# Architectural Models of Space Networking

**Authors:**

Peter Shames
Mgr, JPL Information Systems Standards Program
Jet Propulsion Laboratory (JPL)
4800 Oak grove Drive
Pasadena, CA 91109
818 354-5740

Dr. Takahiro Yamada
Institute of Space and Astronautical Science (ISAS)
3-1-1 Yoshinodai
Sagamihara 229
Japan

**Focus Issues:**

- Models of networking in space
- Architectural representation and analysis
- Standards and interoperability
- Space and ground communication architectures

## ABSTRACT

Architectures for data systems that are built and managed by a single organization are inherently complex. In order to understand a large scale space data system architecture, and to judge its applicability for its nominal task, a description must be produced that exposes a number of distinct viewpoints. Such descriptions will typically cover the uses that are to be made of the system, the functions that the system performs, the elements that compose the system, the information that flows among these elements, and the specific technologies that are integrated into the system.

Within the CCSDS Architecture Working Group (AWG) we have adapted the Reference Model for Open Distributed Processing (RM-ODP) to describe these large, multi-national, space data systems. This modeling approach provides views on a system that go from the organizational (Enterprise) to the abstract (informational, computational), to the more concrete (Engineering, Technology). These systems exhibit all of the complexities of typical terrestrial systems, but are frequently compounded by involvement of several space agencies, some unusual organizational cross-support arrangements, and use of contractors in a number or roles.

This methodology, based upon RM-ODP, provides the necessary concepts and notation for describing these complex space data systems. The reference architecture is intended for use by two different, but related, user communities: the system users and the system and standards developers. The approach is intended to be general enough to permit description of civilian, military, and commercial space data systems, the spacecraft, ground systems, processing and communications resources, and organizational arrangements.

Any architectural methodology must deal with the complexities of operating systems in space, including all of the physical constraints and challenges that that environment brings. The most fundamental challenge is the physical space environment (motion, obscuration, long round trip light times, episodic connectivity, low signal strength, asymmetric data paths) which constrains how these systems are engineered and operated, and often requires different protocols for communications than those that can be used terrestrially. In some cases Internet protocols may be adapted to operate successfully, in others the constraints in the space environment clash with the fundamental models implicit in the IP Suite design.

In this paper we will introduce the RA_SDS design methodology and then show how it can be applied to an analysis of the issues involved with networking in space.


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Peter Shames

Mgr, JPL Information Systems Standards Program

+1.818.354.5740

peter.shames@jpl.nasa.gov

# NASA DATA SYSTEM STANDARDS PROGRAM


- Overview and Purpose
- Architectural Viewpoints
- Architecture Notation
- Example RASDS Views
- Application to Space Internetworking
- Next Steps

# NASA DATA SYSTEM STANDARDS PROGRAM

## A Physical View of a Space Data System

- Establish an overall CCSDS approach to architecting and to developing domain specific architectures
- Define common language and representation so that challenges, requirements, and solutions in the area of space data systems can be readily communicated
- Provide a kit of architect's tools that domain experts will use to construct many different complex space system architectures
- Facilitate development of standards in a consistent way so that any standard can be used with other appropriate standards in a system
- Present the standards developed by CCSDS in a systematic way so that their functionality, applicability, and interoperability may be clearly understood

Business Concerns
Organizational perspective

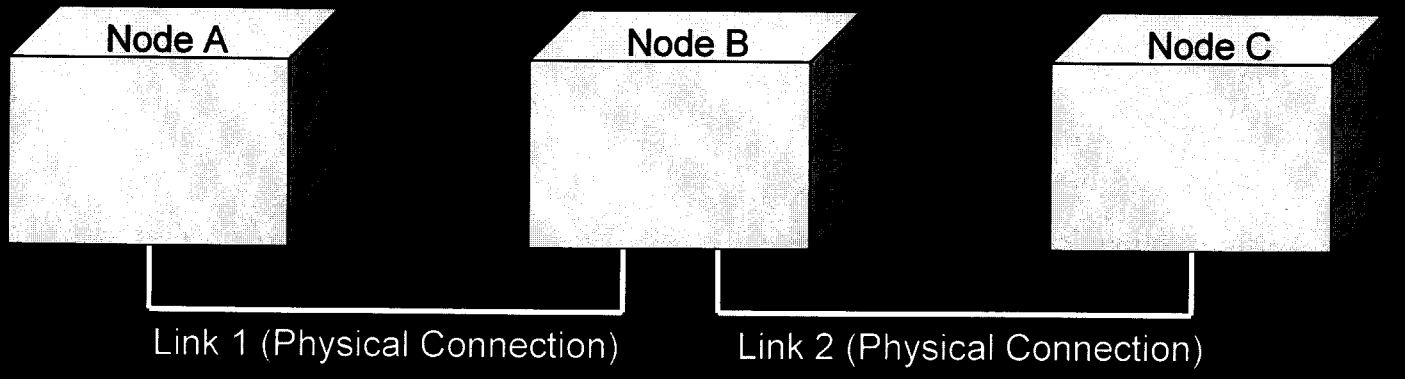
Physical Concerns
Node & Link perspective

Computational Concerns
Functional composition

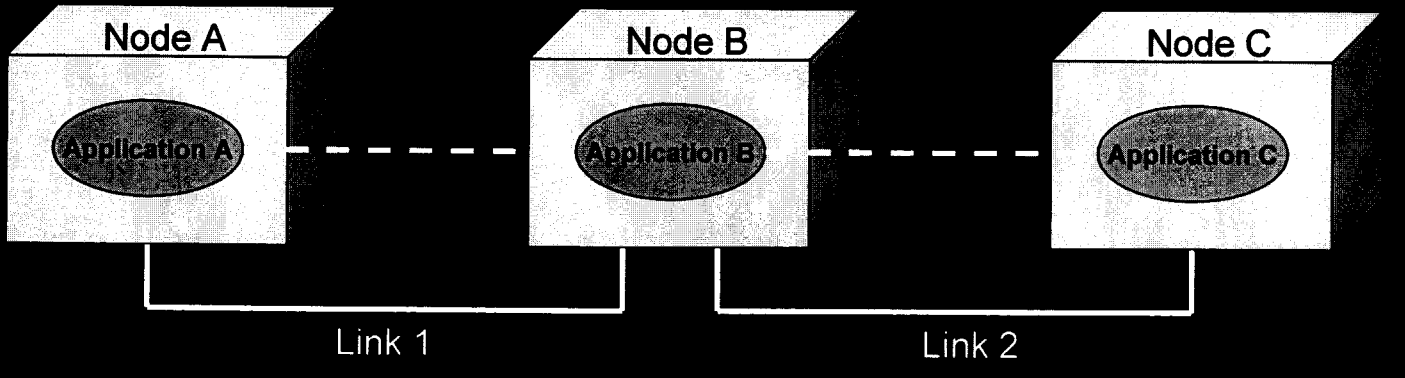
Data Concerns
Relationships and transformations

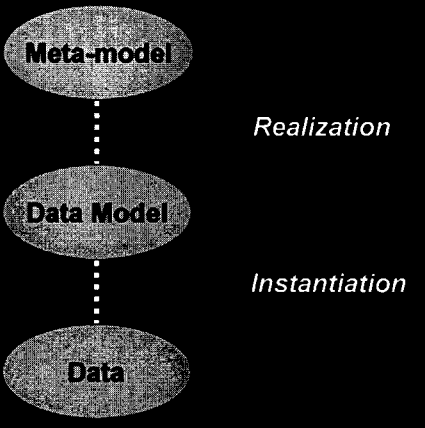
Protocol Concerns
Communications stack perspective


Enterprise P
Enterprise Q
Agreement,
Contract, etc.

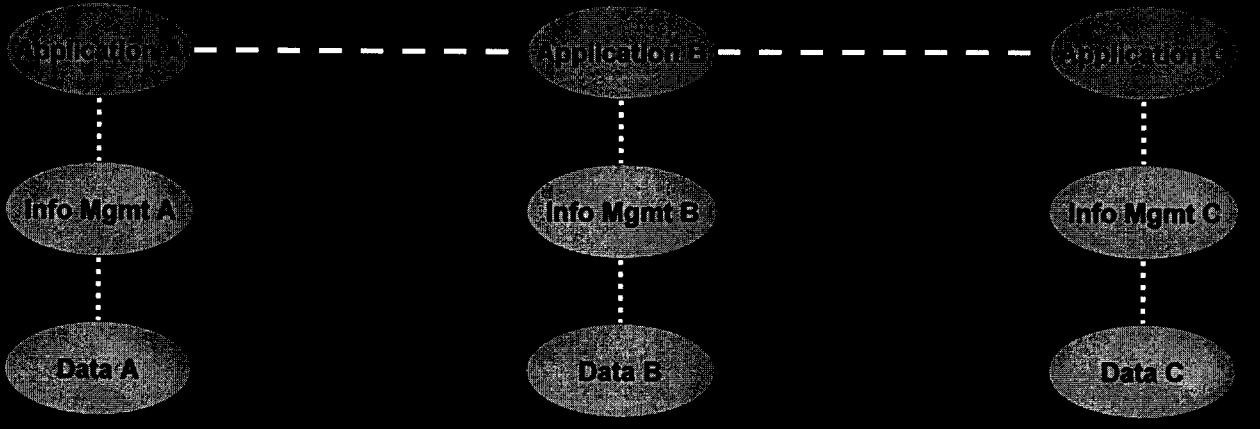

Node A
Node B
Node C
Link 1 (Physical Connection)
Link 2 (Physical Connection)

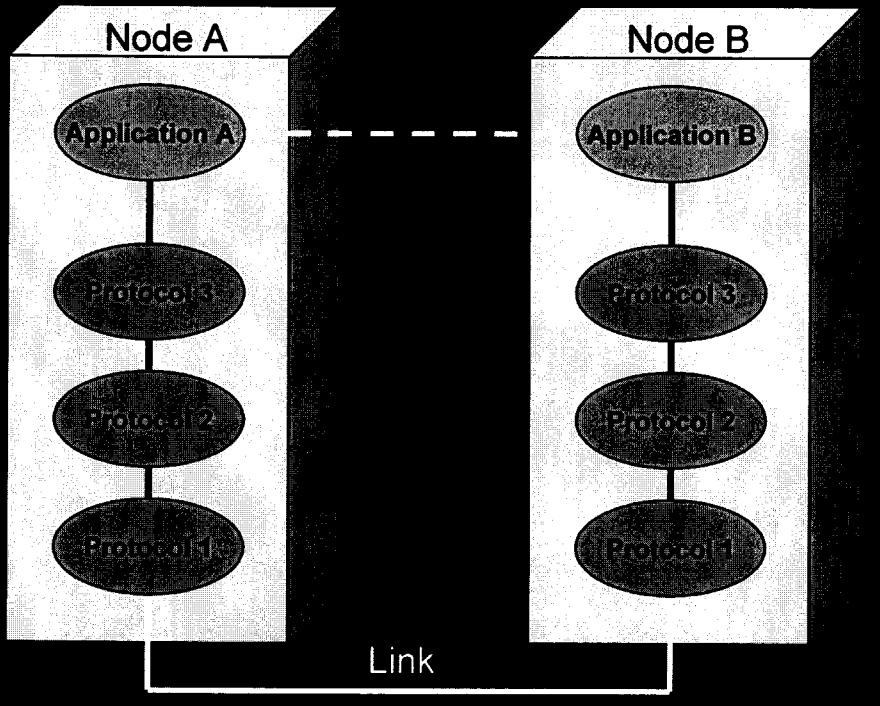

# Connectivity+Functional View (Nodes, Links and Functional Objects)






## Functional+Information View (Functional Objects and Information Objects)

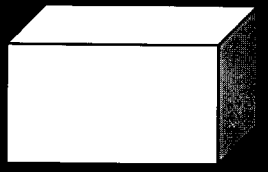



Node A
Application A
Protocol 3
Protocol 2
Protocol 1
Node B
Application B
Protocol 3
Protocol 2
Protocol 1
Link

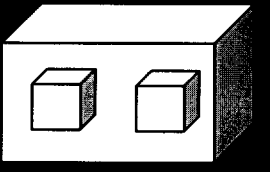
Object

Object with Interface

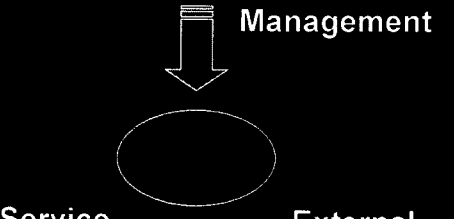
Object Encapsulation



Node (physical location)



Node Encapsulation (physical aggregation)






Logical Link

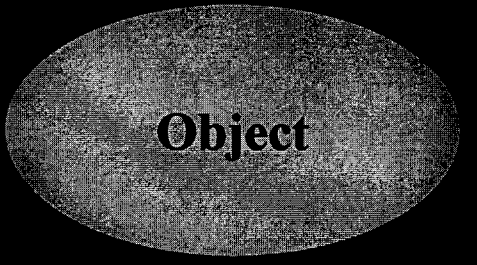


Physical Link

Space Link (rf or optical)

# Unified Object Representation

**Management Interfaces:**
How objects are configured controlled, and reported upon

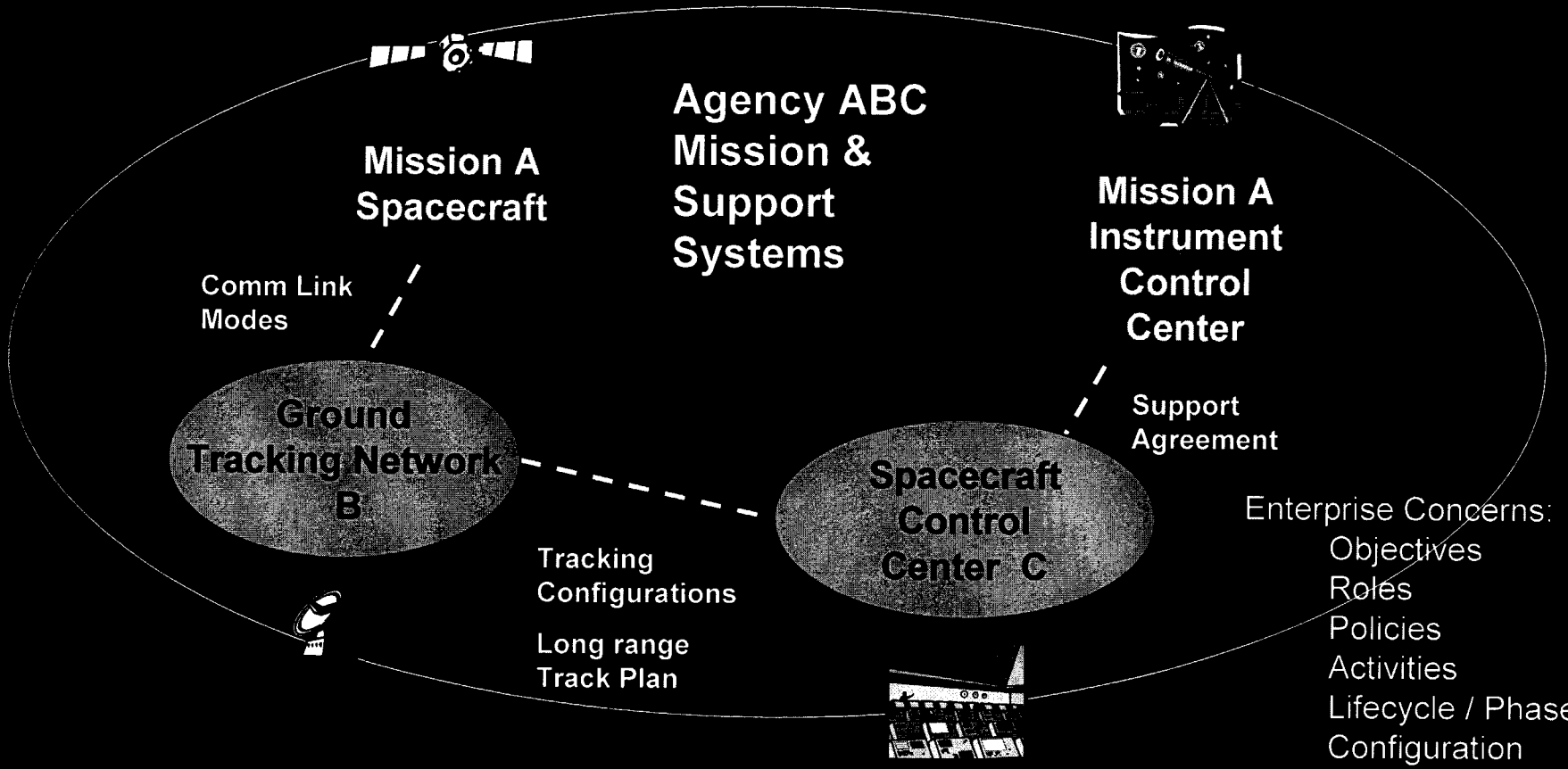



**Service Interfaces:**
How services are requested & supplied

**Core Functions**
What the object does

**External Interfaces:**
How external elements are controlled

**Concerns:**
Issues
Resources
Policies

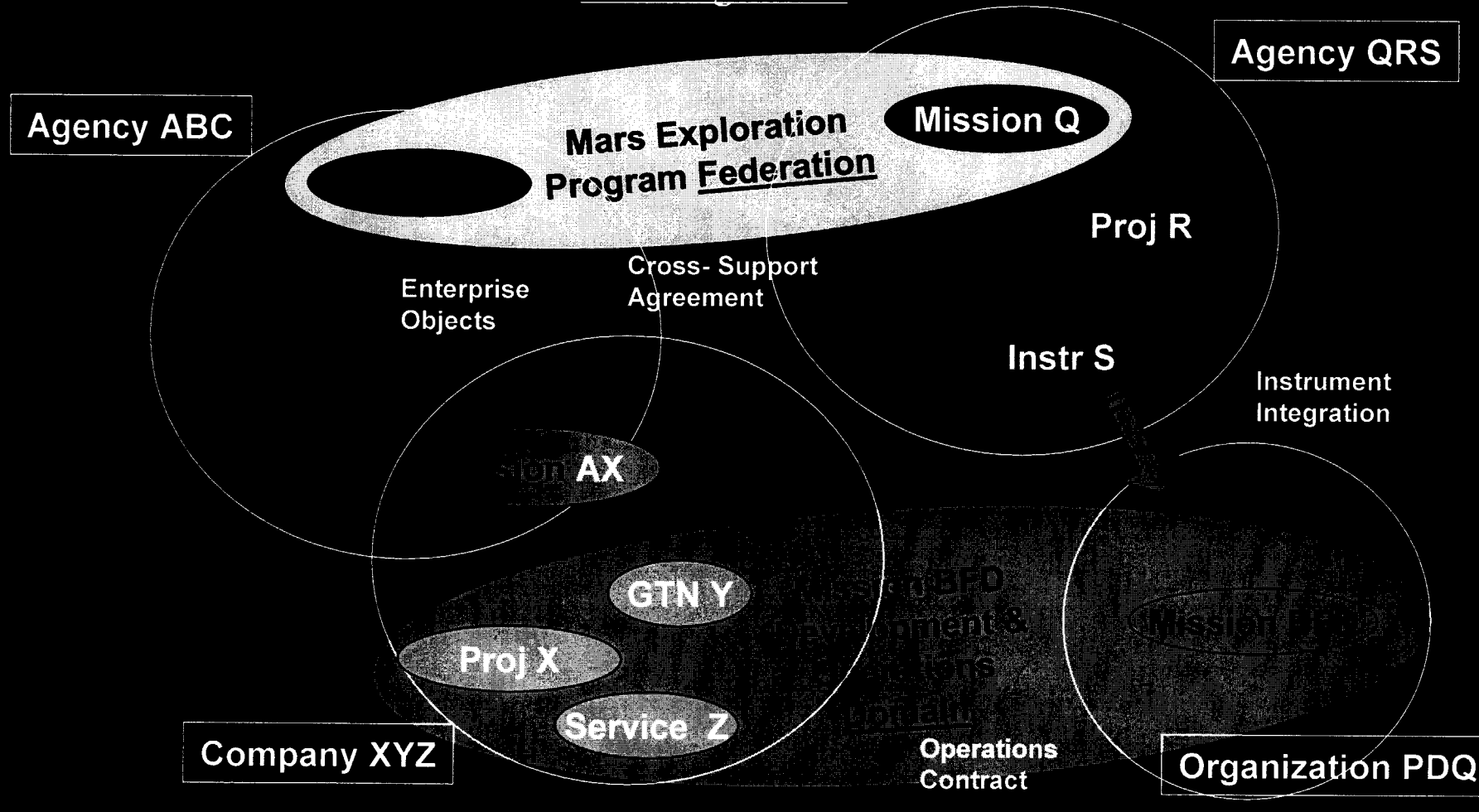

Agency ABC Mission & Support Systems
Mission A Spacecraft
Comm Link Modes
Ground Tracking Network B
Mission A Instrument Control Center
Support Agreement
Spacecraft Control Center C
Tracking Configurations
Long range Track Plan
Enterprise Concerns:
Objectives
Roles
Policies
Activities
Lifecycle / Phases
Configuration
Contracts

# NASA DATA SYSTEM STANDARDS PROGRAM

## Enterprise View

### Federated Enterprises with Enterprise Objects

### Planning Phase



Agency ABC
Mission A
Operations
Domain

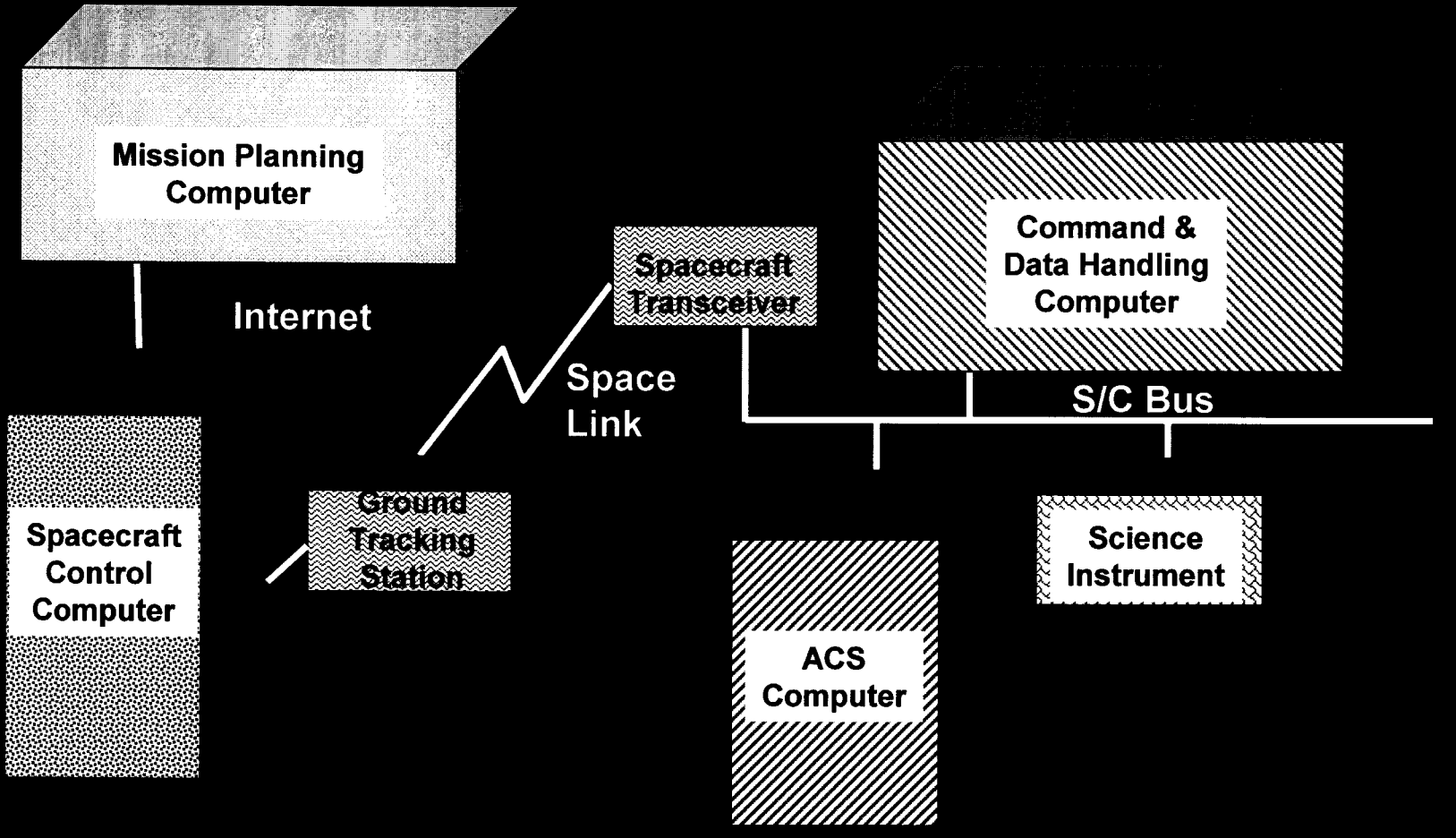
Science
Spacecraft

Science
Institute

Tracking
Station

S/C Control
Center

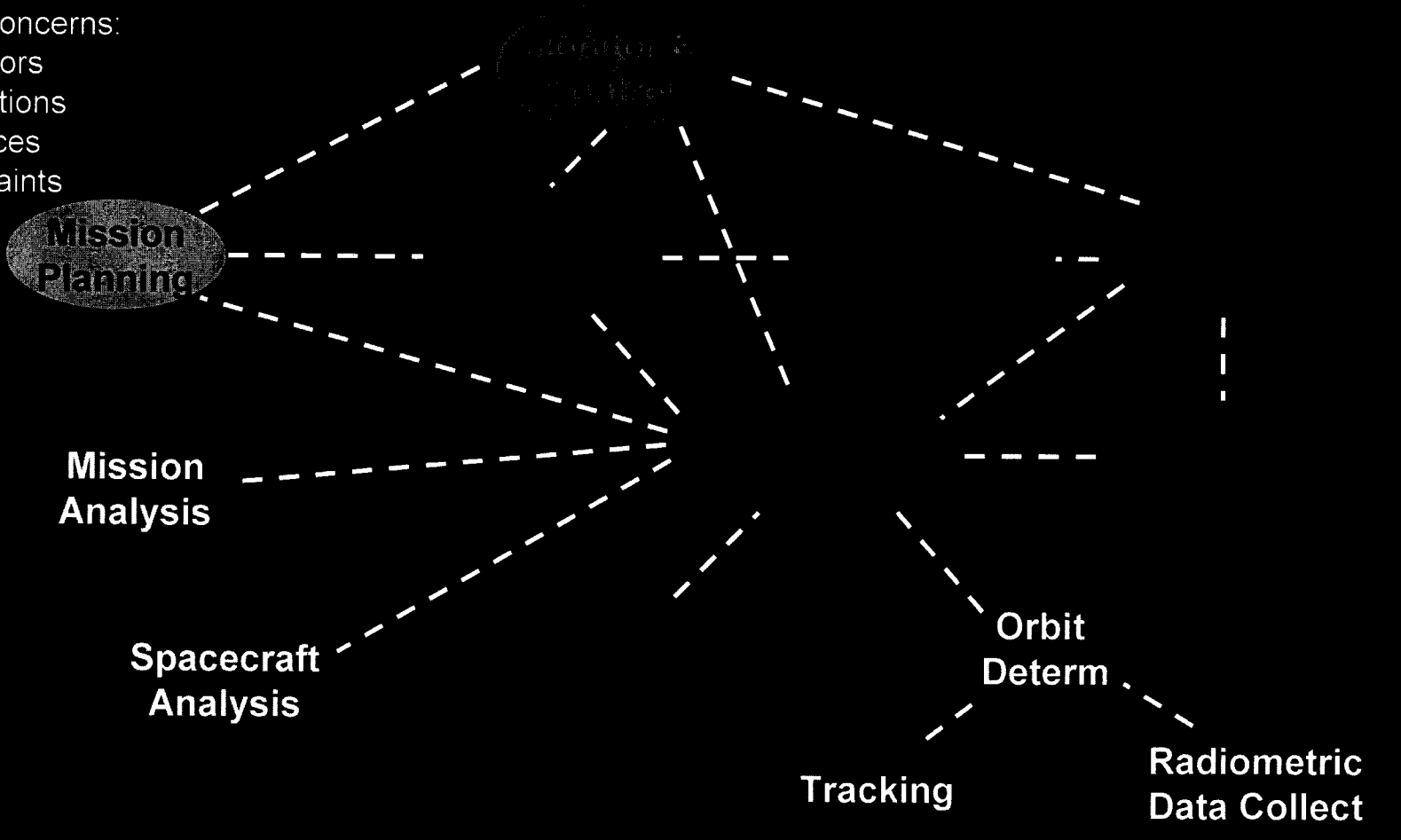
Connectivity Concerns:
- Distribution
- Communication
- Physical Environment
- Behaviors
- Constraints
- Configuration

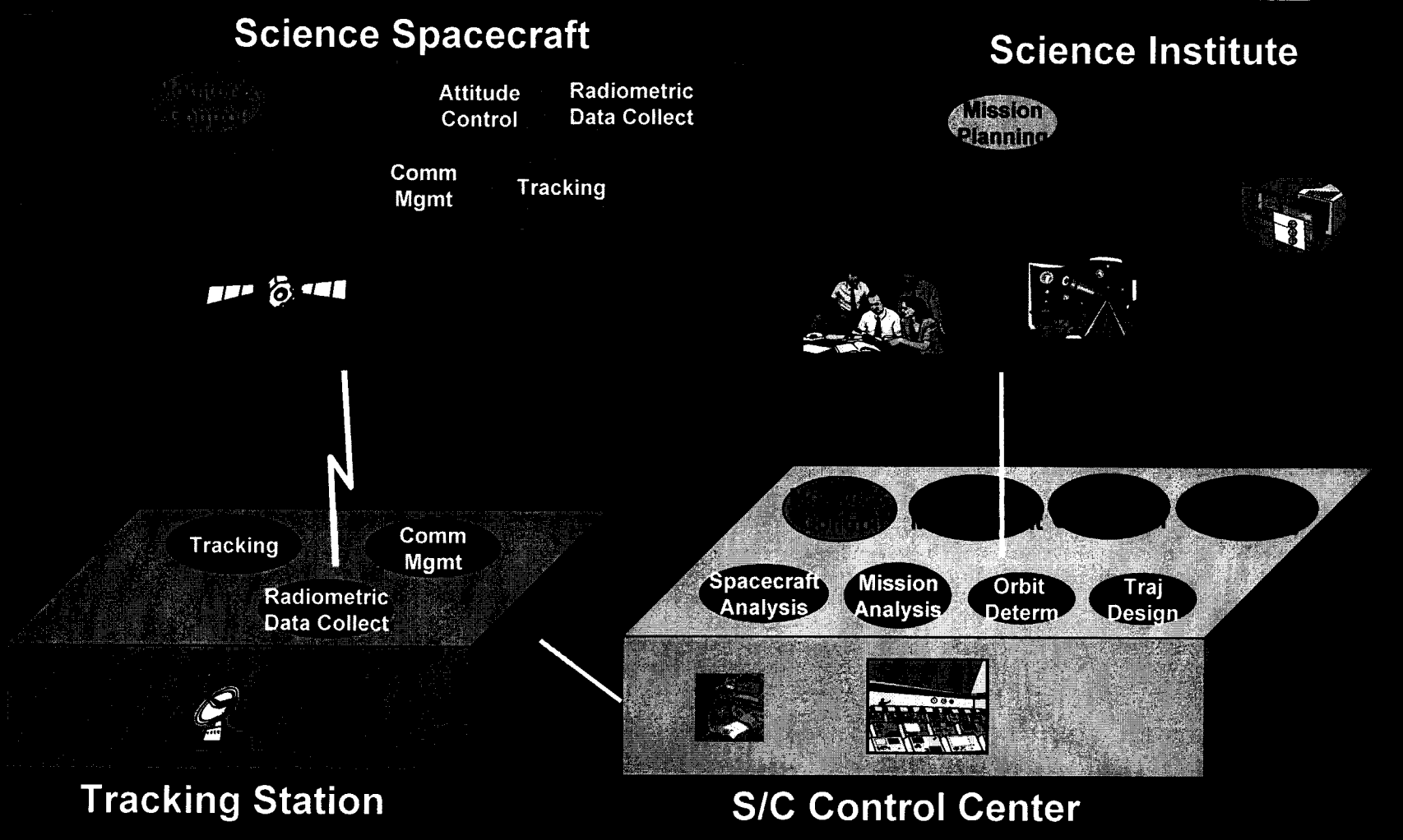

Mission Planning Computer
Internet
Spacecraft Transceiver
Space Link
Command & Data Handling Computer
S/C Bus
Spacecraft Control Computer
Ground Tracking Station
ACS Computer
Science Instrument

# Functional View

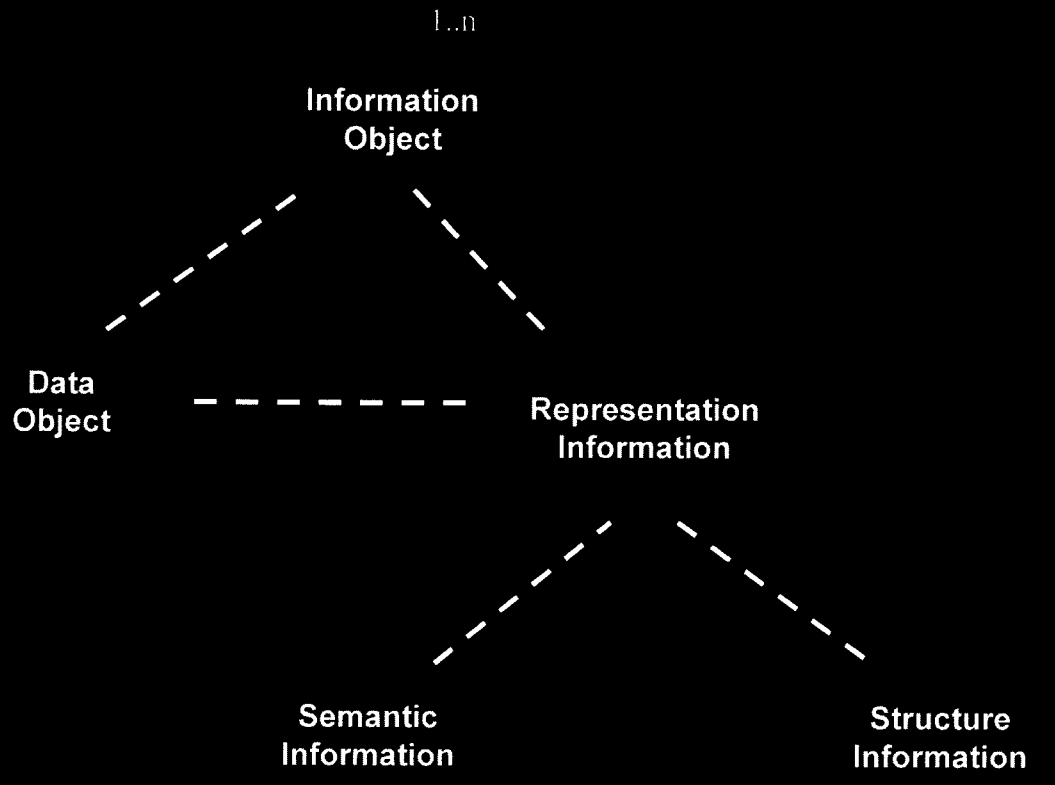
## Example Functional Objects & Interactions

Functional Concerns:
- Behaviors
- Interactions
- Interfaces
- Constraints




Science Spacecraft
Attitude Control
Radiometric Data Collect
Comm Mgmt
Tracking
Science Institute
Mission Planning
Tracking
Comm Mgmt
Radiometric Data Collect
Spacecraft Analysis
Mission Analysis
Orbit Determ
Traj Design
Tracking Station
S/C Control Center

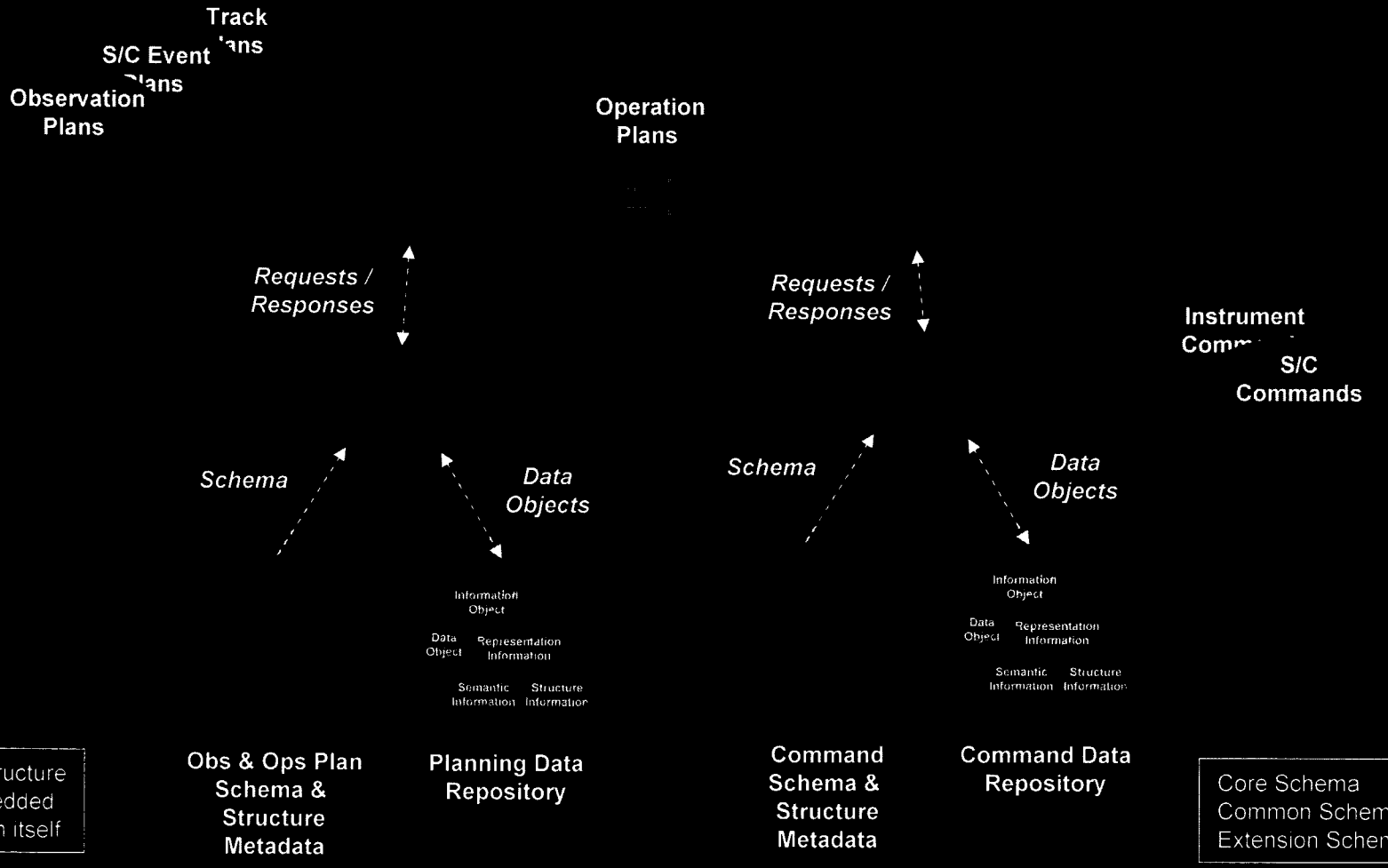
# Information Object
# Basic Relationships




Information Concerns:
- Structure
- Semantics
- Relationships
- Permanence
- Rules

# NASA DATA SYSTEM STANDARDS PROGRAM

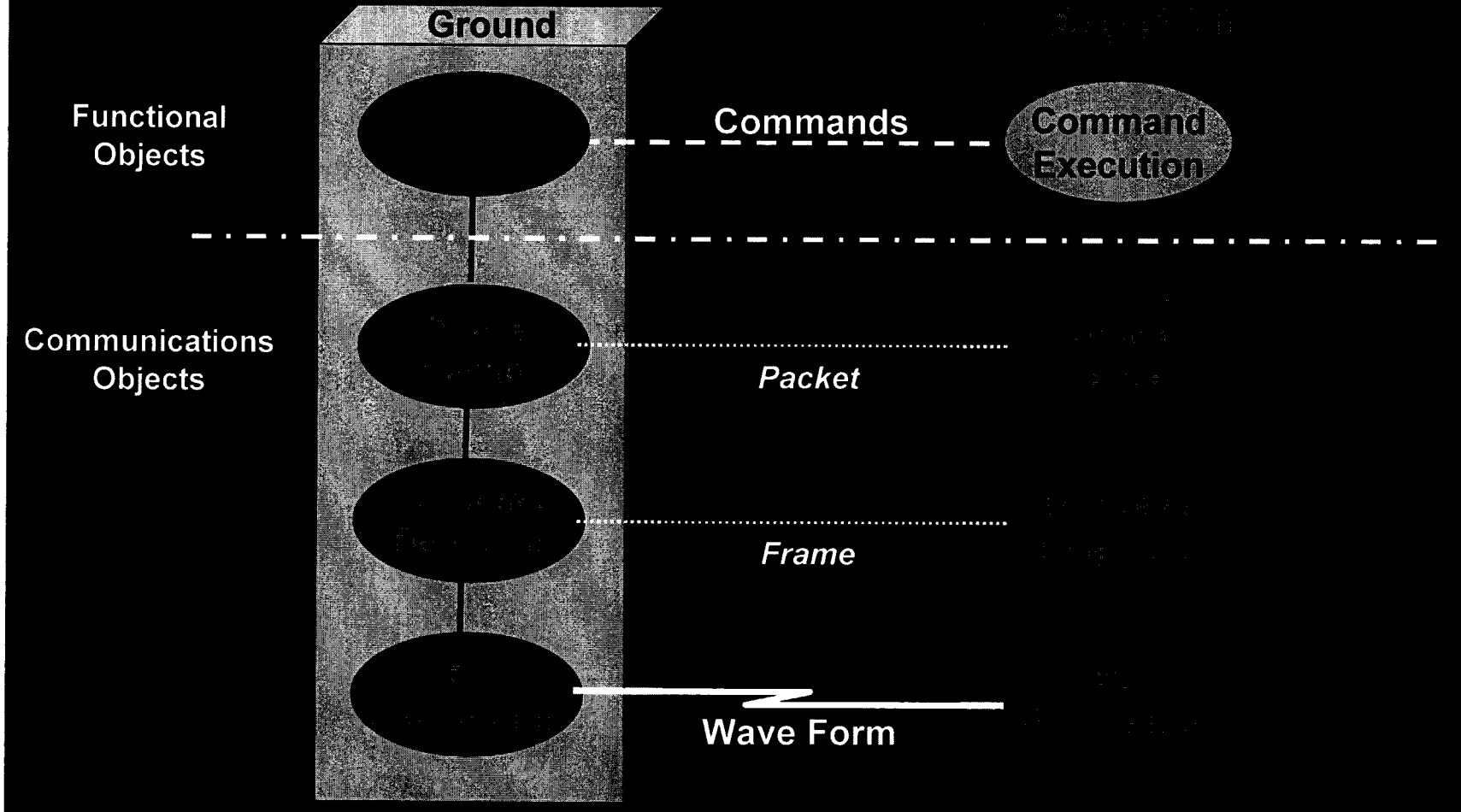
## Information Objects
## Relationship to Functional View



# NASA DATA SYSTEM STANDARDS PROGRAM

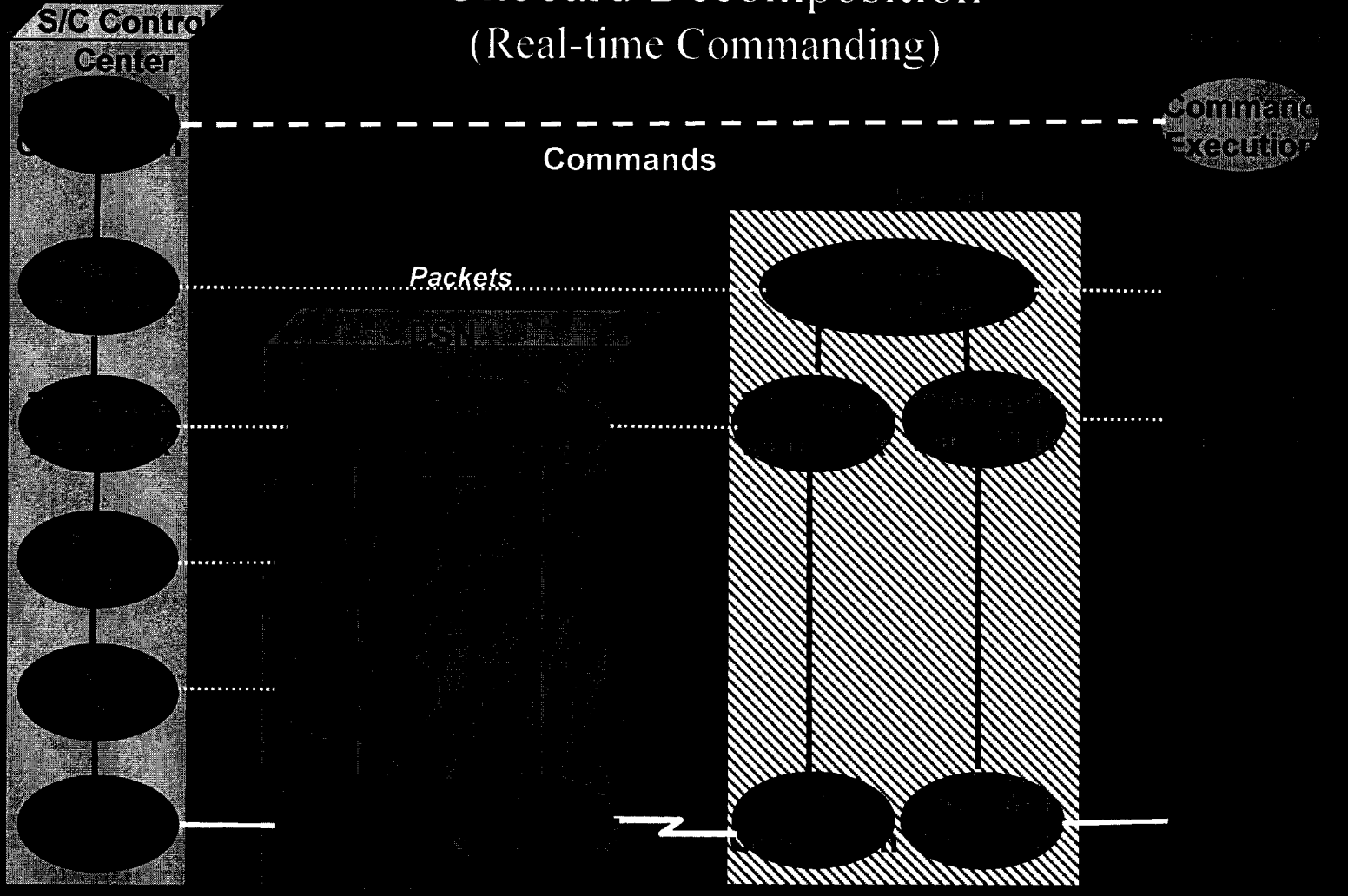
## Communications View

### Simple Example

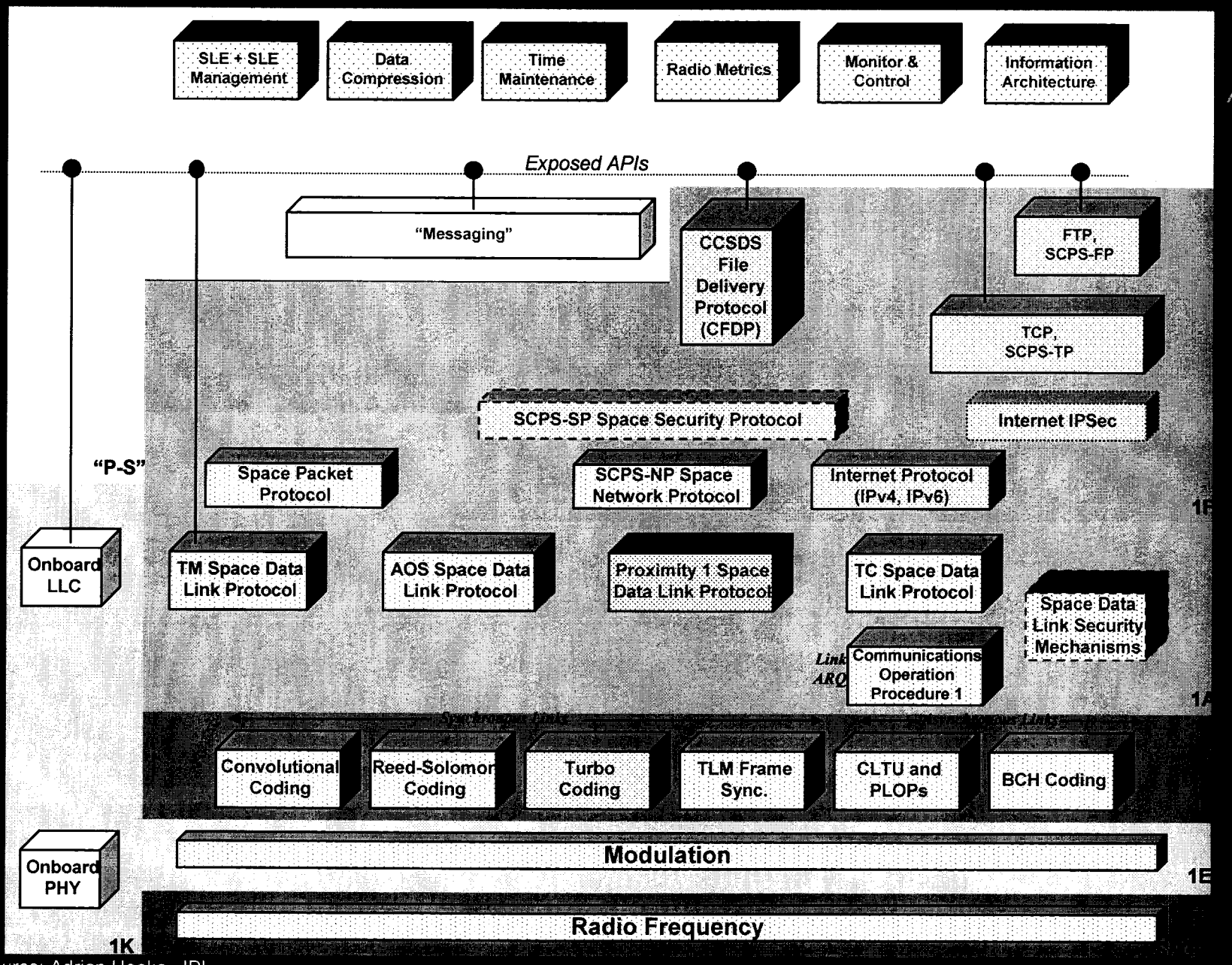


# NASA DATA SYSTEM STANDARDS PROGRAM

## Communications View
## Onboard Decomposition
## (Real-time Commanding)



# CCSDS Space Communications Standards

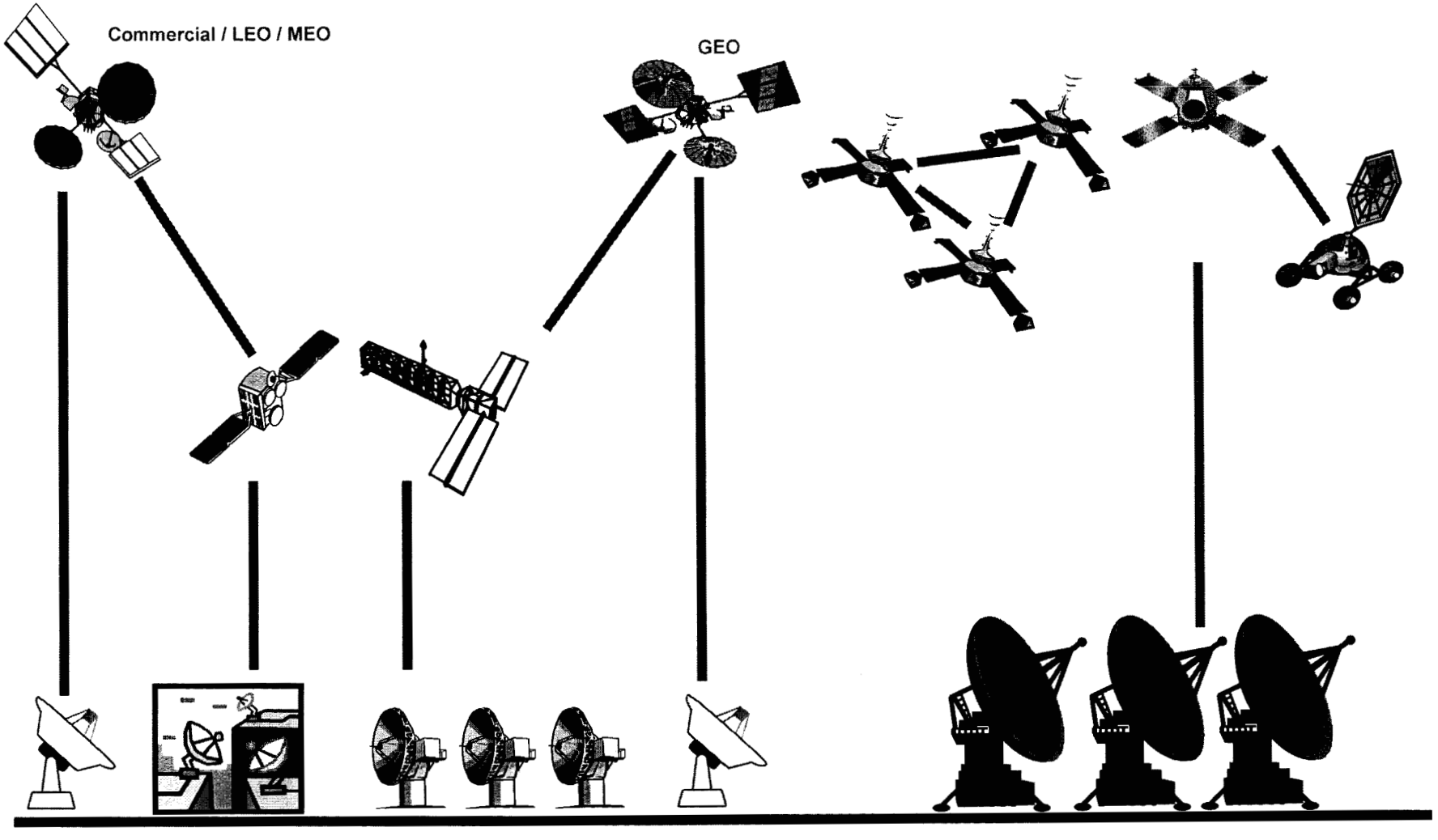



Source: Adrian Hooke, JPL

# Application to Space Internetworking

- Only a single Functional example shown, many are possible
- Types of Space Links
- Connectivity Issues
- Communications Views
  - Near Earth
  - Deep Space
  - Proximity
- Other Considerations

# Connector Properties: Types of Space Links




Near-Earth, LEO Direct

Near-Earth, GEO Relay

Near-Earth, Commercial LEO/MEO Relay

Near-Earth, Direct Broadcast

Deep Space Direct (DSN, other)

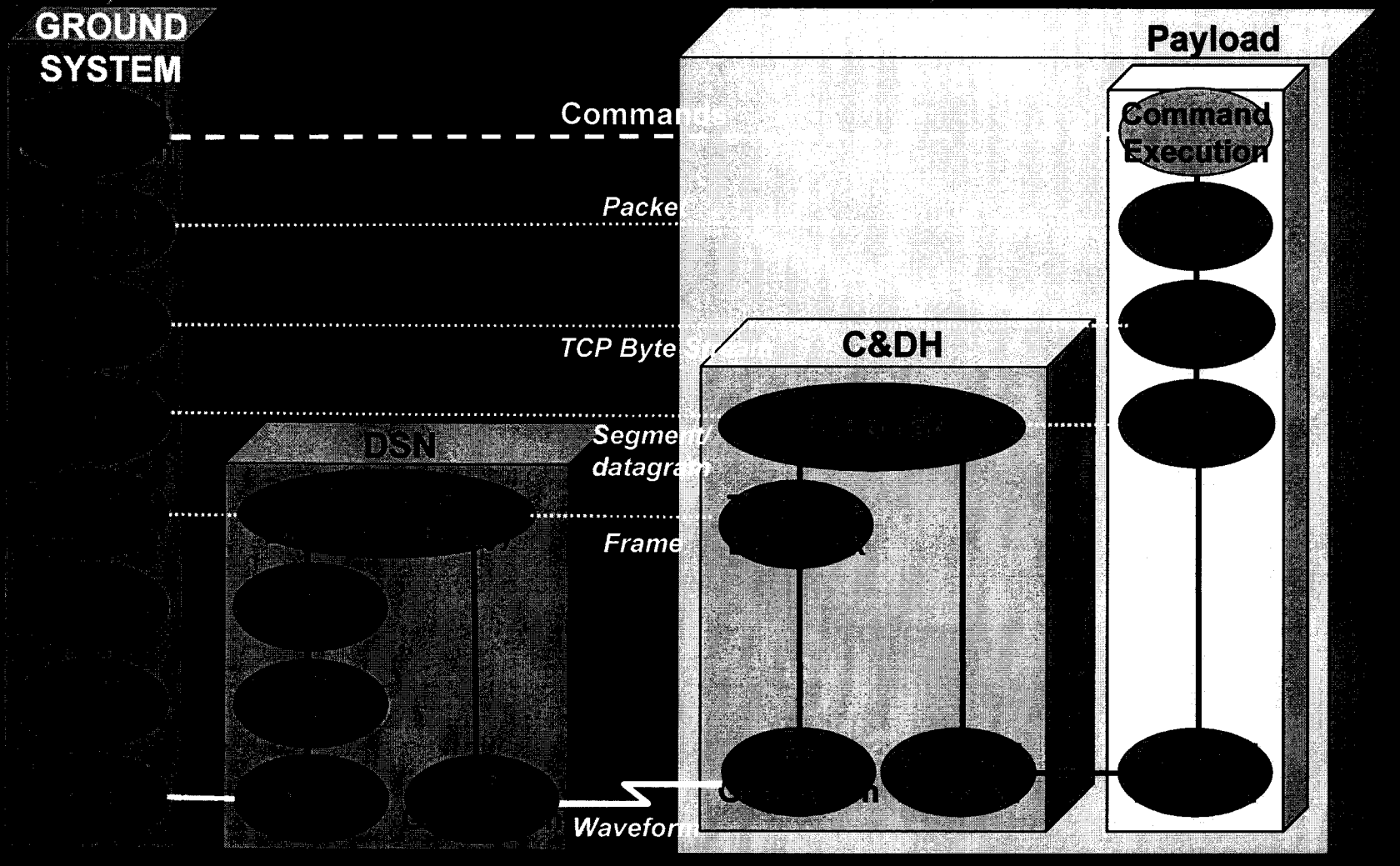
In-Space Proximity/Relay

Source: A. Hooke, NASA/JPL

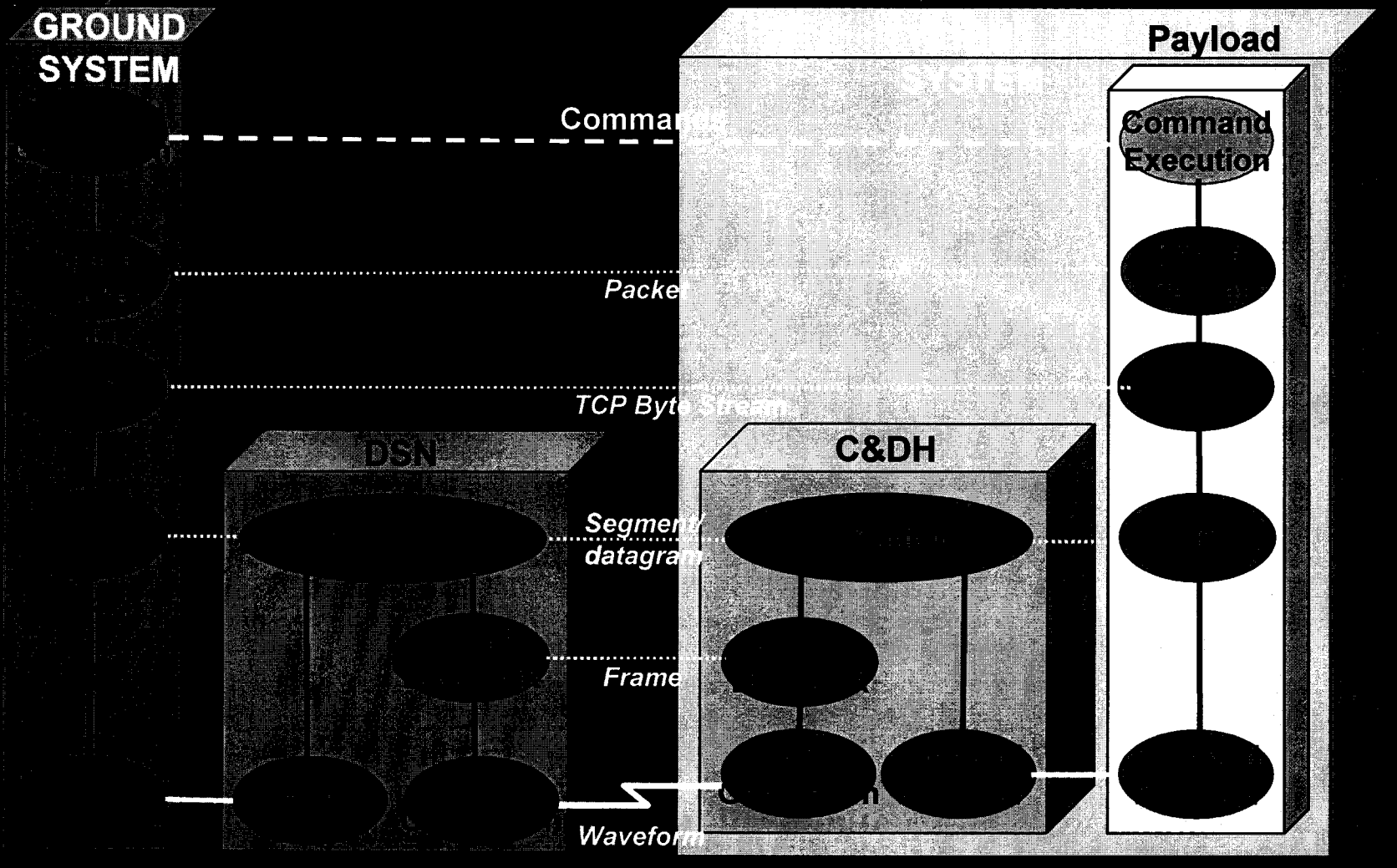
# Connectivity Issues

- Near Earth
  - Internet protocol suite will work, modulo short pass times, link (re-)establishment, and RTLT issues
  - SCPS protocols (w/ NGSI extensions) recommended solution
- Proximity / In-Situ
  - Internet protocol suite will work, modulo short pass times, link (re-)establishment, and resource issues
  - Resource constraints on landed assets may preclude use of higher level protocols than simple link like Prox-1
- Deep Space
  - Internet protocol suite ***will not*** work, almost every assumption built into protocol design is violated
  - Possible to transport data between separate domains using long haul protocols or new DTN / IPN approach

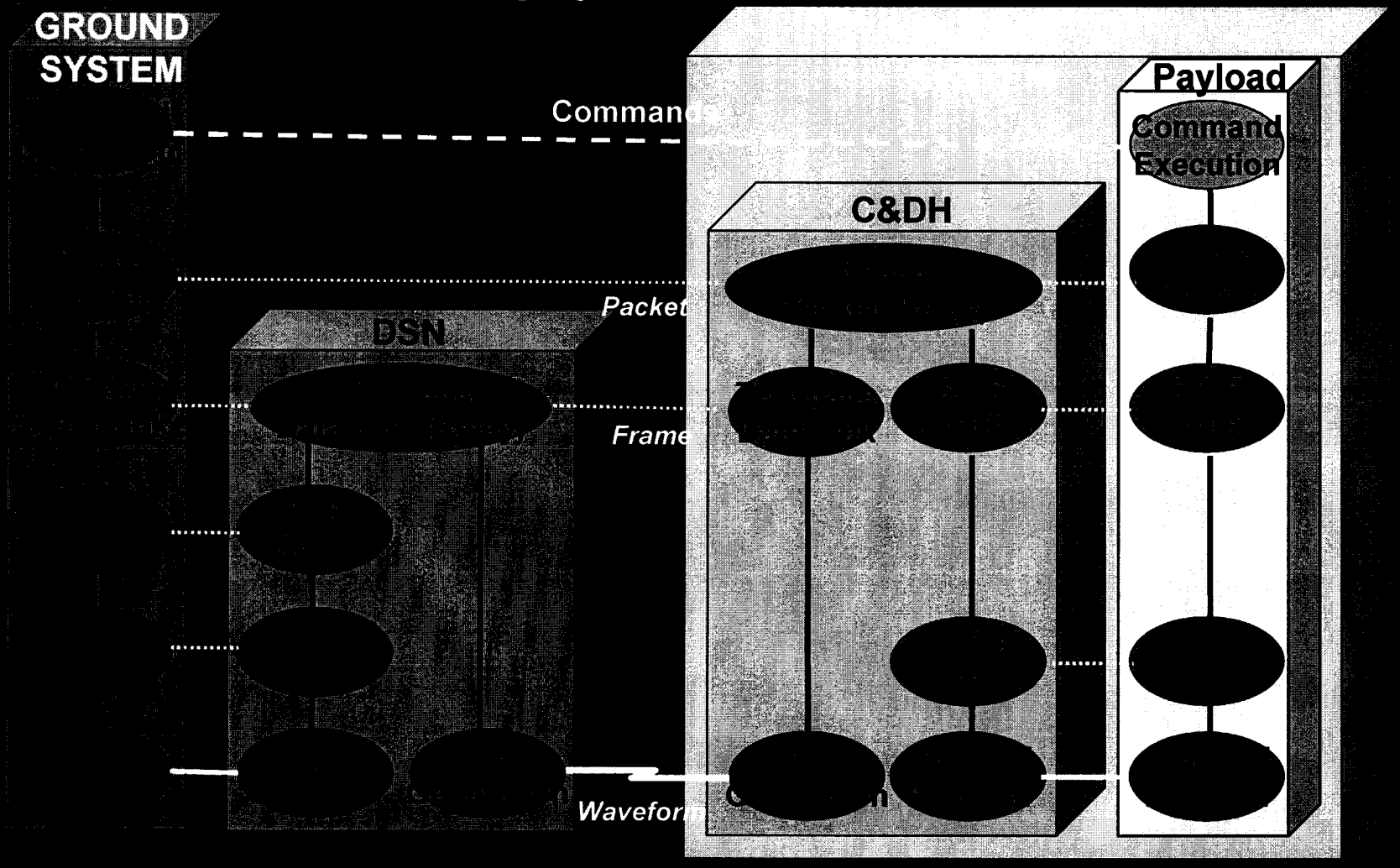
NASA

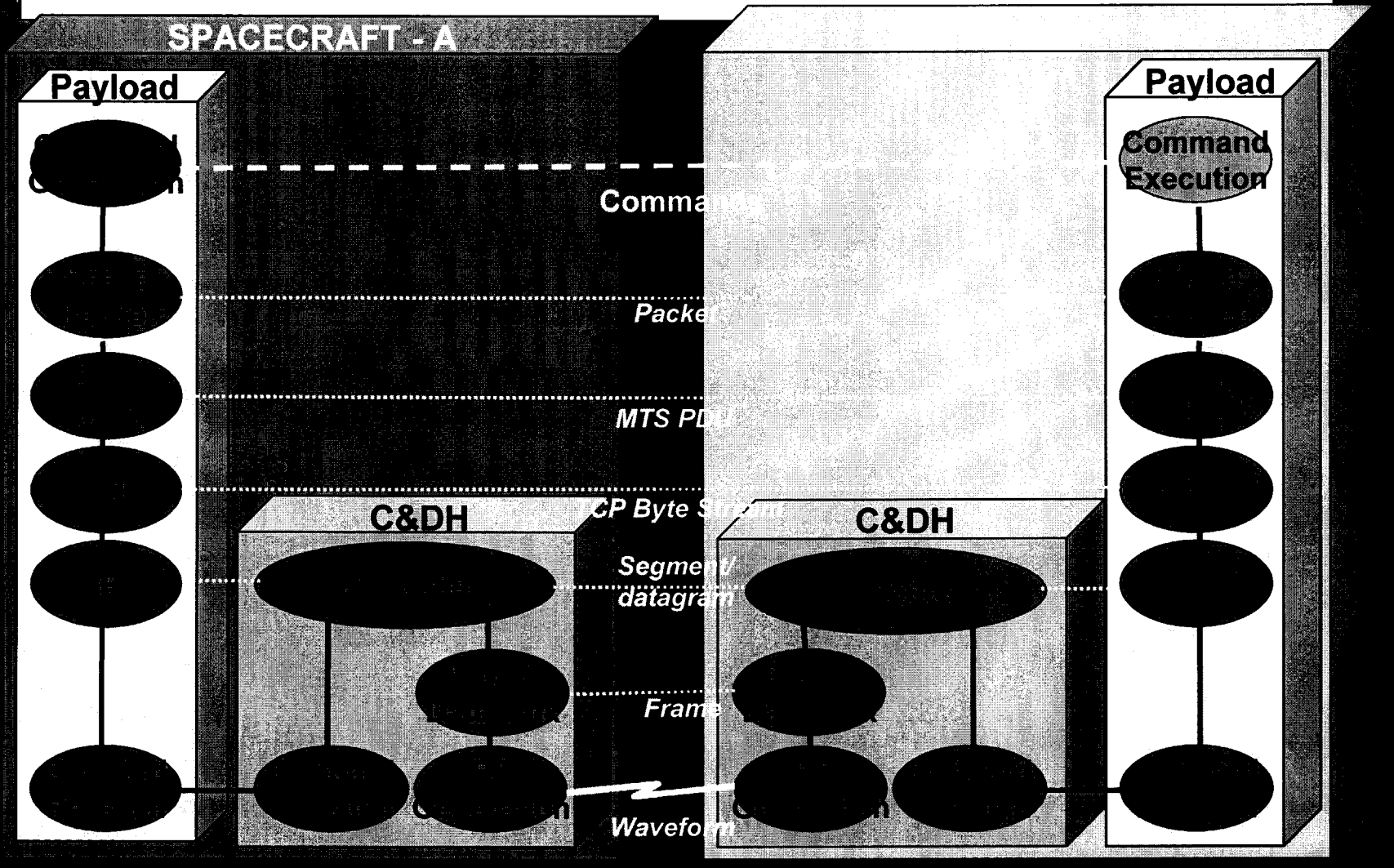

GROUND SYSTEM
Payload
Command
Command Execution
Packe
TCP Byte
C&DH
DSN
Segment/
datagram
Frame
Waveform

NASA


GROUND SYSTEM
Payload
Command
Command Execution
Packet
TCP Byte Stream
DSN
C&DH
Segment/ datagram
Frame
Waveform

NASA


GROUND SYSTEM
Command
Payload
Command Execution
C&DH
Packet
DSN
Frame
Waveform


SPACECRAFT - A
Payload
Payload
Command Execution
Packet
MTS PDU
C&DH
CP Byte Stream
C&DH
Segment/ datagram
Frame
Waveform

# Other Considerations

- Emergency Commanding
  - How to support this in an Internet environment?
- Security Concerns
  - Maintain Spacecraft Health & Safety
  - Prevent Denial of Service attacks
- Intermittent Connectivity
  - Most standard Internet protocols fail
  - Where do you put recovery mechanisms?
- Application "cleavage"
  - Where do you allocate functionality, flight or ground?
  - What can migrate?

- Enable sharing and exchange of information on architectures and systems among different organizations
  - Agree to common language and representation
  - Develop formal methods for describing architectures and systems (i.e., UML profiles and XML schemas)
- Facilitate generation and manipulation of architectures and system models
  - Develop software tools for generation and manipulation of architectures and system models
  - Tools should be based on existing COTS or GOTS tools

- This task was carried out as part of the program of work of Consultative Committee for Space Data Systems (CCSDS).
- It was performed by the Architecture Working group (AWG), chaired by Takahiro Yamada, ISAS
- Other AWG members who actively participated are listed below:

  - Fred Brosi, NASA/GST
  - Dan Crichton, NASA/JPL
  - Adrian Hooke, NASA/JPL
  - Steve Hughes, NASA/JPL
  - Niklas Lindman, ESA/ESOC
  - Nestor Peccia, ESA/ESOC
  - Lou Reich, NASA/CSC
  - Don Sawyer, NASA/GSFC
  - Peter Shames, NASA/JPL
  - Anthony Walsh, ESA/Vega