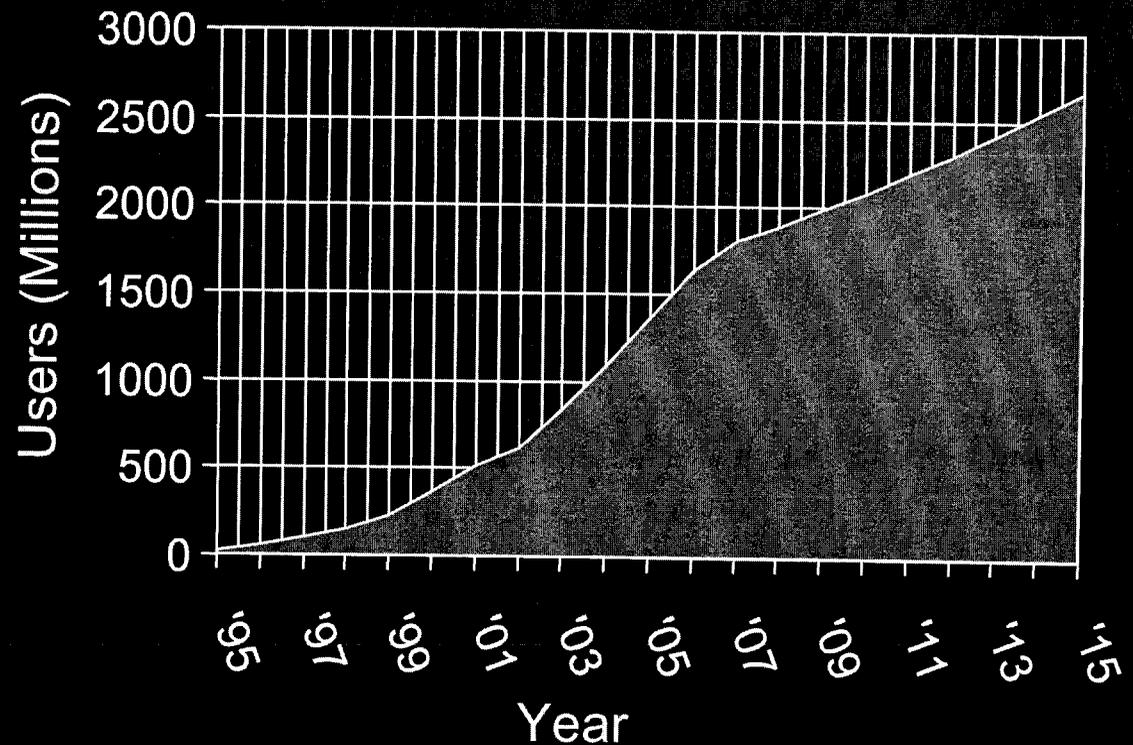
■ Latin Am

□ Africa

□ Mid East

(Source www.nua.ie)

Internet User Trends

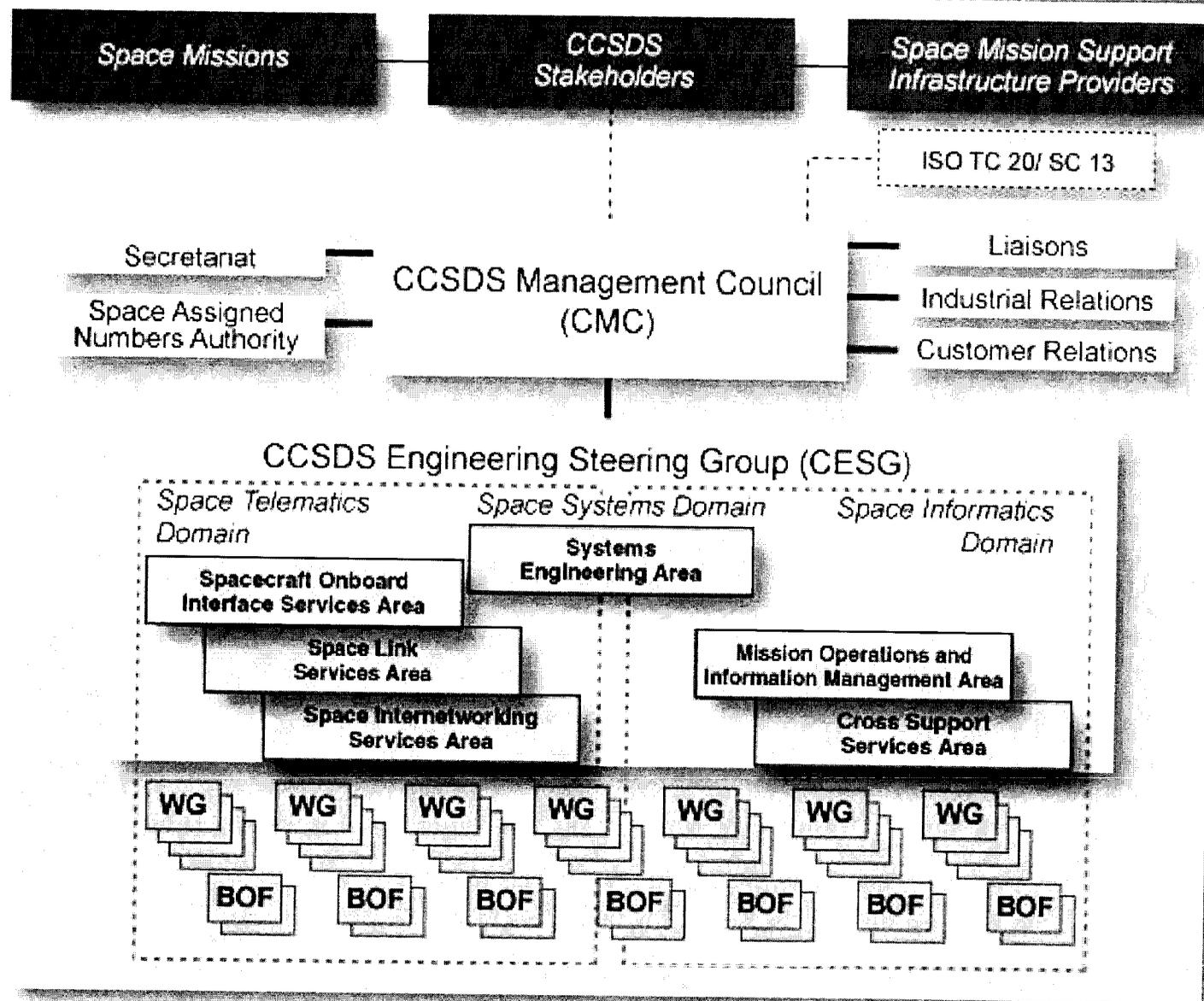


Estimate revised 4/2003

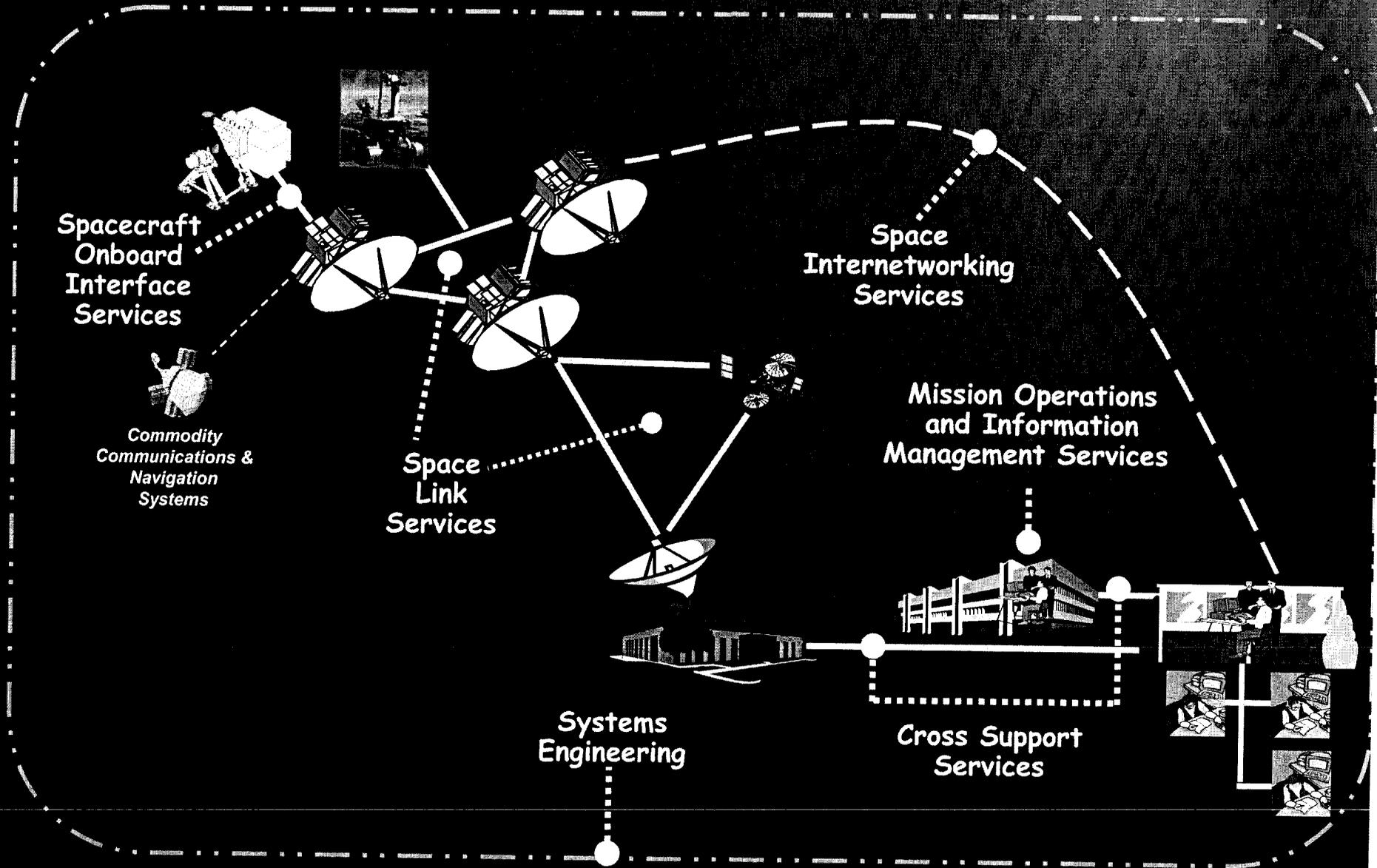
Source: Nua Internet Surveys + vgc projections

Consultative Committee for Space Data Systems (CCSDS)

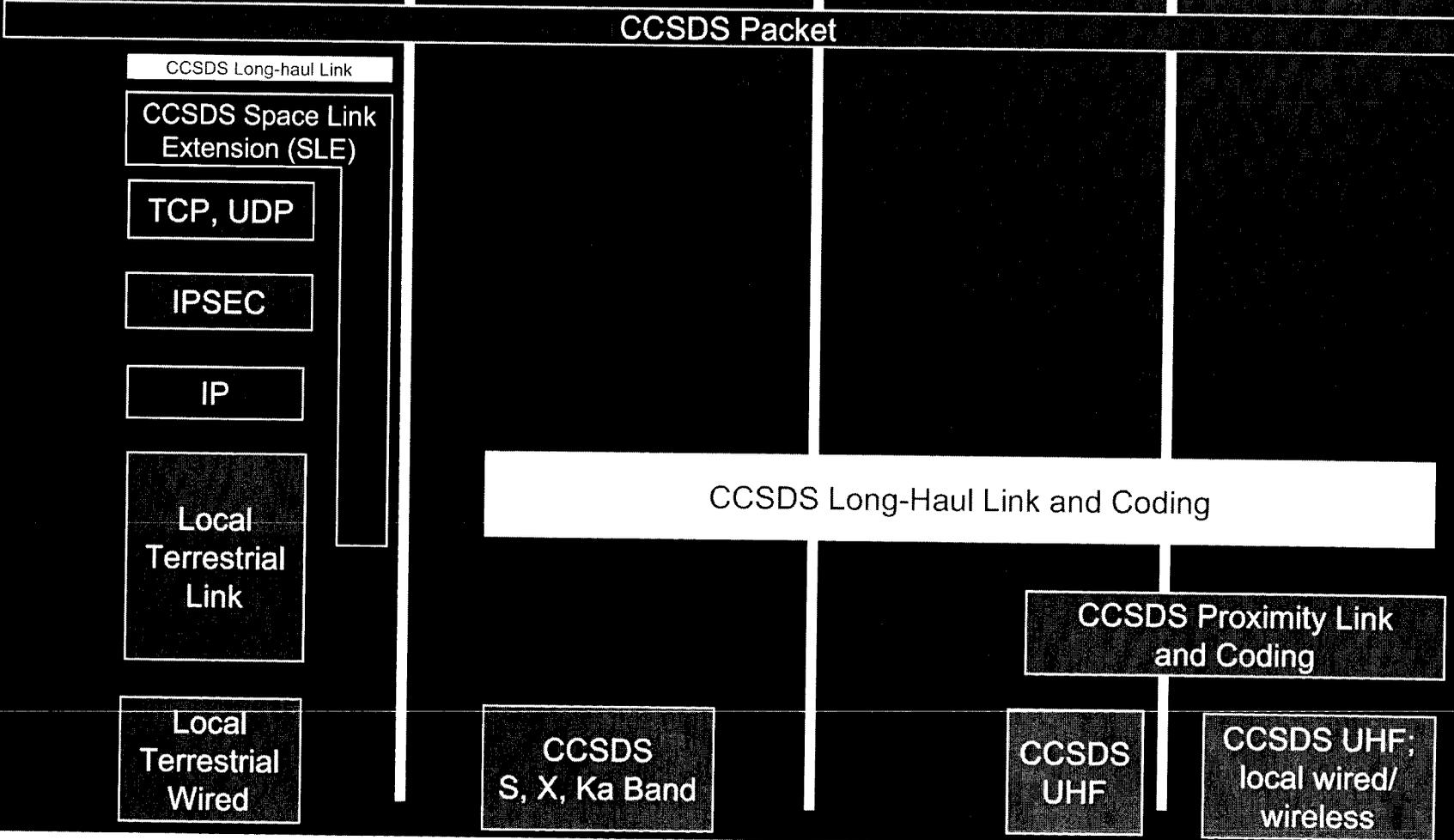
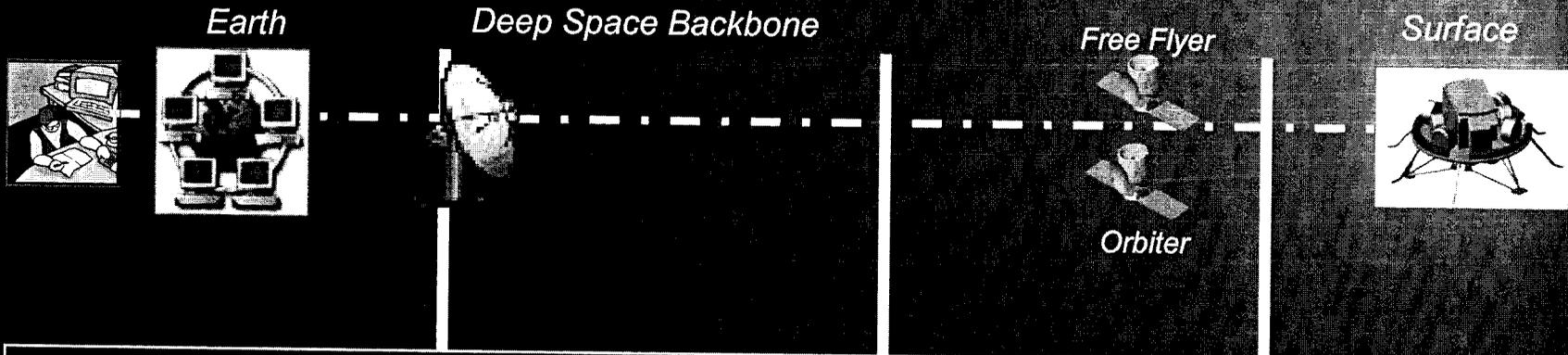
ASI/Italy
BNSC/UK
CNES/France
CSA/Canada
DLR/Germany
ESA/Europe
INPE/Brazil
NASA/USA
NASDA/Japan
RSA/Russia
ASA/Austria
CAST/China
CRC/Canada
CRL/Japan
CSIR/South Africa
CSIRO/Australia
CTA/Brazil
DSRI/Denmark
EUMETSAT/Europe
EUTELSAT/Europe
FSST&CA/Belgium
HNSC/Greece
IKI/Russia
ISAS/Japan
ISRO/India
KARI/Korea
MOC/Israel
KFKI/Hungary
NOAA/USA
NSPO/Taipei
SSC/Sweden
SUPARCO/Pakistan
TsNIIMash/Russia
USGS/USA



Scope of the Areas



Current CCSDS Protocol Scenario



CCSDS: The Fleet

Space Domain
Spacecraft Platforms
On-Board Systems
Space Qualified ASICs

CCSDS
Consultative Committee for Space Data Systems

256 Missions now using
CCSDS Space Link Protocols
<http://www.ccsds.org/CCSDS/missions.jsp>

Ground Domain
Commercial Ground Networks
Command & Telemetry Data Processing

Shuttle CS Gateway



1970

1980

1990

2000

NASA Telemetry Standardization

"Packet" Spacecraft Telemetry and Telecommand



02 January, 1996
STRV-1b
IP address:
192.48.114.156

Baselined by Space Station and Ground Network

NASA/ESA Working Group

Basic Space/Ground Communications Standards for Space Missions



Consultative Committee for Space Data Systems (CCSDS)

CCSDS Recommendation for Advanced Orbiting Systems

International Space Station

File Transfer: FTAM
Transport: TP4
Network: ISO 8473

The Dark Age Of GOSIP

Extension of Standards for More Complex Space Missions

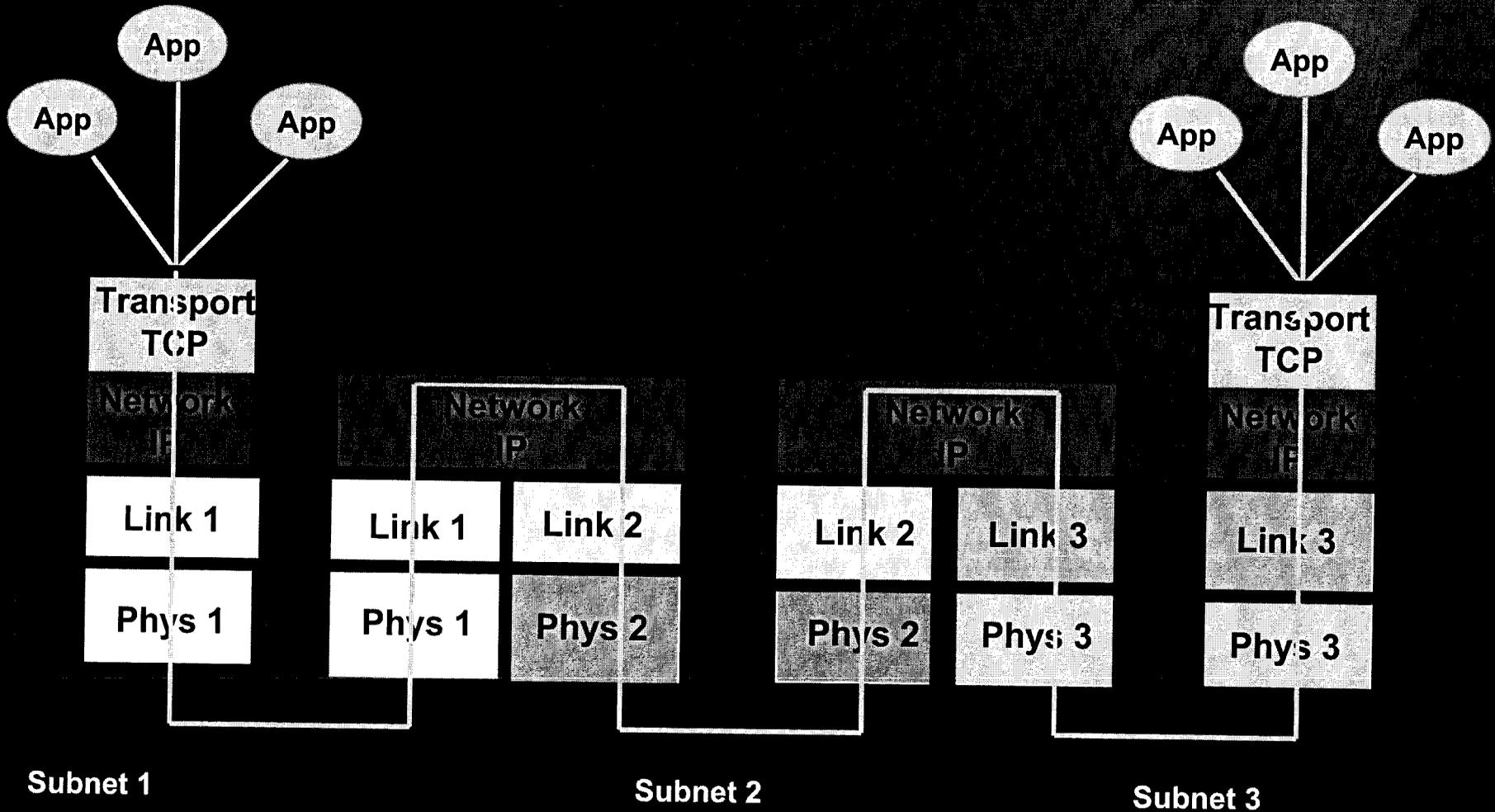
Extension of the Terrestrial Internet into Space

NASA/DOD/CCSDS Space Communications Protocol Standards (CCSDS-SCPS) Project

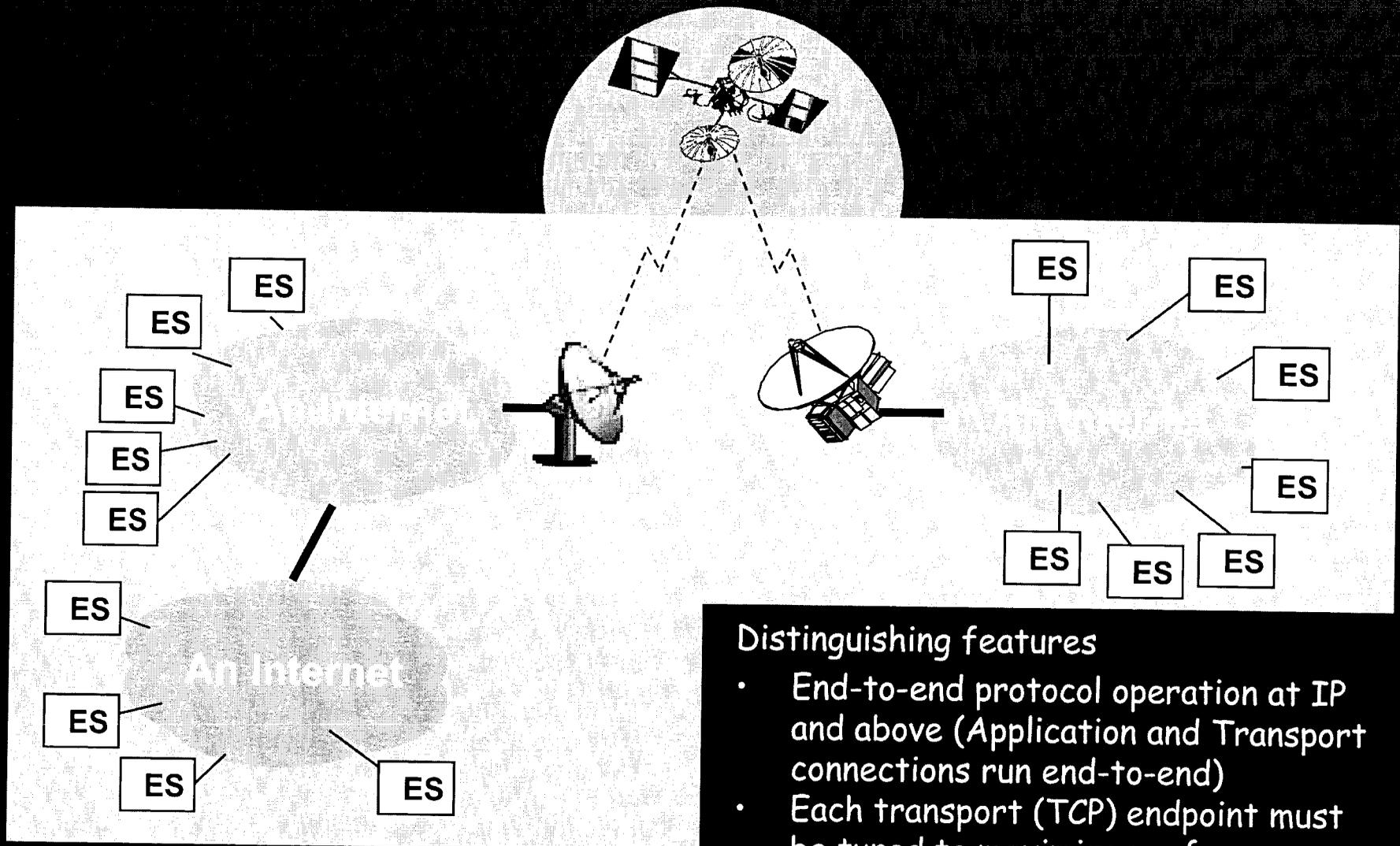
File Transfer: FTP
Transport: TCP
Network: IP



The Internet: a Network of Connected Sub-Networks



Internet-in-Space Architectural Alternatives: 1. End-to-End Operation



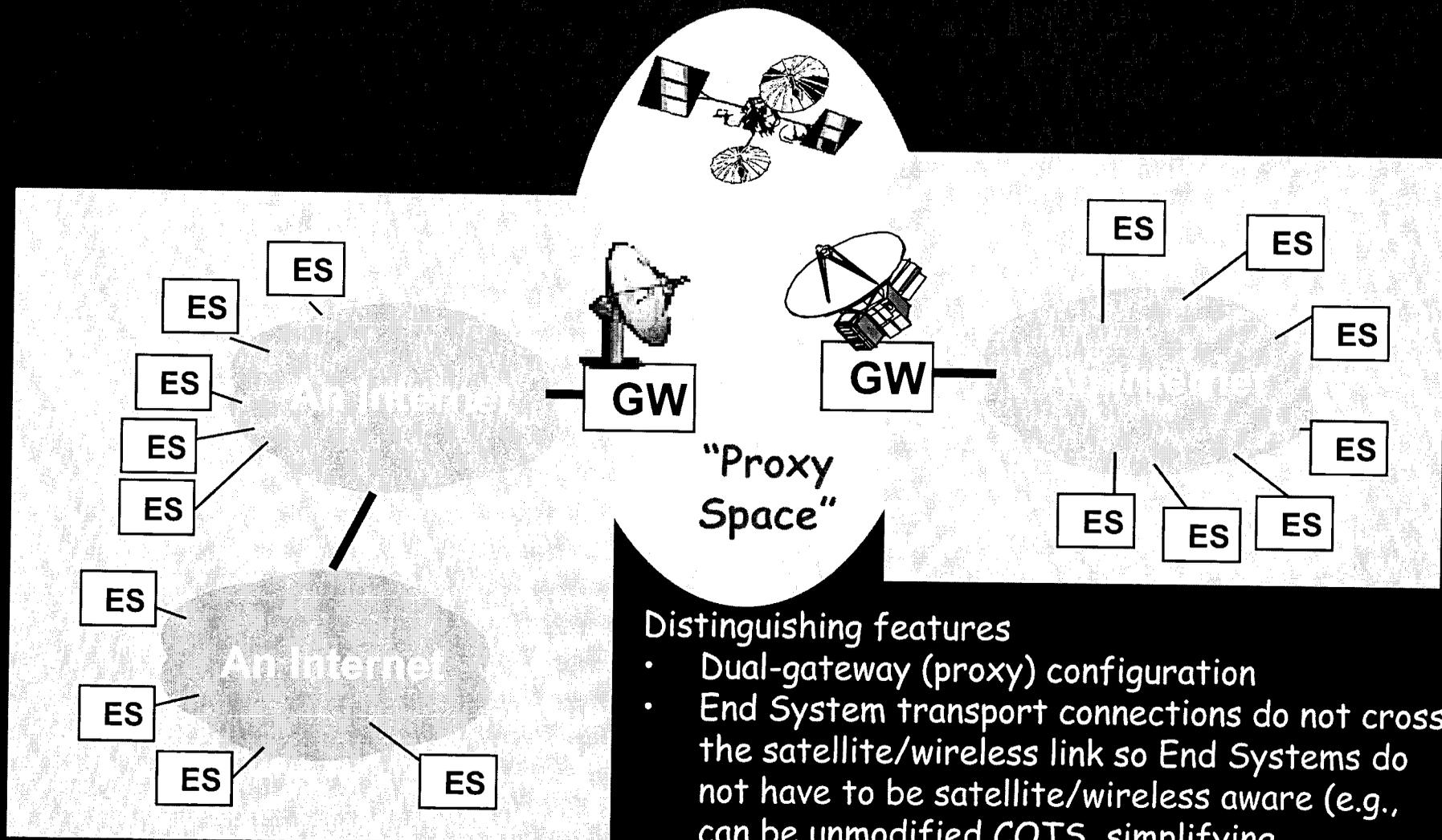
Distinguishing features

- End-to-end protocol operation at IP and above (Application and Transport connections run end-to-end)
- Each transport (TCP) endpoint must be tuned to maximize performance and utilization over satellite link

ES = End System

Internet-in-Space Architectural Alternatives:

2. Proxy-Based Operation



ES = End System
GW = Transport Layer Gateway (Proxy)

Distinguishing features

- Dual-gateway (proxy) configuration
- End System transport connections do not cross the satellite/wireless link so End Systems do not have to be satellite/wireless aware (e.g., can be unmodified COTS, simplifying deployment)
- Security above transport or via trusted gateways

Current CCSDS Space Internet Protocol Options

Space extensions to FTP

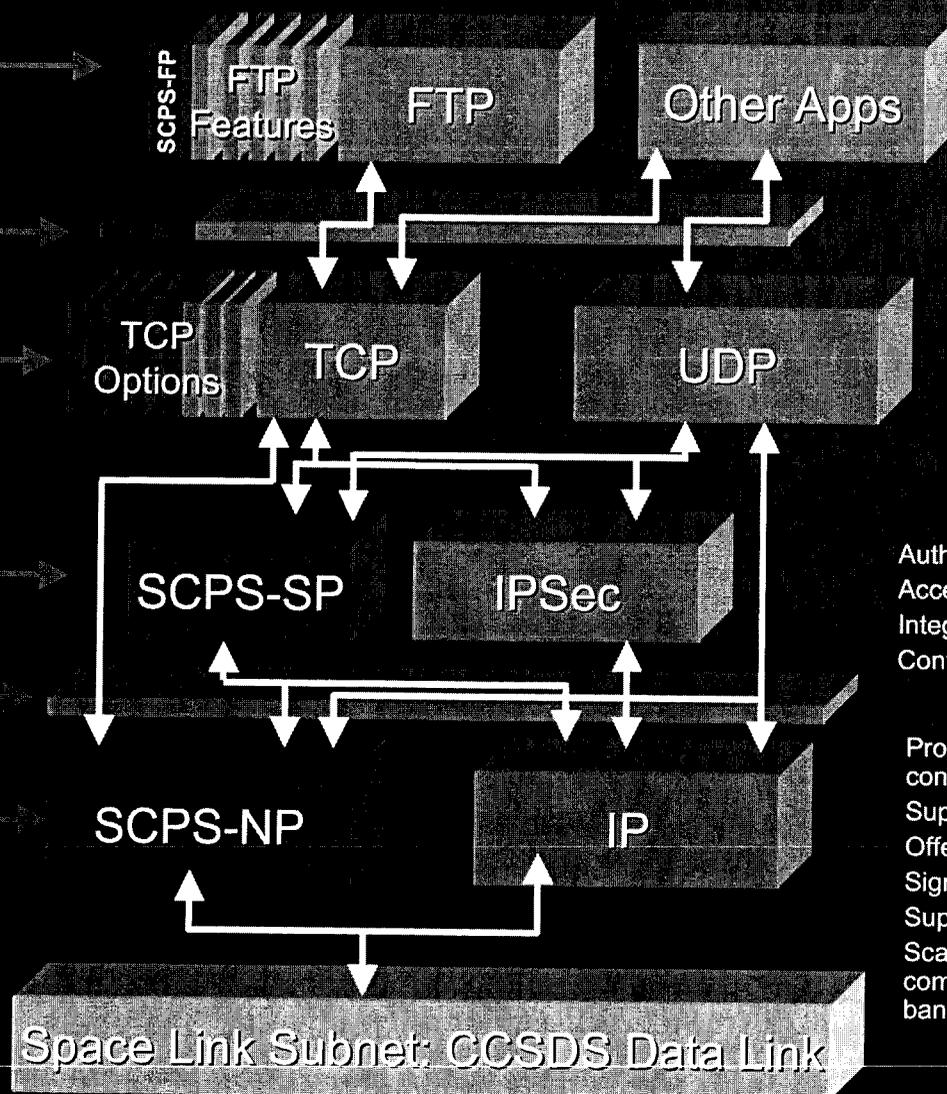
Space extensions to the Socket Interface

SCPS-TP "TCP Tranquility" options

Space-optimized IPsec variant

Common Network-Layer Interface

Space-optimized IP variant



Record read & record update;
File & record Integrity;
Automatic restart;
User suspend/resume;
Suppress ASCII reply codes.

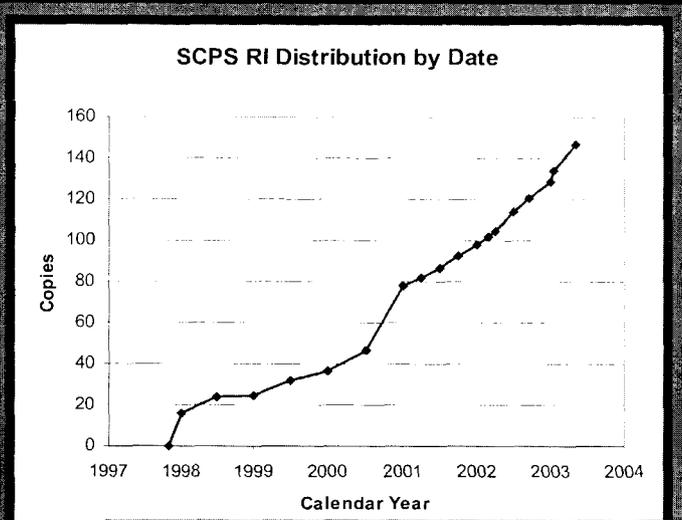
Congestion control appropriate for mixed-loss environments (congestion, corruption, outage);
Selective negative acknowledgment;
Robust header compression;
Partial Reliability service (BETS);
Delimitation of record boundaries;
RFC 1323: Window scaling, time stamps, sequence number extension

Authentication: guarantee of the identity of a source;
Access Control: prevention of unauthorized access;
Integrity: protection against modification;
Confidentiality: protection from disclosure.

Provides both connectionless and managed-connection routing;
Supports precedence (priority) based handling;
Offer multiple routing options;
Signals errors to the layer above;
Supports packet lifetime control;
Scalable - tailor capability to need, e.g., high communications efficiency in constrained bandwidth conditions.

The CCSDS protocol suite supports either "native" or "space enhanced" Internet services, at the discretion of the Project organization

SCPS Reference Software



NetAcquire
Distributed Systems for Test, Measurement, and Communication

Home Search Products News Services Careers Support

APPLICATIONS
Telemetry
Aerospace Test
Communication
Remote Monitoring
Industrial Automation
Protocol Conversion
Simulation
Extreme Applications

HARDWARE
Overview
Analog I/O
Serial I/O
Digital I/O
GPIB/IEEE-488
Digital Multimeter
Hardware Gate Array

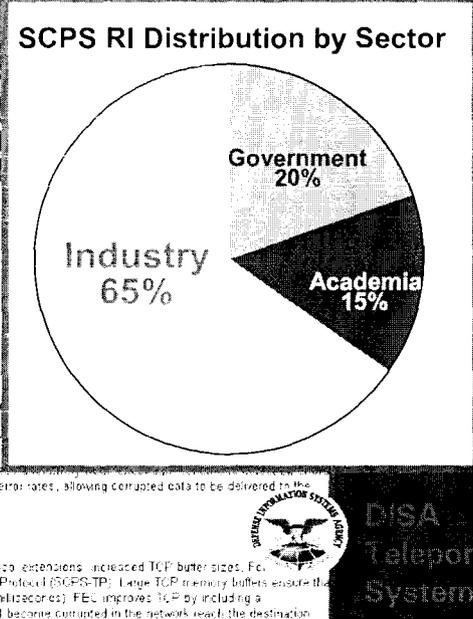
SOFTWARE
Overview
WWW Server
Data Storage
PublicKeySubscribe
Java Toolkit
Windows Toolkit
Time Server
Extension Toolkit
Decommutation
CCSDS

Communications on Degraded Networks
Certain applications, especially those involving space communications links, require special operation. The NetAcquire server contains advanced networking technology to support specialized network environments. Plain TCP, in particular, performs poorly over propagation delay and significant bit errors.

Limitations of TCP
A key limitation with TCP in high bit error networks is the lack of error correction. Single bit within a packet is corrupted in transit, the receiver will discard the whole packet. In addition, TCP can recover from the loss of only one packet per round trip. If it can tolerate only one packet loss per 500 milliseconds. To illustrate the impact, for a bit error rate of 10^{-5} , TCP can send data at a maximum rate of 200 kbps.

Another limitation of TCP is the strength of its data corruption protection. TCP uses checksums to protect data in each packet. The approach fails to detect bit errors relatively often at high bit error rates, allowing corrupted data to be delivered to the application undetected!

NetAcquire TCP Enhancements and SCPS
NetAcquire Corporation has enhanced TCP by implementing three network protocol extensions: increased TCP buffer sizes, Forward Error Correction (FEC), and Space Communications Protocol Specification-Tier 1 Protocol (SCPS-TP). Large TCP memory buffers ensure that maximum throughput is achieved even when network delay is long (up to 1000 milliseconds). FEC improves TCP by including a Reed-Solomon Forward Error Correction code in each packet. Most packets that become corrupted in the network reach the destination.



Apple Acrobat - [ShareGate_Datatest.pdf]

File Edit Document Tools View Window Help

SNAPgear

Microsoft Internet Explorer - [http://www.sharegate.com/Products/Information/NetAcquire] The file you are connecting to...

SKIPWARE
THE NEXT GENERATION of wireless protocol products, research & consulting

About Technology Solutions Support

Global Science & Technology, Inc. is the world leader in Internet-over-Satellite performance enhancement. Specializing in the implementation of SkipWare™, the industry's first commercial implementation of the Space Communications Protocol Standards (SCPS) for satellite and hybrid networks.

XipLink Gateways
Accelerated Internet over Satellite in a box.

XipLink Gateways are full hardware units that makes the most of your bandwidth in stressed communications environments.

The XipLink Gateway includes all of the features of our XipLink technology for optimized TCP performance by including:

- Fast Start Technology
- Rate Control Options
- Header Compression
- Faster retransmissions

XipLink Gateways are protocol gateways as well known as performance enhancers to provide implementing an open, internationally recognized standard. Compatibility with existing TCP/IP systems makes deployment easy. They are highly configurable and customizable to address your specific needs. In addition, they are designed to support the unique requirements of XipLink technology with an "out of the box" configuration. A web-based interface is provided to make the effective tracking of performance gains with terrestrial networks.

XipLink SCPS-TP

IP communications through stressed links

High performance, robust feature-rich implementation

Hotlens

May 2, 103

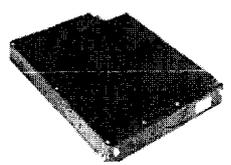
Home
Products
Download
About

Making high speed solutions practical

Bandwidth TurboBooster™ 1.0

- Are you looking to increase your satellite or terrestrial network access speed?
- Are you looking to deliver your corporate applications faster to your remote offices?
- Are you looking to expand your network capacity?

Bandwidth TurboBooster™ is an ideal and cost effective solution for ISPs and enterprises to provide high speed Internet access and fast applications delivery through satellite, wireless and long-haul terrestrial networks that have significant network latency and packet loss.



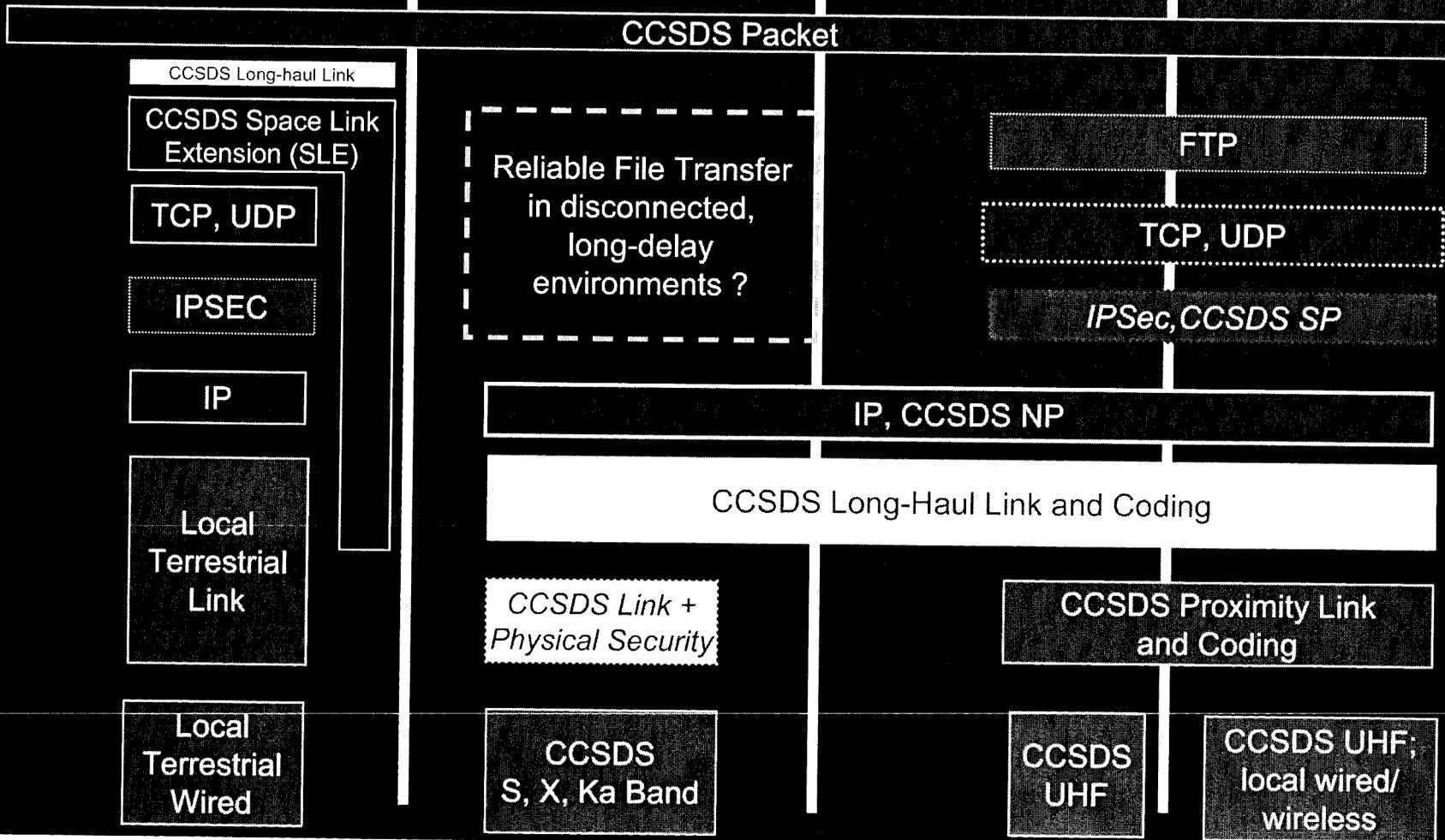
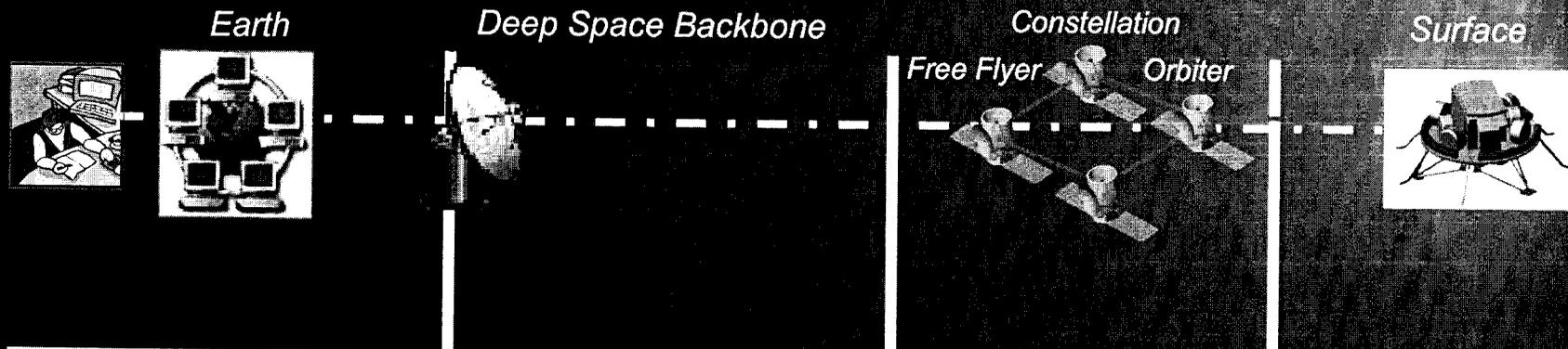
How does it work?

Bandwidth TurboBooster™ implements the latest NASA and DOD SCPS TCP acceleration as well as data compression technology to deliver 5 - 30 times faster data transfer depending on network latency, packet loss and utilization.

It accelerates TCP traffic through SCPS technology which includes window scaling, selective negative acknowledgement, improved congestion control and acknowledgement strategies for highly asymmetric communication channels.

13

"Space Internet" CCSDS Protocol Scenario



CFDP Build 1 - Blue Book 1 - Spring 2002

- ❖ 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
- ❖ CFDP "Build 1" provides non-routed, non-custodial delivery through a single hop.

It supports:

- the user application

And consists of:

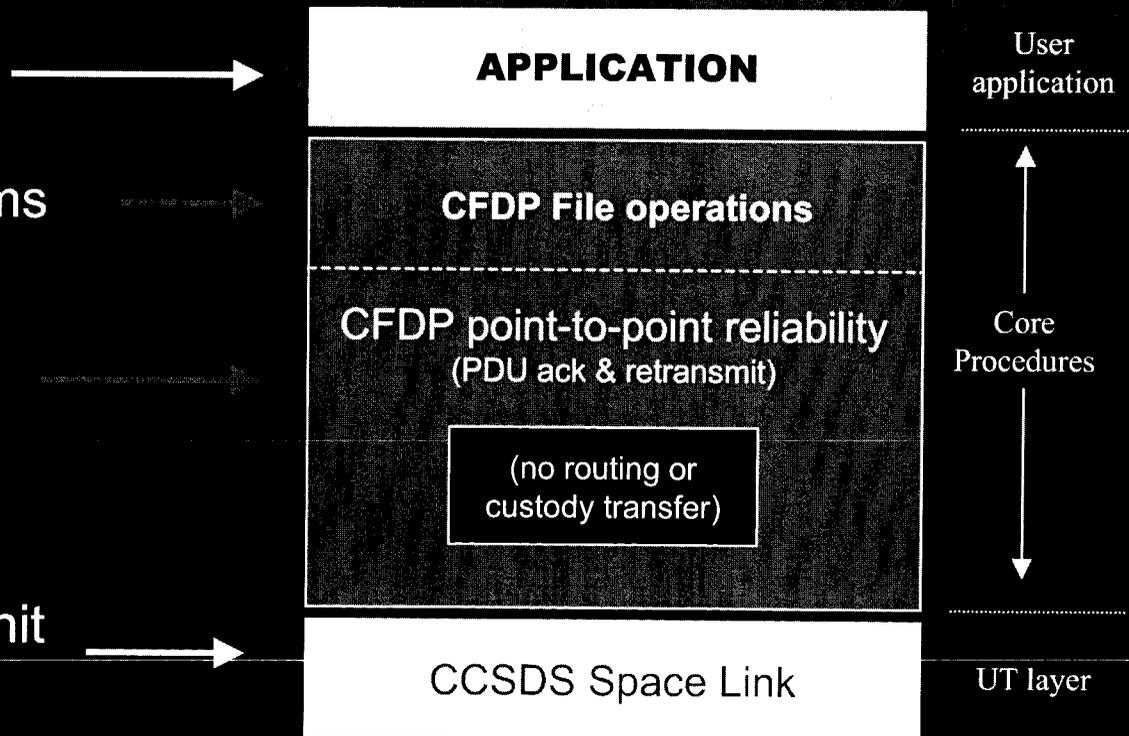
- file handling mechanisms

+

- point-to-point reliability mechanisms

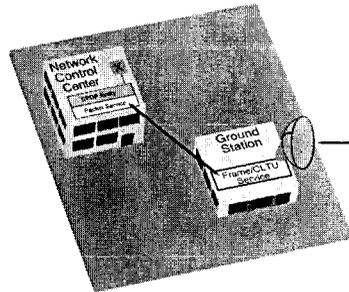
It draws upon:

- underlying space link unit data transfer services



CFDP Operations Scenarios

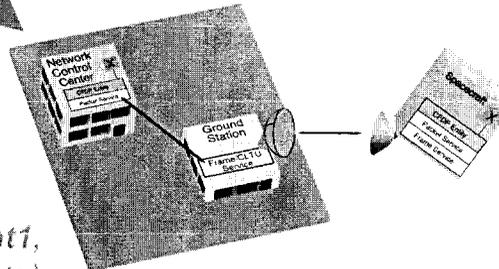
Build 1 CFDP



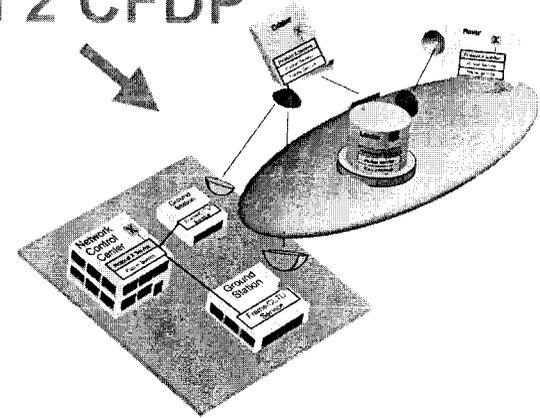
1. point-to-point,
unacknowledged

*Currently in
deployment (AISat1,
DI, JWST, MRO, etc)*

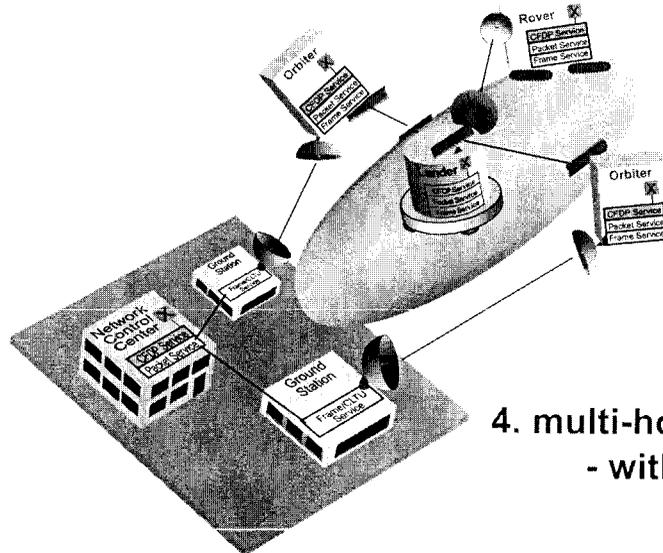
Build 2 CFDP



2. point-to-point,
acknowledged



3. multi-hop, in series

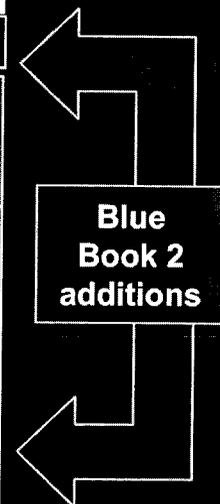
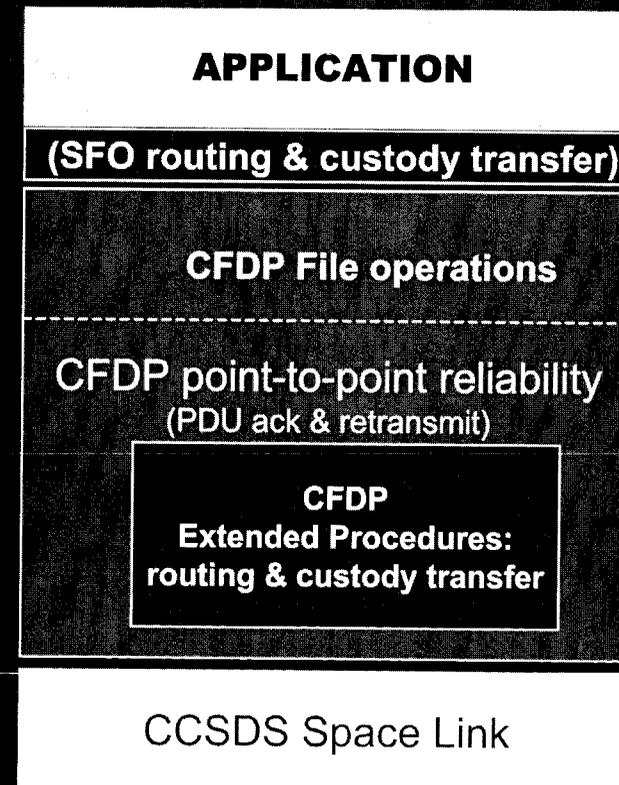
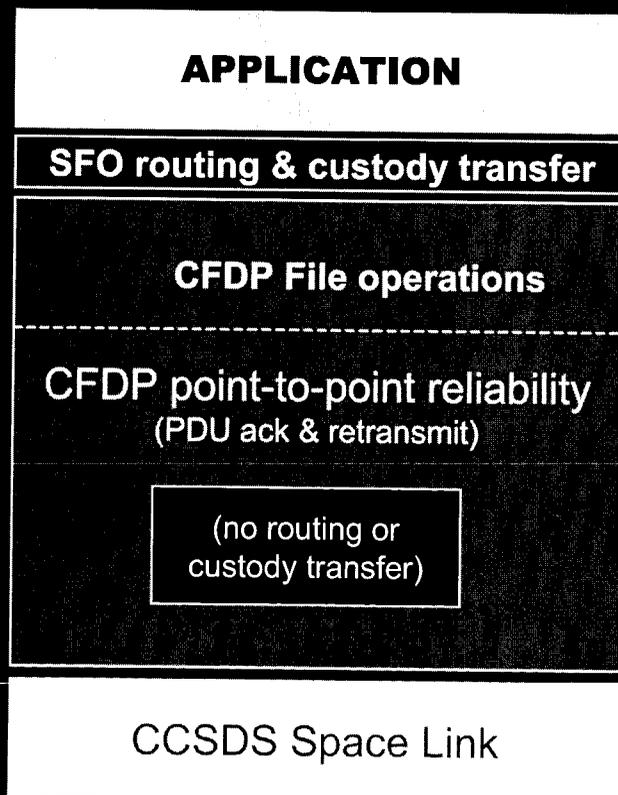


4. multi-hop, in parallel
- without cross-links

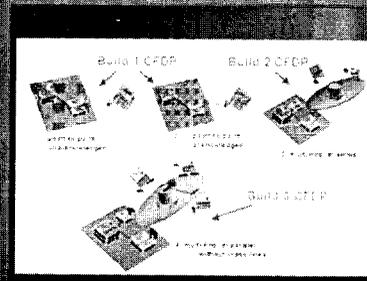
Build 3 CFDP

CFDP Build 2 - Blue Book 2 - Autumn 2002

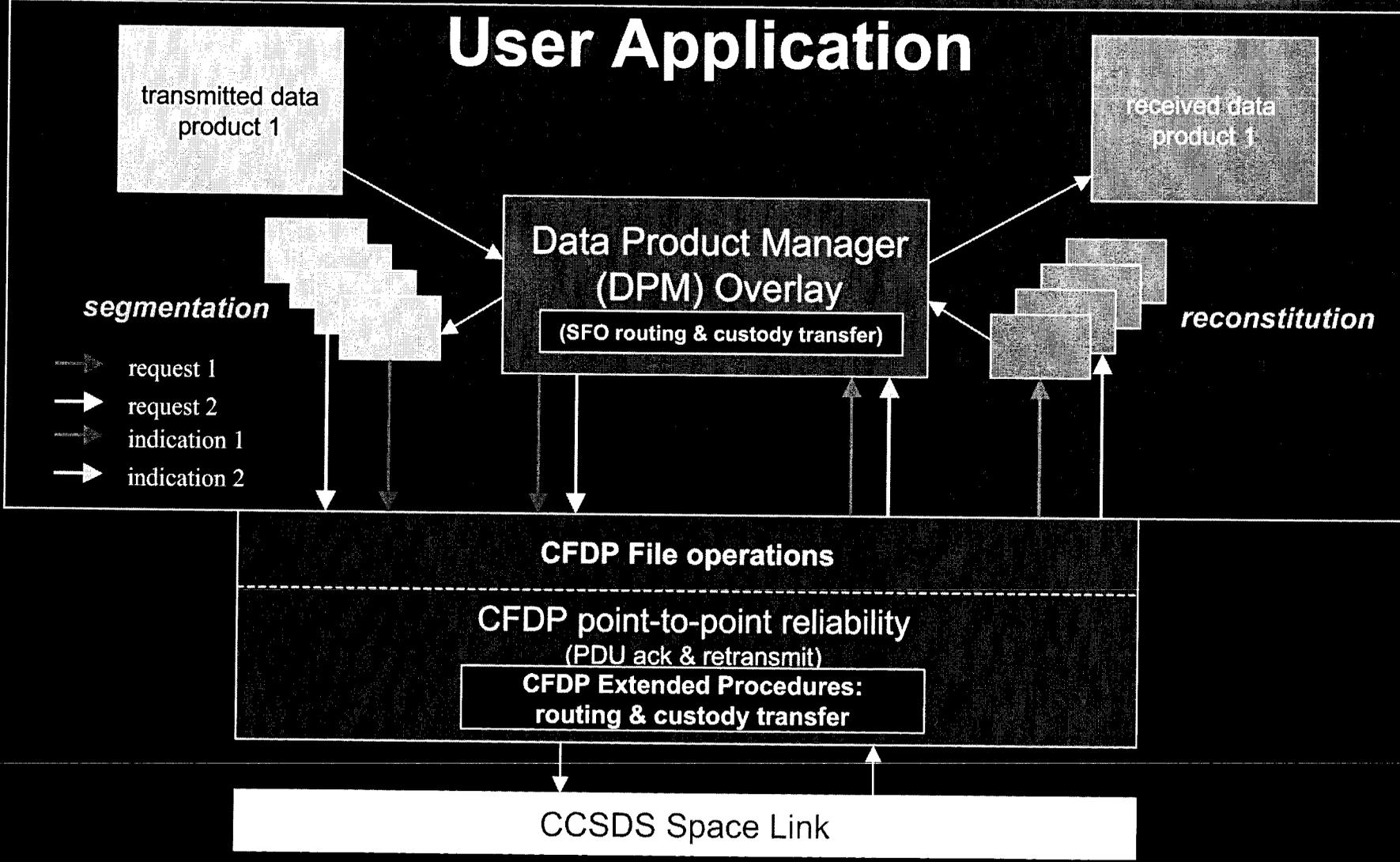
- Supports Scenario 3 (multi-hop, serial transfer) using either - or both - of two mechanisms:
 - A Store-and-Forward Overlay (SFO) that uses unmodified Build 1 and is not part of CFDP. This application code provides multi-hop routing and custody transfer services
 - Additional "Extended Procedures" 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



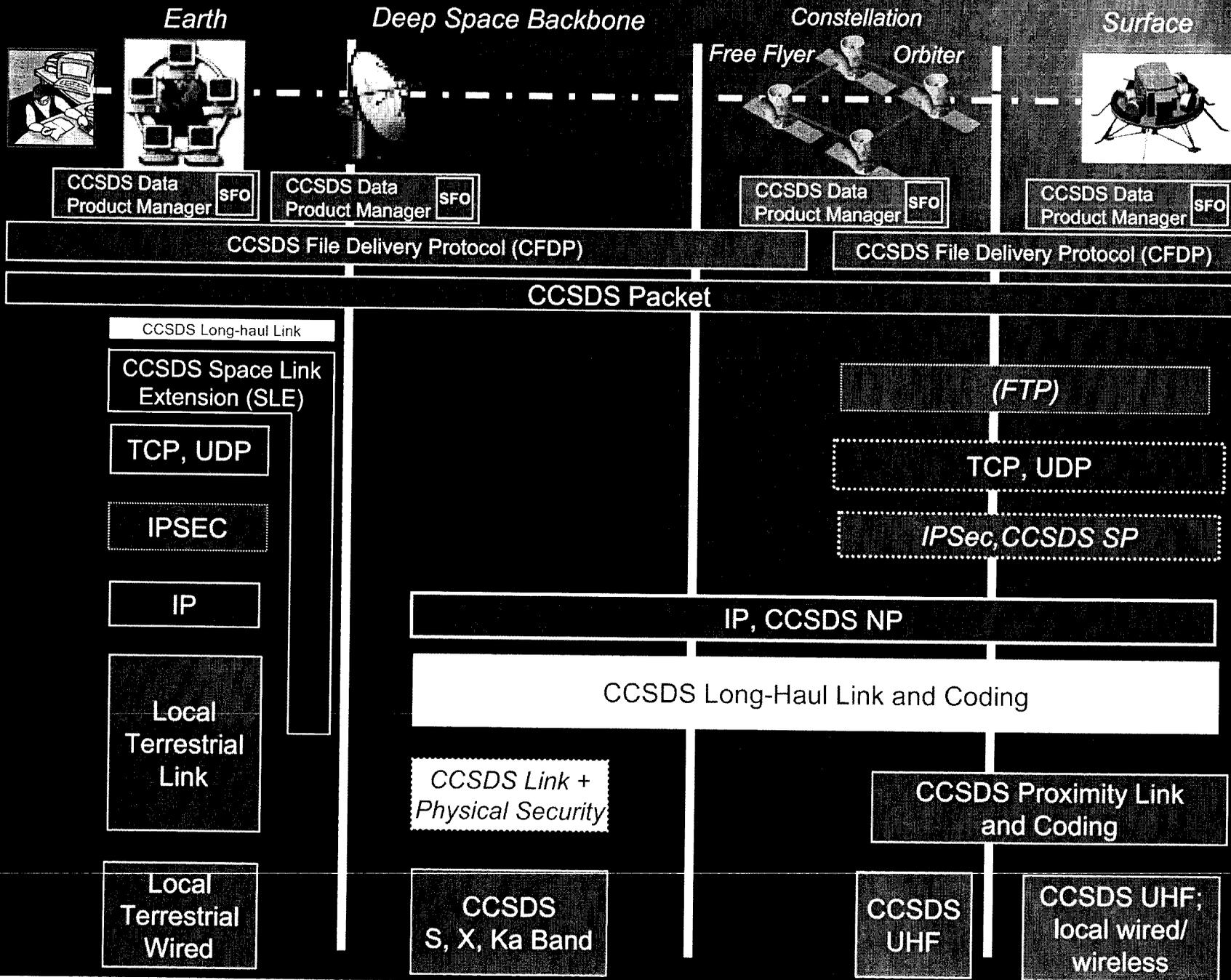
- As an interim measure to support “Mars Network” operations, Scenario 4 (multi-hop, parallel transfer) can also be supported by an *additional* “Data Product Manager” application overlay. The DPM segments user products into pieces that are small enough to transfer as independent CFDP files during a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



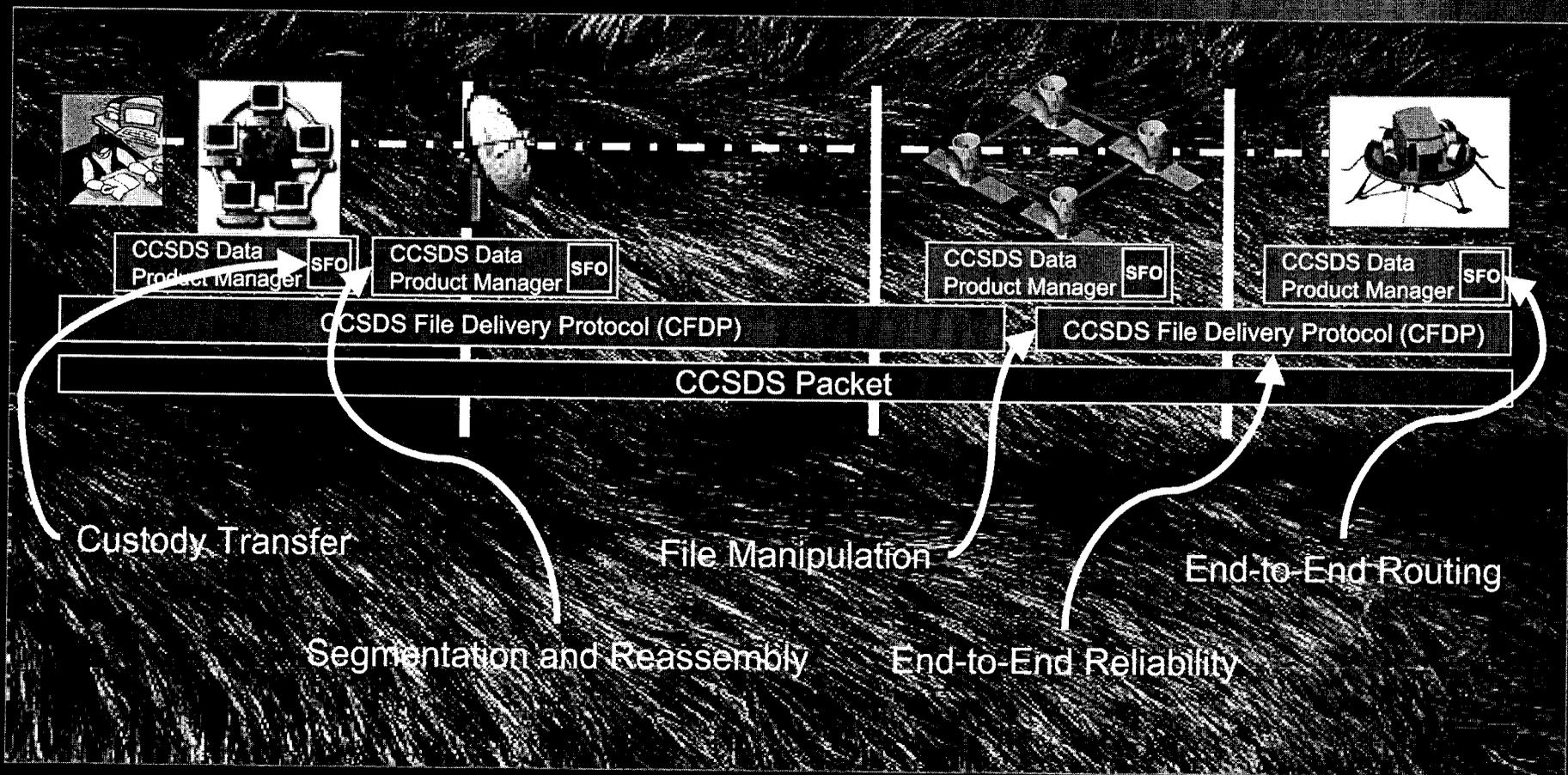
User Application



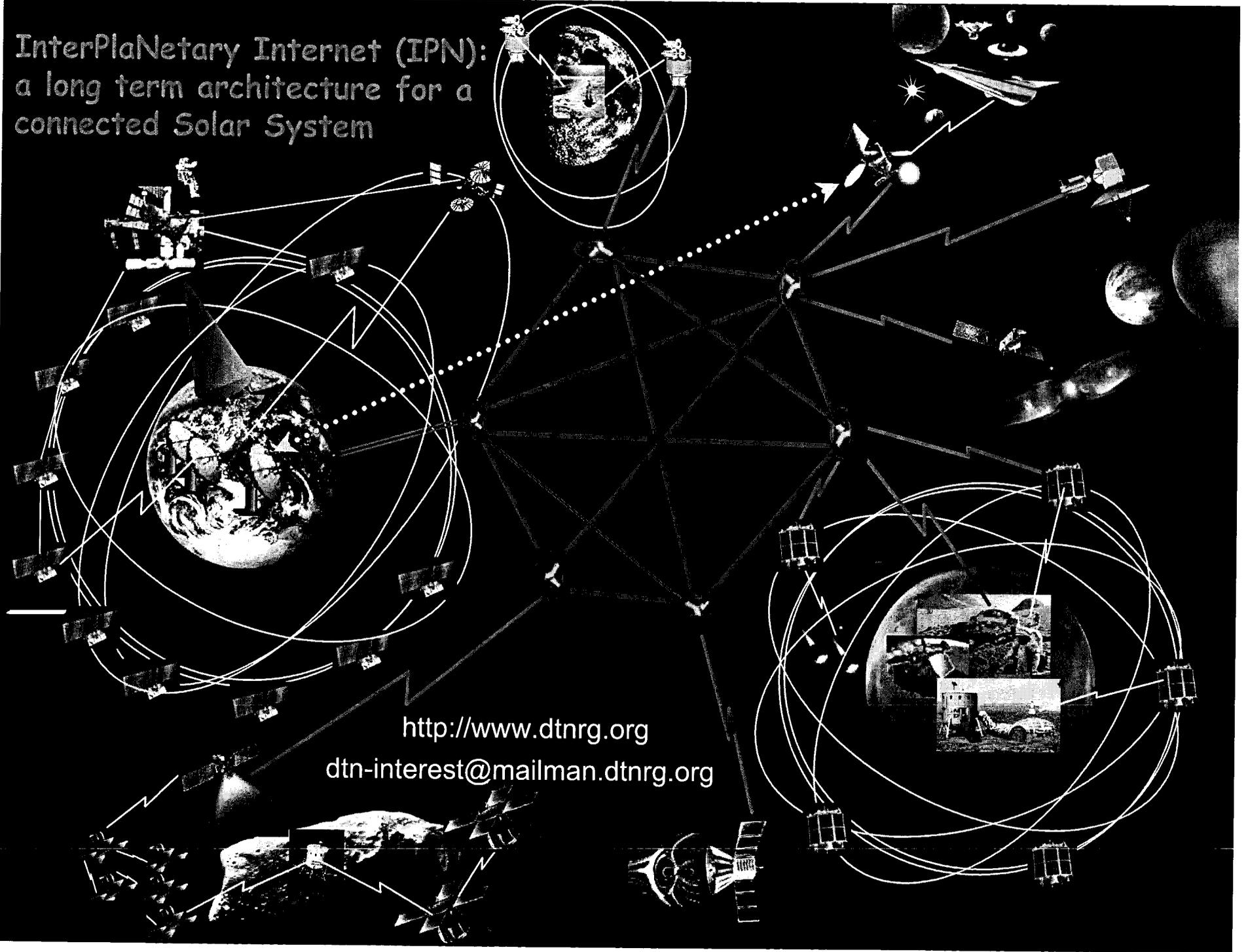
"CFDP-Era" (2005+) CCSDS Protocol Scenario



There's a lot of hair starting to grow in the Application layer.....



InterPlaNetary Internet (IPN):
a long term architecture for a
connected Solar System



<http://www.dtnrg.org>
dtn-interest@mailman.dtnrg.org

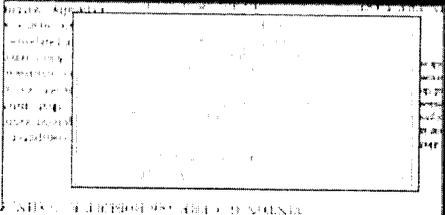
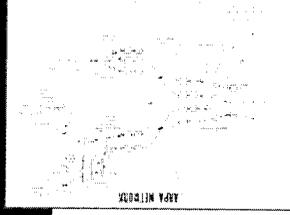
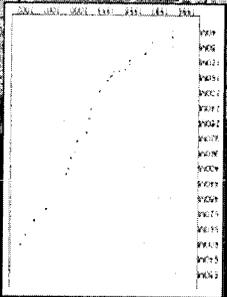


Evolution of the terrestrial Internet



InterPlanetary
Internet (IPN)

2002:
605
million
users



A Protocol for Packet Network Intercommunication



Evolution of space standards

Extension of the Terrestrial Internet into Space

Extension of Standards for More Complex Space Missions

Basic Space/Ground Communications Standards for Space Missions

The Dark Age of 30SIP
File Transfer: FTAM
Transport: TP4
Network: ISO 8473

International Space Station

CCSDS Recommendation for Advanced Orbiting Systems

Consultative Committee for Space Data Systems (CCSDS)



NASA/ESA Working Group

NASA Telemetry Standardization

"Packet" Spacecraft Telemetry and Telecommand

Baselined by Space Station and Ground Network

02 January, 1996
STRV-1b
IP address:
192.48.114.156



2000

1990

1980

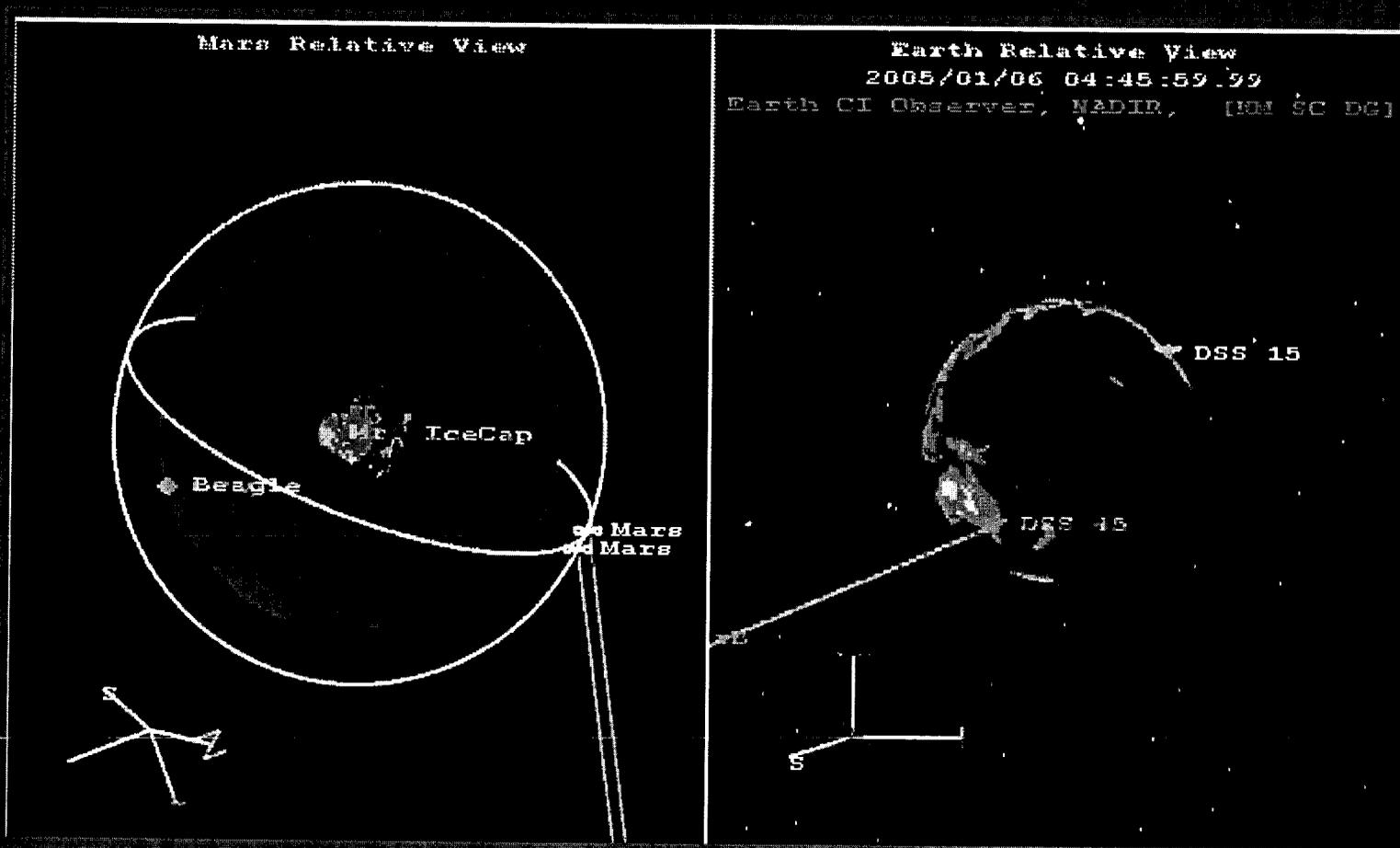
1970



The Internet is a connected, chatty 'network of networks' based on a wired backbone with negligible delay and errors (with untethered "edges" emerging)



The InterPlaNetary Internet is a often disconnected, store-and forward 'network of Internets' based on a wireless backbone with huge delays and error prone links



Deep Space Backbone Region



Terrestrial Region

TRUNK LINE TO EARTH

Communications
Relay Orbiter

Mars Orbit Region

Science
Orbiters

Mars Region 2

Science
Balloons

Space missions are increasingly moving from point-to-point to networked architectures

- internal to each spacecraft
- on and around other planets

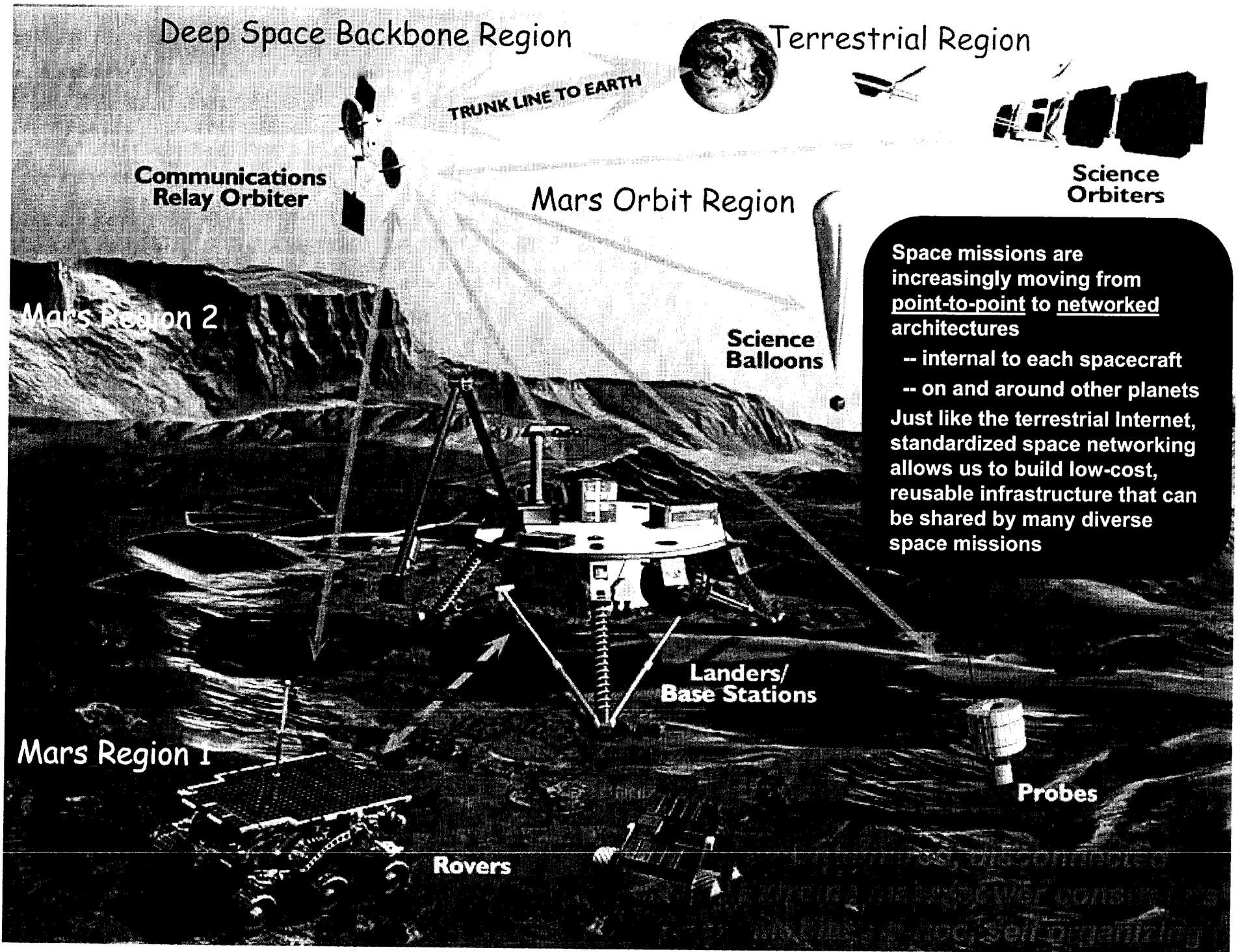
Just like the terrestrial Internet, standardized space networking allows us to build low-cost, reusable infrastructure that can be shared by many diverse space missions

Landers/
Base Stations

Mars Region 1

Probes

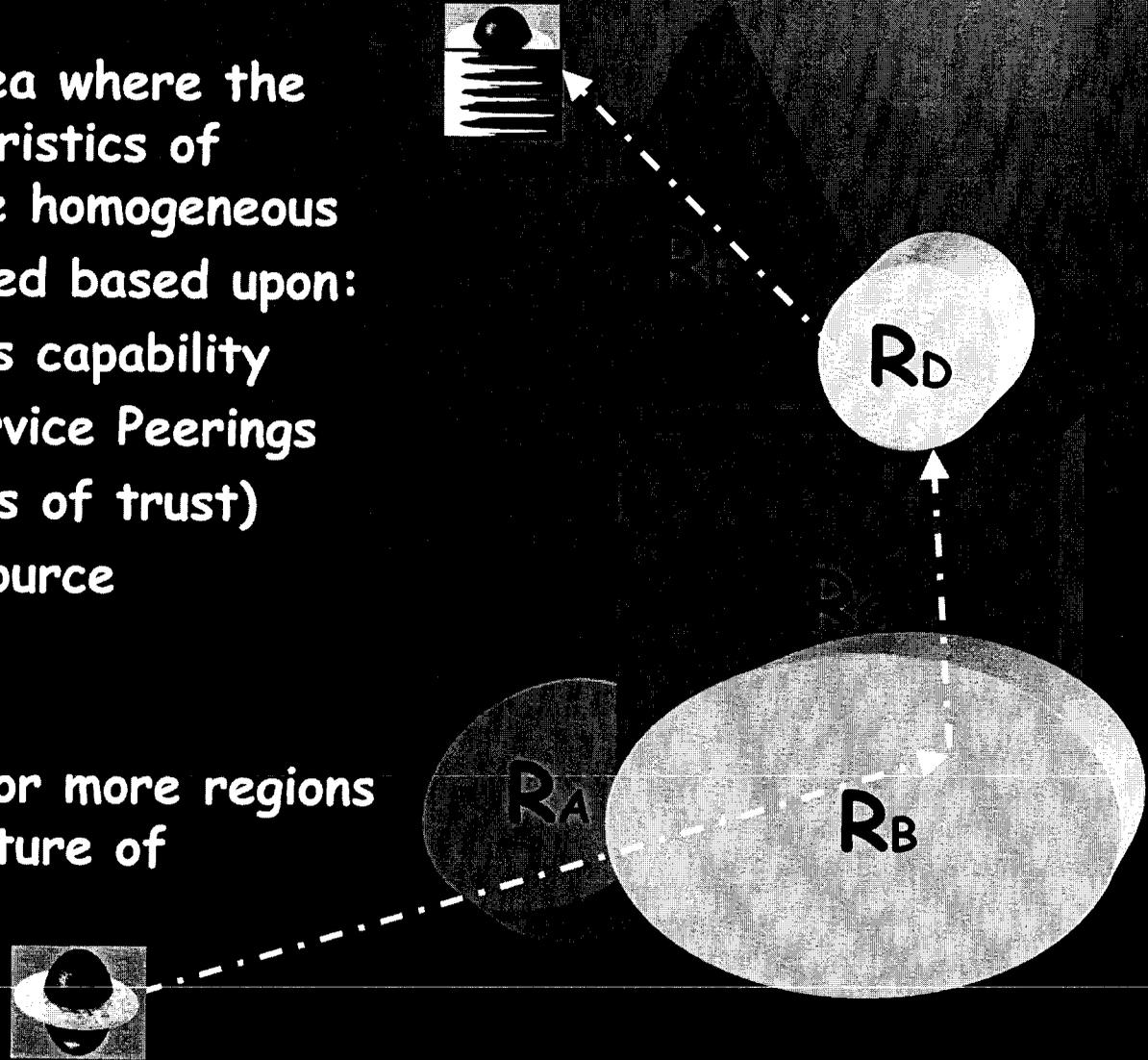
Rovers



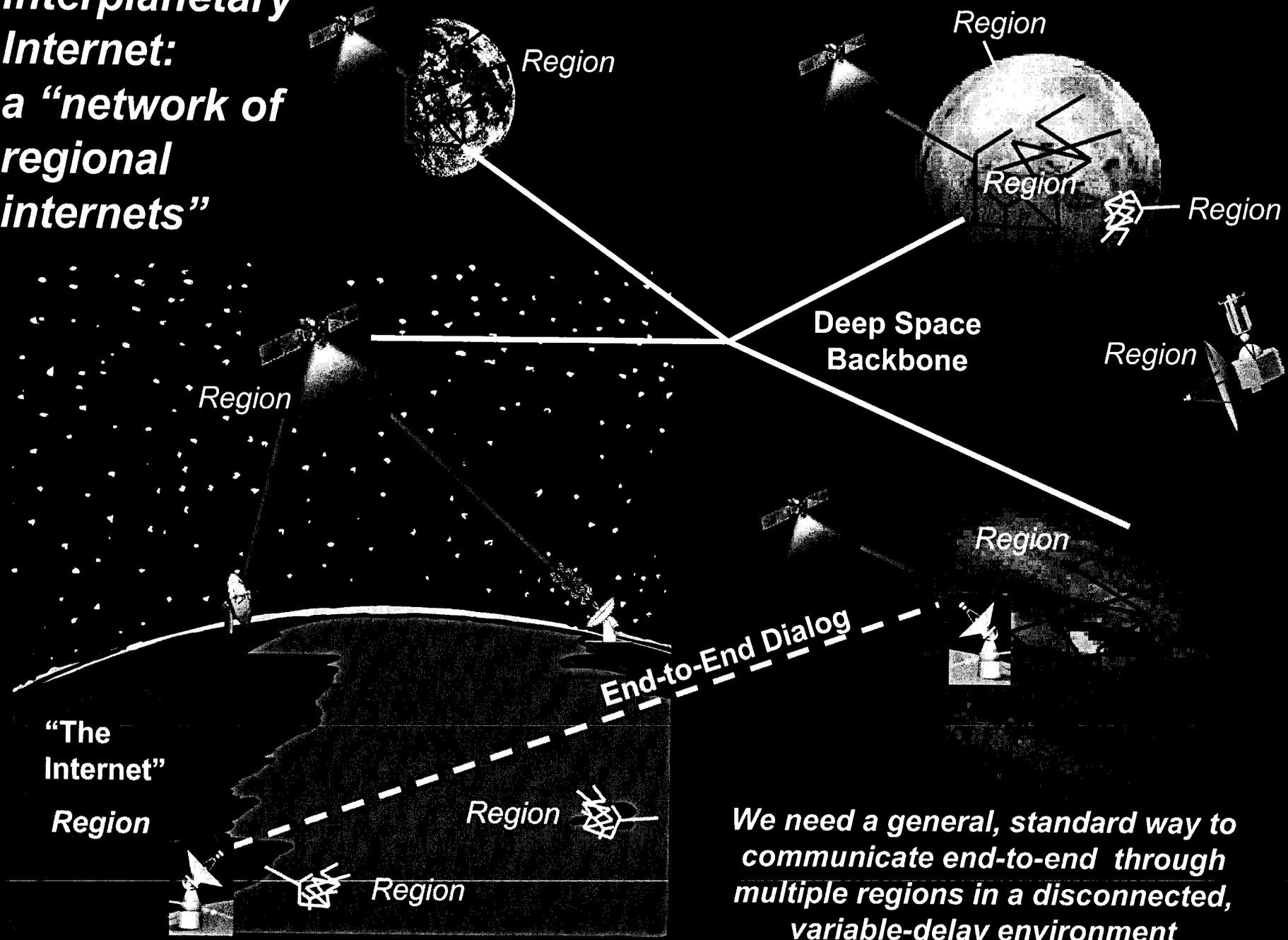
The Interplanetary Internet:

An overlay network for interconnection of regions

- A *region* is an area where the relevant characteristics of communication are homogeneous
- Regions are defined 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

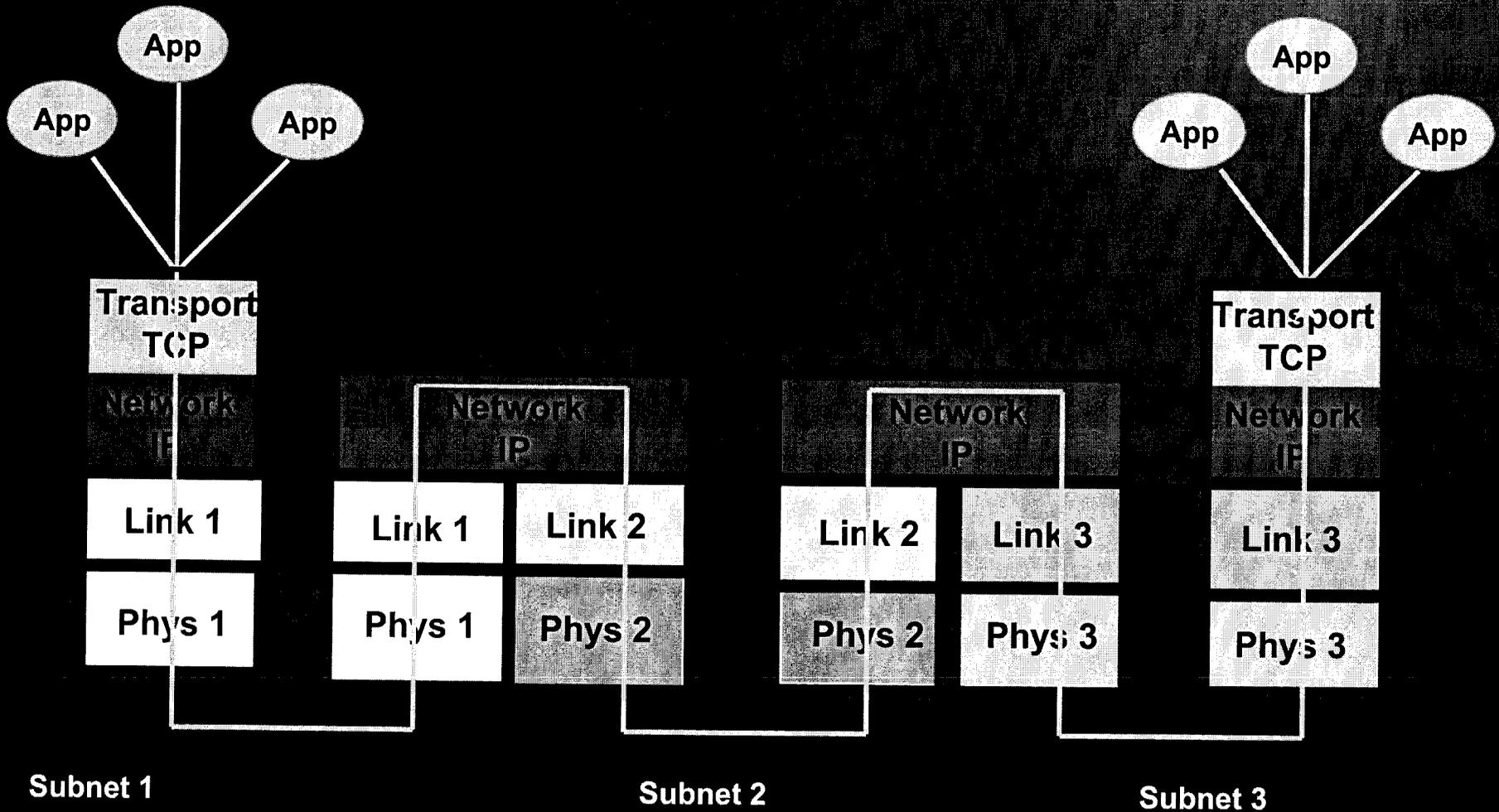


**Interplanetary
Internet:
a "network of
regional
internets"**



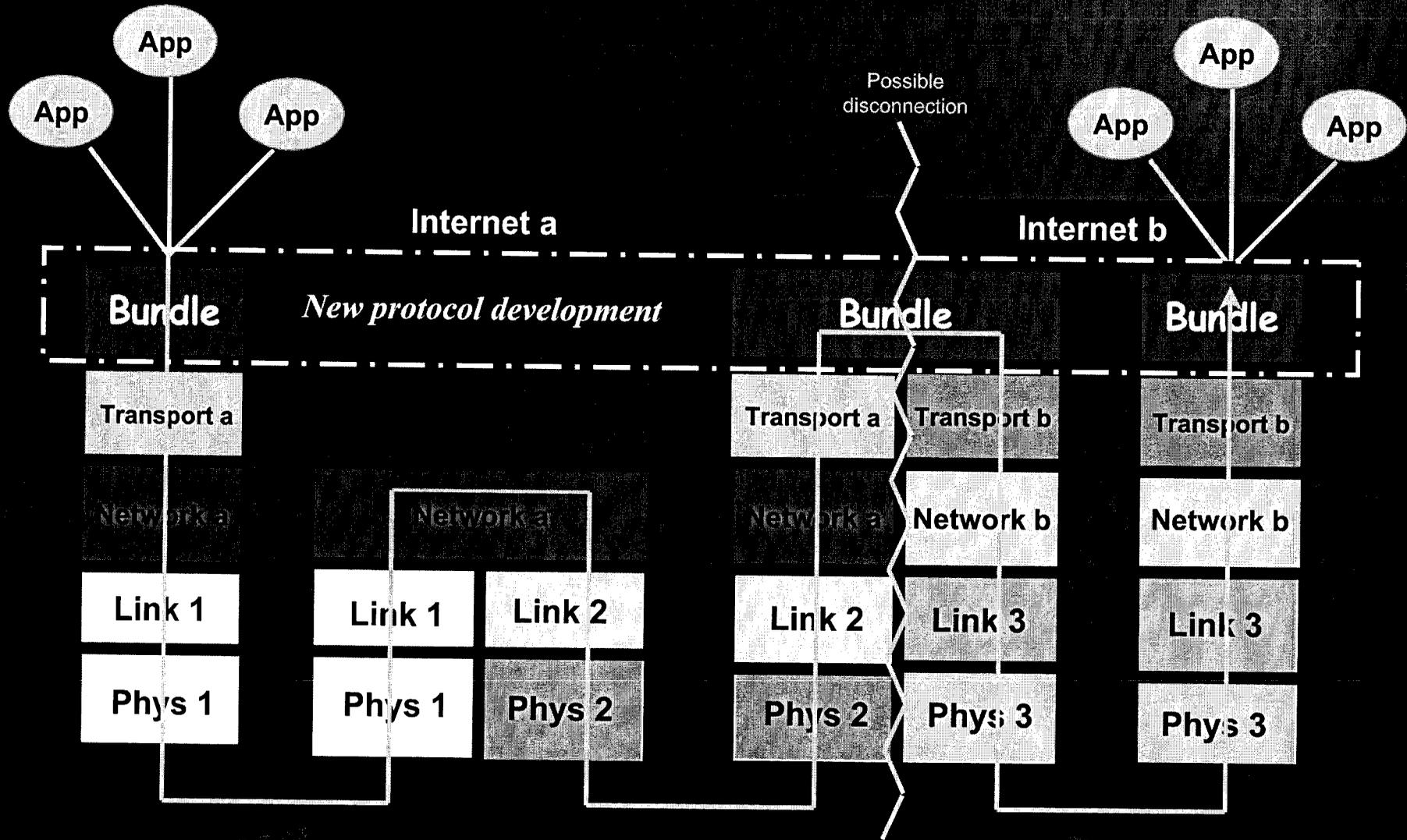
*We need a general, standard way to
communicate end-to-end through
multiple regions in a disconnected,
variable-delay environment*

The Internet: a Network of Connected Sub-Networks



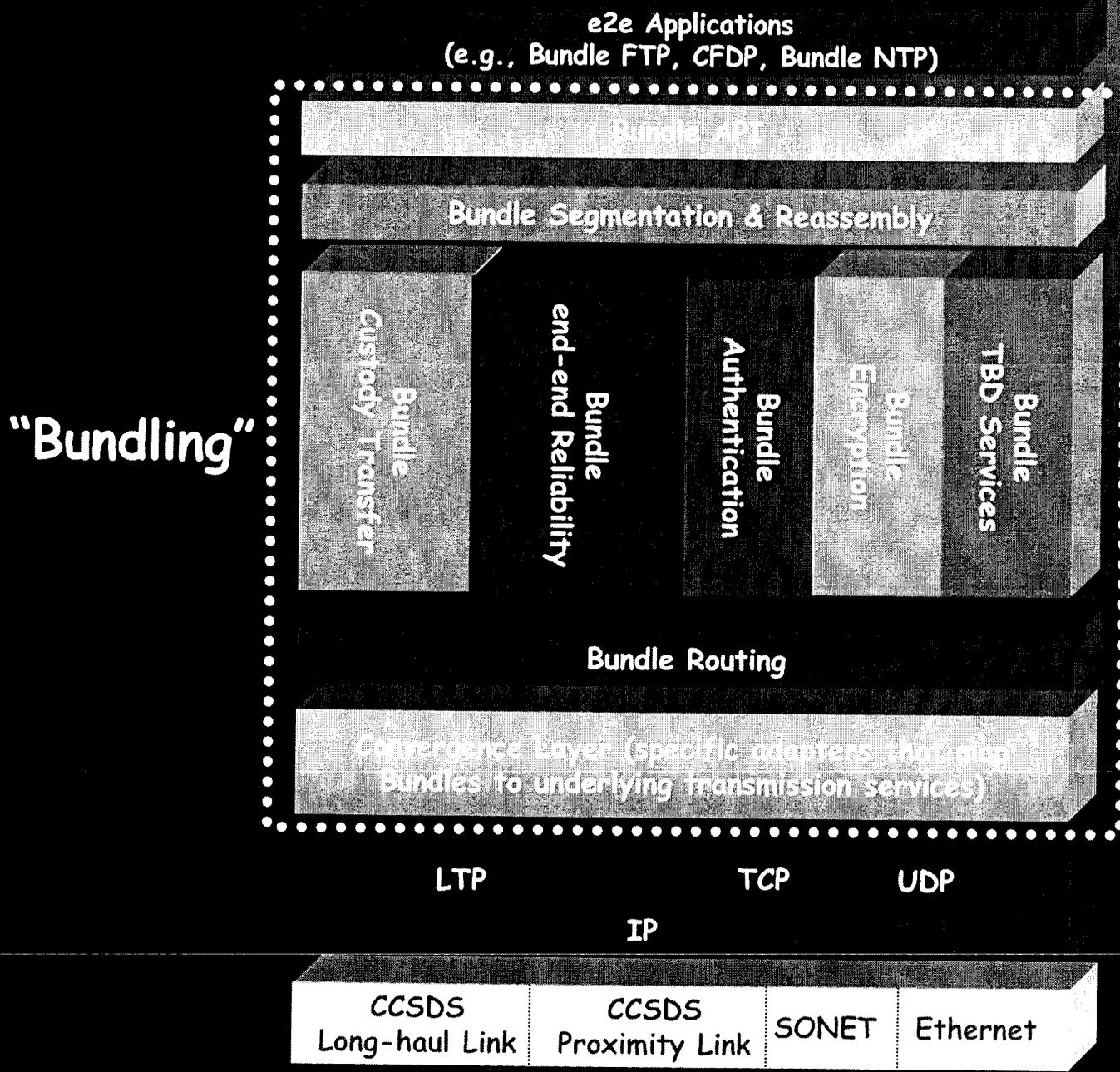
Bundles: A Store and Forward Application Overlay

The "Thin Waist" of the Interplanetary Internet

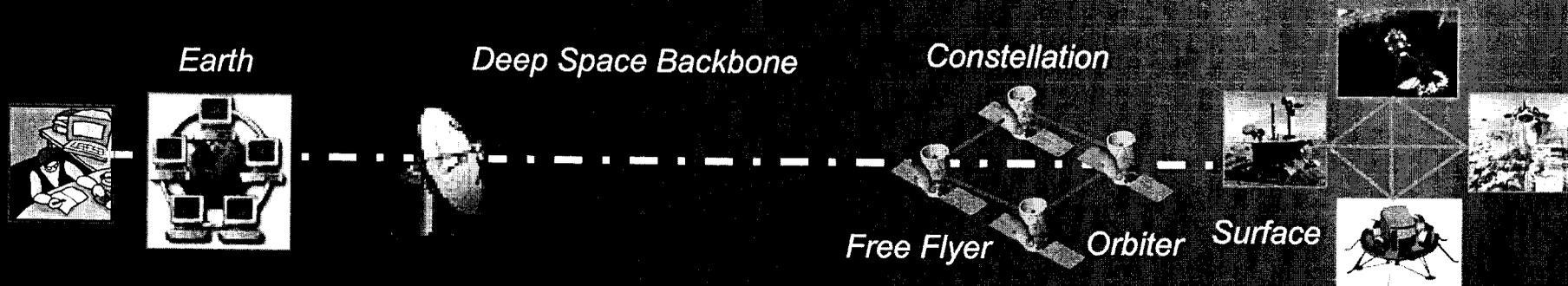


A "network of internets" spanning dissimilar environments

Bundle Service Layering



"Interplanetary Networking": 2007+



CCSDS Space Applications Protocols (CFDP, Messaging, Streaming, etc.)

CCSDS Bundling

- The Bundling protocol suite will provide general purpose delay tolerant protocol services in support of many diverse applications in highly networked configurations:
 - Custody transfer
 - Segmentation and reassembly
 - End-to-end reliability
 - End-to-end security
 - End-to-end routing



IPN Architecture
(Internet Draft 1)
May 2001



DTN Architecture
(Internet Draft 2)
August 2002



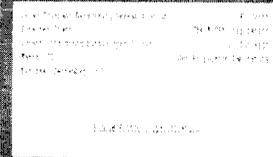
Bundle Protocol Specification, Draft 1
September 2002



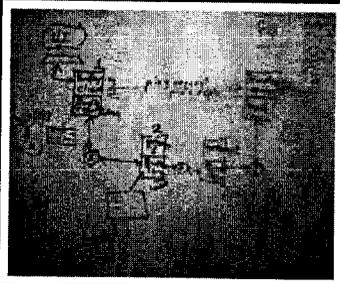
DTN Architecture
(Internet Draft 3)
March 2003



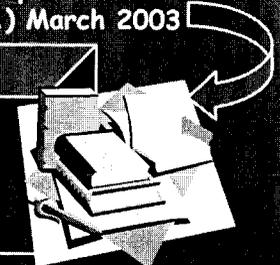
IPN Bundle Transfer
(Internet Draft 1) March 2003



Bundle Protocol Specification
(Internet Draft 1) March 2003



Bundle Specification

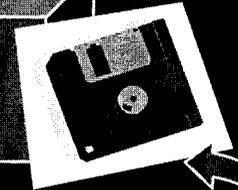


Specifications

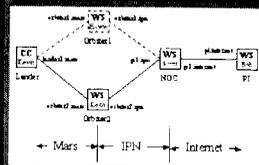
Code base



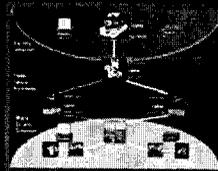
Bundle Prototyping



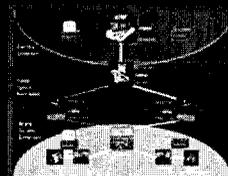
1st Rough Code
August 2000



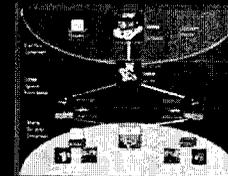
2nd Proto. Code
May 2002



3rd Proto. Code
July 2002



4th Proto. Code
Sept. 2002

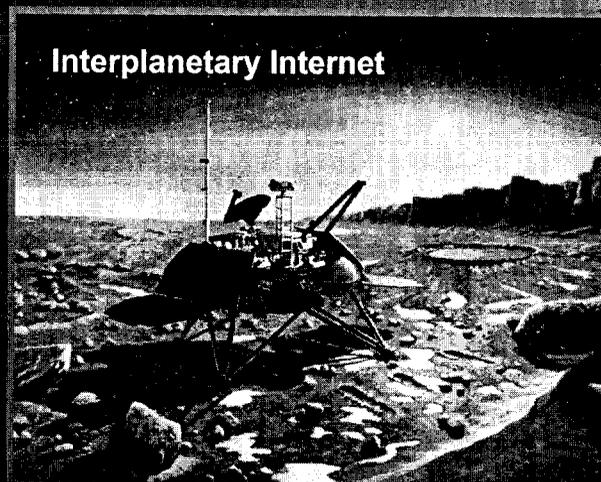
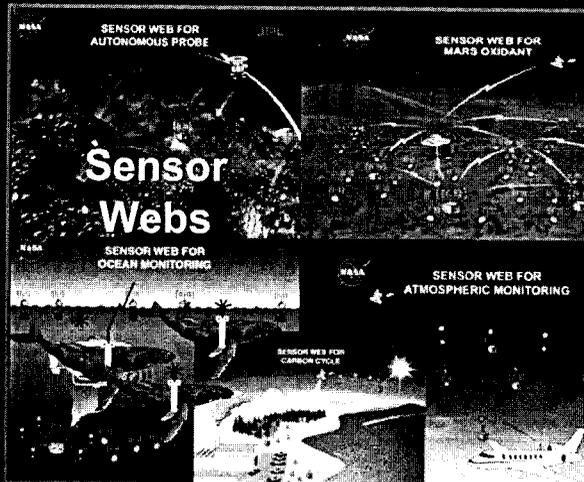


5th Proto. Code
Nov. 2002

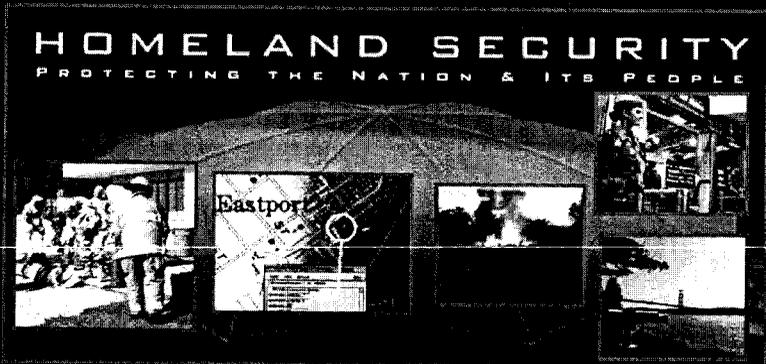
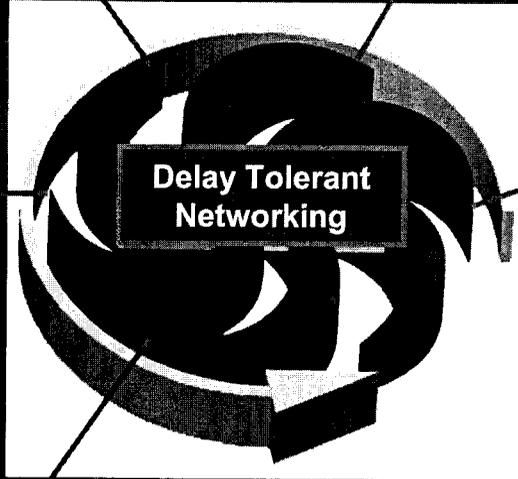


Open Source
Release 1 Code
March 2003

Code available at <http://www.dtnrg.org>

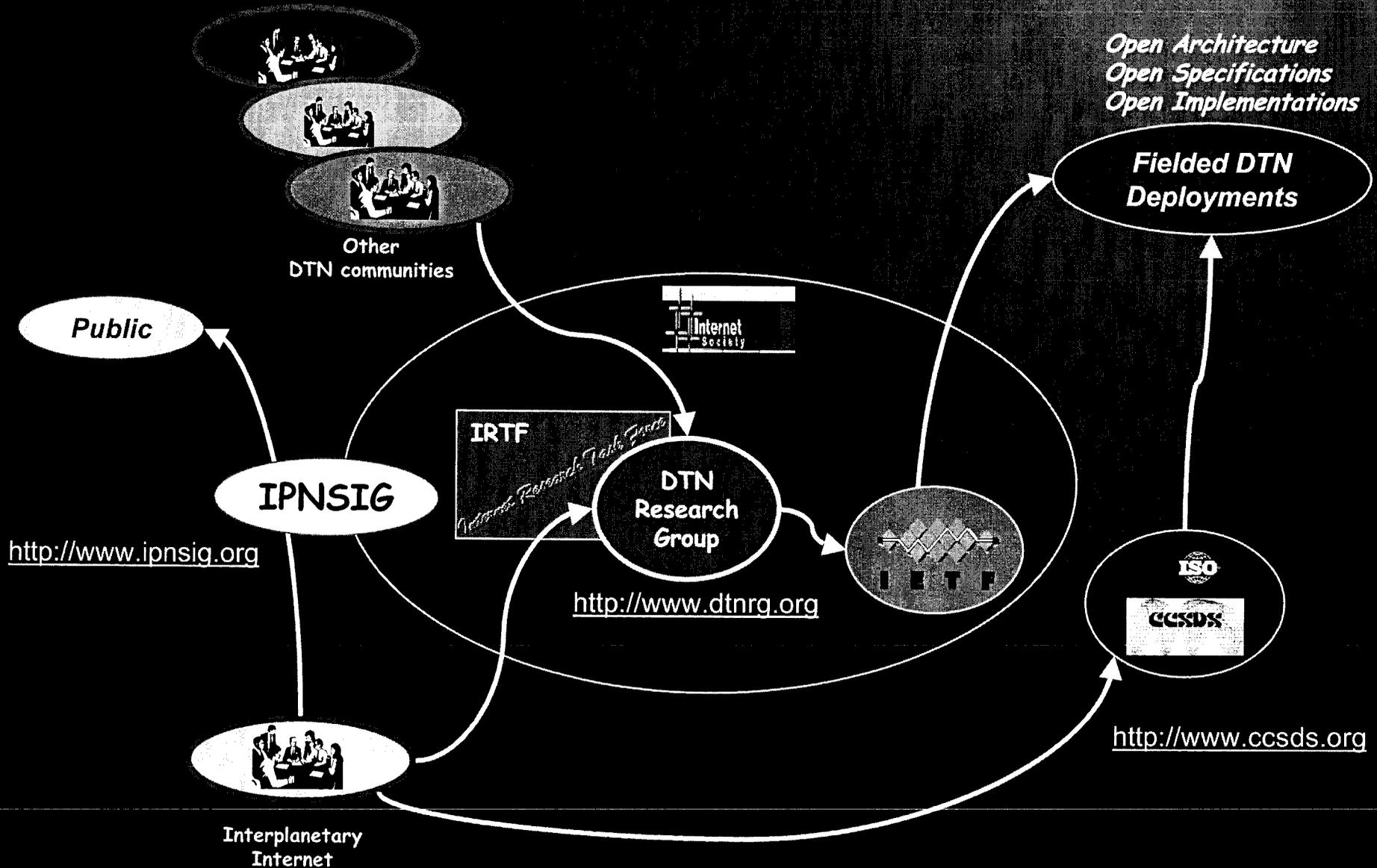


- "Non-chatty" message-oriented communications
- Store-and-forward between nodes
- Routing algorithms cognizant of scheduled connectivity
- Use transport and network technologies appropriate to the environment
- Integral infrastructure protection



IPN evolution:
Broader applicability
Nearer term utility
Larger research community

Delay Tolerant Networking: a broad community effort



BBC NEWS

You are in: **Technology**
 Wednesday, 23 November, 2002, 10:56 GMT

Hi-tech answer to reindeer tracking



Wireless technology has been used for many things but reindeer tracking is perhaps one of the strangest.

The Saami Network Connectivity Project (SNCP) is currently seeking funding to put a remote group of reindeer herders in touch with the internet.

The Saami are a population of nomadic herders that live in and around Lapland, Russia, Sweden and Finland and who track reindeer for food.

Save also

- 24 Dec 00 | Europe: Norway's radioactive re-nuclear
- 03 Feb 00 | Europe: Top 100 IT products

Internet links:

- The Saami people
- SamiNet
- BBN's Reindeer information
- Global Herders of Lapland
- The Saami Network Connectivity Project

The BBC is not responsible for the content of external internet sites.

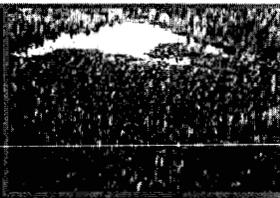
Top Technology stories from:

- Real-time surveillance
- Explosion detection on road security
- Intel looks to the future
- Indian police hunt for digital crime
- Belgium's time is running out
- Phone mast emissions will be limited
- Mobile phone firms lock to future
- Robots get cheeky

links to more Technology stories are at the foot of the page.

Bogometer

- Wetland drainage is a problem
- Nodes fixed in place
- Measure level of water below node
 - Want alert if levels change
- Don't want to damage wetland by visiting nodes
 - RV tracks on a bog aren't really eco-friendly
- "Drive-by" periodically
 - Maybe once a month?



Networking

- Three sorts of entity
 - Nodes are embedded systems
 - Routers are PDAs or better
 - The Sink is a host on the Internet
- Stack
 - Convergence Layers
 - Router --- Node: UDP, 802.11b
 - Router --- Sink: TCP, whatever
 - DTN bundle layer
 - Application layer

Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet

Philo Juang Hidekazu Oki Yong Wang
 Margaret Martonosi Li-Shiuan Peh Dan Rubenstein



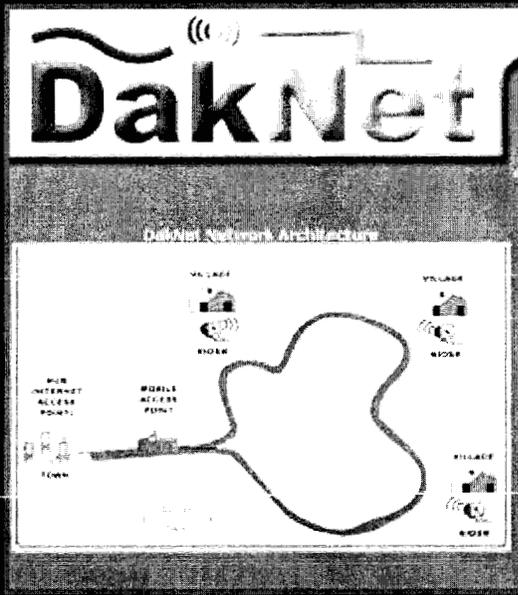
Dept. of Electrical Engineering
 Dept. of Computer Science
 Dept. of Ecology and Evolutionary Biology

Princeton University



The ZebraNet Wildlife Tracker

Dept. of Electrical Engineering
 and
 Dept. of Ecology and Evolutionary Biology
 Princeton University



SICS

Juan Alonso, SICS

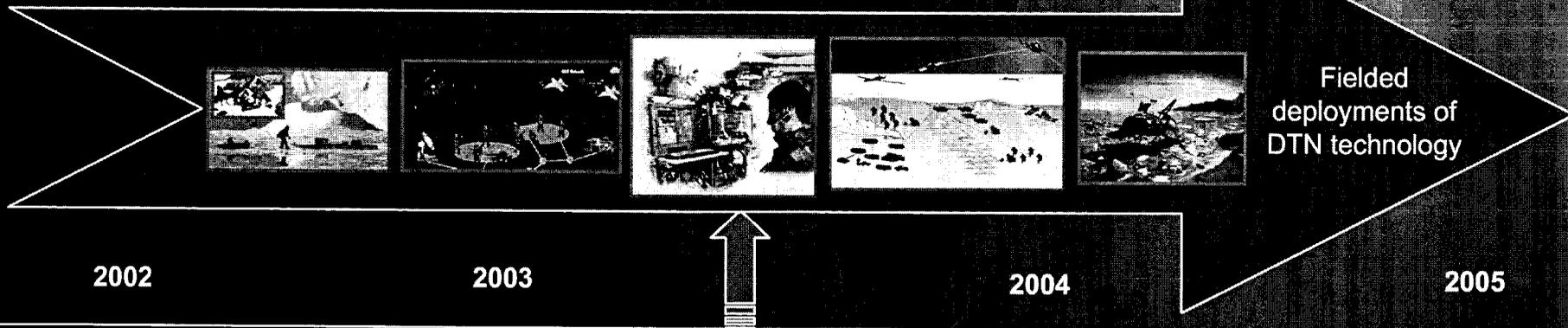
Purpose, goals and research issues. The purpose of the project is to contribute to the design and implementation of the general Delay Tolerant Network (DTN) architecture with special focus on wireless sensor and sensor/actuator networks (SN). The aim of the general DTN architecture is to achieve interoperability between and among challenged networks. Of particular interest for this research proposal is using DTN to achieve interoperability between wireless SNs and the Internet. In practical terms, this means being able to access, operate and control wireless sensor networks through the Internet.

SICS Lab - SICS Computer Networks Architecture Laboratory
 Education: Ph.D. (1984) Stockholm University, Doctor (1981)

Research Interests: Routing in computer networks, optimizations, done some work in Risk Management, and a life long interest in Geometry, Topology and



DARPA Advanced Technology Office



2002

2003

2004

2005

Fielded
deployments of
DTN technology

DTN Research Group:

Focal point
for DTN



DTN Core Engineering

- DTN Architecture
- DTN Design Documents

DTN Open Source

- Reference Software
- Configuration Control

DTN Standardization

- International Standards

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

Bundle API

Bundle Segmentation & Reassembly

Bundle
Custody Transfer

Bundle
end-end Reliability

Bundle
Authentication

Bundle
Encryption

Bundle
TBD Services

Bundle Routing

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

CCSDS Long-haul Link CCSDS Proximity Link SONET Ethernet

APPLICATIONS

CFDP File operations

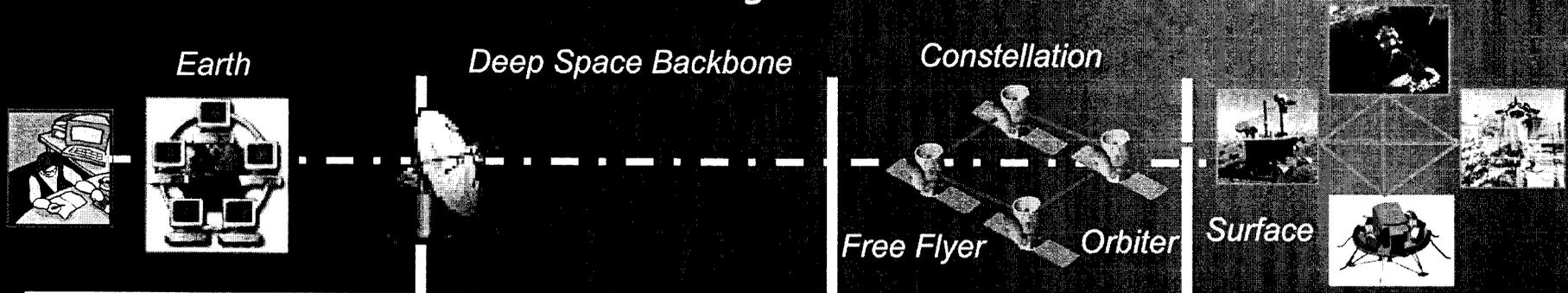
[CFDP point-to-point reliability]

BUNDLE

Custody transfer;
e2e security, reliability, routing

CCSDS Reliable Space Link

2007-2012 "Bundling-era" Protocol Scenario



CCSDS Space Applications Protocols (Packet, CFDP, Messaging, Streaming, etc.)

CCSDS Bundling

CCSDS Long-haul Link

CCSDS Space Link Extension (SLE)

TCP, UDP

IPSEC

IP

Local Terrestrial Link

Local Terrestrial Wired



CCSDS NP

(TCP, UDP)

IP, CCSDS NP

Long-haul Link ARQ CCSDS Long-Haul Link and Coding

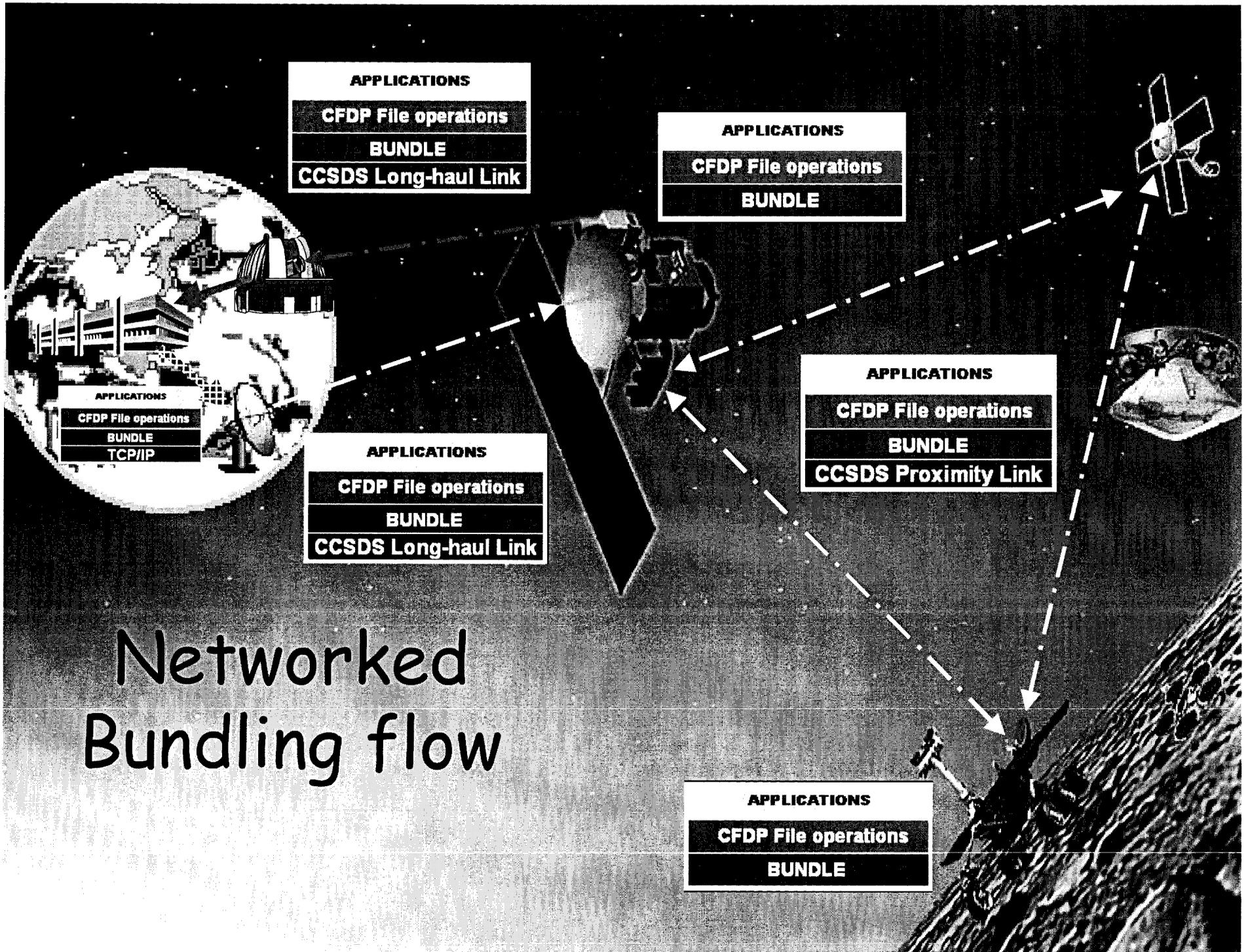
CCSDS Link + Physical Security

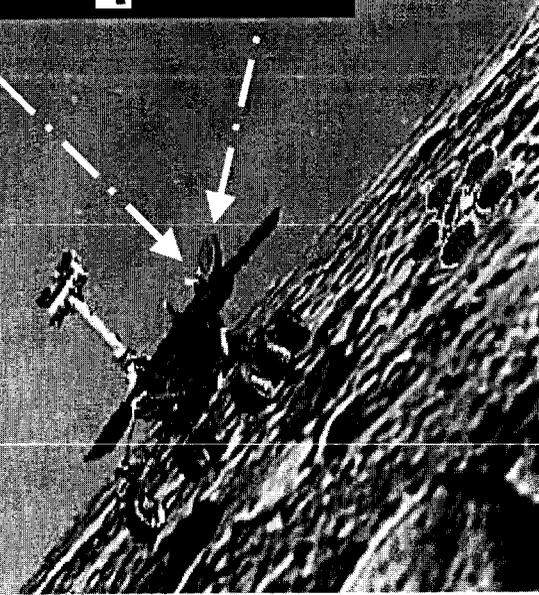
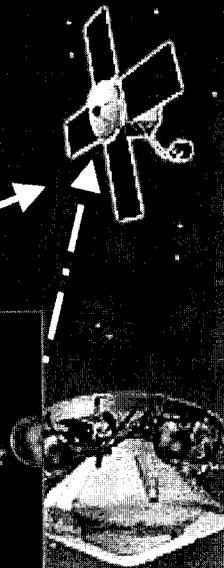
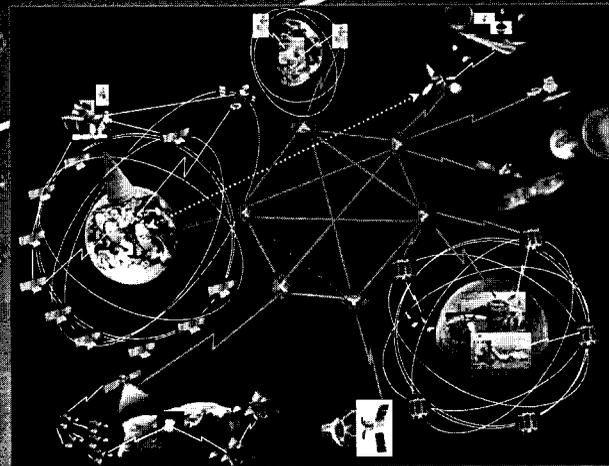
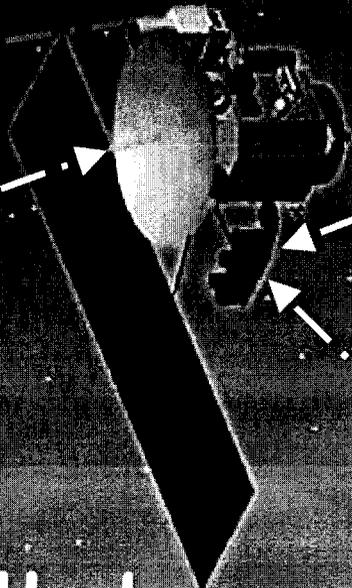
CCSDS Proximity Link and Coding

CCSDS S, X, Ka Band; Optical

CCSDS UHF

CCSDS UHF; local wired/wireless





We can be well down
the road to the
Interplanetary
Age by 2009.....