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

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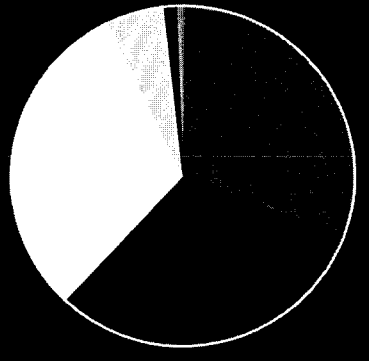
Jet Propulsion Laboratory
California Institute of Technology

- *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

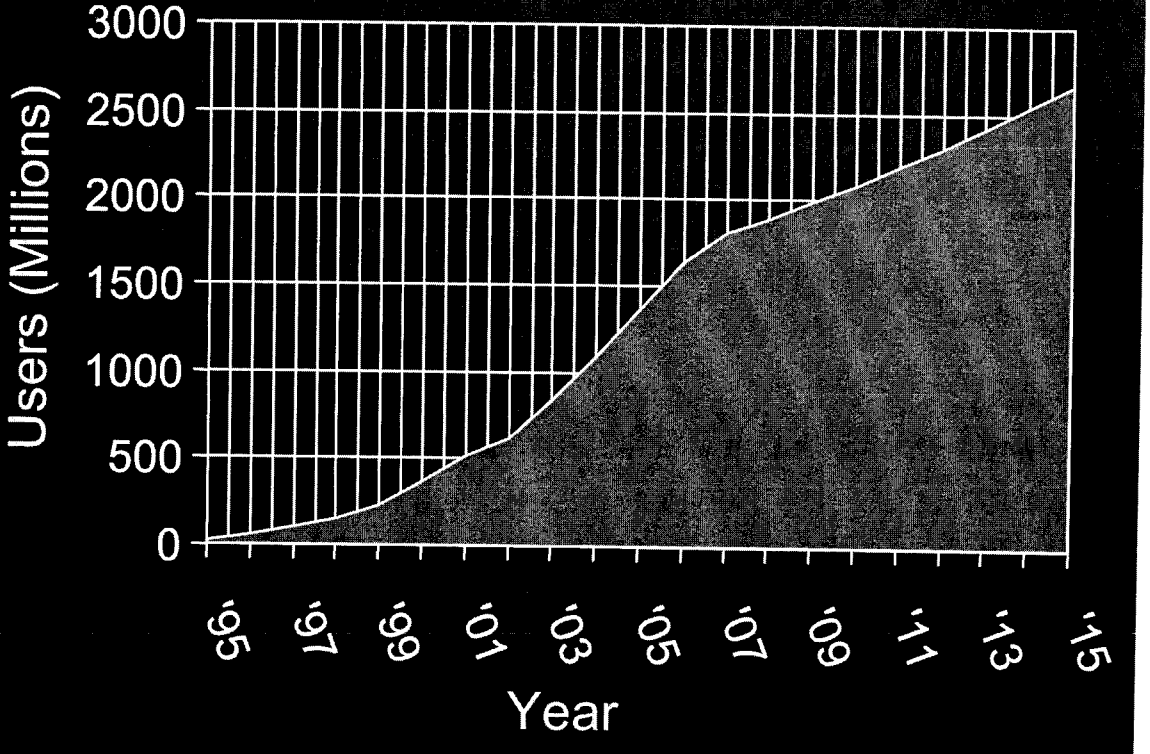
- Total - 605.6 M



- CAN/US
- Europe
- Asia/Pac
- Latin Am
- Africa
- Mid East

(Source www.nua.ie)

Internet User Trends

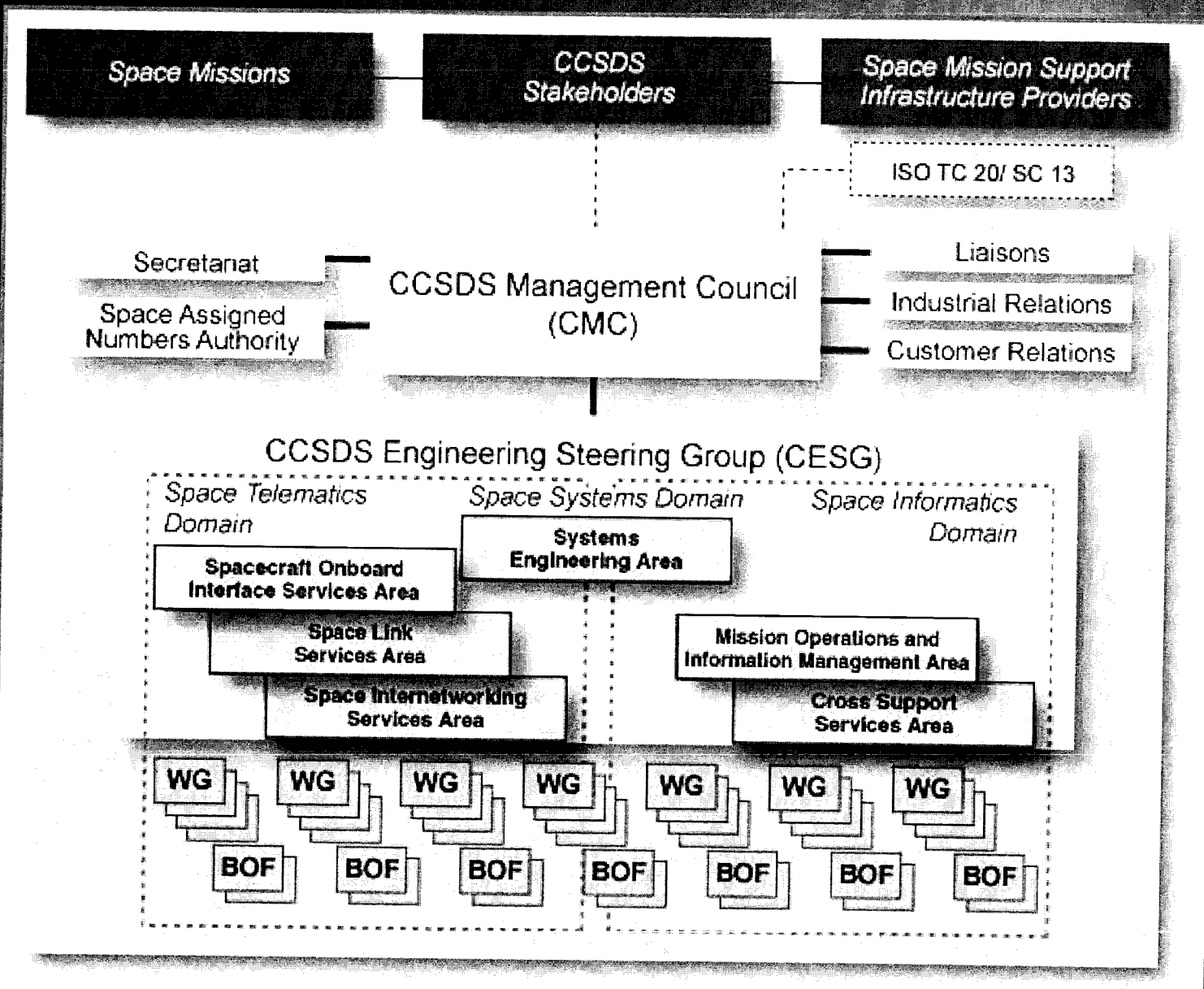


Estimate revised 4/2003

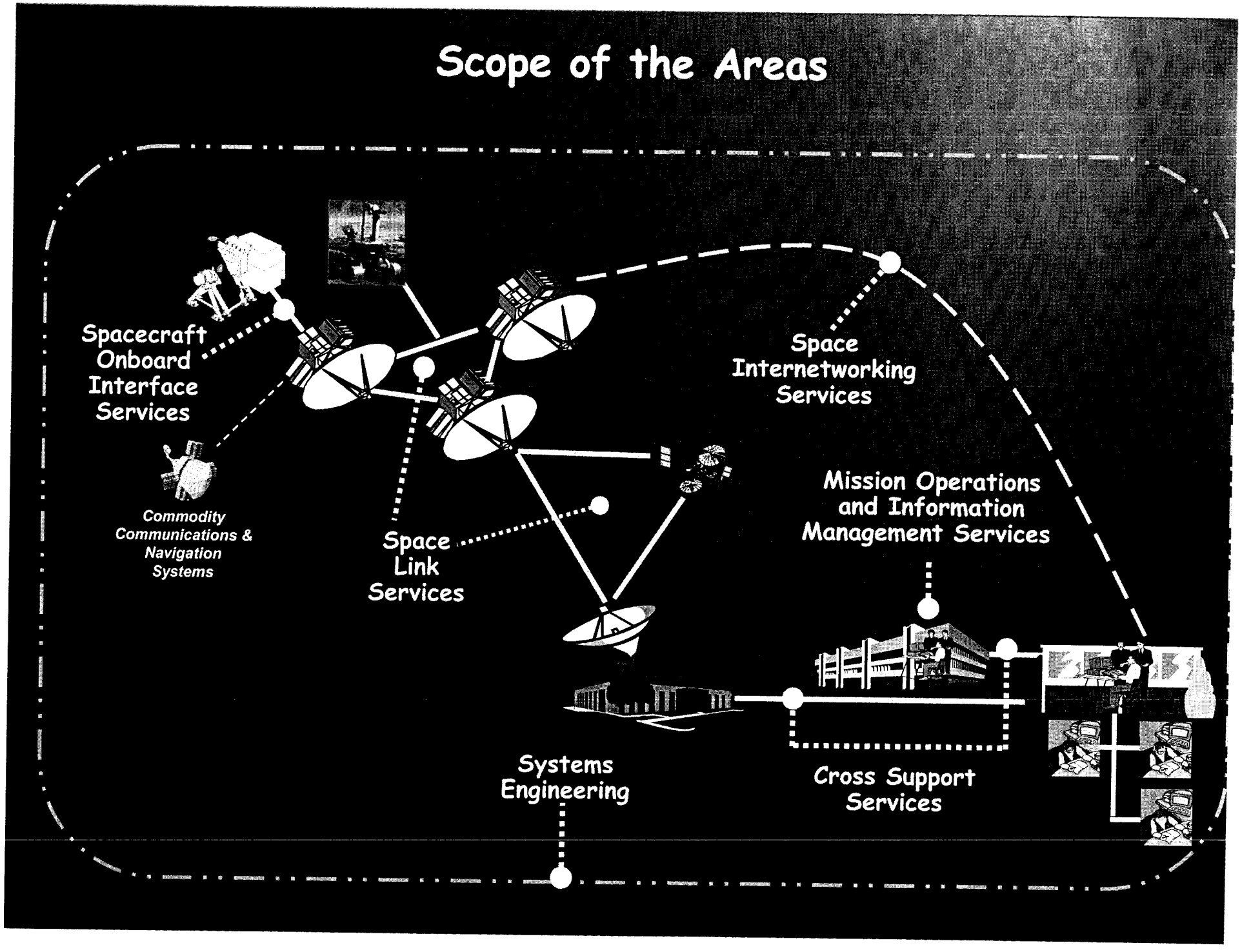
Source: Nua Internet Surveys + vgc projections

Consultative Committee for Space Data Systems (CCSDS)

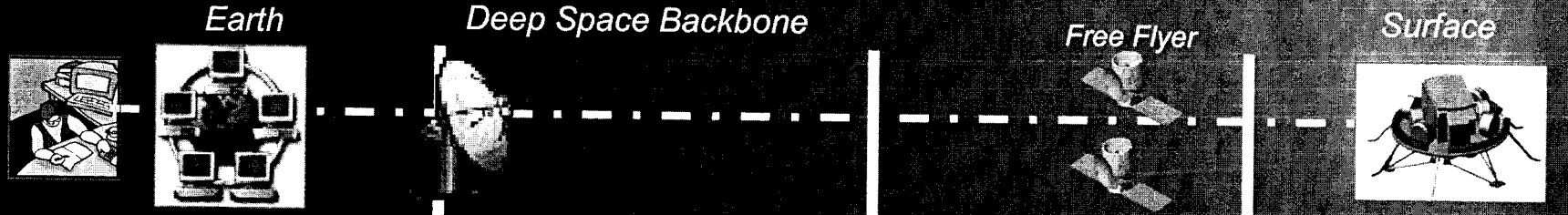
- ASI/Italy
- BNSC/UK
- CNES/France
- CSA/Canada
- DLR/Germany
- ESA/Europe
- INPE/Brazil
- NASA/USA
- NASDA/Japan
- RSA/Russia
- ASA/Austria
- CAST/China
- CRC/Canada
- CRL/Japan
- CSIR/South Africa
- CSIRO/Australia
- CTA/Brazil
- DSRI/Denmark
- EUMETSAT/Europe
- EUTELSAT/Europe
- FSST&CA/Belgium
- 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 Packet

CCSDS Long-haul Link

CCSDS Space Link Extension (SLE)

TCP, UDP

IPSEC

IP

Local Terrestrial Link

CCSDS Long-Haul Link and Coding

CCSDS Proximity Link and Coding

Local Terrestrial Wired

CCSDS S, X, Ka Band

CCSDS UHF

CCSDS UHF; local wired/ wireless


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

1970

1980

1990

2000

NASA Telemetry Standardization

"Packet" Spacecraft Telemetry and Telecommand

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

NASA/ESA Working Group

Baselined by Space Station and Ground Network

Basic Space/Ground Communications Standards for Space Missions

CCSDS

Consultative Committee for Space Data Systems (CCSDS)

CCSDS Recommendation for Advanced Orbiting Systems

Extension of Standards for More Complex Space Missions

International Space Station

File Transfer: FTAM
Transport: TP4
Network: ISO 8473

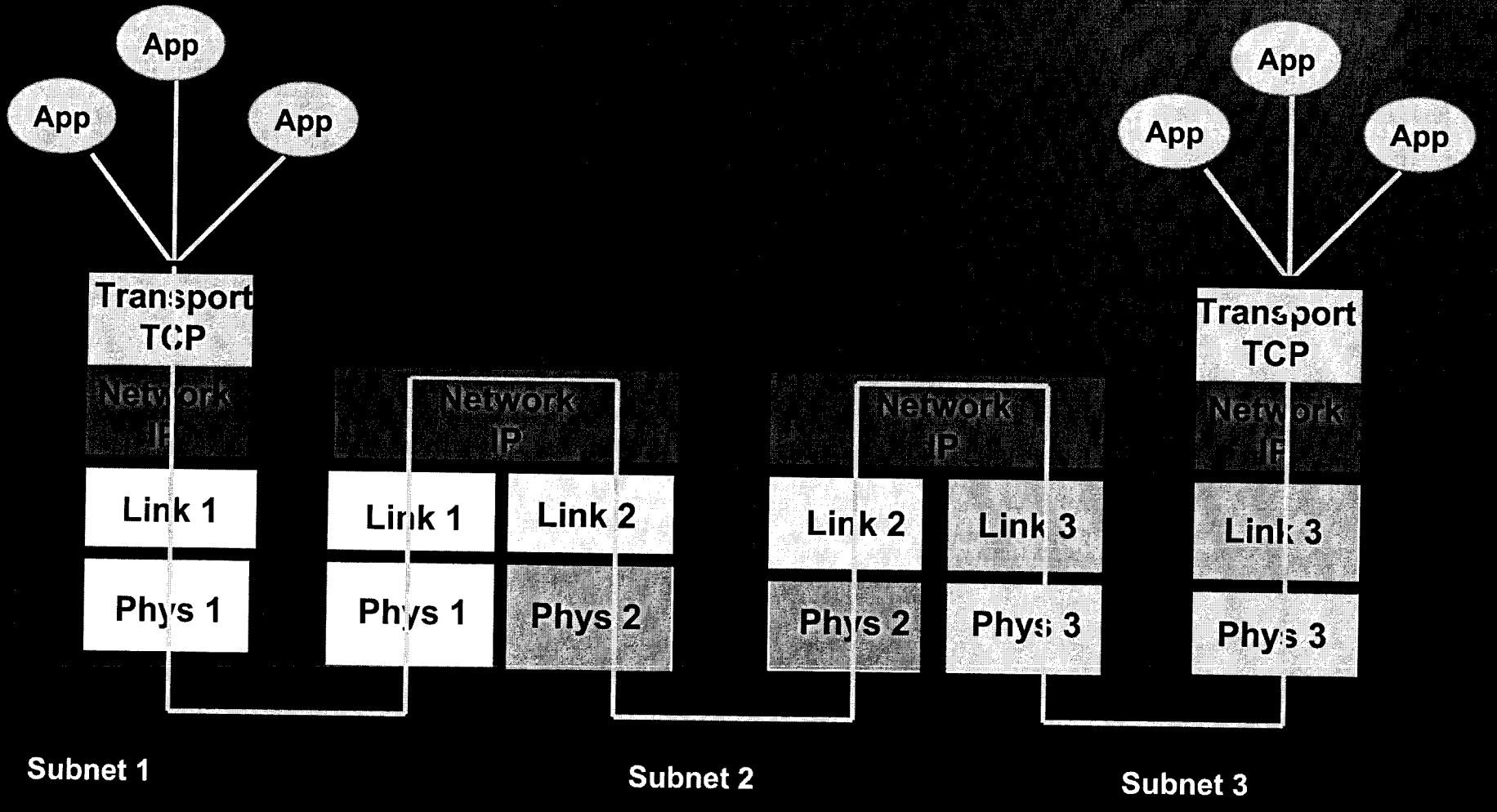
The Dark Age Of OSIP

Extension of the Terrestrial Internet into Space

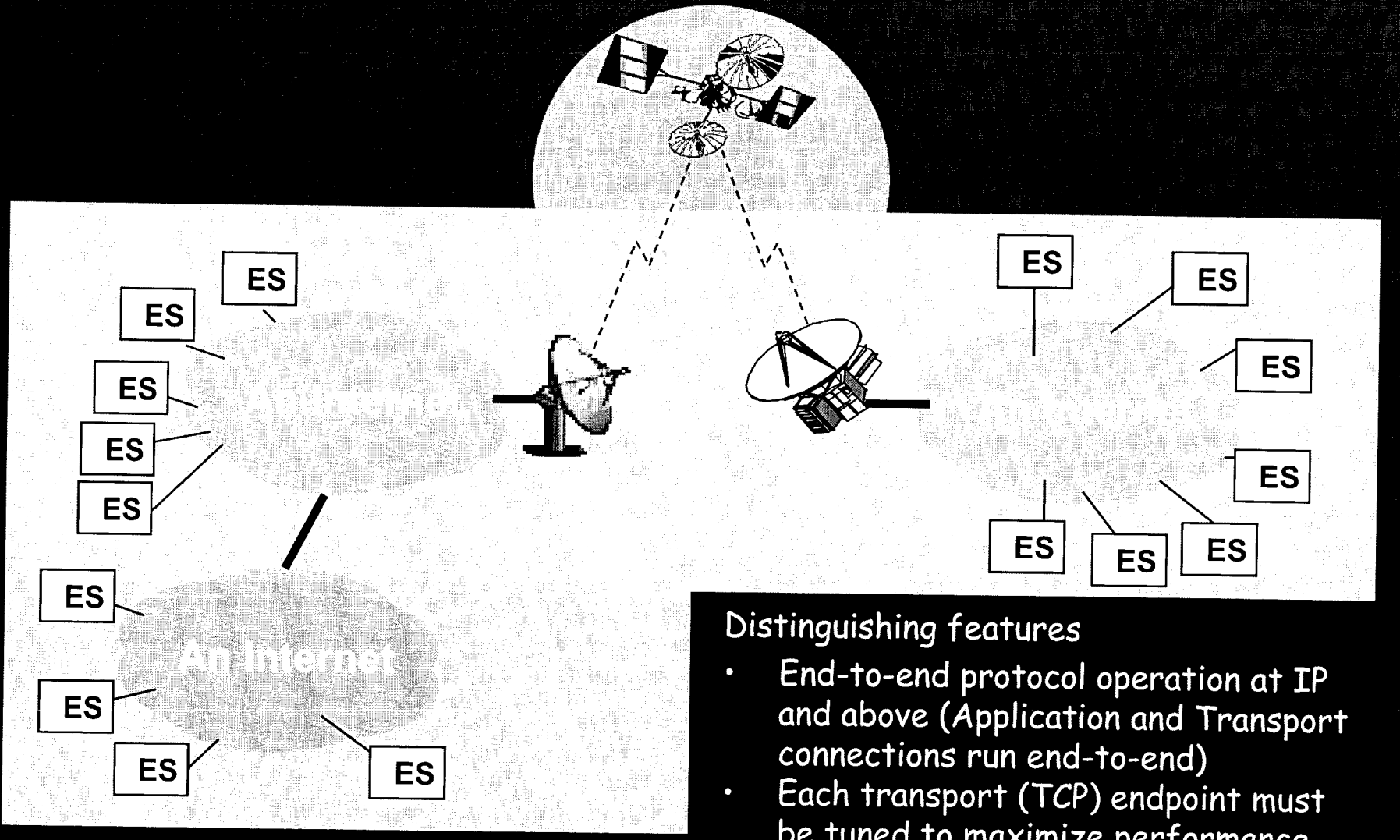
NASA/DOD/CCSDS Space Communications Protocol Standards (CCSDS-SCPS) Project

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

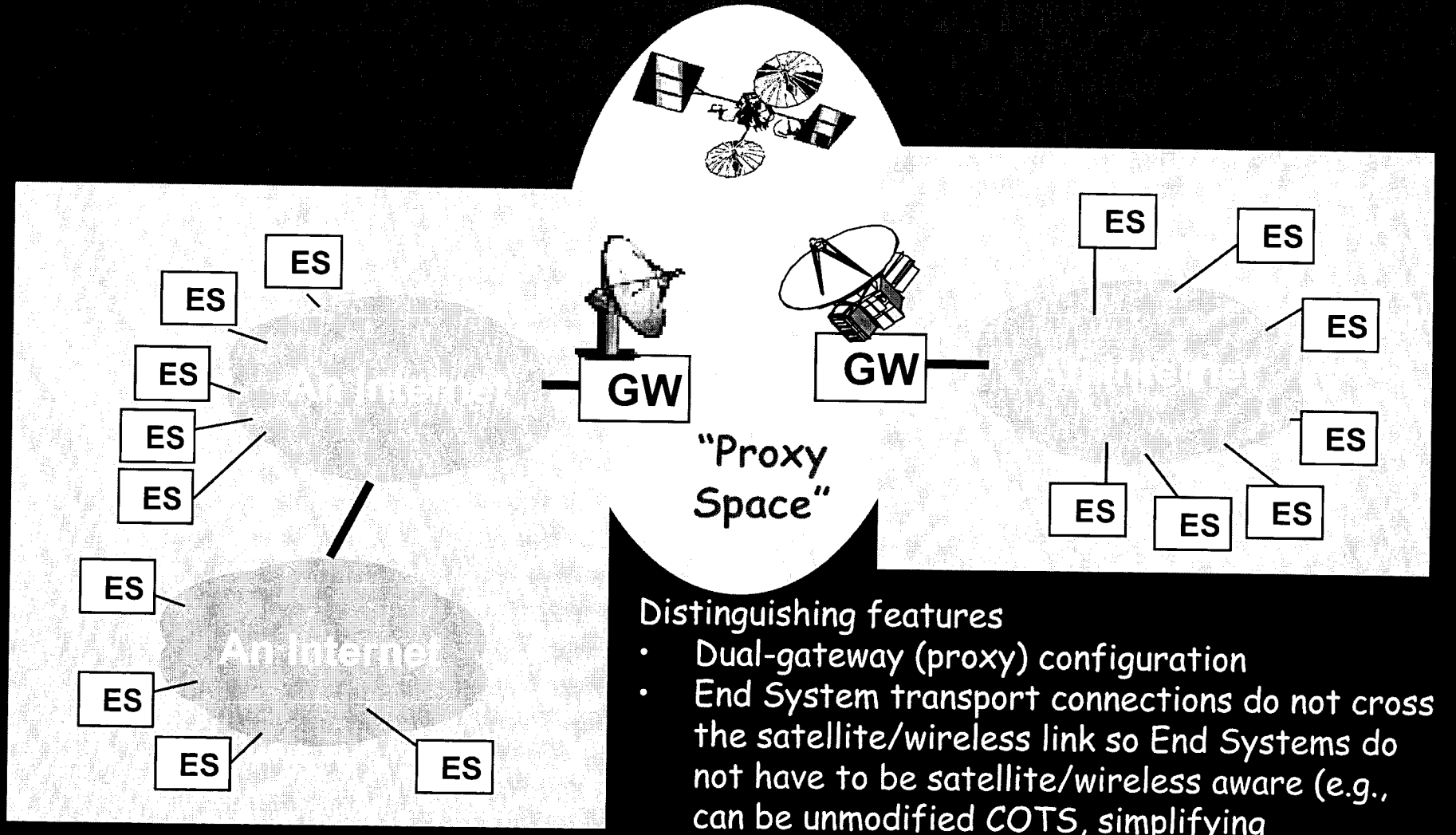


Distinguishing features

- 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

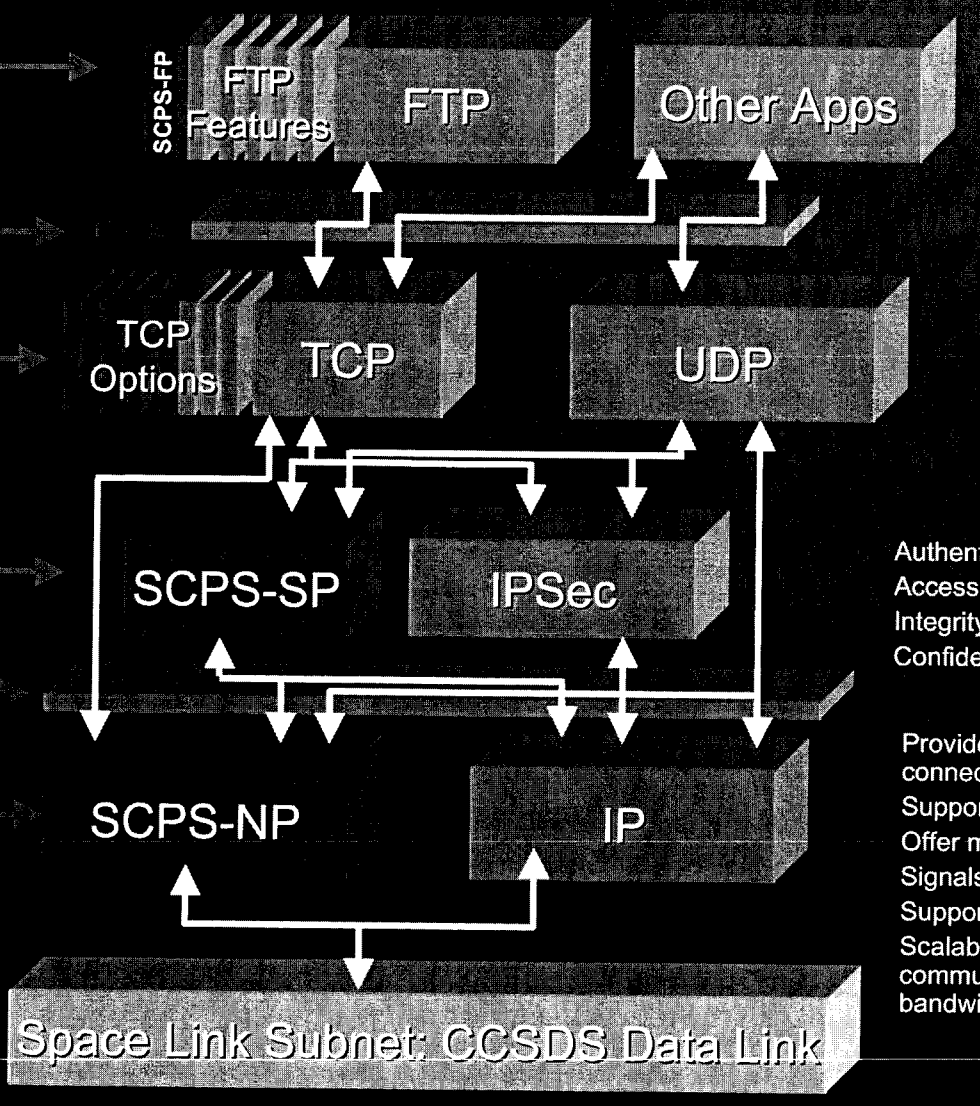


ES = End System
GW = Transport Layer Gateway (Proxy)

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.

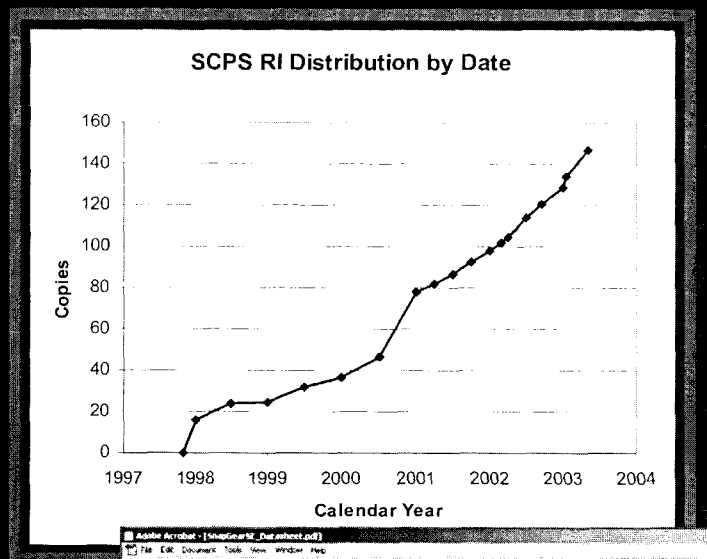
Congestion control appropriate for mixed-loss environments (congestion, corruption, outage);
Selective negative acknowledgment;
Robust header compression;
Partial Reliability service (BETS);
Delimitation of record boundaries;
RFC 1323: Window scaling, time stamps, sequence number extension

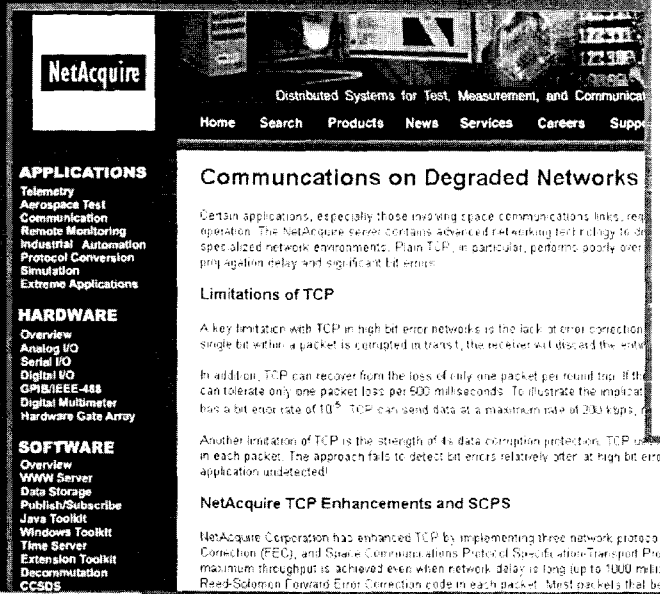
Authentication: guarantee of the identity of a source;
Access Control: prevention of unauthorized access;
Integrity: protection against modification;
Confidentiality: protection from disclosure.

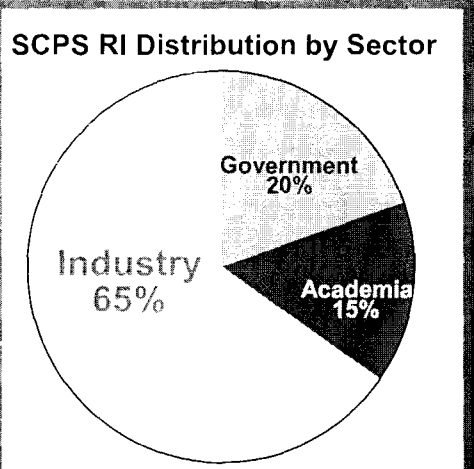
Provides both connectionless and managed-connection routing;
Supports precedence (priority) based handling;
Offer multiple routing options;
Signals errors to the layer above;
Supports packet lifetime control;
Scalable - tailor capability to need, e.g., high communications efficiency in constrained bandwidth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

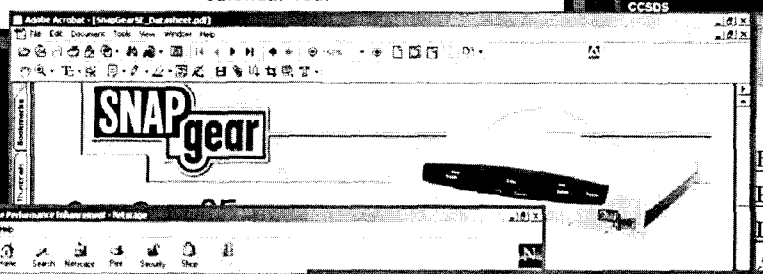
The CCSDS protocol suite supports either "native" or "space enhanced" Internet services, at the discretion of the Project organization

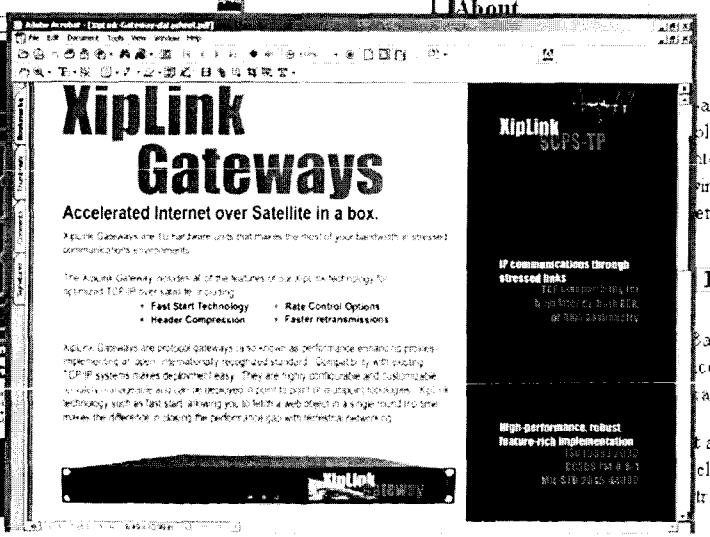
SCPS Reference Software

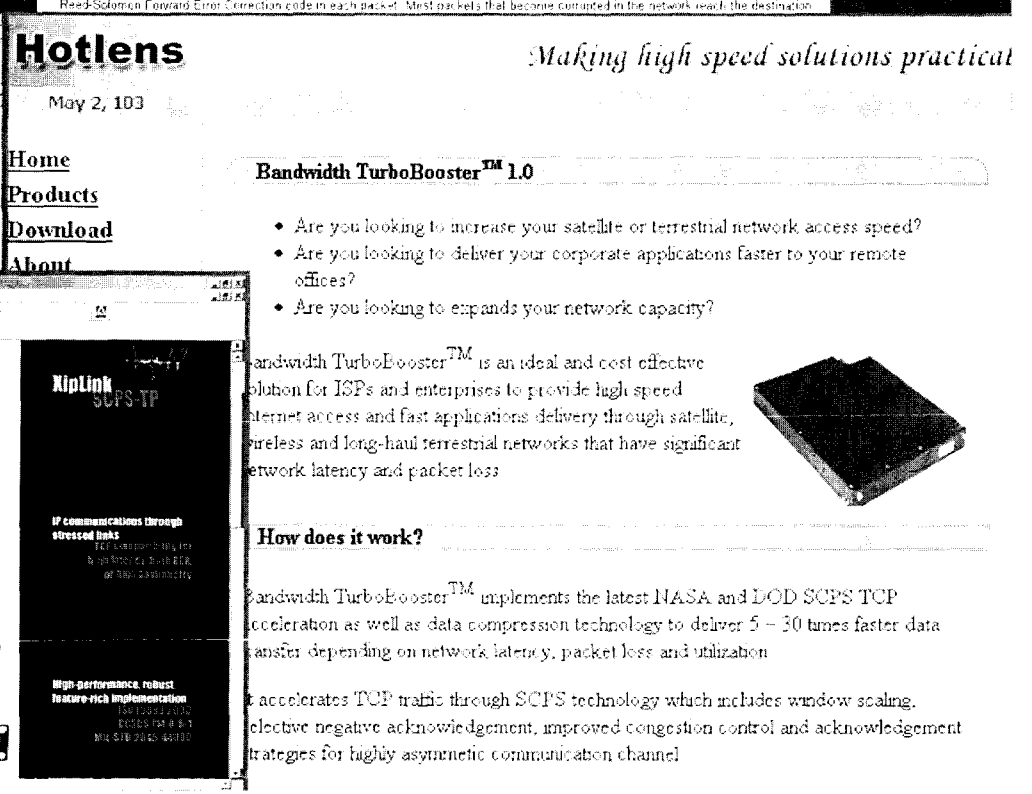




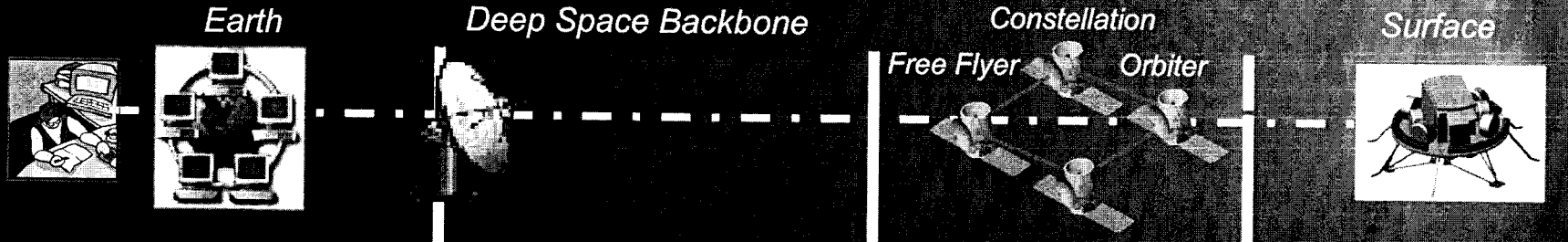








"Space Internet" CCSDS Protocol Scenario



CCSDS Packet

CCSDS Long-haul Link

CCSDS Space Link Extension (SLE)

TCP, UDP

IPSEC

IP

Local Terrestrial Link

Local Terrestrial Wired

Reliable File Transfer in disconnected, long-delay environments ?

FTP

TCP, UDP

IPSec, CCSDS SP

IP, CCSDS NP

CCSDS Long-Haul Link and Coding

CCSDS Link + Physical Security

CCSDS Proximity Link and Coding

CCSDS S, X, Ka Band

CCSDS UHF

CCSDS UHF; local wired/ wireless

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:

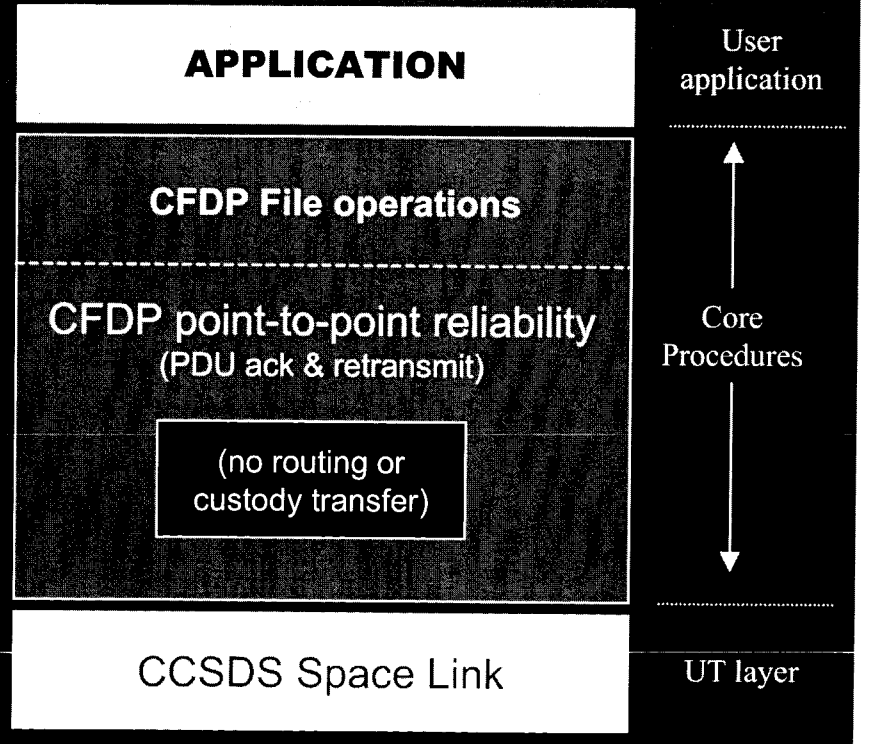
- file handling mechanisms

+

- point-to-point reliability mechanisms

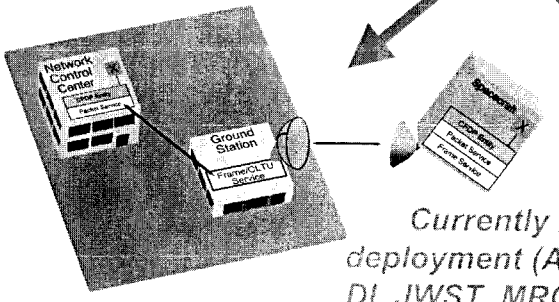
It draws upon:

- underlying space link unit data transfer services



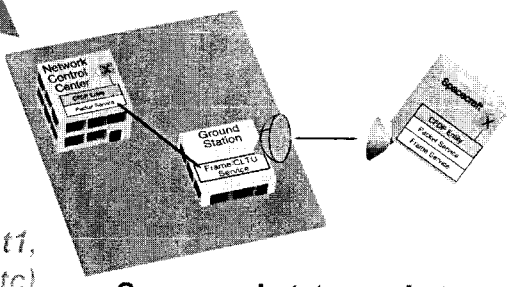
CFDP Operations Scenarios

Build 1 CFDP



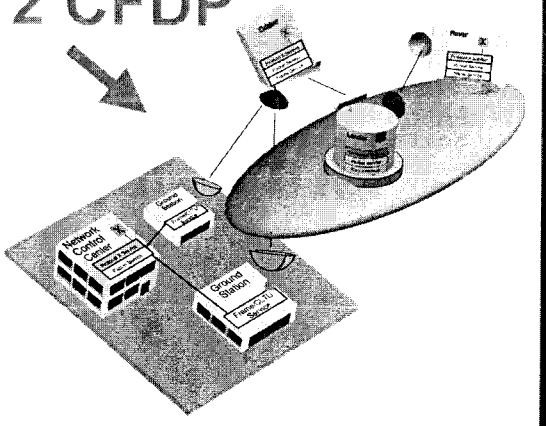
Currently in deployment (AISat1, DI, JWST, MRO, etc)

1. point-to-point, unacknowledged



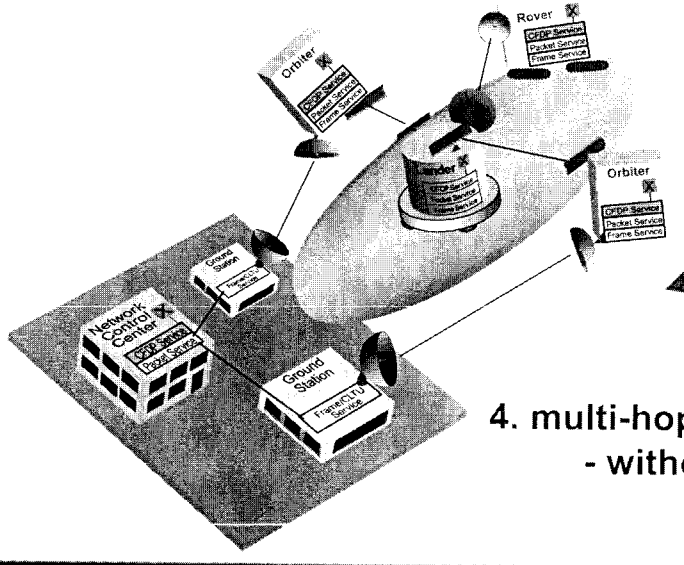
2. point-to-point, acknowledged

Build 2 CFDP



3. multi-hop, in series

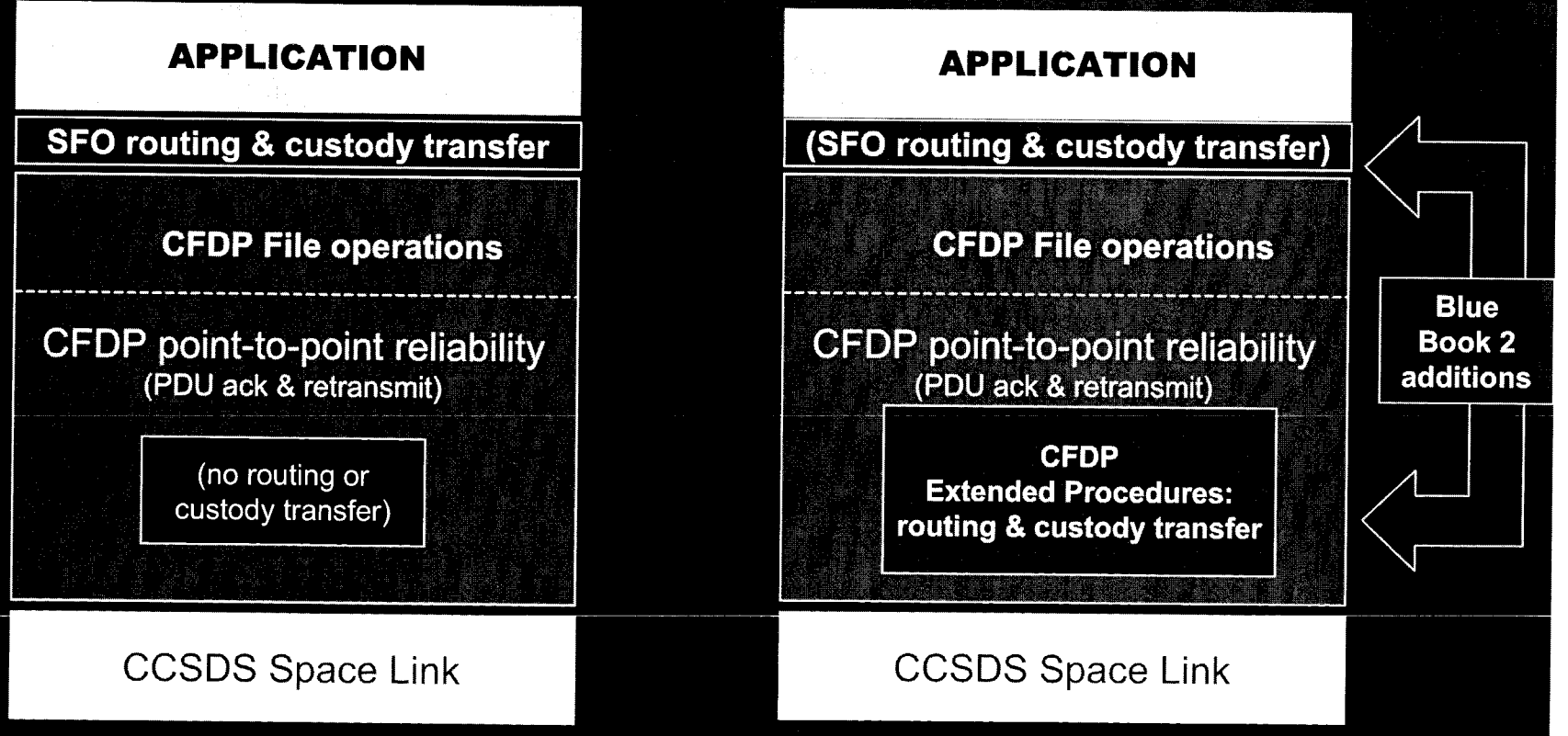
Build 3 CFDP



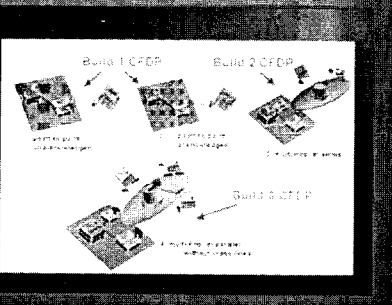
4. multi-hop, in parallel
   - without cross-links

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 <u>not part</u> of CFDP. This application code provides multi-hop routing and custody transfer services
  - Additional "Extended Procedures" that <u>are part</u> 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

transmitted data product 1

received data product 1

Data Product Manager (DPM) Overlay

(SFO routing & custody transfer)

segmentation

reconstitution

request 1

request 2

indication 1

indication 2

CFDP File operations

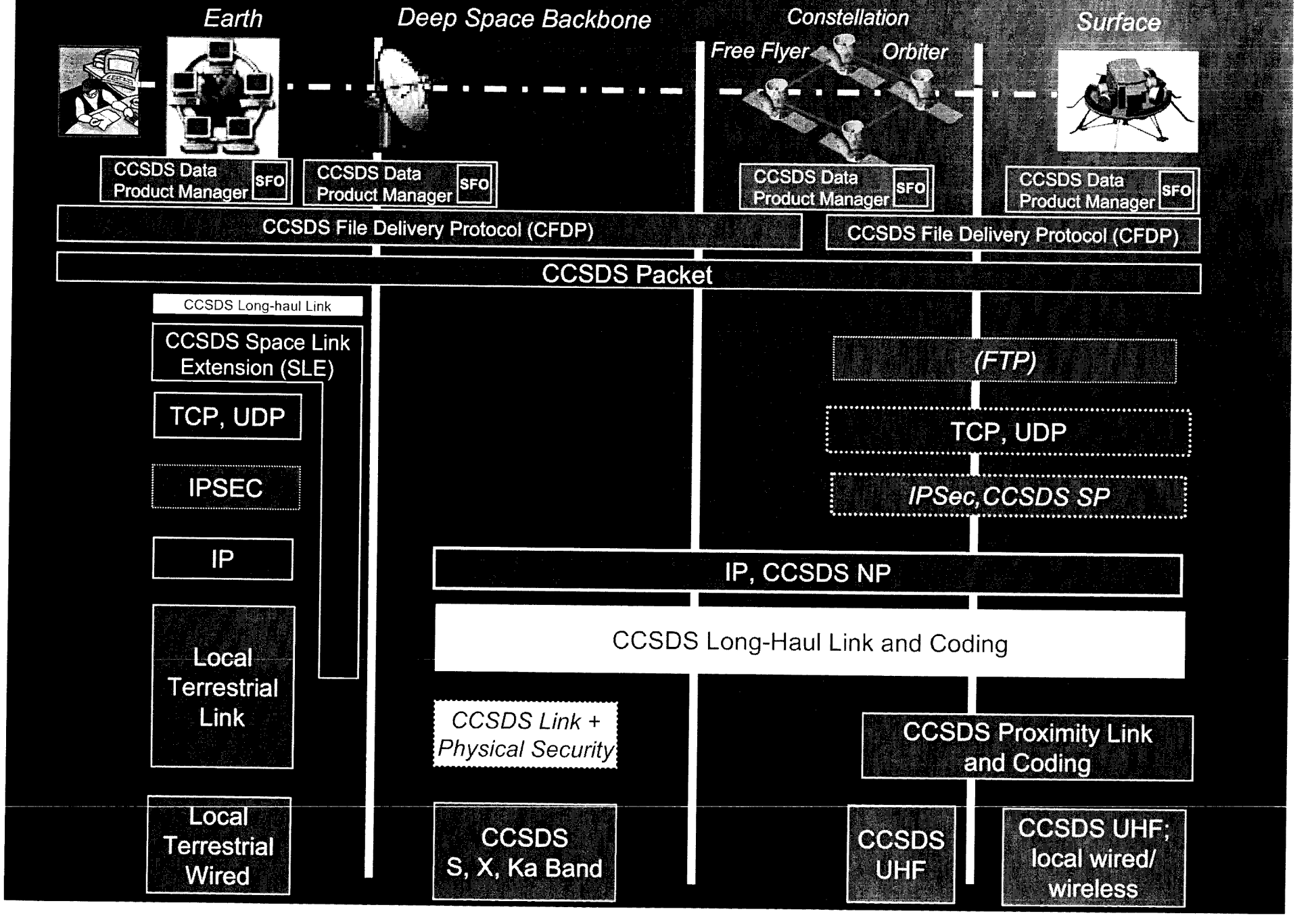
CFDP point-to-point reliability

(PDU ack & retransmit)

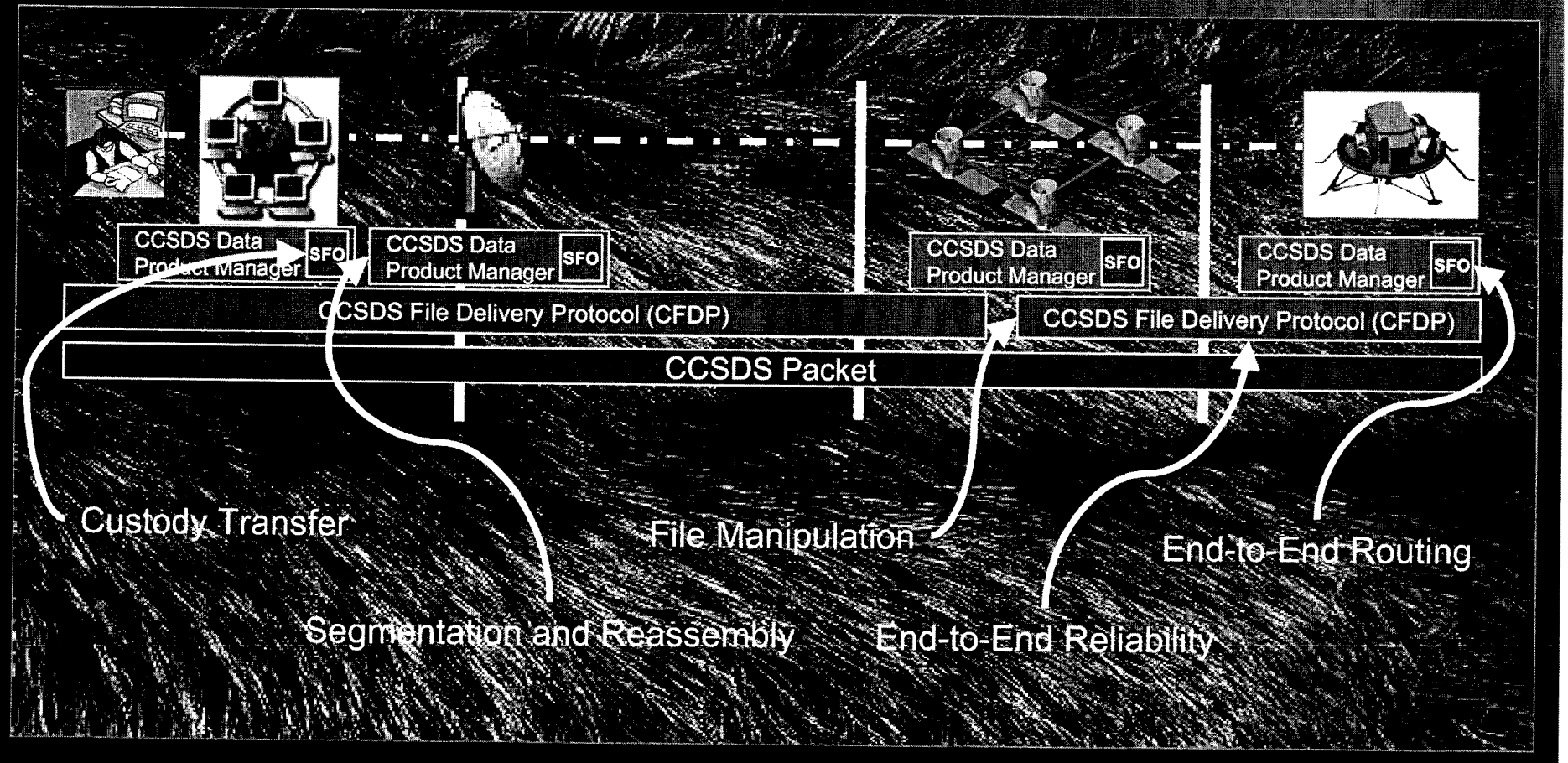
CFDP Extended Procedures: routing & custody transfer

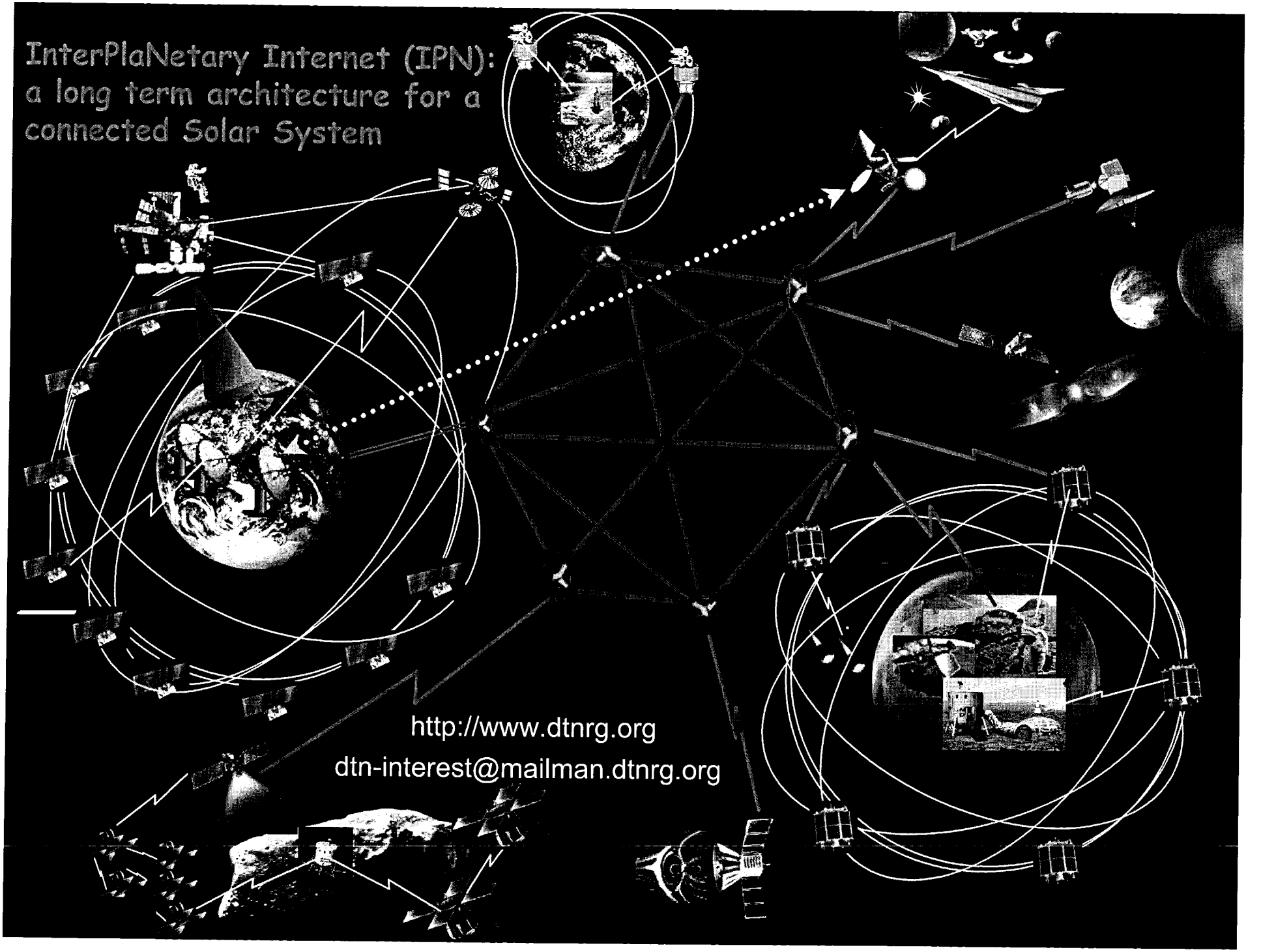
CCSDS Space Link

"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

1970

1980

1990

2000

NASA Telemetry Standardization

"Packet" Spacecraft Telemetry and Telecommand

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NASA/ESA Working Group

Basic Space/Ground Communications Standards for Space Missions

Baselined by Space Station and Ground Network

CCSDS

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CCSDS Recommendation for Advanced Orbiting Systems

Extension of Standards for More Complex Space Missions

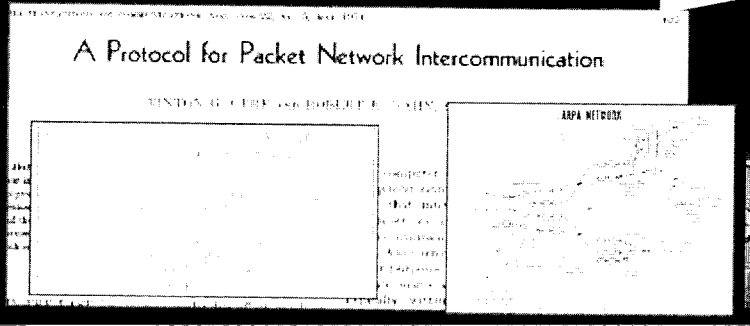
International Space Station

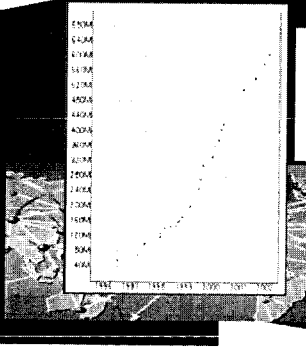
File Transfer: FTAM
Transport: TP4
Network: ISO 8473

The Dark Age Of OSIP

Extension of the Terrestrial Internet into Space

Evolution of space standards





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

File Transfer: FTP
Transport: TCP
Network: IP

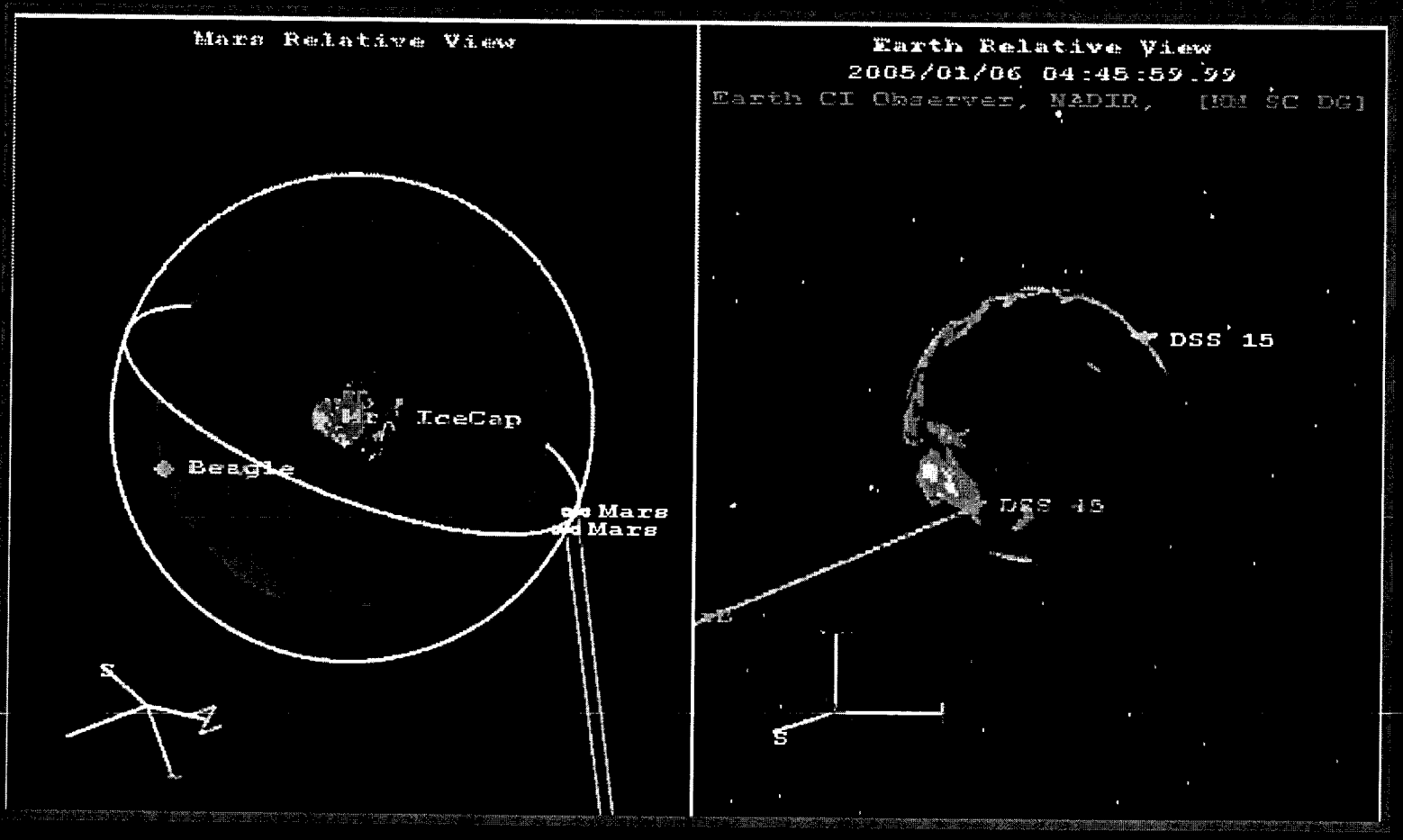
2002: 605 million users

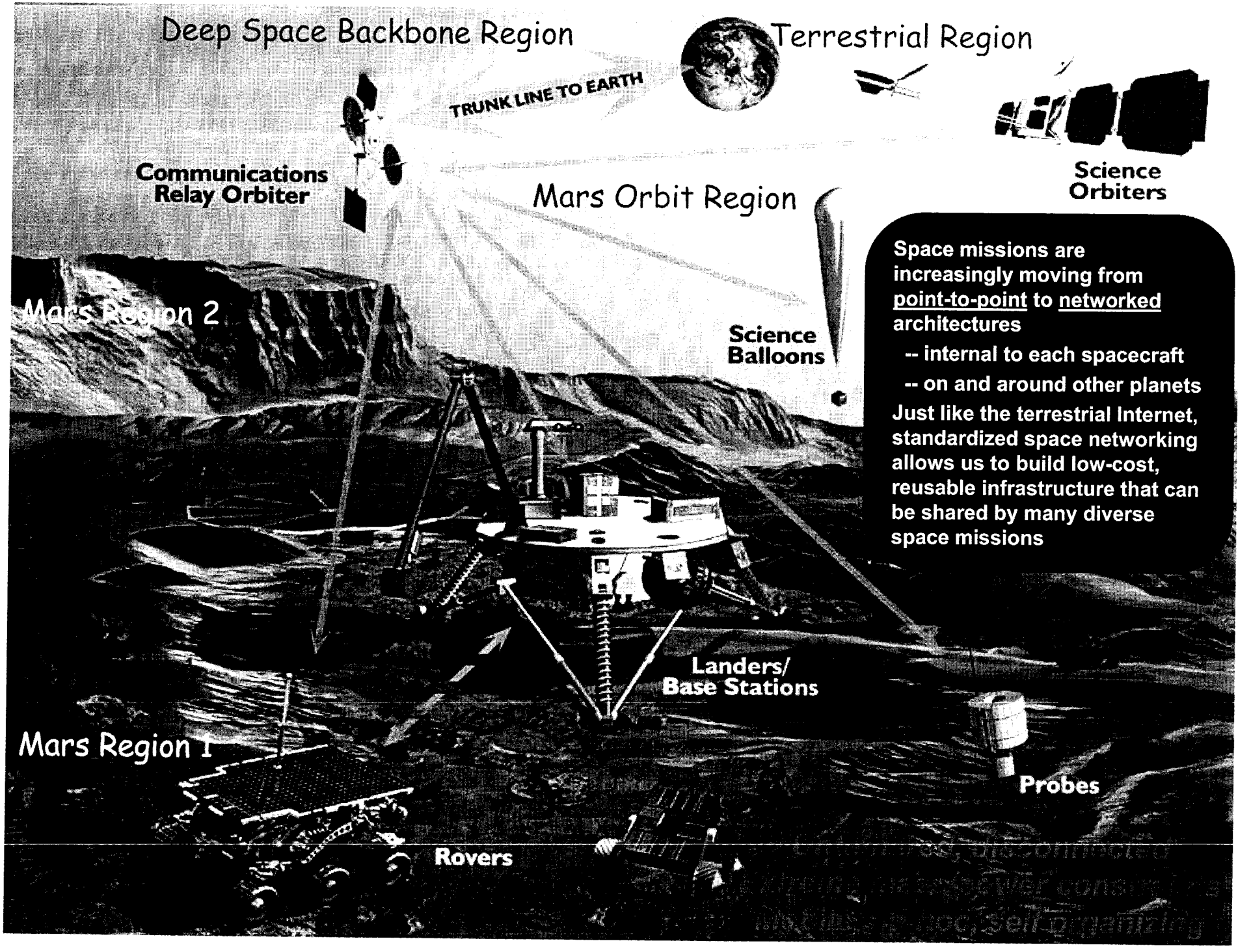
InterPlaNetary Internet (IPN)

Evolution of the terrestrial Internet

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

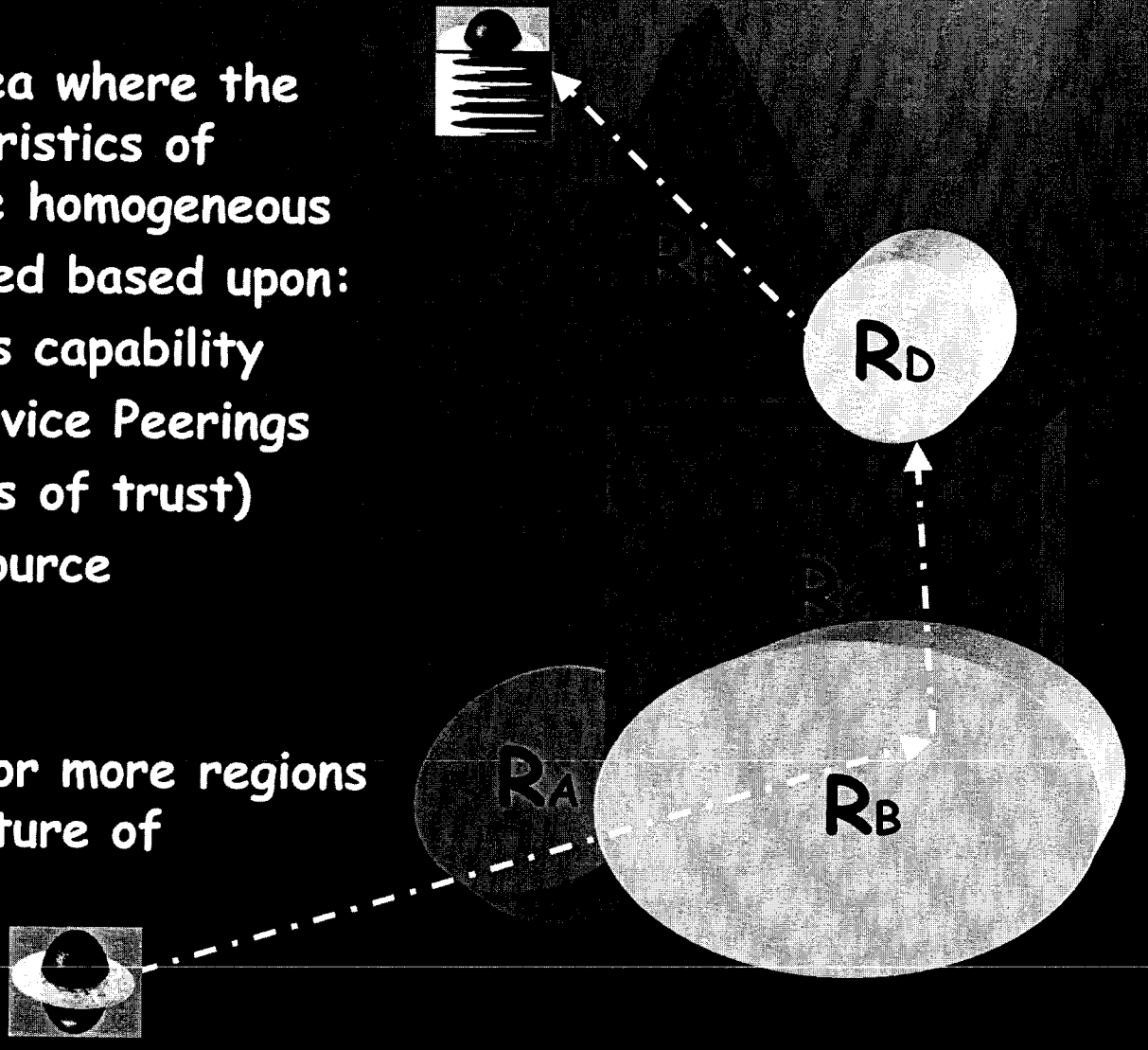


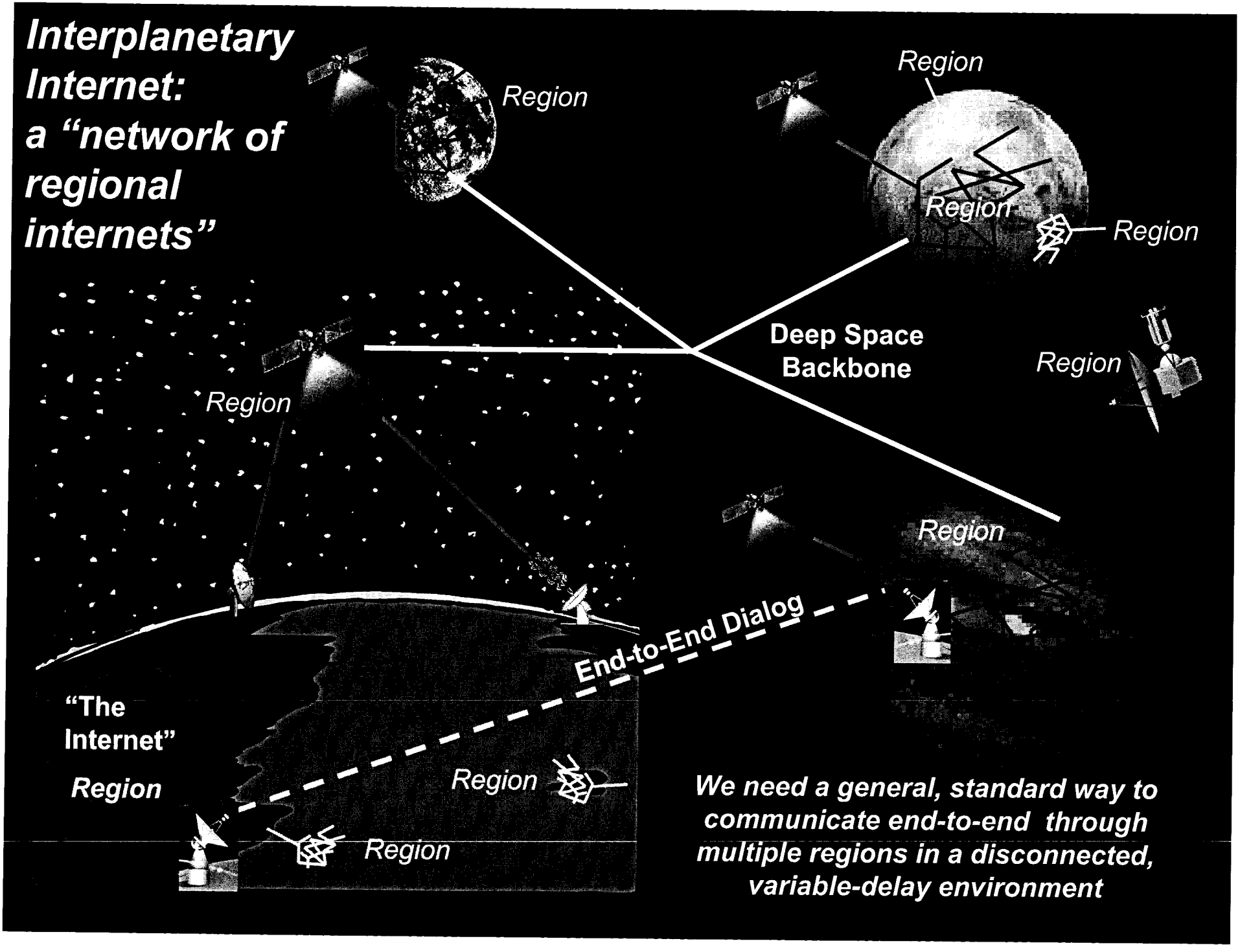

Deep Space Backbone Region
Terrestrial Region
TRUNK LINE TO EARTH
Communications Relay Orbiter
Mars Orbit Region
Science Orbiters
Mars Region 2
Science Balloons
Space missions are increasingly moving from point-to-point to networked architectures
-- internal to each spacecraft
-- on and around other 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:

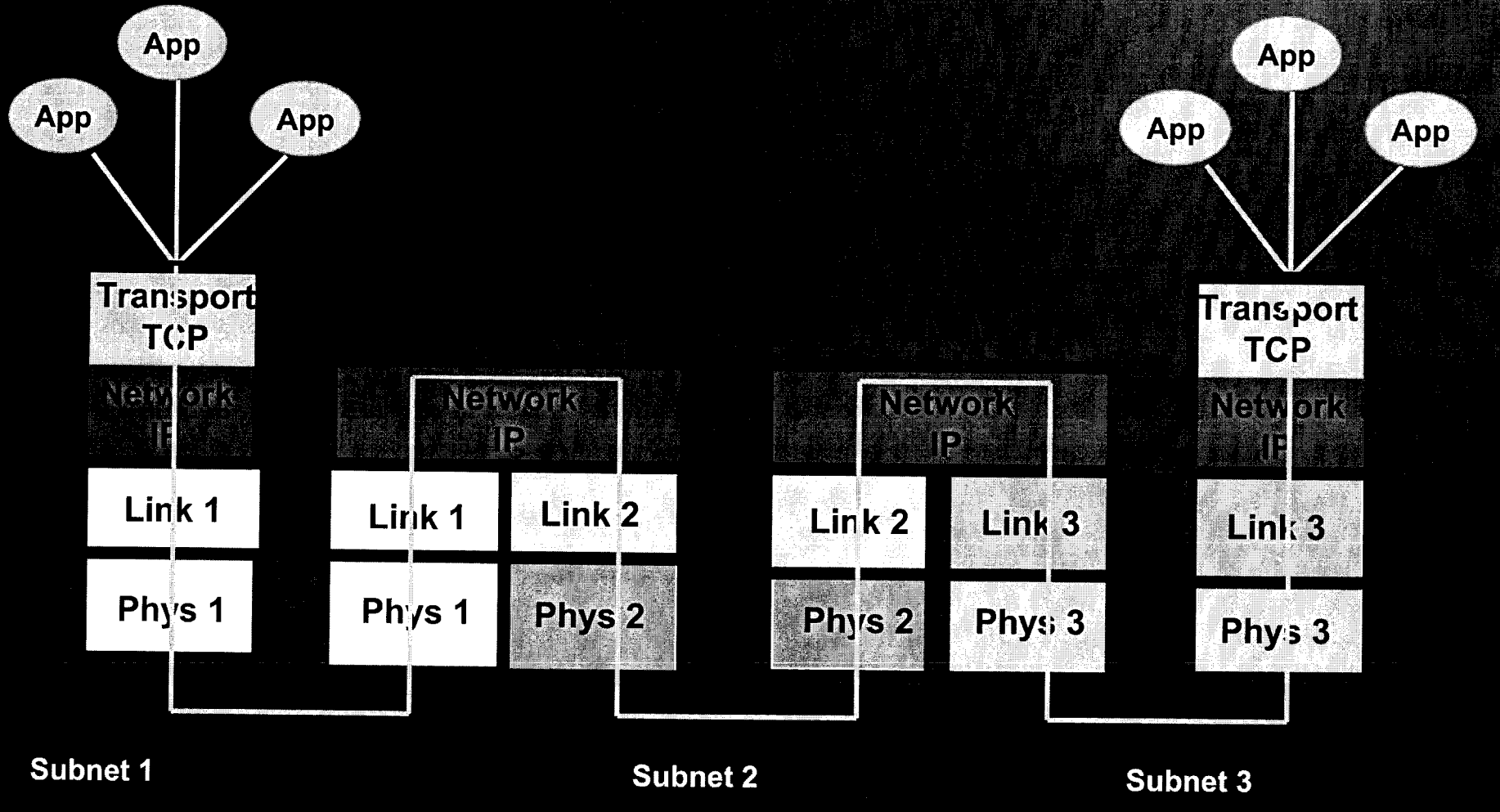
An overlay network for interconnection of [illegible]

- *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



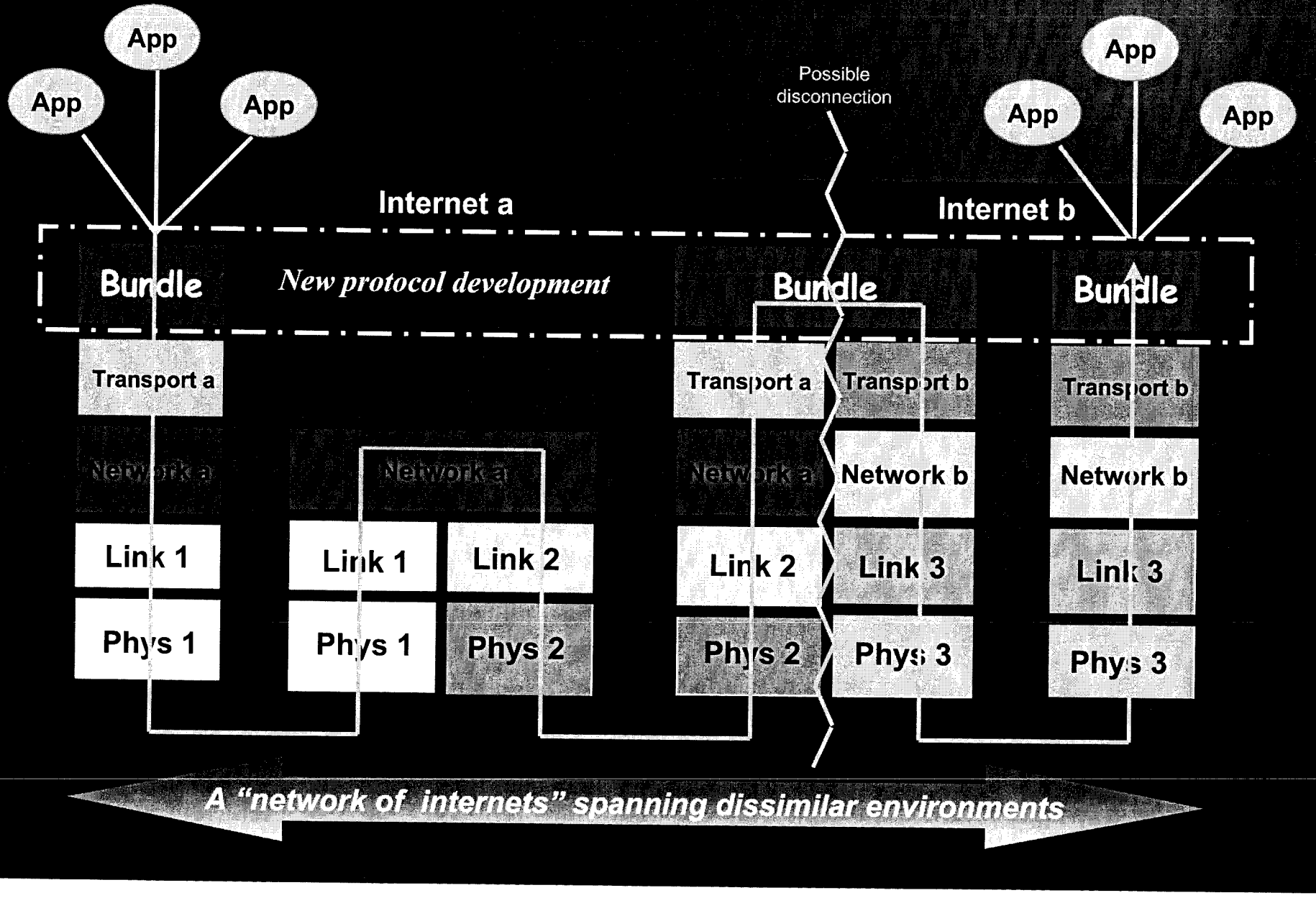

Interplanetary Internet: a "network of regional internets"
Region
Region
Region
Region
Region
Region
Deep Space Backbone
Region
End-to-End Dialog
"The Internet"
Region
Region
Region
We need a general, standard way to communicate end-to-end through multiple regions in a disconnected, variable-delay environment

The Internet: a Network of Connected Sub-Networks

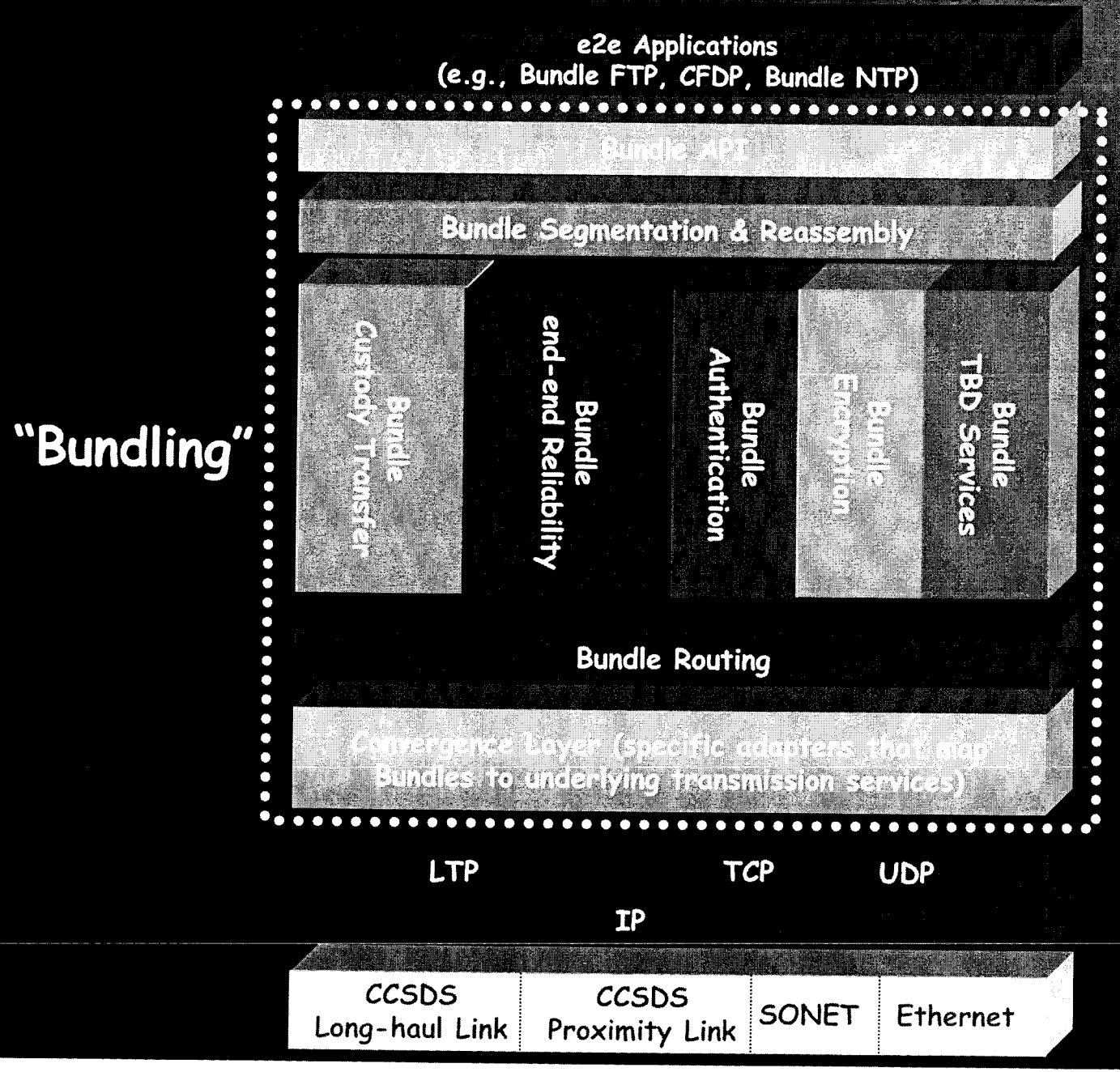


Bundles: A Store and Forward Application Overlay

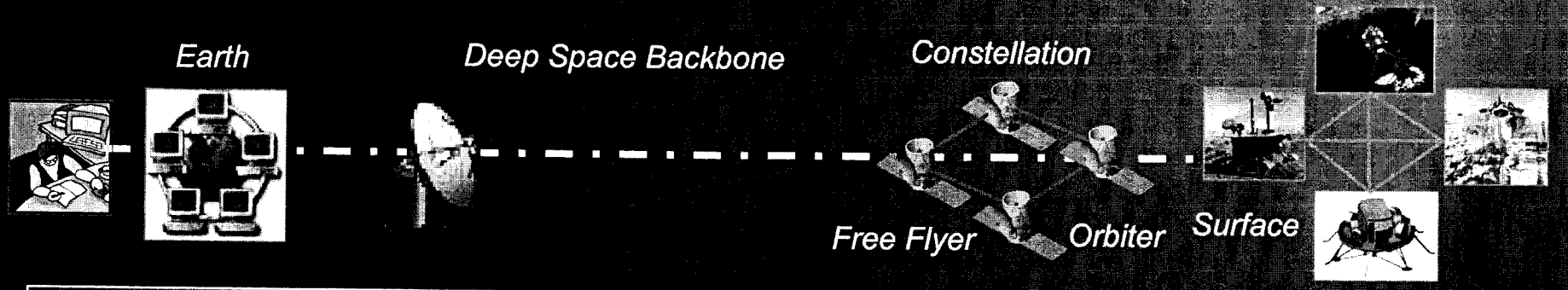
The "Thin Waist" of the Interplanetary Internet



Bundle Service Layering



"Interplanetary Networking ": 2007+



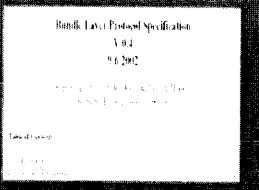
CCSDS Space Applications Protocols (CFDP, Messaging, Streaming, etc.)

CCSDS Bundling

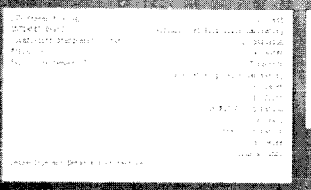
- The Bundling protocol suite will provide general purpose delay tolerant protocol services in support of many diverse applications in highly networked configurations:
  - Custody transfer
  - Segmentation and reassembly
  - End-to-end reliability
  - End-to-end security
  - End-to-end routing

IPN
Architecture
(Internet Draft 1)
May 2001

DTN
Architecture
(Internet Draft 2)
August 2002



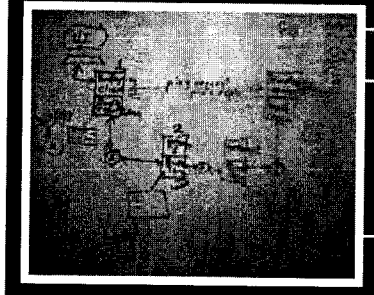
Bundle Protocol
Specification, Draft1
September 2002



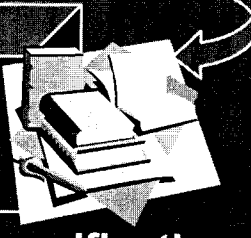
DTN
Architecture
(Internet Draft 3)
March 2003

IPN Bundle Transfer
(Internet Draft 1) March 2003

Bundle Protocol Specification
(Internet Draft 1) March 2003

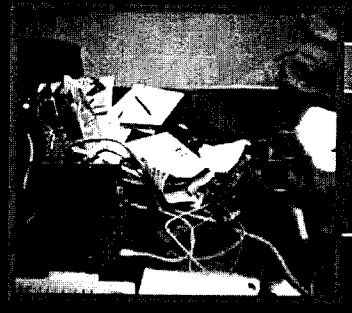


Bundle Specification



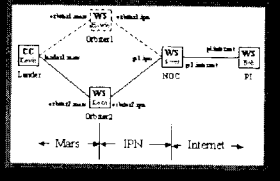
Specifications

Code base

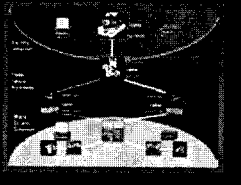


Bundle Prototyping

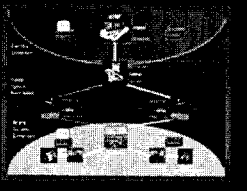
1st. Rough Code
August 2000



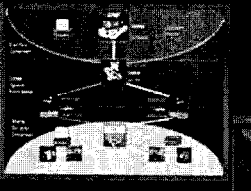
2nd. Proto. Code
May 2002



3rd. Proto. Code
July 2002



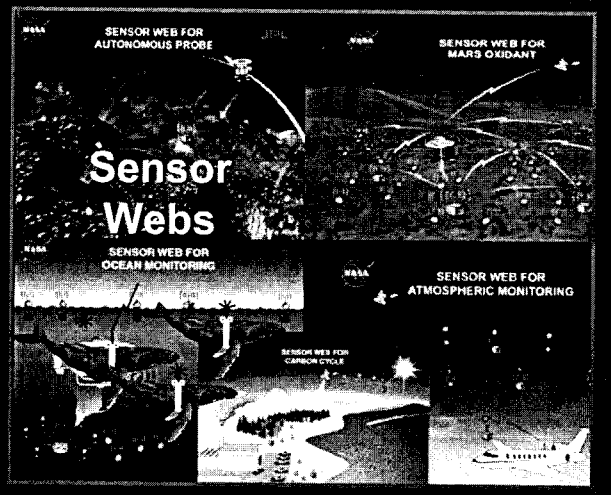
4th Proto. Code
Sept. 2002

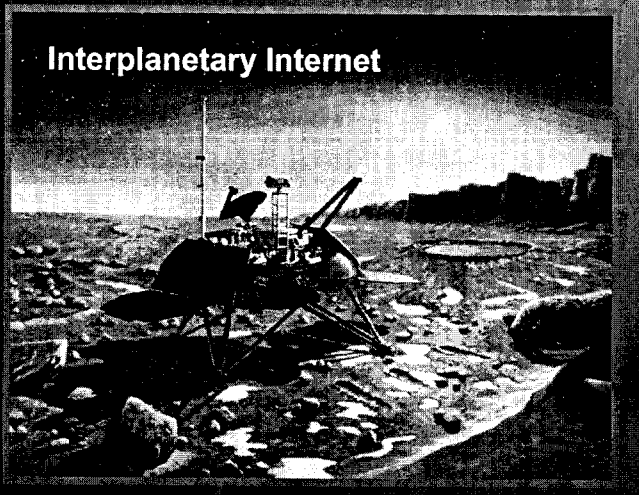


5th Proto. Code
Nov. 2002

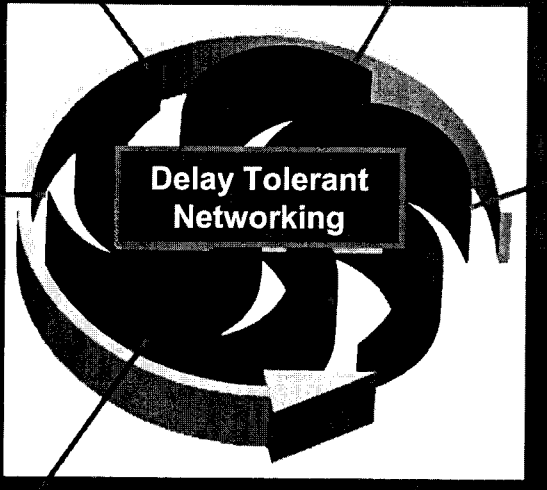
Open Source
Release1 Code
March 2003

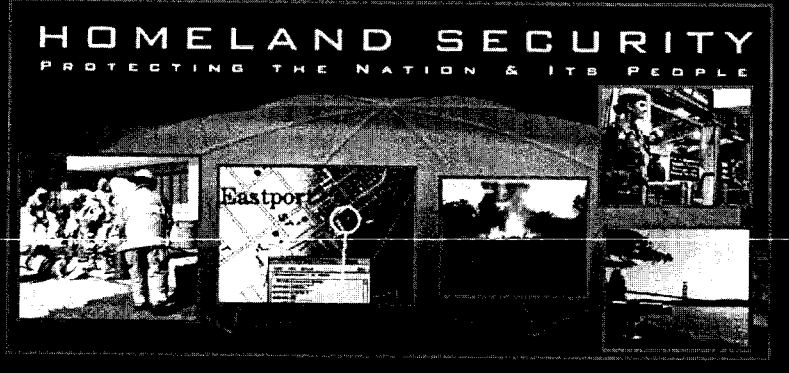
Code available at http://www.dtnrg.org





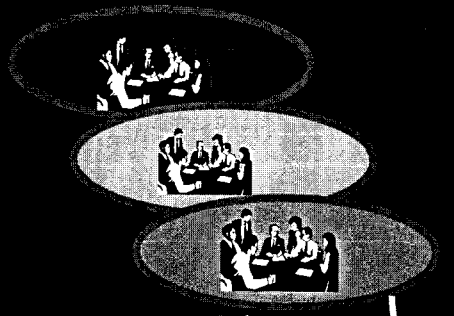
- "Non-chatty" message-oriented communications
- Store-and-forward between nodes
- Routing algorithms cognizant of scheduled connectivity
- Use transport and network technologies appropriate to the environment
- Integral infrastructure protection





IPN evolution:
Broader applicability
Nearer term utility
Larger research community

Delay Tolerant Networking:
a broad community effort



Other
DTN communities

Open Architecture
Open Specifications
Open Implementations

Fielded DTN Deployments

Public

Internet Society

IRTF
Internet Research Task Force

DTN Research Group

http://www.dtnrg.org

IETF

IPNSIG

http://www.ipnsig.org

ISO

CCSDS

http://www.ccsds.org

Interplanetary
Internet


BBC NEWS

You are in: Technology
Wednesday, 20 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 (SNC) 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.

See also:

Internet links:

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

Top Technology stories now:

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

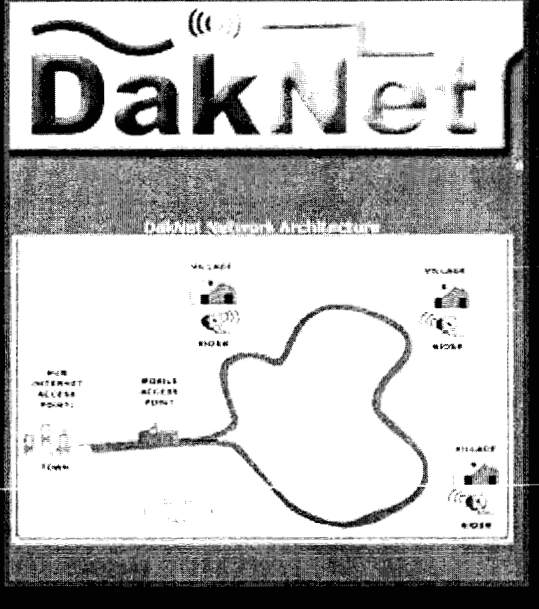
Energy-Efficient Computing for Wildlife Tracking: Design Tradeoffs and Early Experiences with ZebraNet

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

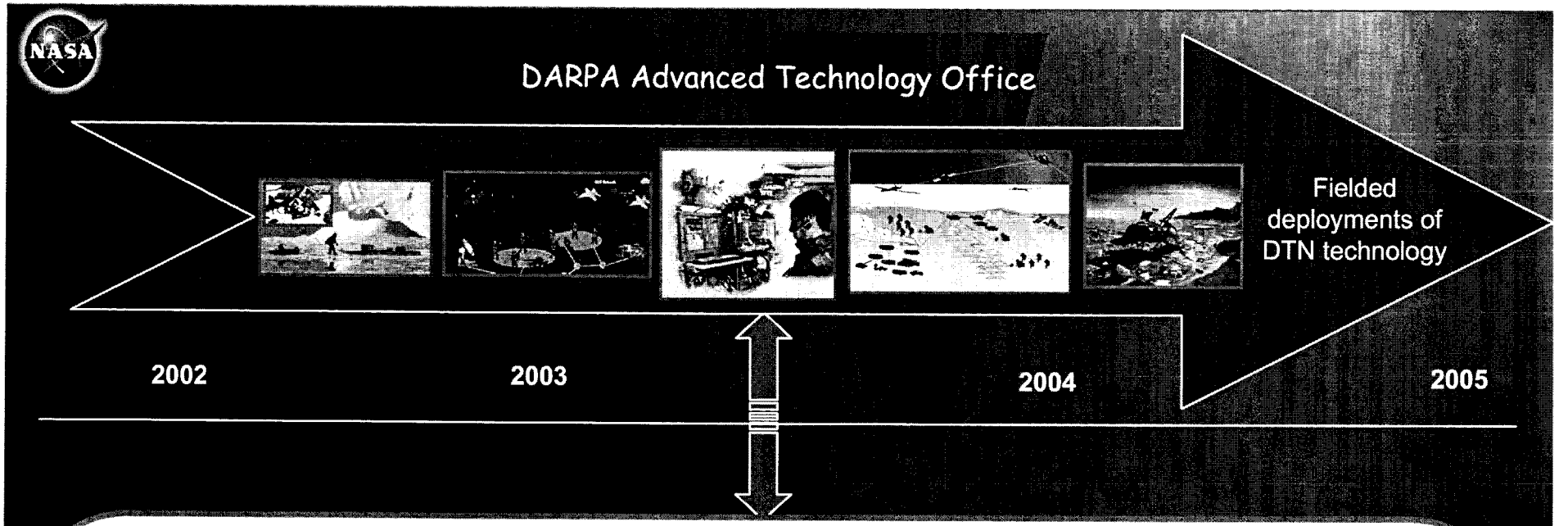


SICS

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. Docent (1991)
Research Interests: Routing in computer networks, Optimization, [illegible] done some work in Risk Management, and [illegible] a life long interest in Geometry, Topology and



DTN Research Group:

Focal point for DTN

Delay Tolerant Networking

DTN Core Engineering

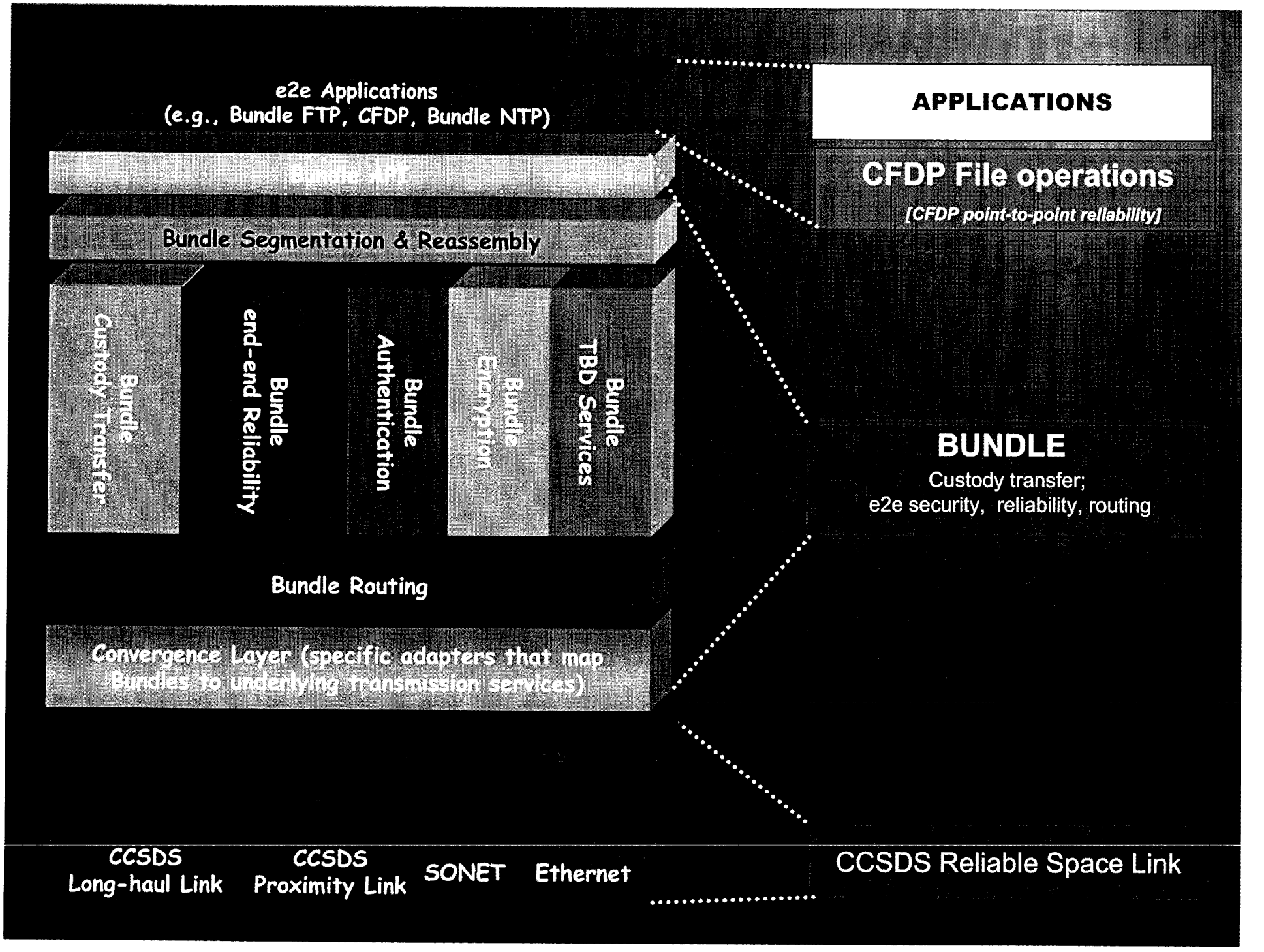
- DTN Architecture
- DTN Design Documents

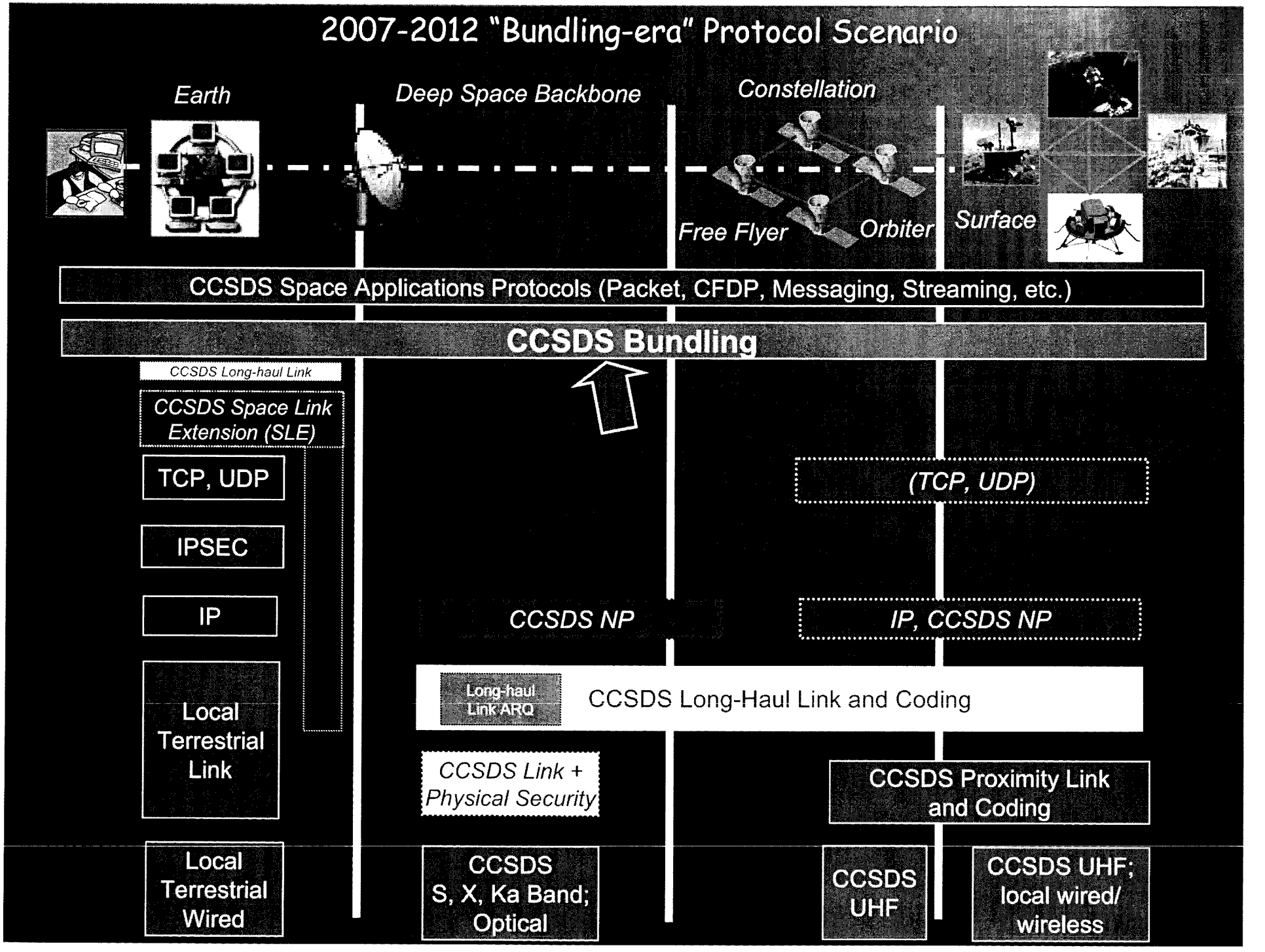
DTN Open Source

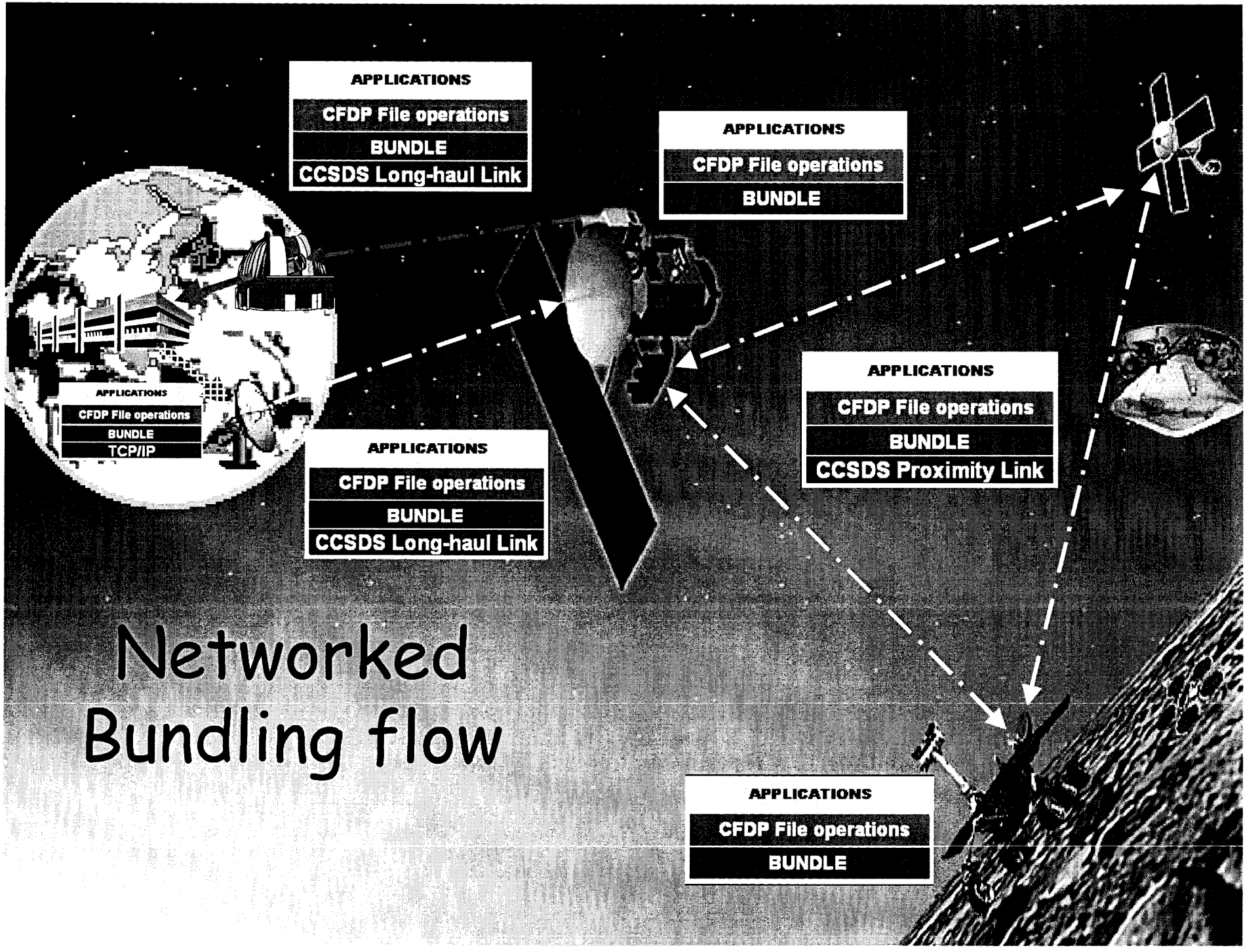
- Reference Software
- Configuration Control

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
Earth
Deep Space Backbone
Constellation
Free Flyer
Orbiter
Surface
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
(TCP, UDP)
CCSDS NP
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


APPLICATIONS
CFDP File operations
BUNDLE
CCSDS Long-haul Link
APPLICATIONS
CFDP File operations
BUNDLE
APPLICATIONS
CFDP File operations
BUNDLE
TCP/IP
APPLICATIONS
CFDP File operations
BUNDLE
CCSDS Long-haul Link
APPLICATIONS
CFDP File operations
BUNDLE
CCSDS Proximity Link
APPLICATIONS
CFDP File operations
BUNDLE
Networked
Bundling flow


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