The Internet of Space

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With Contributions from
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What is the Internet of Things?

* The term the "Internet of Things" or IoT symbolizes a 'new' way to connect devices and enable inter-device interactions in a way that has never been possible before.

* This presentation looks at the concept of 'IoT' as it applies to space communications.

* People:

  – Scott Burleigh - DTN engineer, Flight software programmer, DTN architect for NASA, NASA lead for ION DTN software development and releases. Works for the Interplanetary Network Directorate at JPL, with Vint Cert at Google and is a core member of the DTNRG and CCSDS.

  – Leigh Torgerson is the Director of the JPL Protocol Technology Lab and is a NASA rapporteur to CCSDS for the CCSDS File Delivery Protocol. He was the Experiment Operations Manager for the Deep Impact Networking experiments where DTN was qualified on a deep space probe. The JPL Protocol Technology Lab, which hosts the JPL node on the nationwide NASA-sponsored DTN Experimental Network. He was an avionics engineer in the Lockheed Skunk Works.

  – Amalaye Oyake - Flight software programmer for the first deep space flight validation of DTN onboard the EPOXI mission in 2008. Did first VxWorks and RTEMS port of ION. Proposed the draft CCSDS specification Spacecraft Monitor and Control Protocol (SMCP) with Dr. Takahiro Yamada at JAXA (JAXA uses this on all their missions). *SMCP is used extensively at JAXA.*

General IoT Ideas

* The IoT is the "next big thing".
* To use IoT one needs a persistent connection to the Internet (a network address).
* One needs TCP, UDP, JavaScript, HTTP + *something cool sounding*.
* Devices can been networked using various web based protocols.
* One can even purchase very powerful IoT frameworks to enable smart devices.

* Ignore everything listed above!

* These are ideas are not new or original, and you may not need 'much' to network something.
* Also note, there are many standards bodies (ITU, CCITT, CCSDS, OMG, IETF, DTNRG, OSF, ISO, ARRL) that actually deal with communication that have been doing this for a long time.

What is the Internet of Things?

* **While the IoT has been presented as something new, it is not.**

* **People have been networking 'things' for a long time with sound, fire, smoke, the sun, electrical signals, telegraphs.**

* **Examples include:** *Source from "Design and Validation of Computer Protocols G.J. Holzmann Prentice-Hall, Englewood Cliffs New Jersey, 1991."*
  - **Alexander the Great's 12 foot megaphone**
  - **Claude Chappe's semaphore system, 1793**
  - **"C.M.'s" electric telegraph concept, 1753**
  - **G. Huth's "telephone", 1796**
  - **Swedish telegraph system, 1796 (*data rate of 0.5 bits/sec*)**
  - **Cooke & Wheatstones Electric Telegraph, 1837**
  - **Many of these systems used simple or advanced protocols to varying degrees of success (read up on the Clayton Tunnel Train crash)**

* **Networks such as Aloha, AUTODIN I, ARPANET, SATNET, AUTODIN II, SABRE and many others.**

* **Networks, concepts and technical demonstrations by ARPA/DARPA, BBN, RAND Corporation, MITRE, University of Hawaii, UCLA, CERN, Airlines, Banks and many others!**

- Asynchronous Message Service/Alan Kay – *"The big idea is "messaging" -- that is what the kernel of Smalltalk/Squeak is all about (and it's something that was never quite completed in our Xerox PARC phase)"*, prototypes vs classes was: Re: Sun's HotSpot/Sat Oct 10 04:40:35 UTC 1998. *Source: Gregor Hophe*

- Joseph Carl Robnett Licklider (J.C.R) Licklider – *"MEMORANDUM FOR: Members and Affiliates of the Intergalactic Computer Network", April 23, 1963*

- Bundle Protocol/Vint Cerf – *"Store-and-Forward packet switching, discussed in Packet Communication Technology, Protocols and Techniques for Data Communication Networks, 1981"*

- Heterogeneous Networks/Paul Baran – *"On Distributed Communication Networks, Rand Corporation, 1962, 1964".*

Historical Antecedents

Source: Memorandum RM-3420-PR On Distributed Communications Networks, Paul Baran, August 1964, Rand Corporation

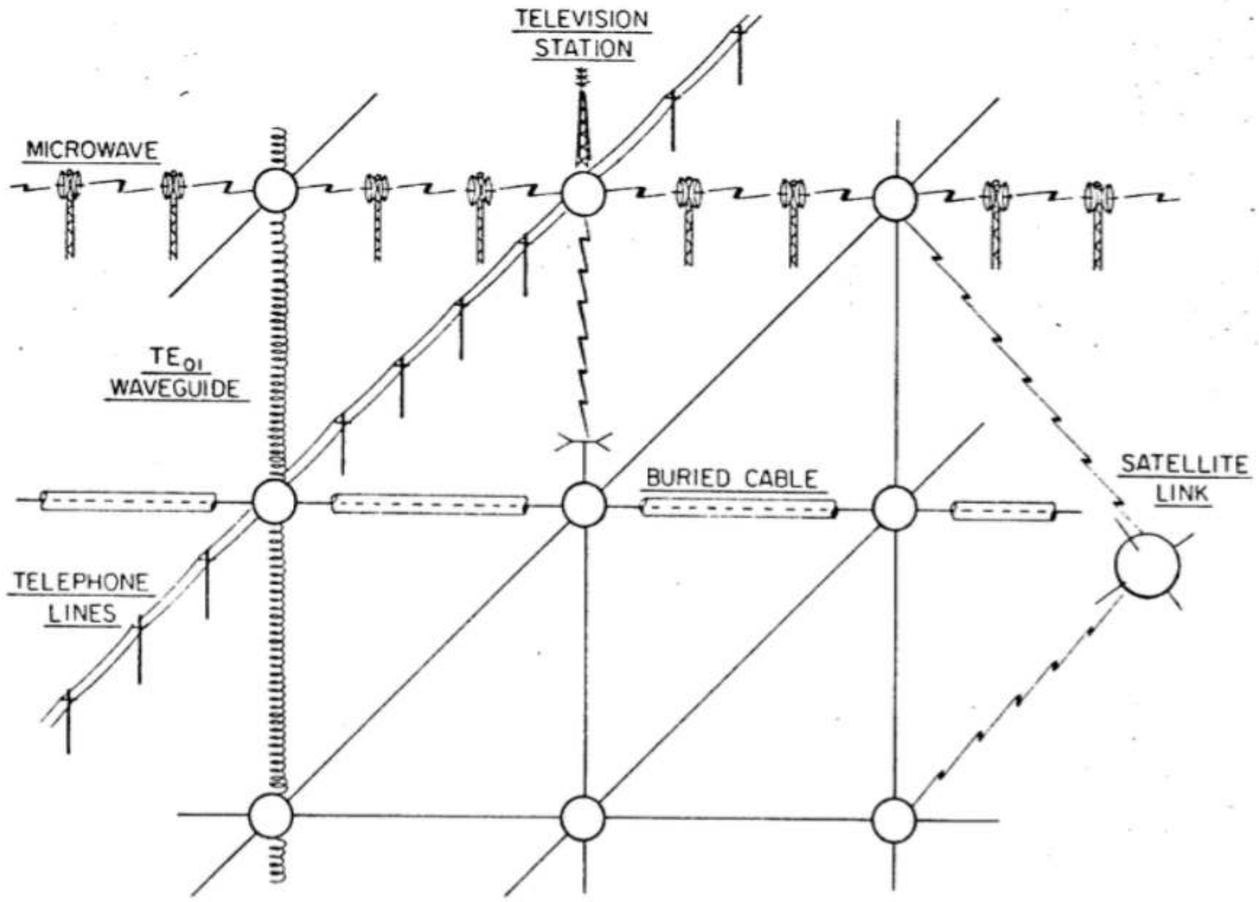
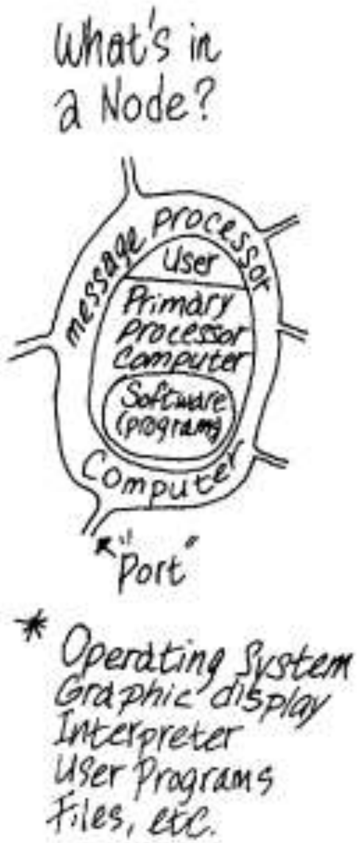
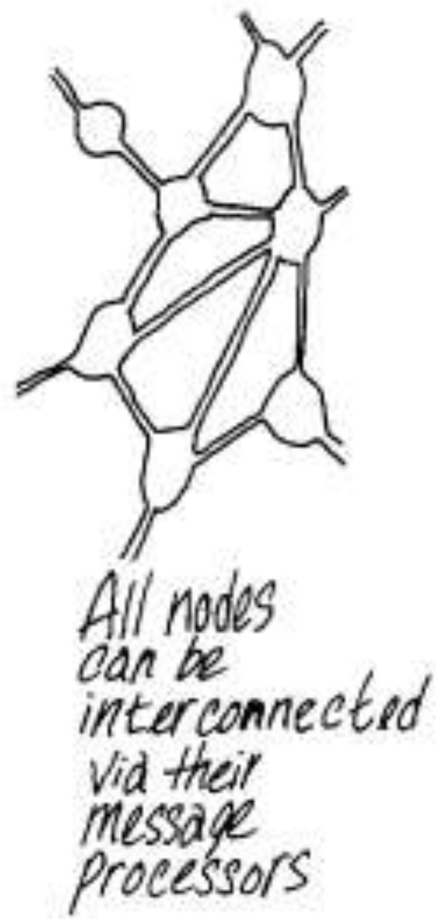


FIG. 9 – All Digital Network Composed of Mixture of Links

Historical Antecedents

Source: The Computer as a Communication Device, J.C.R. Licklider and Robert W. Taylor, Science and Technology, April 1968.





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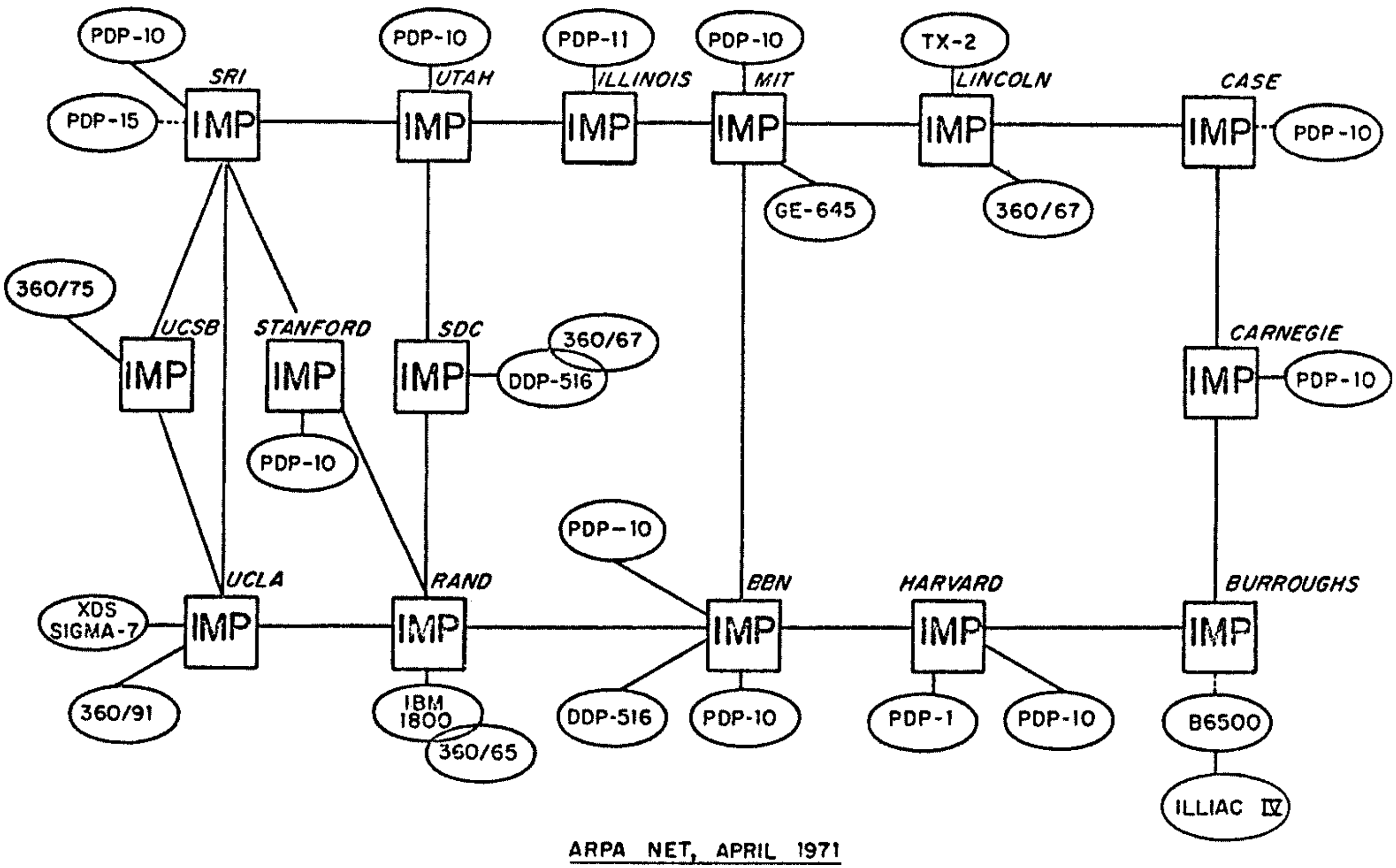
Source: (BBN Diagrams), Bradley Fidler (UCLA), Morgan Currie (UCLA), "The Production and Interpretation of ARPANET Maps", IEEE Annals of the History of Computing, vol. 37, no. , pp. 44-55, Jan.-Mar. 2015, doi:10.1109/MAHC.2015.16



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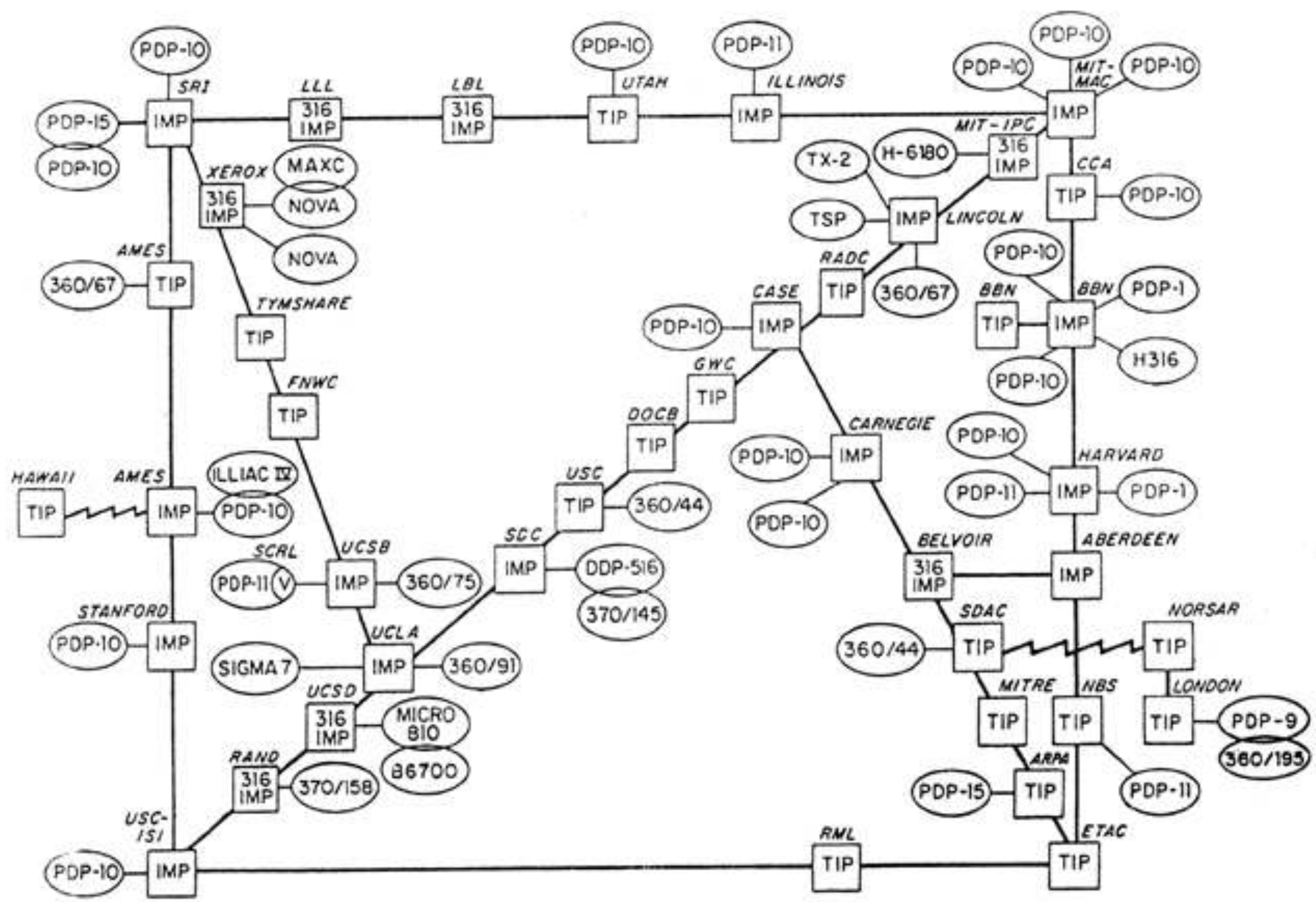
ARPA NETWORK, LOGICAL MAP, SEPTEMBER 1973



Historical Antecedents

Source: Design issues for mixed media packet switching networks by D. Huynh, H. Kobayashi, and F. F. Kuo, University of Hawaii, June 7, 1976

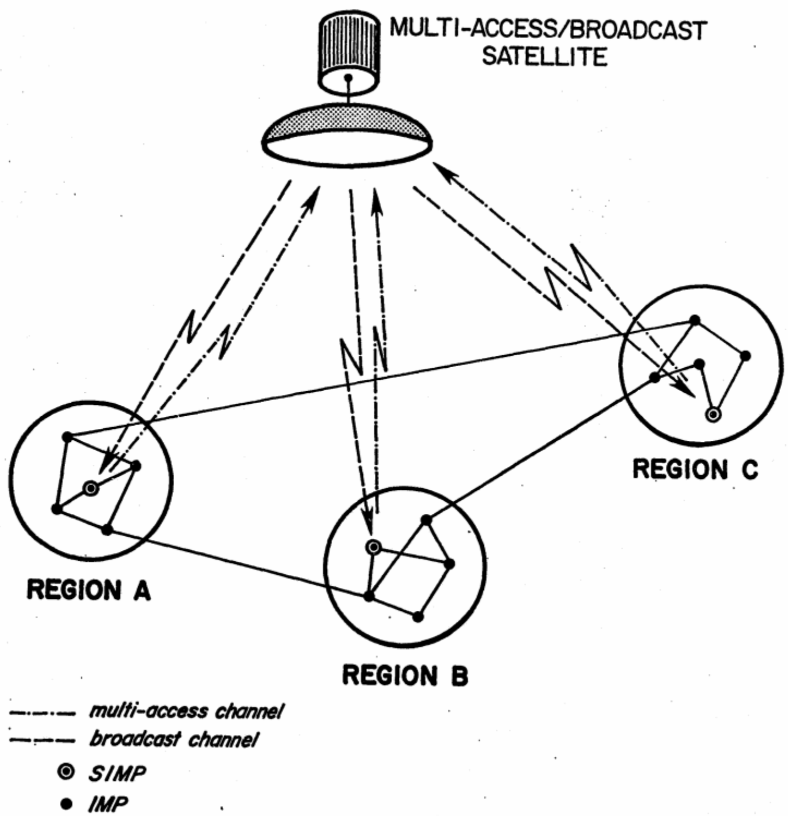


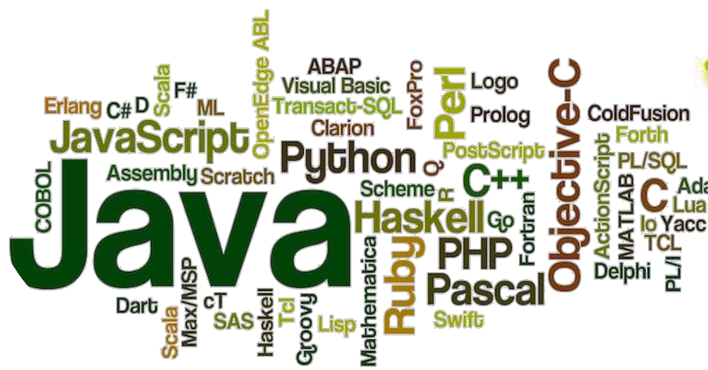
Figure 1

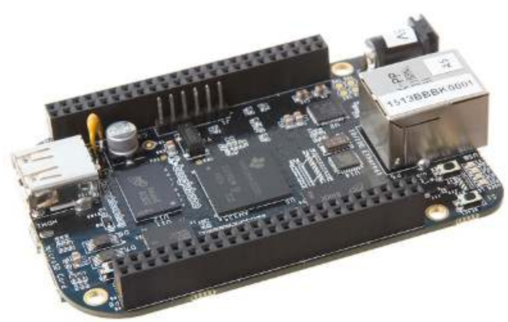
THE PROPOSED NETWORK MODEL

What is New?

- What is new is the easy availability of small low cost 'Interface Message Processors' (IMPs) or compute nodes – Arduinos, Raspberry Pis, Beagle Boards, and the associated enabling software (*all the cool stuff I disparaged earlier*).

- Danger: Every tool is a 'nail'!





IoT and the "Internet of Space"

* How do we do IoT in space? **We use the ION DTN framework!**
* Delay and Disruption Tolerant Networking (DTN) is an approach to computer network architecture that seeks to address the technical difficulties for communicating in environments which lack continuous network connectivity.
* Examples of nodes in challenged environments include remote sensors in Antarctica, a spacecraft in deep space, submersible vessels etc.
* In a DTN, asynchronous variable-length messages (called bundles) are routed in a store and forward manner between participating nodes over a heterogeneous network.
* Implementations include ION, DTN2, BP-RI and DASM.
* We understand the requirements and capabilities of the underlying infrastructure and we use it.

DTN Overview

DTN is… an internetworking protocol suite suitable for disrupted, mobile, airborne, near-Earth and deep-space communications:

- **DTN is an architecture, not a protocol -- it encompasses multiple protocols including Bundle Protocol, LTP, delay-tolerant application service protocols (such as AMS and, soon, CFDP), future network management protocols, future routing protocols, etc.**

- **<u>Security</u> features that protect the infrastructure from unauthorized traffic and provide standard end-to-end security capabilities (e.g. integrity, confidentiality) and 'over-the-air' key management.**

- **A <u>network management system</u> to configure, monitor, and provide accounting for traffic passing through the system.**

- **<u>Based on international standards</u> (IETF & CCSDS)**

DTN Overview

DTN is… an internetworking protocol suite suitable for disrupted, mobile, airborne, near-Earth and deep-space communications:

- **An internetworking layer that functions efficiently in environments with time-disjoint and/or simplex links.**
- **A reliable data link layer that improves efficiency of end-to-end delivery by leveraging local link information and tighter local control loops.**
- **Disruption Tolerant Routing services that can take advantage of scheduled and expected future connectivity in addition to current connectivity and that can interoperate with or without a terrestrial routing infrastructure.**
- **Quality of Service mechanisms to provide user control over the order in which traffic is served by the overlay internetworking layer and is independent of the underlying network segments.**

DTN Overview

DTN is… an internetworking protocol suite suitable for disrupted, mobile, airborne, near-Earth and deep-space communications:

* **Improved Operations and Situational Awareness: The DTN store-and-forward mechanism along with automatic retransmission provides more insight into events during communication outages and significantly reduces the need for ground-based scheduling.**
* **Interoperability and Reuse: A standardized DTN protocol suite enables interoperability of <u>multi-agency</u> communication assets and also allows NASA to use the same communication stack for future missions (LEO, NEO or Deep Space).**
* **Space Link Efficiency, Utilization and Robustness: DTN enables more reliable and efficient data transmissions resulting in more usable bandwidth. DTN also improves link reliability by having multiple network paths and assets for potential communication hops.**

Original slide source: Scott Burleigh, Leigh Torgerson Jet Propulsion Laboratory, California Institute of Technology

DTN Overview

DTN is… an internetworking protocol suite suitable for disrupted, mobile, airborne, near-Earth and deep-space communications:

- **Security: The DTN Bundle Security Protocol (BSP) allows for integrity checks, authentication and encryption, even on links where not previously used.**

- **Quality of Service: The DTN protocol suite allows for many priority levels to be set for different data types, ensuring that the most important data is received ahead of less important data.**

DTN Overview

* Interplanetary Overlay Network (ION) is a DTN implementation that is specifically designed for use in resource-constrained embedded systems, such as interplanetary robotic spacecraft.

* ION development began in June 2003; first announced in November 2003.

* The first use of ION in space flight was during the Deep Impact Network (DINET) experiment in October-November 2008.

* Since May of 2016, ION has been operational on both the payload and crew networks on the International Space Station.

Original slide source: Scott Burleigh, Leigh Torgerson Jet Propulsion Laboratory, California Institute of Technology

ION Features

* Asynchronous Message Service.
* Bundle Protocol.
* Licklider Transmission Protocol.
* Adaptors for various transport and datalink mechanisms (wired or wireless).

Bundle Protocol

* The Bundle Protocol (BP) is a store and forward protocol, that implements an overlay network providing

* Custody-based retransmission.

* Ability to cope with intermittent connectivity.

* Ability to take advantage of scheduled, predicted, and opportunistic connectivity (in addition to continuous connectivity).

* Late binding of overlay network endpoint identifiers to constituent internet addresses.

Source: RFC 5050

Bundle Protocol

* The Licklider Transmission Protocol (LTP) aka Long-haul Transmission Protocol is designed to provide retransmission-based reliability over links characterized by extremely long message round-trip times and/or frequent interruptions in connectivity.

* LTP is named in honor of JCR Licklider of (D)ARPA, one of the pioneers of ARPANET who envisioned having interplanetary links (MEMORANDUM FOR: Members and Affiliates of the Intergalactic Computer Network, J. C. R. Licklider, ARPA).

* Communication in interplanetary space is the most prominent example of this sort of environment, and LTP is principally aimed at supporting "long-haul" reliable transmission over deep-space RF links.

* It is described in RFC 5327.

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The Licklider Transmission Protocol

- **LTP is designed to provide retransmission based reliability of data transmissions over deep-space RF links. In the bundling protocol stack designed by the Delay Tolerant Networking Research Group DTNRG , it serves as a reliable datalink convergence layer for deep-space links.**

- **Deep-space links have many constraints: Extremely long signal propagation delays, on the order of seconds, minutes, or hours rather than milliseconds. Frequent and lengthy interruptions in connectivity. Low levels of traffic coupled with high rates of transmission error. Meager bandwidth and highly asymmetrical data rates.**

- **These environmental characteristics - long delays, low and asymmetric bandwidth, intermittent connectivity, and relatively high error rates - make using unmodified TCP for end to end communications in the Interplanetary Network (IPN) infeasible.**

* The Interplanetary Overlay Network (ION) software distribution is JPL's implementation of Delay-Tolerant Networking (DTN) architecture as described in Internet RFC 4838.

* It is designed to enable inexpensive and low risk insertion of DTN functionality into embedded systems such as robotic spacecraft.

* The ION package includes BP, LTP and AMS.

* Download it - https://ion.ocp.ohiou.edu … OpenSource!!!

Overview: Why Use DTN?

* **Communications Robustness:** Adds robustness to communications for these more risk tolerant missions developed by universities and others new to deep space mission development and operations.

* **Inherent Lower Priority for Communication Support:** CubeSats, for example, may not receive the same level of tracking support as typical missions. DTN reduces the cost of downlink planning by automating this process and provides capabilities for data prioritization so that the most important data is returned when a communication link is available.

* Similarly, DTN makes Opportunistic Multiple Spacecraft per Aperture (OMSPA) more viable because tracking time is not guaranteed and planned. Being able to retain prioritized data until the link comes available is more important.

Overview: Why Use DTN?

- **Improved Operations and Situational Awareness:** The DTN store-and-forward mechanism along with automatic retransmission provides more insight into events that occurred during communication outages and significantly reduces the need for ground-based scheduling.

- **Interoperability and Reuse:** A standardized DTN protocol suite enables interoperability of multi-agency communication assets and also allows NASA to use the same communication stack for future missions (LEO, NEO or Deep Space).

- **Space Link Efficiency, Utilization and Robustness:** DTN enables more reliable and efficient data transmissions resulting in more usable bandwidth. DTN also improves link reliability when exploiting multiple network paths for communications

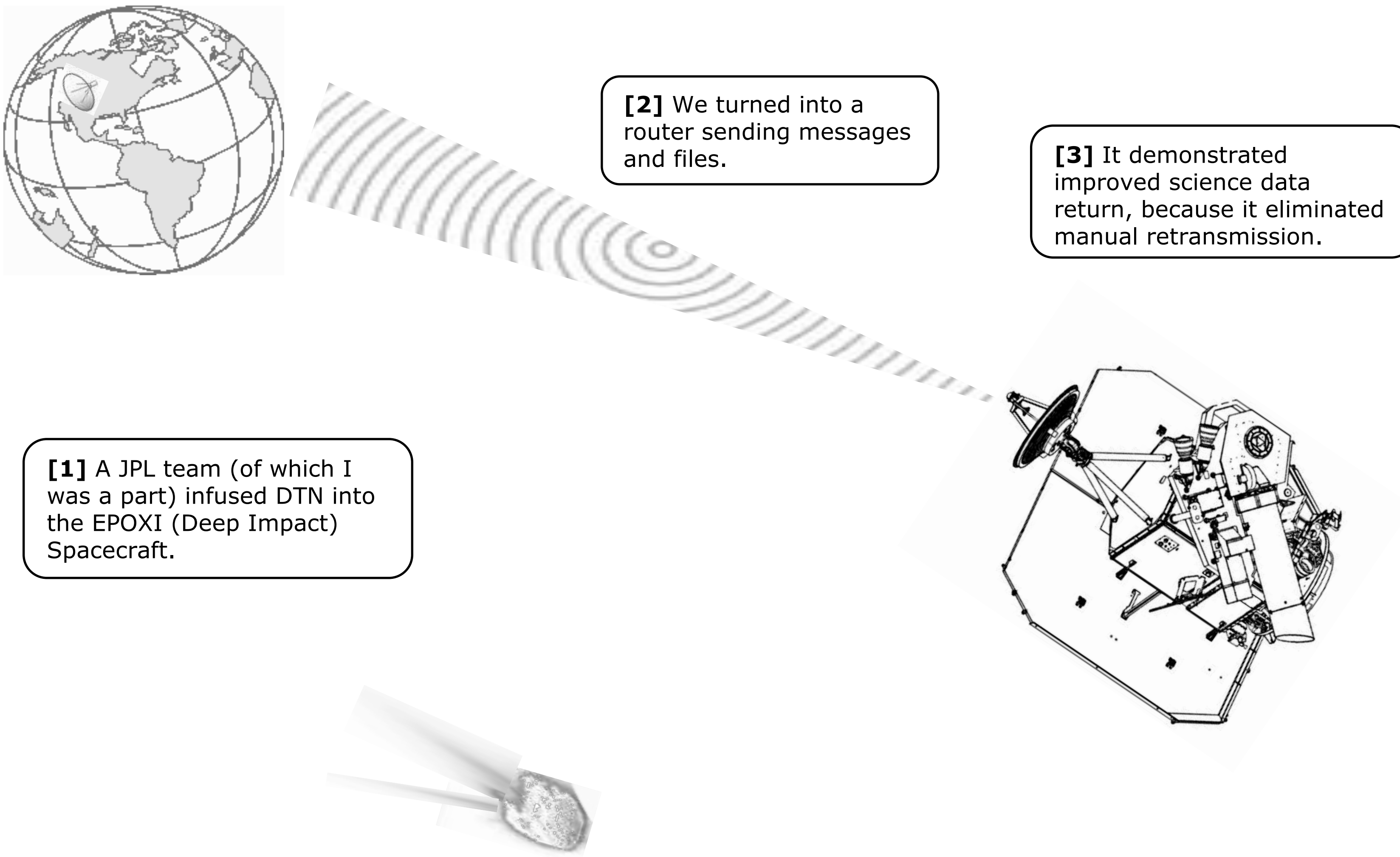
- **Security:** The DTN Bundle Security Protocol (BSP) allows for integrity checks, authentication and encryption, even on links where not previously used.

- **Quality of Service:** The DTN protocol suite allows for many priority levels to be set for different data types, ensuring that the most important data is received ahead of less important data.

Overview: Why Use DTN?

* Minimize data exchanges. “Push” instead of “query”. Publish/subscribe instead of client/server. Anticipate:
  – Ask now for the information you think you will need in the future.
  – Send new information ASAP to everyone who has asked for it.
* “Bundle” parameters with requests, metadata with data.
* Time is fundamental. “Time to live” in minutes, not hops.
* Detect and correct data loss inside the network, not just end-to-end. Persistent buffers, long ack loops.
* Protect data inside the network (both in transit and at rest), not just end-to-end.
* Applications must be as delay-tolerant as the network.

Case 1 - DINET Deep Space DTN Test



[2] We turned into a router sending messages and files.

[3] It demonstrated improved science data return, because it eliminated manual retransmission.

[1] A JPL team (of which I was a part) infused DTN into the EPOXI (Deep Impact) Spacecraft.

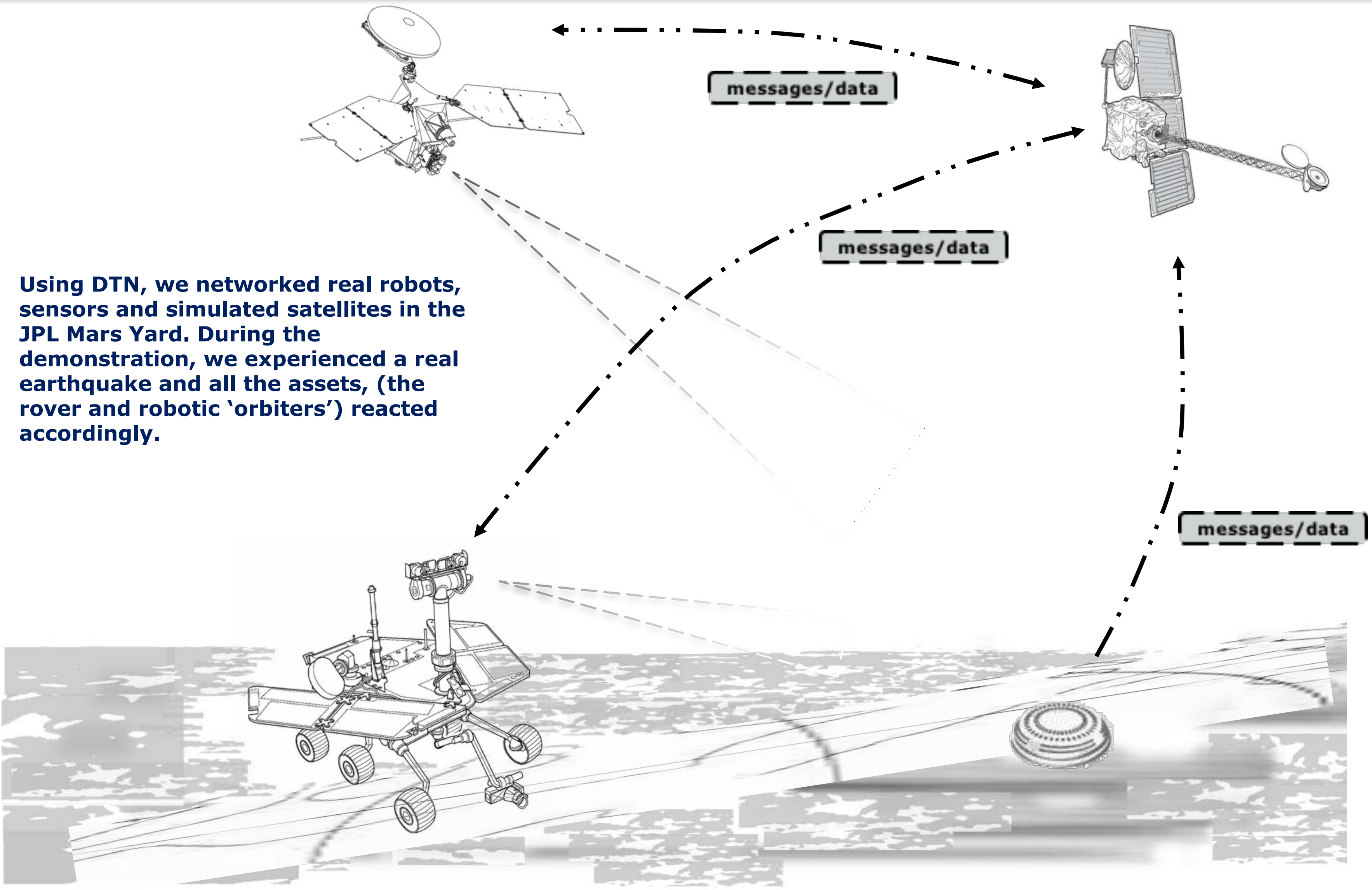
Success! NASA Tests First Deep-Space Internet!

NASA Tests First Deep-Space Internet
Sunday, February 01 2009
http://www.techbriefs.com/component/content/article/3552

NASA has successfully tested the first deep-space communications network modeled on the Internet. Part of a NASA wide team, engineers from the Jet Propulsion Laboratory in Pasadena, CA, used software called Disruption-Tolerant Networking (DTN) to transmit dozens of space images to and from a NASA science spacecraft located more than 20 million miles from Earth.

Case 2 - Mars Yard Autonomous Science Demonstration

* Using DTN, we networked real robots, sensors and simulated satellites in the JPL Mars Yard. During the demonstration, we experienced a real earthquake and all the assets, (the rover and robotic 'orbiters') reacted accordingly.



Other Examples

1. **EPOXI Deep Space Flight Validation in 2008**
   - **1st deep space implementation of DTN**

2. **Onboard ISS - JPL Radio on SCaN Testbed (also known as the CoNNeCT Radio).**
   - **Demo December 2016**

3. **Onboard ISS - Ecostress radio**
   - **Launch: 2018**

4. **DTN ground node implementation on MSU 21m**
   - **Expected operation August 2017**

5. **Networked Mission Concepts R&TD Mars-yard experiment**
   - **Demonstrated DTN running end-to-end in an emulated Mars rover and orbter.**

6. **iPAS**
   - **Protocol Test Lab provides DSN simulation to a DTN network involving AES avionics hardware/software at JSC**

7. **Multi-center Interoperability Task**
   - **Leverages DTN Engineering network infrastructure to enable shared operations between JSC, JPL, and MSFC.**

8. **GSFC-JSC Core Flight Software DTN Integration**
   - **JPL provided the initial port of DTN to CFS for use in all human spaceflight missions beyond EM-1.**

9. **FY16-18 Networked Constellations R&TD**
   - **DTN embedded into Iris could be enabling for mission proposals JPL may take forward in the next 3-5 years**

ION Features

- Reliable distribution of short messages to multiple recipients (subscribers) residing in such a network.
- Management of traffic through such a network.
- Facilities for monitoring the performance of the network.
- Robustness against node failure.
- Portability across heterogeneous computing platforms.
- High speed with low overhead.
- Easy integration with heterogeneous underlying communication infrastructure, ranging from Internet to dedicated spacecraft communication links.

Why not Internet in space?

- **The Internet evolved from the telephone system, and its functional model is still telephony.**
  - **You (a client) connect to a source or destination of information (a server).**
  - **You engage in a conversation over this connection.**

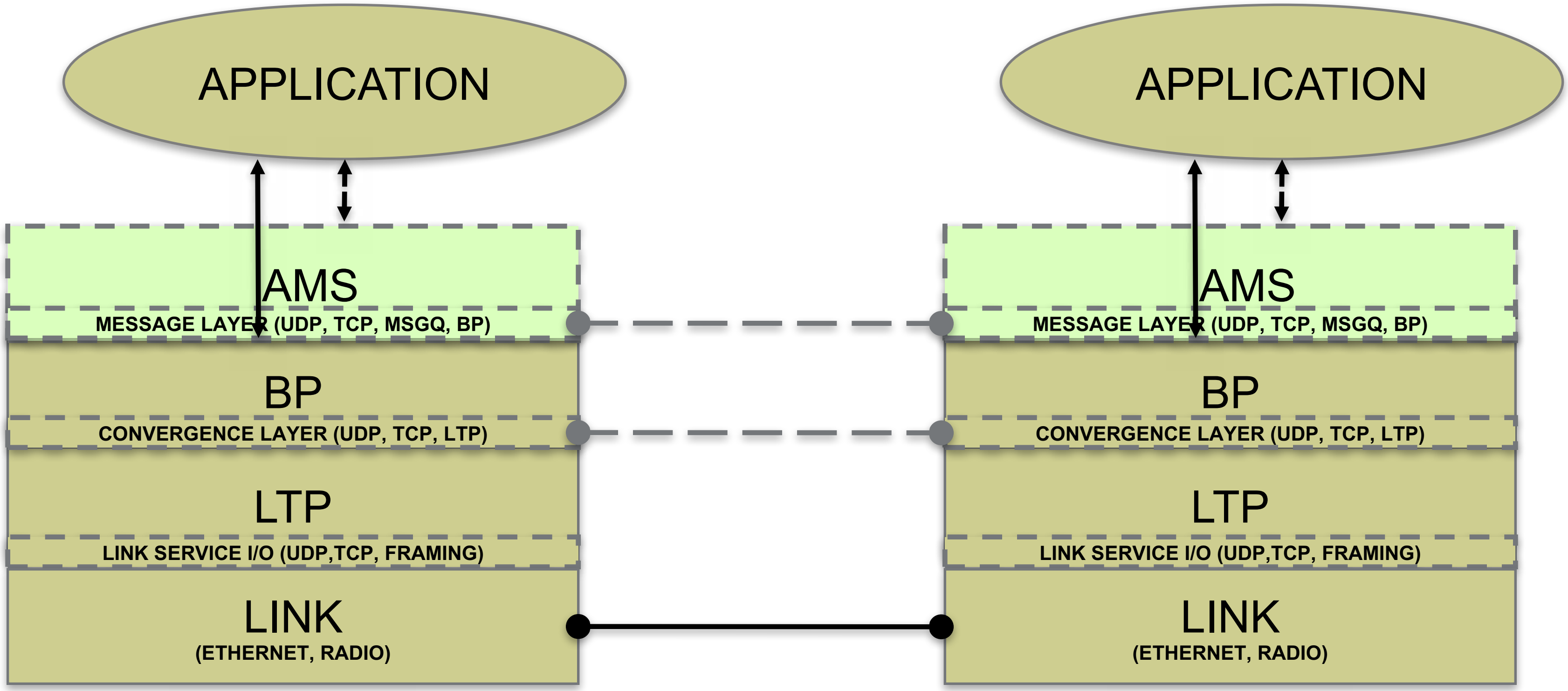
- **When *disruption* or signal propagation *latency* retard connection establishment and conversational exchange, communication is degraded.**

- **The solution: *communication that is not degraded by delay*.**
  - **Asynchrony (message exchange) instead of synchrony (conversation).**

Design of ION

- The design of ION uniquely addresses these constraints.
  - Built-in private dynamic management of memory allocated at startup.
  - High-speed shared direct access to built-in object database.
  - System-wide transaction mechanism, for safety:
    - Ensures mutual exclusion, preventing lockouts and race conditions.
    - Enables reversal of all database updates made within the current transaction in case of software failure.
  - Compressed bundle headers, for transmission economy.
  - Zero-copy objects, for processing and storage economy.
  - Written in C, for processing economy and small footprint.
    - About 60,000 physical lines of code.
    - About 35,000 logical lines of code (omitting comments and whitespace).
  - Portable among POSIX operating systems, including RTOS.
    - Currently available for Linux, Solaris, OS/X, FreeBSD, VxWorks, RTEMS.

ION Stack


APPLICATION
APPLICATION
AMS
MESSAGE LAYER (UDP, TCP, MSGQ, BP)
BP
CONVERGENCE LAYER (UDP, TCP, LTP)
LTP
LINK SERVICE I/O (UDP,TCP, FRAMING)
LINK
(ETHERNET, RADIO)
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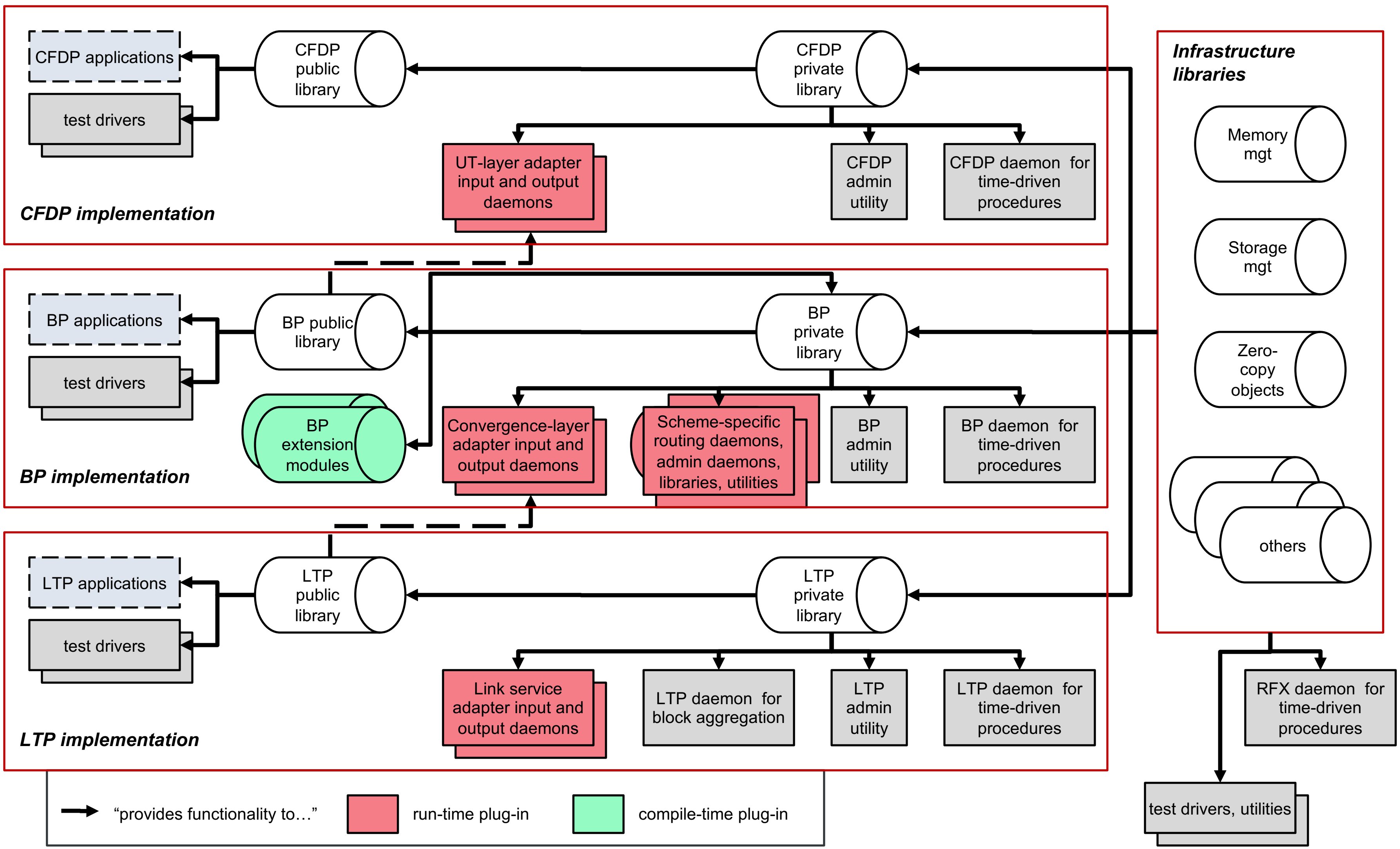
Constraints on DTN Implementations for Space

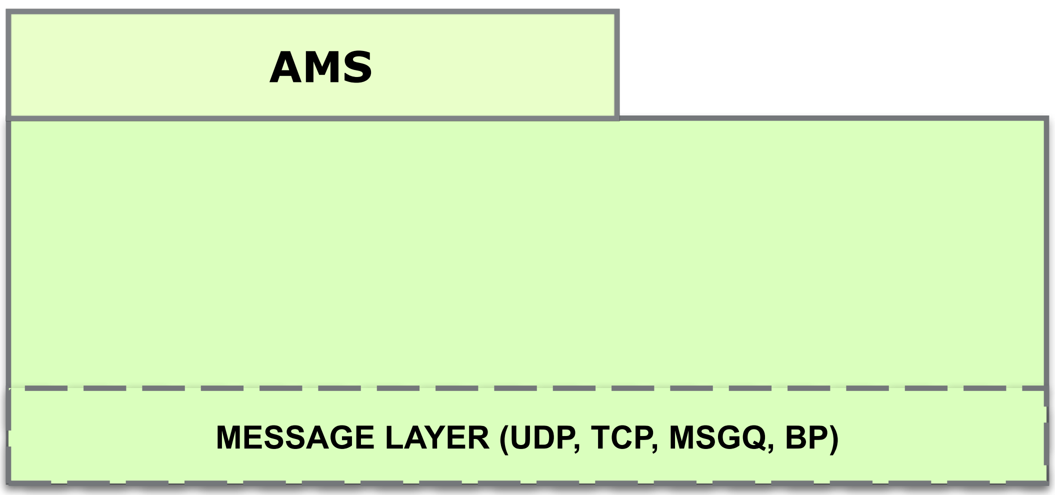
	Terrestrial DTN	DTN for Space Flight
Links	Ethernet or Wi-Fi Fast, cheap, symmetrical	Directed, highly attenuated Relatively slow, very expensive, asymmetrical Must use reception/transmission contacts efficiently.
CPU, memory	Commodity generic chips Fast, cheap	Limited-production radiation-hardened chips Relatively slow, very expensive Must use processing resources efficiently.
Resource management	Reboots are easy. Dynamic management of memory is routine.	Hands-on repair is impossible; must minimize risk. Dynamic memory management is unpredictable. Fixed memory allocation is provided at startup.
Operating System	Commercial O/S with memory protection; tasks run in user space.	Real-time O/S, normally no memory protection – all tasks run in kernel space. Must be RTOS-compatible.

Core components of ION

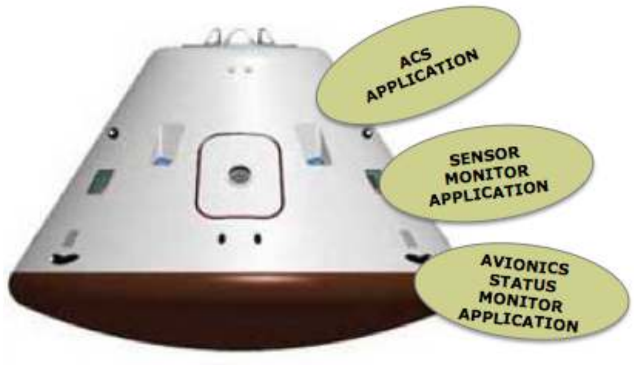


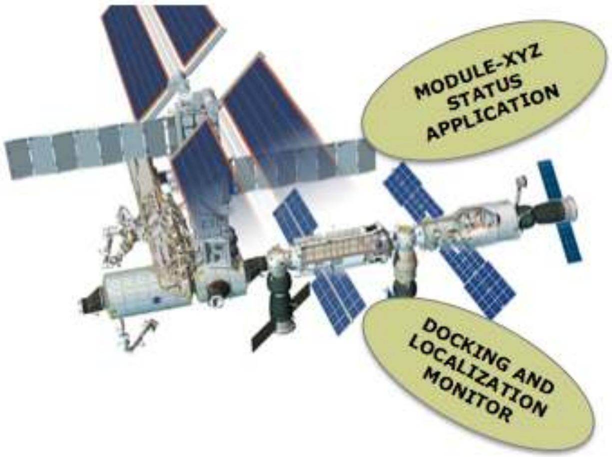
Asynchronous Message Service (AMS)

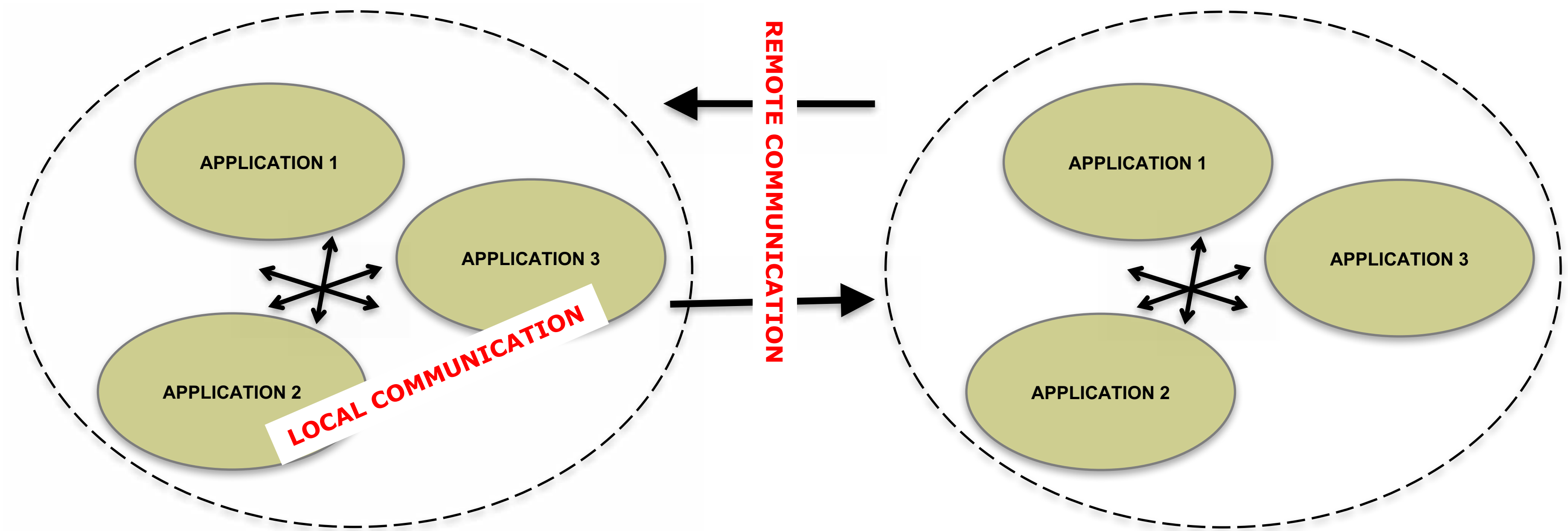
* Publish and subscribe messaging.
* Private messaging.
* Communication over various transport layers (Ethernet, 1553 to VxWorks Message Queues).
* Automatic node discovery and dynamic reconfiguration.
* Support for failsafe configuration, multiple output ports, and DTN messaging layer.



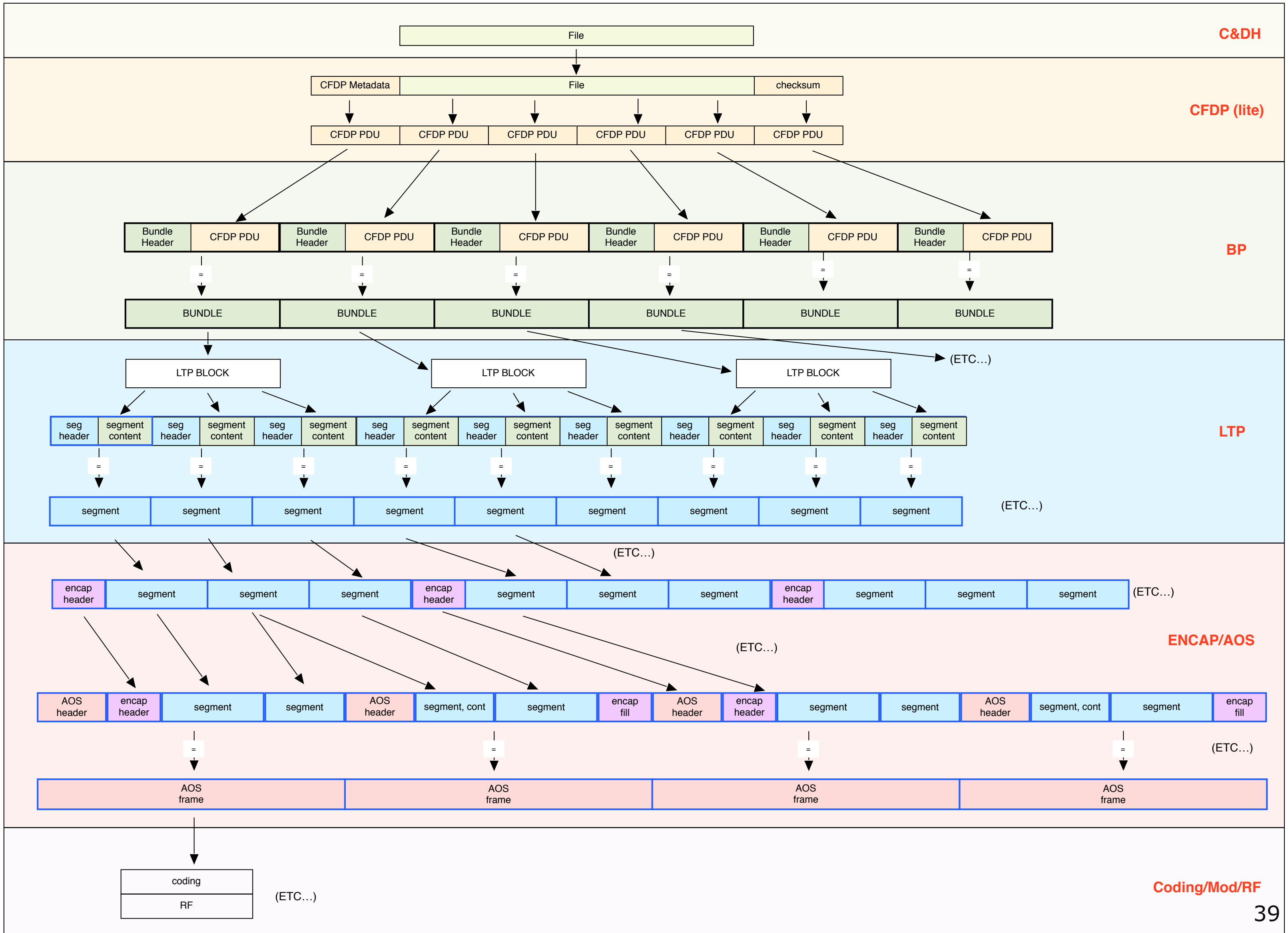
CCSDS Asynchronous Message Service







LAYER DETAIL – frame sizes notional (can be adjusted)



ION Configuration

* Get to know your file system implementation!
* The ION working memory DRAM allocation for each node must be sized appropriately for the application.
* Maximum bundle payload size must be determined.
* Maximum LTP data segment sized to fit over the link layer (Ethernet, radio, etc).
* Bundle time-to-live so that bundles may remain queued for future transmission as needed.
* Collect Bundle Status Reports.

Enabling Technologies for Flight Software Infusion

* Software defined radios (Electra, etc).***
* Fixed UHF master sequence and request profiles.
* Station Allocation Files to tell us when DSN stations are available.
* Proximity-1 protocol.
* Ephemeris information.
* FSW DTN implementation (VxWorks, RTEMS).

Clock/Time Synchronization in DTN

* The clocks of all DTN nodes in the network must have a time reference (TAI/UTC).

* There is no "standard" for time synchronization in deep space. However, GPS is great for LEO.

* There is no nice API to generate a time source for flight software– time(), gettimeofday(), localtime(), gmtime(). POSIX does 'just enough'.

* Hopefully a CCSDS SOIS implementation (include "sois.h") could provide a get_utc/tai/gps_time() and set_utc/tai/gps_time(), otherwise use POSIX.

DTN Spacecraft Scenarios

DTN Operational Scenarios

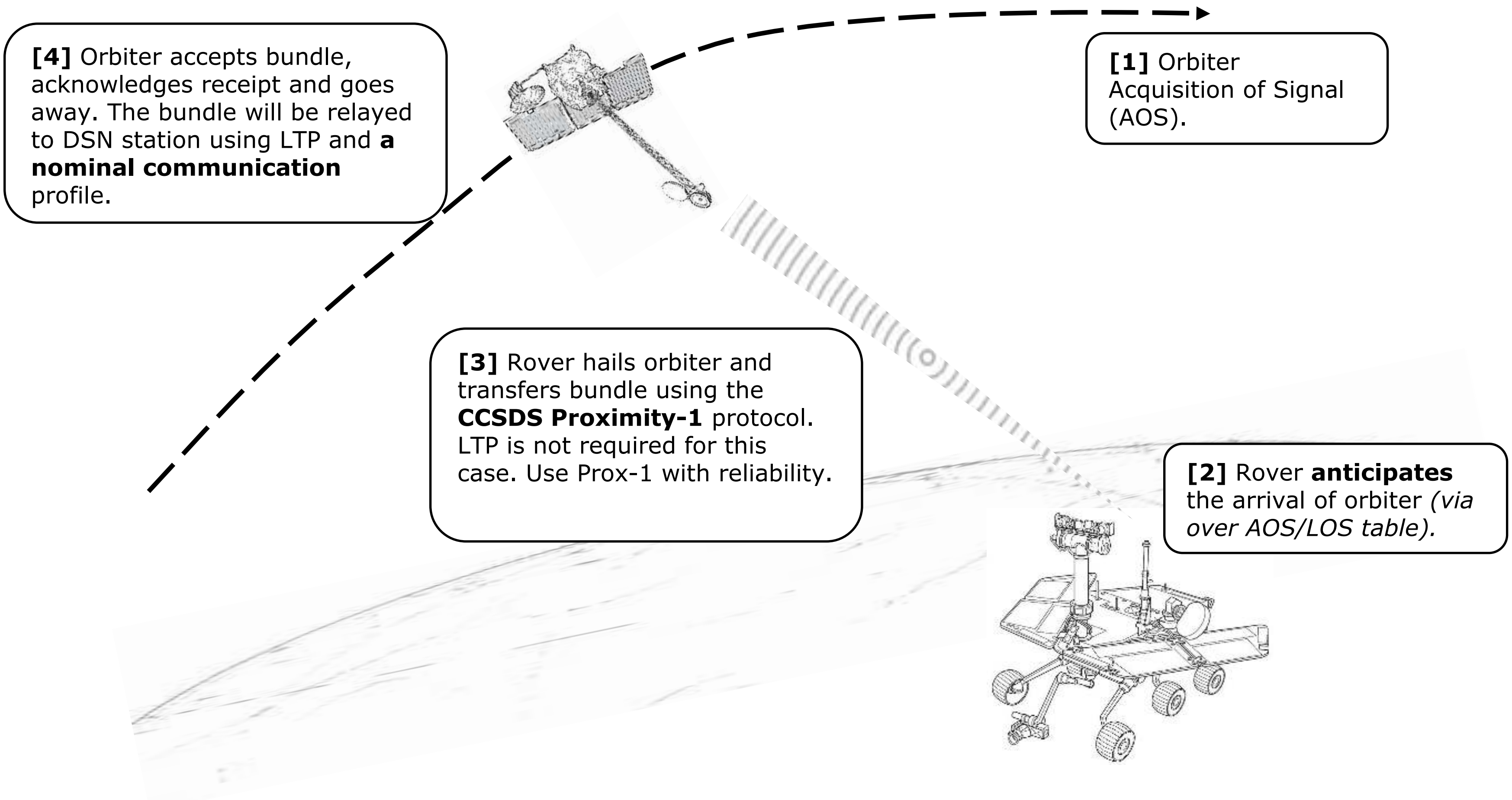
* Some operational scenarios are described:
* Scenario 1: Autonomous Relay Operations
* Scenario 2: Autonomous Deep Space Communications
* Scenario 3: International Space Station Services
* Other scenarios …

Scenario 1: Autonomous Relay Operations

ENABLING TECHNOLOGIES INCLUDE:

* Software defined radios (Electra, etc).
* Fixed UHF master sequence and request profiles.
* CCSDS Prox-1 protocol handshake and bundle transfer.
* Ephemeris (location) information may not be needed.
* VxWorks/RTEMS implementations of ION.

Scenario 1: Autonomous Relay Operations



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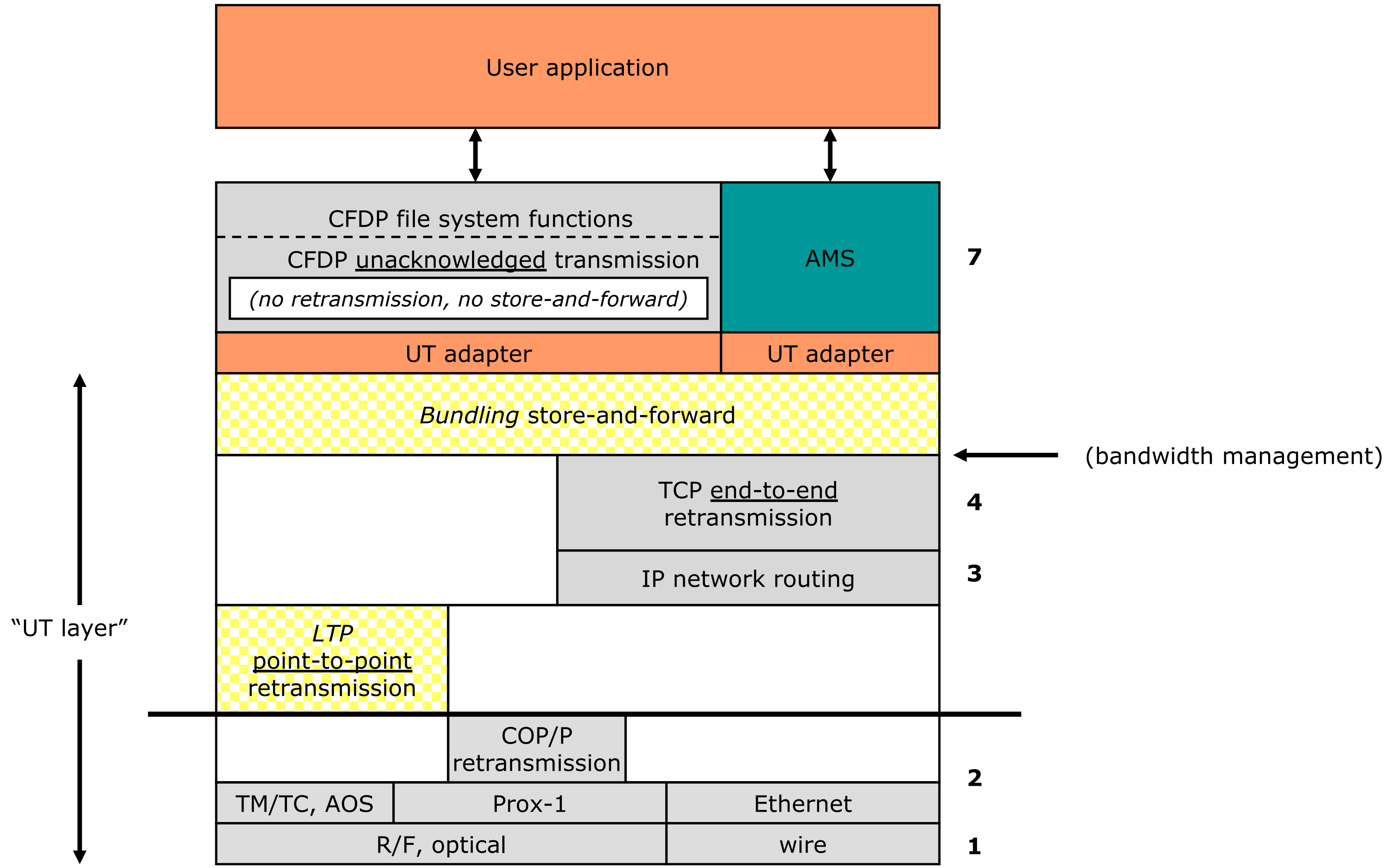
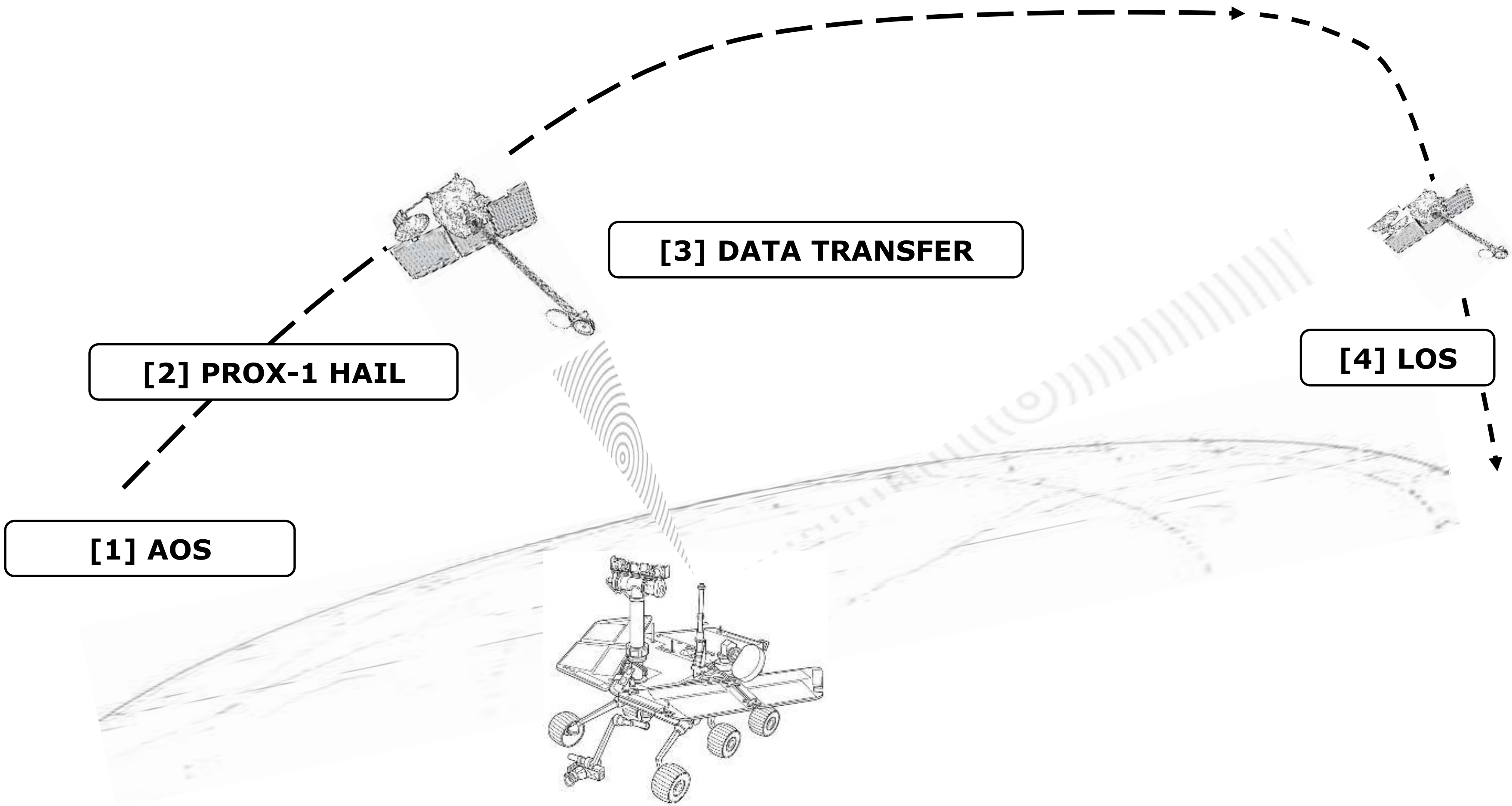
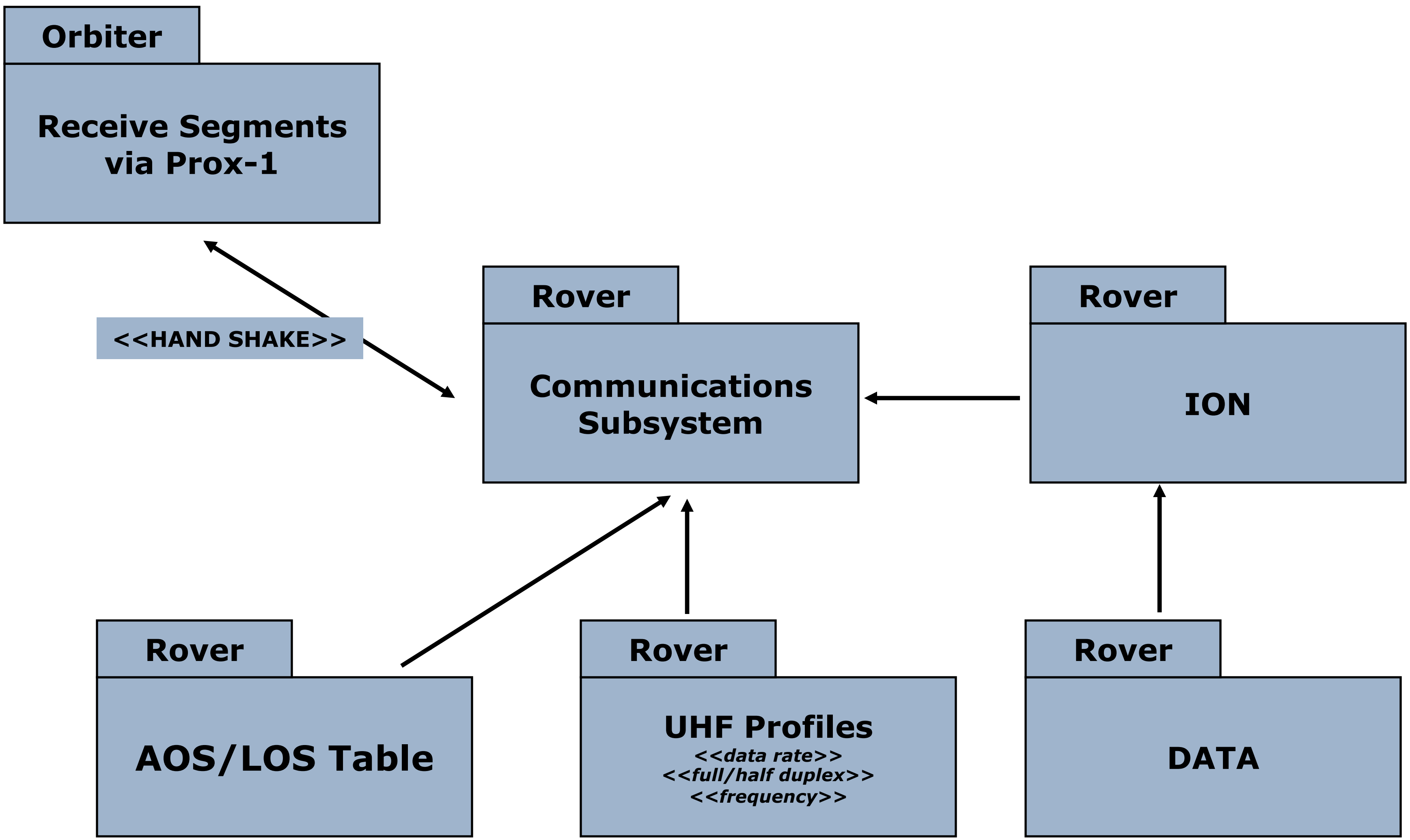


Original slide source: Scott Burleigh, Jet Propulsion Laboratory, California Institute of Technology

Scenario 1: Autonomous Relay Operations



Scenario 1: Autonomous Relay Operations Lander-Orbiter Software Implementation



Scenario 1: Autonomous Relay Operations

* ENABLING TECHNOLOGIES INCLUDE:
* Software defined radios (Electra, Iris, CoNNECT).
* Fixed UHF master sequence and request profiles.
* Prox-1 protocol handshake and bundle transfer.
* Ephemeris information may not be needed.
* FSW DTN implementation (ION).
* VxWorks implementation.

Scenario 1: Autonomous Relay Operations

* UHF communication occurs during opportunistic communication windows, which may occur several times a day/sol.

* The UHF communication profile contains information such as pass ID, window id, transition start time, duration of communication, max elevation of orbiter, data volume (forward and return links), down link rate, coherent/non coherent communication, Is this pass a command pass?, shall the pass be requested?, communication start time, etc

* Create a set of standard UHF profiles
  - Skip Sol, Nominal, High Priority and Emergency profiles.
  - Table driven profiles.

* Only one element (the ground element) may need to know when the orbiter is overhead.

Scenario 1: Autonomous Relay Operations

* Use Proximity-1 and COP-P protocol using the Electra UHF radio.

* Proximity-1 is a short haul delivery protocol designed to establish a two-way communications link between a lander and an orbiter, negotiate data rate and communications mode, and reliably deliver data during short orbiter-to-surface contacts.

* COP-P provides reliability by retransmitting lost or corrupted data to ensure delivery of data in sequence without gaps or duplication over a space link.

Scenario 1: Autonomous Relay Operations Proximity-1 Protocol

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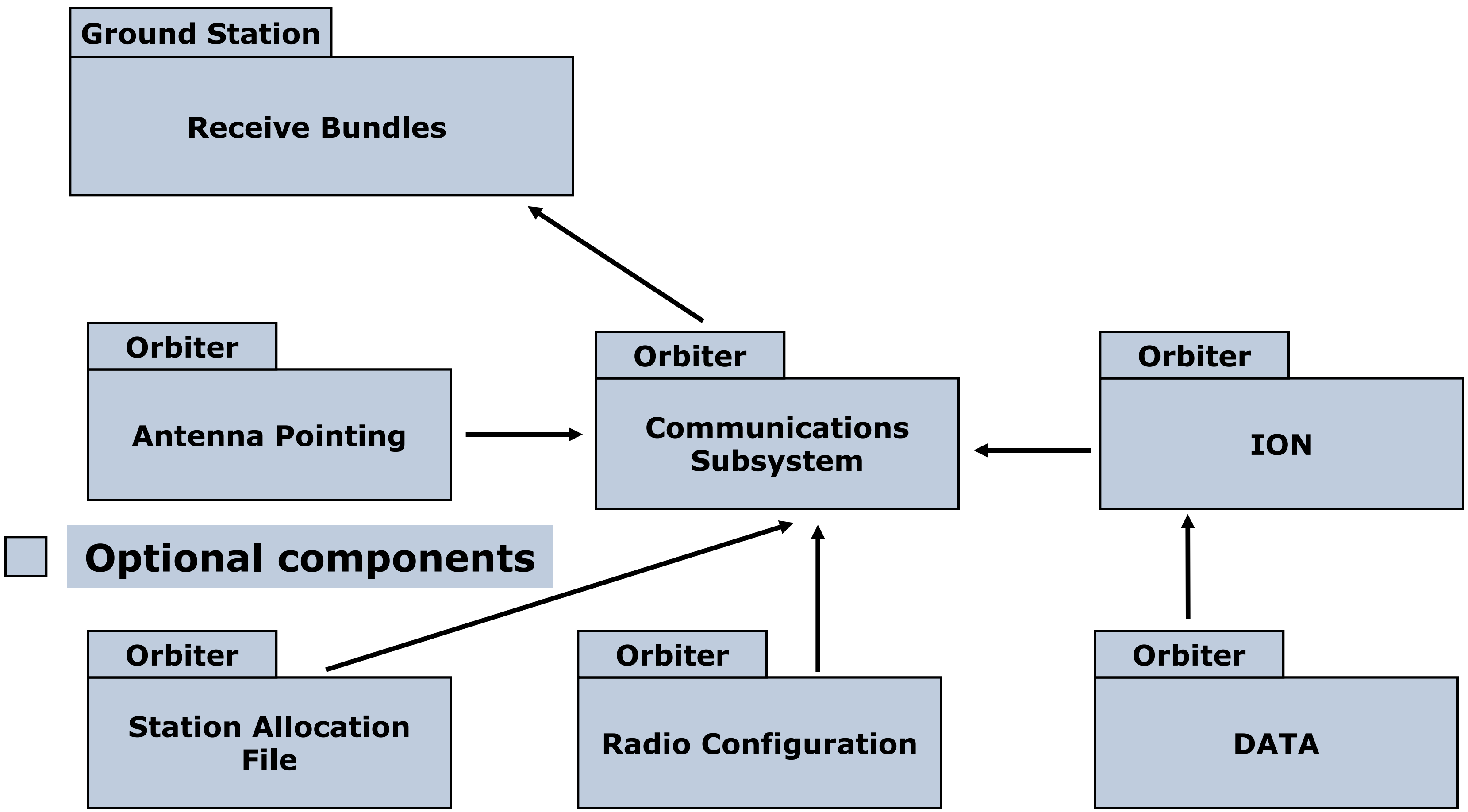
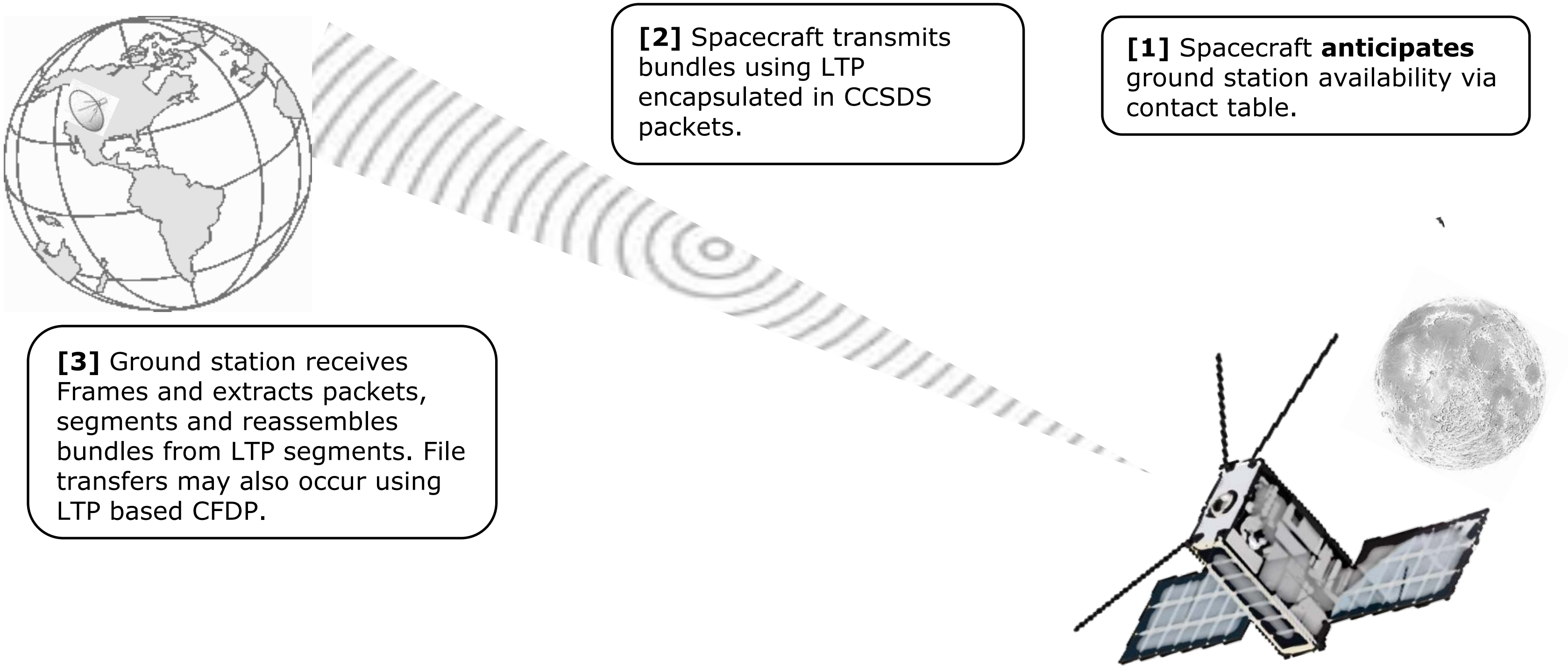
Scenario 2: Autonomous Deep Space Communications



Scenario 2: Autonomous Deep Space Communications



[1] Spacecraft **anticipates** ground station availability via contact table.

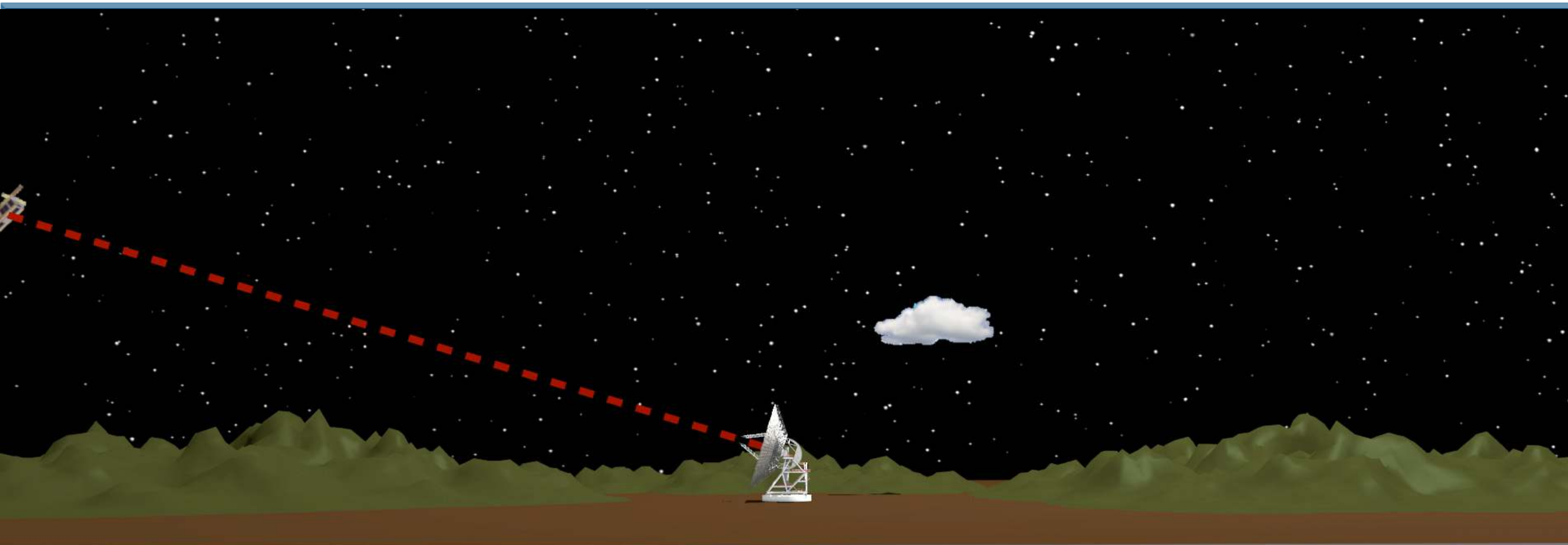
[2] Spacecraft transmits bundles using LTP encapsulated in CCSDS packets.

[3] Ground station receives Frames and extracts packets, segments and reassembles bundles from LTP segments. File transfers may also occur using LTP based CFDP.

Scenario 2: Autonomous Deep Space Communications

- Given updated station availability (via the SAF), the orbiter knows when ground stations are available.
- The spacecraft points it high gain antenna to earth and begins radiating (via NAIF).
- The spacecraft begins forwarding bundles via LTP.
- The ground station receives bundles its LTP proxy.
- The station acknowledges receipt of the bundles.
- Data is then purged from the orbiter automatically.
- A key step is computing the bandwidth-delay product. This is the storage requirement for LTP retransmission due to (lunar, deep-space, etc) round-trip acknowledgement time.

Scenario 2: Autonomous Deep Space Communications



Data recovered with link errors and legacy telemetry

Data recovered with DTN LTP reliability

Video by Leigh Torgerson Jet Propulsion Laboratory, California Institute of Technology

Example: Lunar IceCube

Morehead State University and Goddard are partnering to create the Lunar IceCube mission shown in this artist's rendition.

Morehead State University Age of Deep-Space Exploration with CubeSats Heralded In what scientists say signals a paradigm shift in interplanetary science, NASA has selected a shoebox-size mission to search for water ice and other resources from above the surface of the moon.

The mission is one of several public-private partnerships chosen under NASA's Next Space Technologies for Exploration Partnerships (NextSTEP) Broad Agency Announcement for the development of advanced exploration systems.

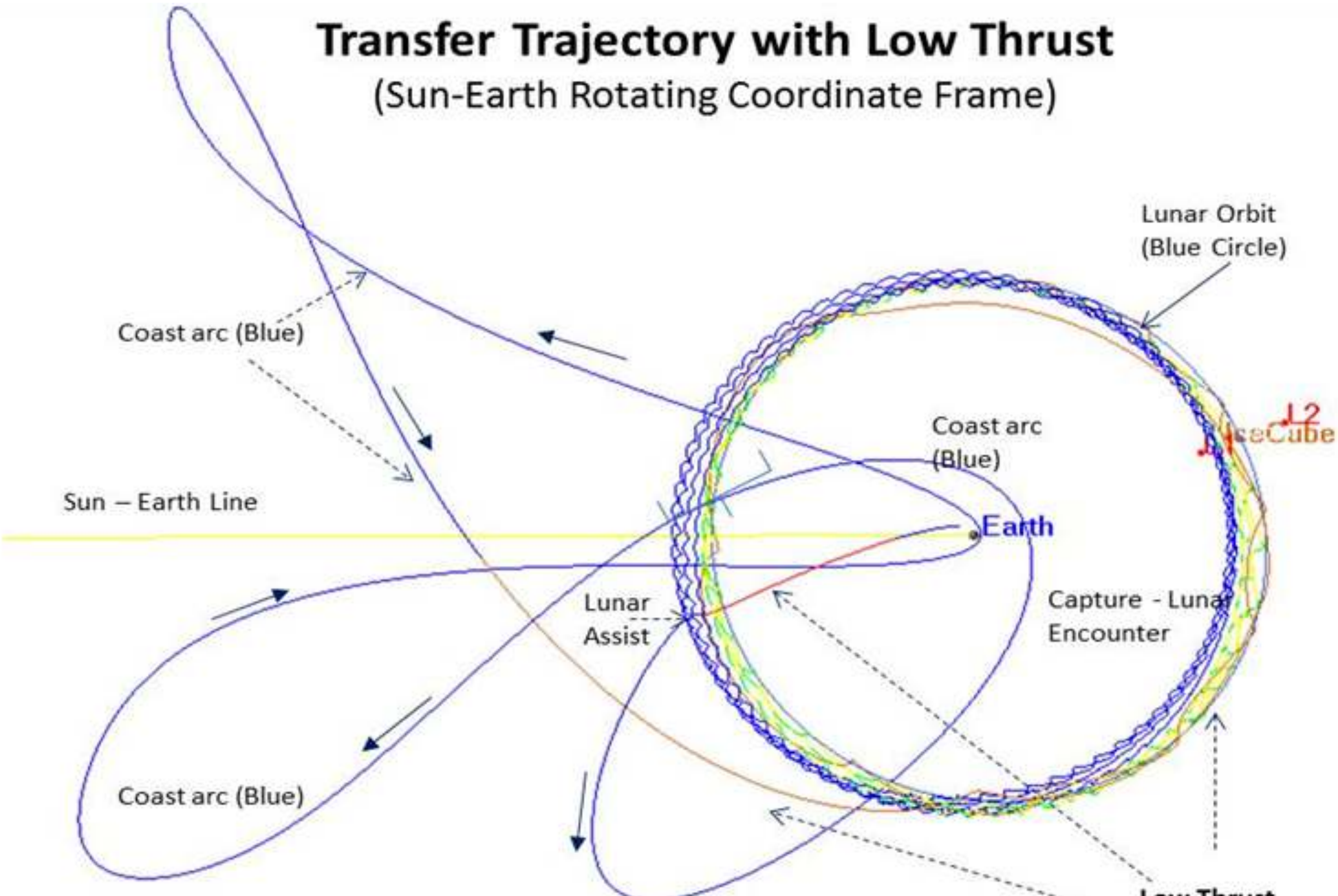
Among the first small satellites to explore deep space, Lunar IceCube will help lay a foundation for future small-scale planetary missions, mission scientists said.

http://www.nasa.gov/feature/goddard/lunar-icecube-to-take-on-big-mission-from-small-package

Example: Lunar IceCube

Transfer Trajectory with Low Thrust

(Sun-Earth Rotating Coordinate Frame)



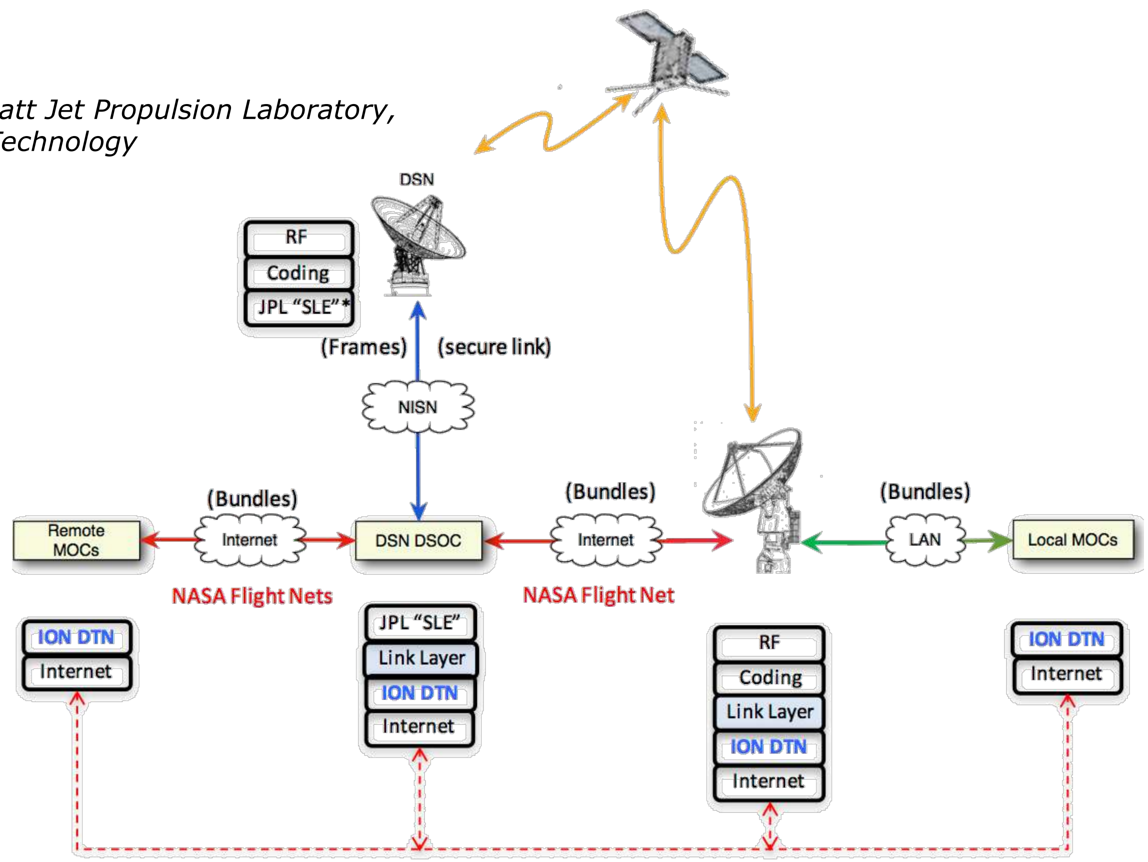
- 4 Day Low Thrust Arc from Deployment to 1st Lunar Encounter
- 59 Day Low Thrust Arc before Lunar Capture

Source: https://www.nasa.gov/feature/goddard/lunar-icecube-to-take-on-big-mission-from-small-package

Example: Lunar IceCube

- DTN is being supported by the NASA Deep Space Network (DSN).
- The Morehead State University DTN node will become integrated into the DSN Service as it comes online and can be operated as a standalone capability.

Image Source: E.J. Wyatt Jet Propulsion Laboratory, California Institute of Technology



ENABLING TECHNOLOGIES INCLUDE:

* Licklider Transmission Protocol (LTP) which is a point-to-point protocol aimed mainly at deep space long-haul links. LTP is seen as a protocol that underpins bundling, so that bundles are transported over LTP on long-haul links.

* FSW DTN implementation (ION).
* VxWorks ION implementation.

* Station allocation files (SAF) – Orbiter knows when ground stations are available.

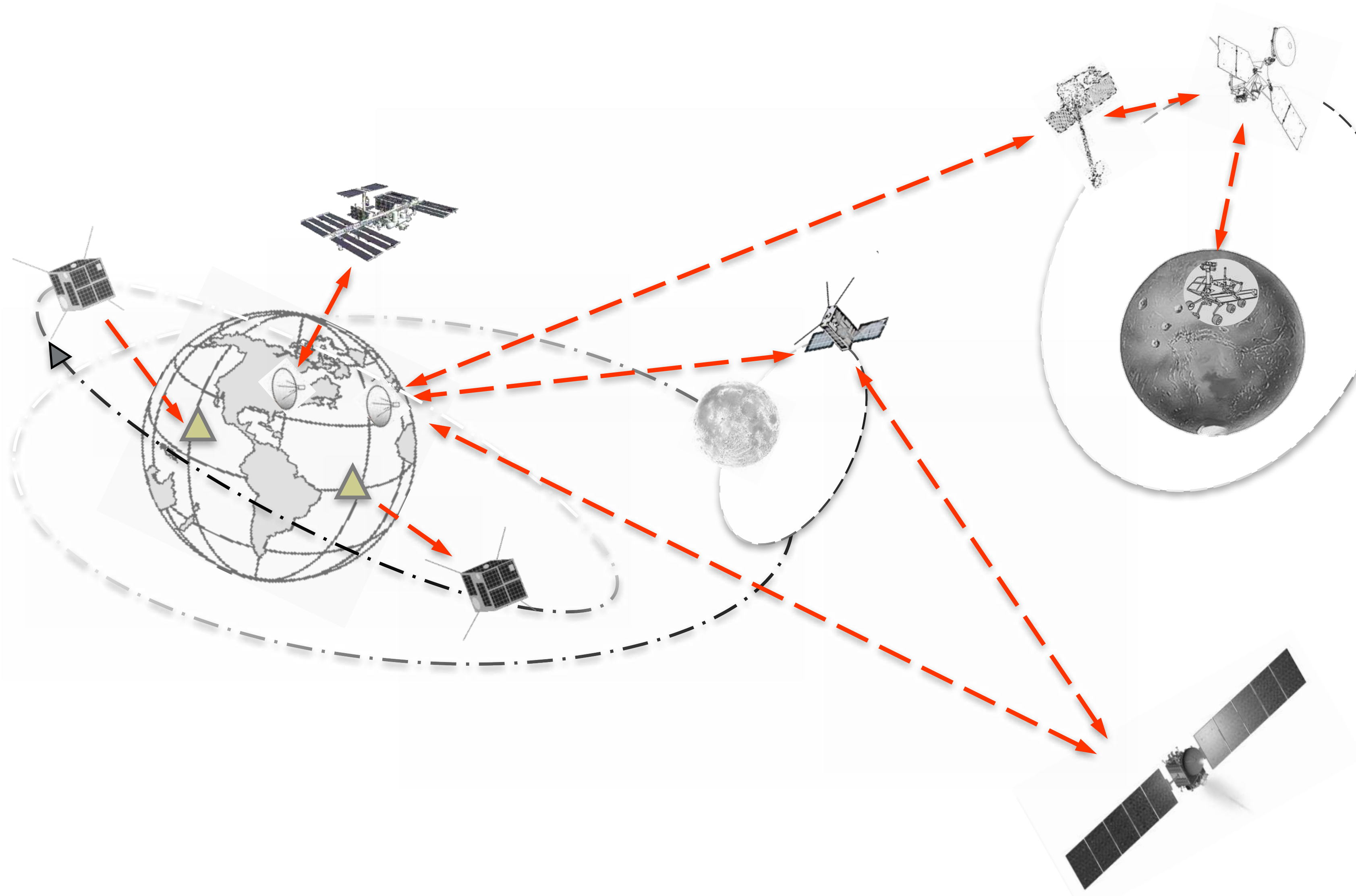
* Ephemeris information needed for instrument pointing. NAIF library provides this.

* Fixed communication (X/S/K) band communication profiles.

Scenario 3: International Space Station

* The ISS has implemented DTN as a standard service for **internal and external payloads**.
* Payloads can use DTN services to simplify and automate their data management.
* Furthermore payloads can be networked using DTN with assets on the ground.

Interplanetary Networking



Backup Slides

Lunar IceCube

"Morehead State University and NASA Goddard Space Flight Center and the Jet Propulsion Laboratory the partnering to create the Lunar IceCube mission shown in this artist's rendition.

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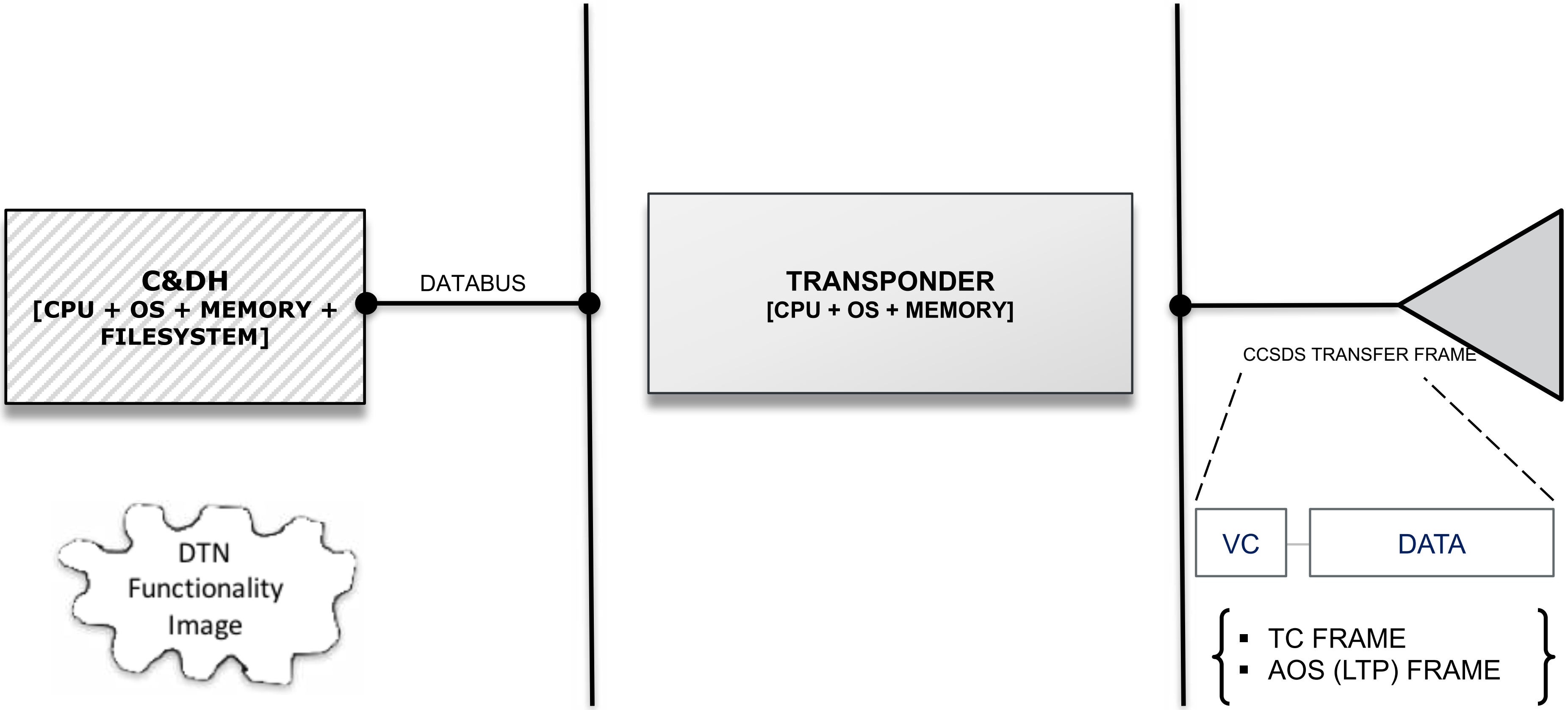
Source:
http://www.nasa.gov/feature/goddard/lunar-icecube-to-take-on-big-mission-from-small-package

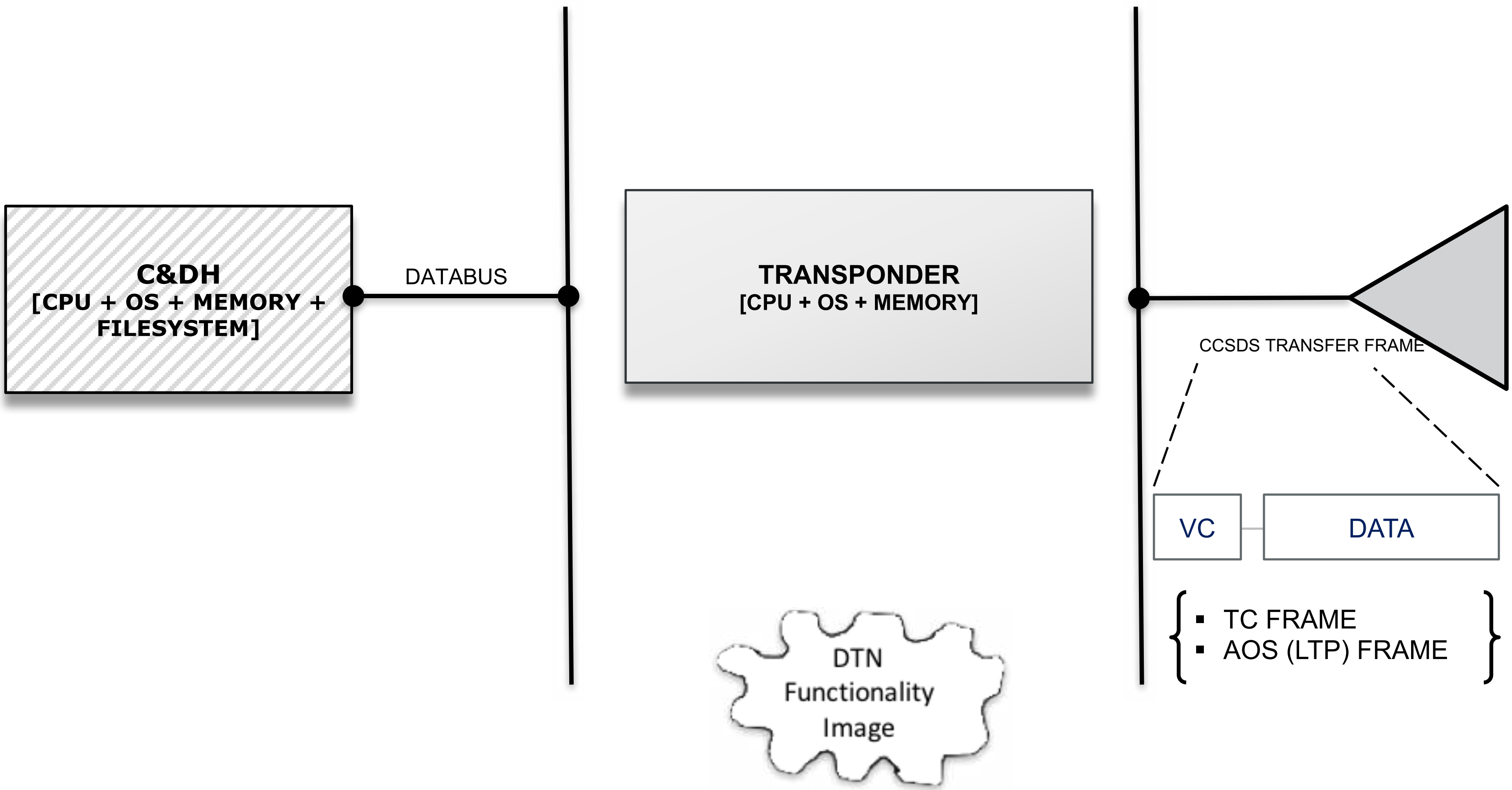
DTN Infusion into Deep Space Transponders

- Extend the capabilities of the transponder by running the Disruption Tolerant Networking (DTN) protocol stack on the onboard processer contained within the transponder hardware.
- Provide an operational capability for deep space CubeSat missions using the transponder
- Motivate/Accelerate infusion of DTN into NASA tracking networks
- Development of a DTN node for use at the Morehead State University 21m antenna is in progress.
- Enable automated relay operations which can 1) lower operations cost by eliminating portions of the downlink coordination process and 2) increase science data throughput.
- Enable coordination among multiple spacecraft to enable new types of science observations

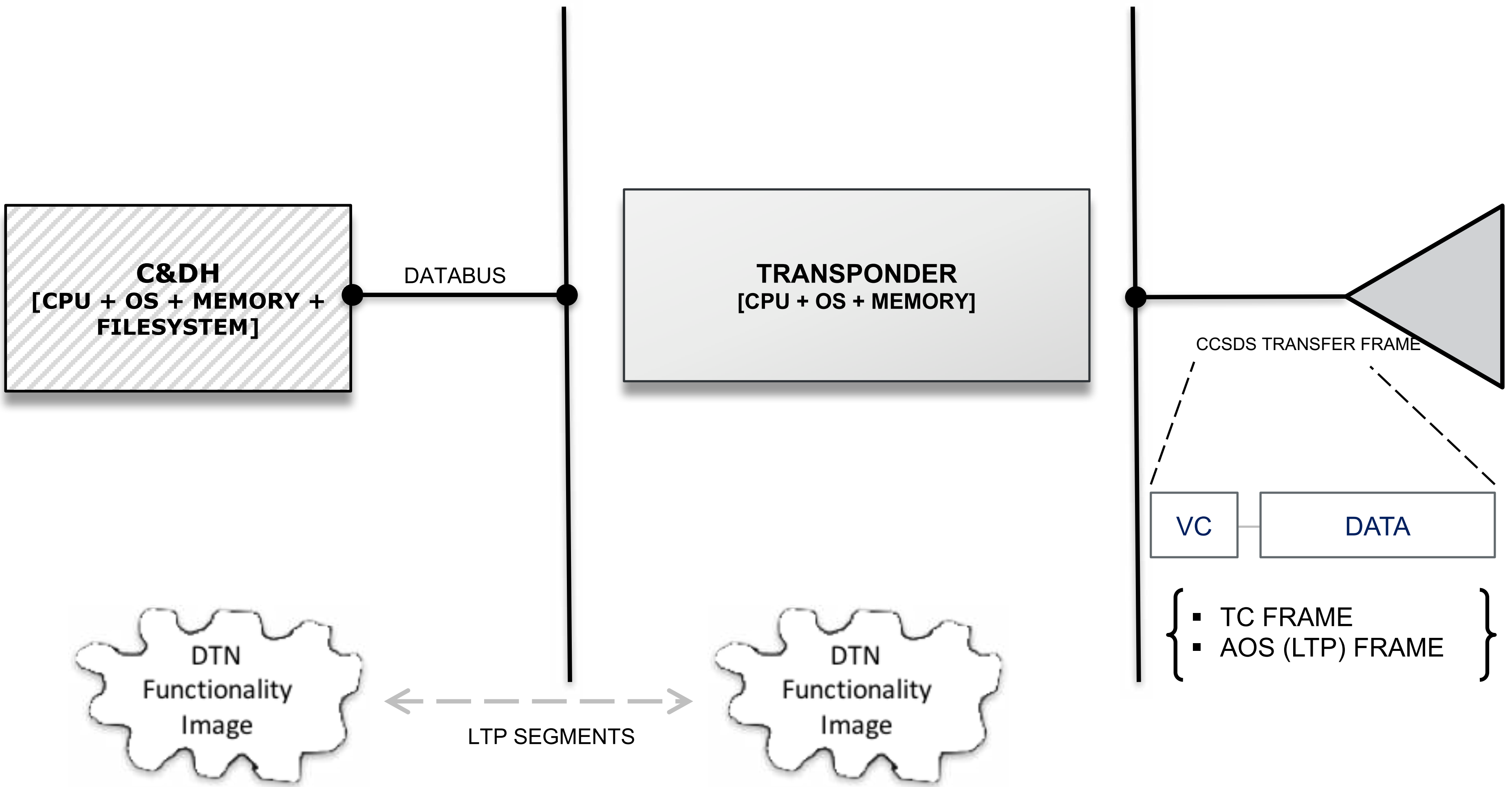
ION on C&DH


C&DH
[CPU + OS + MEMORY + FILESYSTEM]
DATABUS
TRANSPONDER
[CPU + OS + MEMORY]
CCSDS TRANSFER FRAME
VC
DATA
TC FRAME
AOS (LTP) FRAME
DTN
Functionality
Image

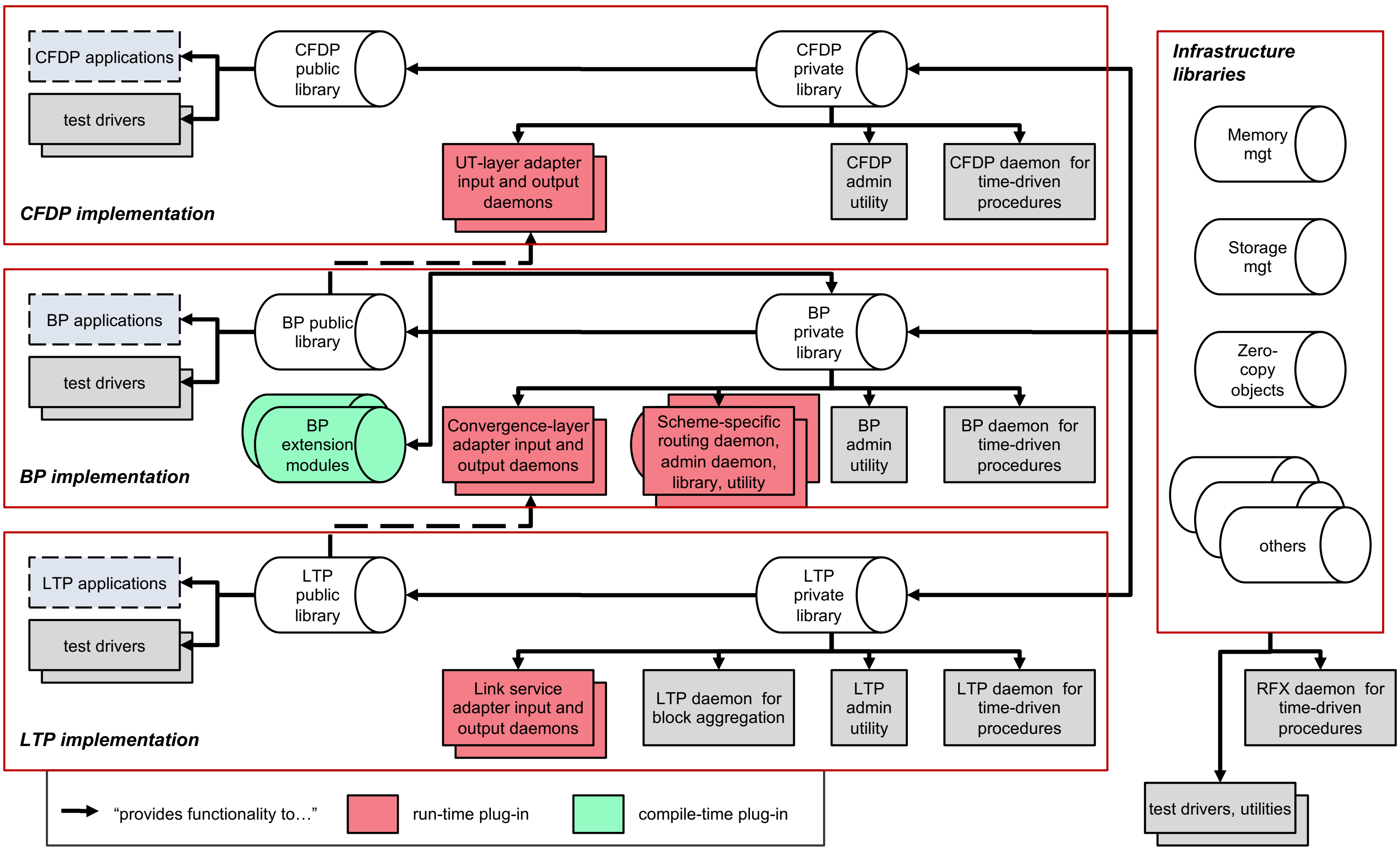
ION on Transponder



ION on both Transponder and C&DH



Core components of ION



Starting ION

```
ionadmin lander.ionrc   #Configure ION

ionadmin global.ionrc   #Configure the contacts

bpadmin lander.bprc     #Configure bundle protocol

ltpadmin lander.ltprc   #Configure LTP
```

Configuring a LTP Span

```
span is as follows:
1 est_max_export_sessions database_bytes_needed

a span peer_engine_nbr max_export_sessions          \
 max_export_session_block_size max_import_sessions \
 max_import_session_block_size max_segment_size    \
 aggregation_size_limit aggregation_time_limit     \
'LSO_command' [queuing_latency]

s 'LSI command'
```

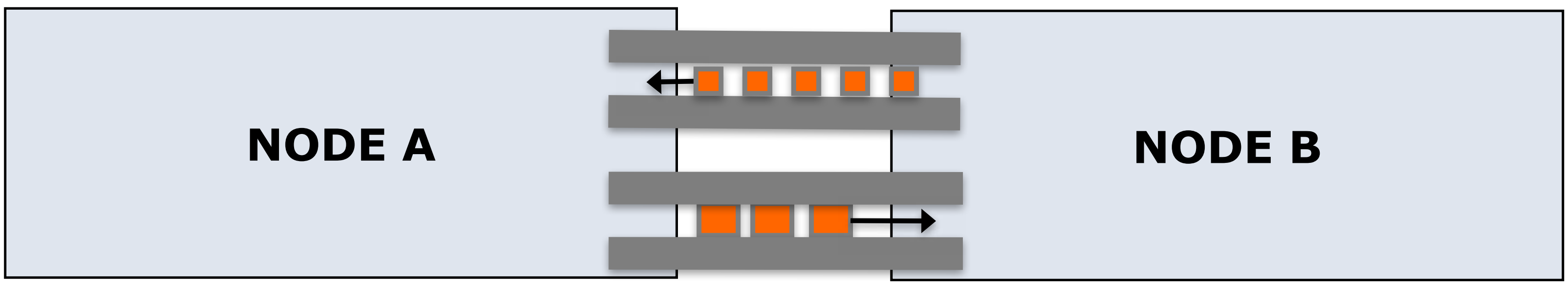
Example LTP Configuration File

```
# LTP Configuration File
1 2 4000000
a span 1 2 500000 2 500000 1000 500000 1'udplso 192.168.10.10:15001'
s 'udplsi 192.168.10.11:15001'
m screening n
m ownqtime  2
w 1
l span
```

Spans Between Two Peers

```
a span 1 2 500000 2 500000 1000 500000 1'udplso 192.168.10.10:15001'
```

SPAN FROM 1 TO 2



SPAN FROM 2 TO 1

LTP Segment I/O