Jet Propulsion Laboratory
California Institute of Technology

MOREHEAD STATE UNIVERSITY

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Validating the Optimization of Mission Operations for the Lunar IceCube Mission Using Delay-Tolerant Networking

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Lunar IceCube Mission Overview

Delay/Disruption-Tolerant Networking Introduction

DTN Benefits

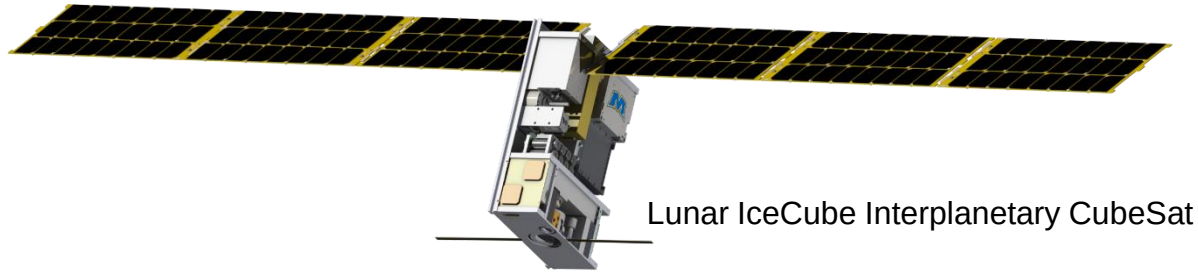
Work to Date

Future Work

In-flight Experiment

Lunar IceCube Mission Overview

- Artemis-1 CubeSat
- Mission is to study water ice and other volatile distribution and interaction on the Moon
- 180-day coast phase offers the opportunity to flight validate DTN for the first time on a CubeSat in deep space without interfering with the primary mission
- Morehead operates a DTN-compatible ground station capable of communicating at lunar distances



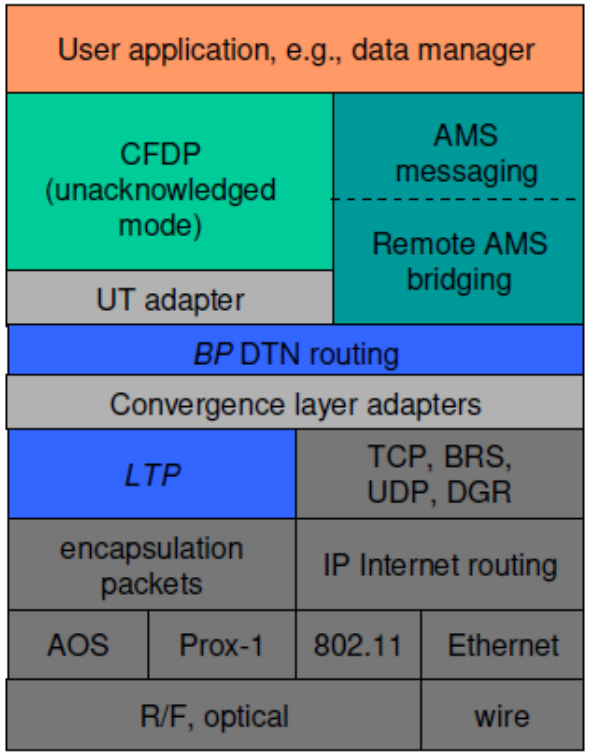
Lunar IceCube Interplanetary CubeSat

Morehead State University's DSN-Affiliated Station DSS-17

Delay/Disruption-Tolerant Networking Introduction

Bundle Protocol

- To provide network connectivity in space, a method that scales better than point-to-point links needs to be developed
- Enter the Bundle Protocol (BP)
  - Data transmission is via bundles which provide built-in security, integrity, and quality service
  - Overlays existing networking and link technology
  - Handles loss & delay via store and forward mechanism
  - Deals with the routing needs of underlying network

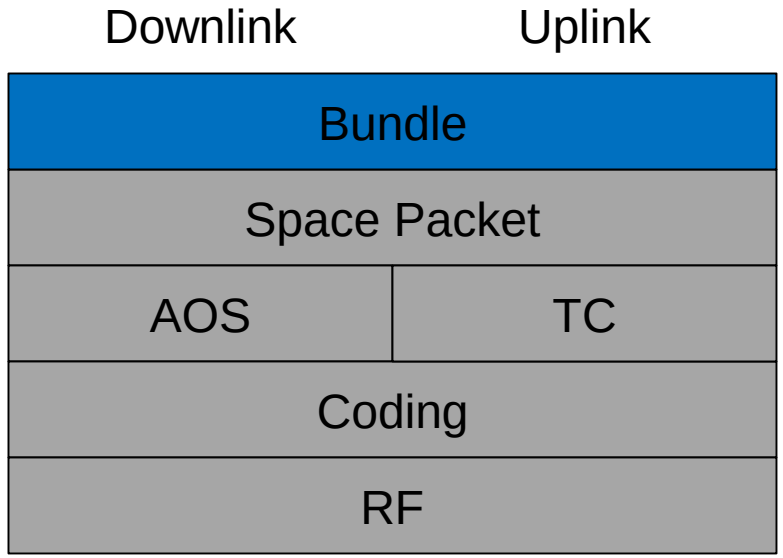


Generic Protocol Stack

Delay/Disruption-Tolerant Networking Introduction

DTN Related to Lunar IceCube

- Terrestrial networking will be handled by Interplanetary Overlay Network (ION)
  - Suite of software providing DTN capabilities developed at JPL
  - https://sourceforge.net/projects/ion-dtn/
- Interface for mission operations software provided by pyION
  - Python 3 package
  - https://github.com/msancheznet/pyion
- Spacecraft networking provided by a Goddard-developed core Flight Software App
  - Originally developed for PACE mission
  - Underlying library is open-source: https://github.com/nasa/bplib



LIC Protocol Stack

DTN Benefits

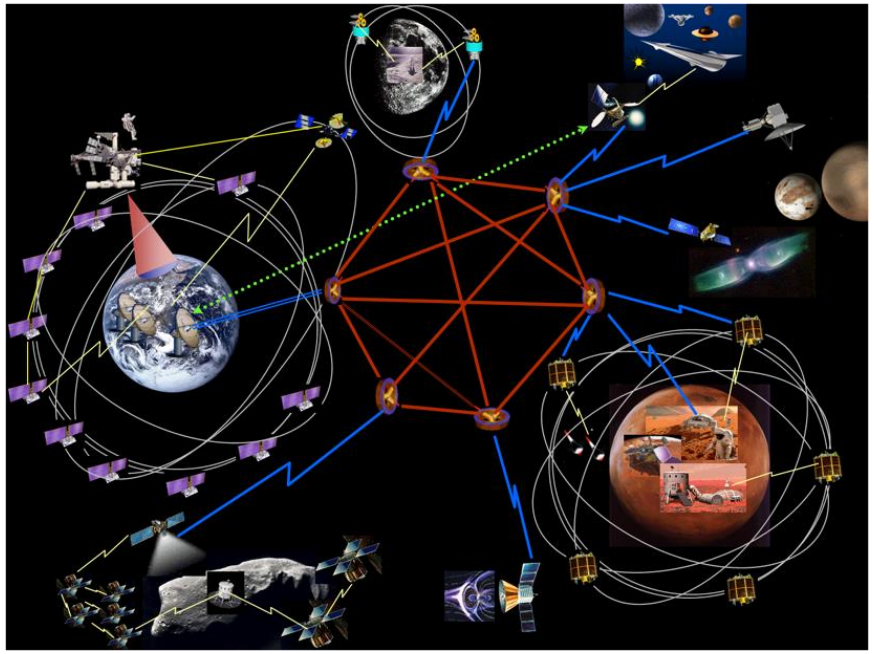
Automation

- BP has two methods of providing automatic end to end reliable transfer to a link
  - Leave it to an underlying protocol
  - Custody Transfer
- Custody Transfer can be augmented using aggregate custody signaling (ACS) to reduce uplink traffic
- Two potential automation benefits will be explored in the Lunar IceCube mission
  - Automatic retransmission of unacknowledged bundles
  - Free up spacecraft resources by deletion of acknowledged bundles

DTN Benefits

Networking

- BP offers standardized mechanism to transfer data over different network topologies
- Since BP overlays existing IP networks, bundles can be forwarded to a DTN destination on an IP network
- Lunar IceCube has several partners at different locations, so any relevant data can automatically be forwarded upon reception on the ground

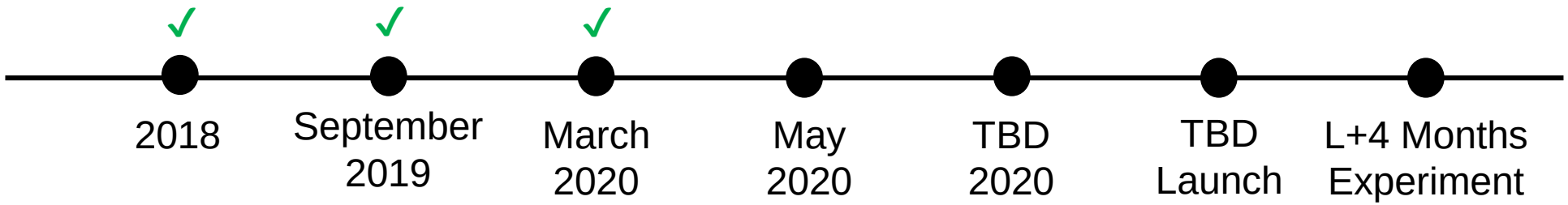


REF: "Operations Concept for a Solar System Internetwork", Interagency Operations Advisory Group (IOAG), 15 Oct, 2010.

Work to Date

Demonstrations

- 2018: Proof of Concept Demonstration
- September 2019: Prototype End-to-End Demonstration
- March 2020: Flight-like Demonstration
- May 2020: Uplink Functional Demonstration
- TBD 2020: Stability Test



Work to Date

Prototype End-to-End Demonstration

- An end-to-end demonstration of the prototype system was performed successfully in September 2019
- Demonstration utilized LIC's flight radio (a JPL-developed Iris 2.1) and its ground station processing hardware
- Goals
  - Receive bundles from spacecraft
  - Ingest bundles into ground network
  - Forward bundles to DTN node standing for MOC

Work to Date

Prototype Block Diagram

JPL DTN Uplink

MSU Ground Station Uplink

DTN Node 21

BCH & CLTU Framing

Uplink Processor

Signal Generator

Up-Converter

Attenuator

Bundles Not Received

LIC Flat-sat

MSU DTN Downlink

ACS Bundles

MSU Ground Station Downlink

DTN Node 20

Demo-1: To file

DTN Node 23

Demo-2: To file

Data Capture

Query

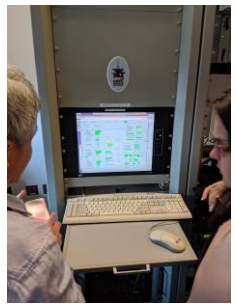
Data Capture Console

Signal Processor

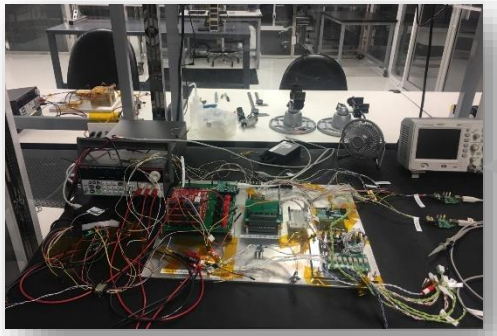
Down-Converter

Telemetry Bundles

MSU MOC



MSU DSN Subsystem



Work to Date

Prototype Demonstration Results

- Successfully flowed bundles from spacecraft into DTN network
- Generated acknowledgements for bundles
- As planned, acknowledgments were transmitted but not received
- Timing across the network was an issue

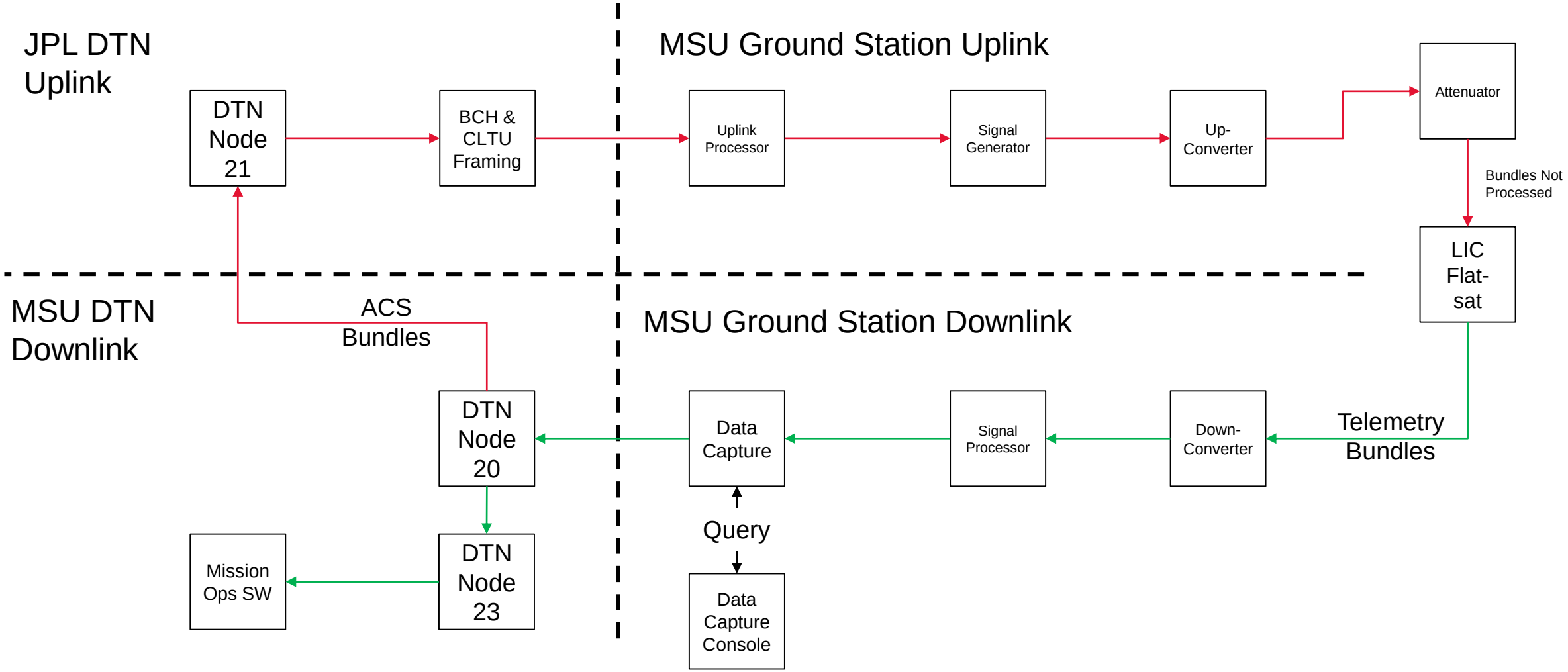
Work to Date

Flight-like Demonstration

- A downlink functional test was successfully performed March 11th, 2020
- The demo was an extension of the September demonstration, and incorporated the mission operations software
- Goal was to repeat prototype demo, but display telemetry with Mission Operations Software

Work to Date

Flight-like Block Diagram



Work to Date

Flight-Like Demonstration Results

- Successfully flowed bundles from spacecraft into DTN network
- Generated acknowledgements for bundles
- As planned, acknowledgments transmitted and received, but not processed
- pyION was unable to serve as a direct interface due to Python version differences, so an extra hop was added between the network and mission ops software

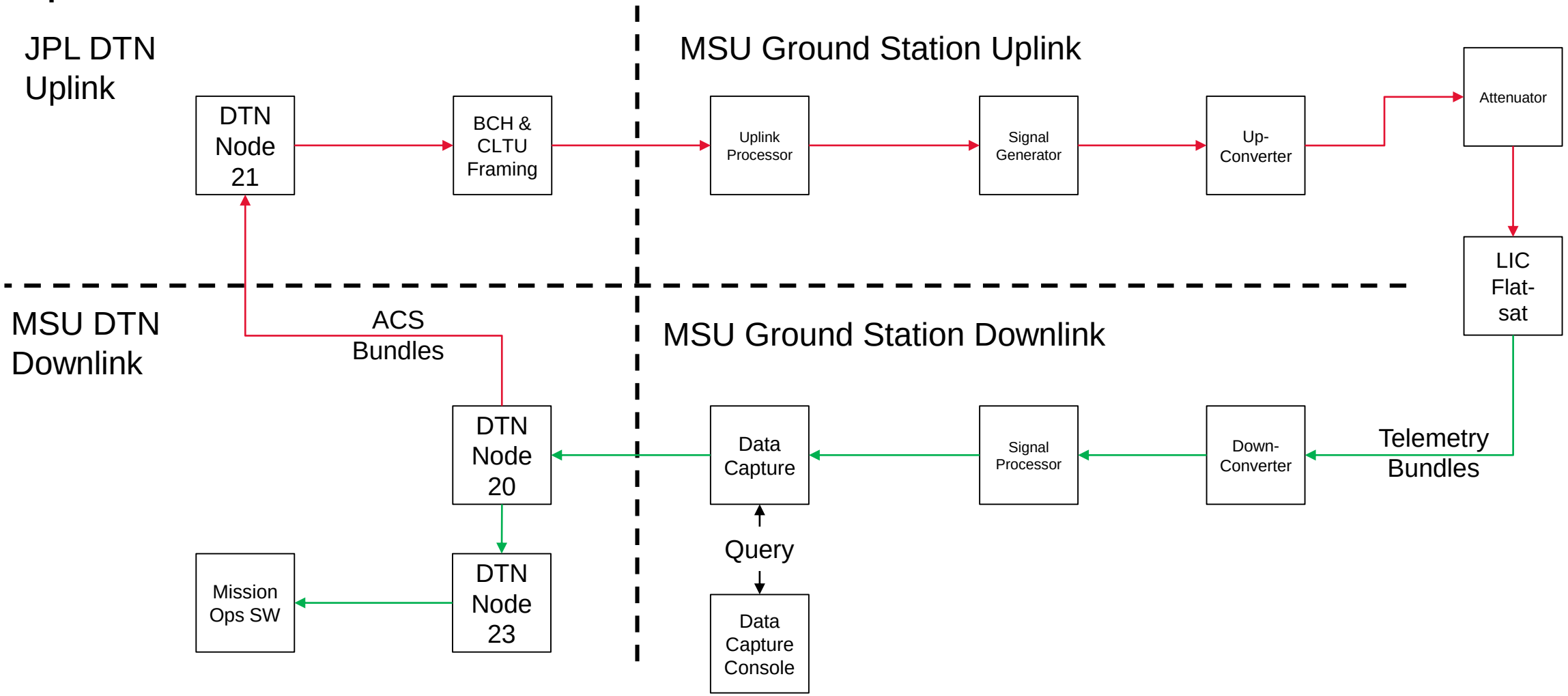
Future Work

Uplink Functional Demonstration

- Similar to downlink functional demonstration
- Planned for later this month
- Goals:
  - Spacecraft reception of ACS bundles
  - Spacecraft deletion of acknowledged bundles
  - Spacecraft reception of at least one bundle containing a command
  - Spacecraft execution of command

Future Work

Uplink Functional Block



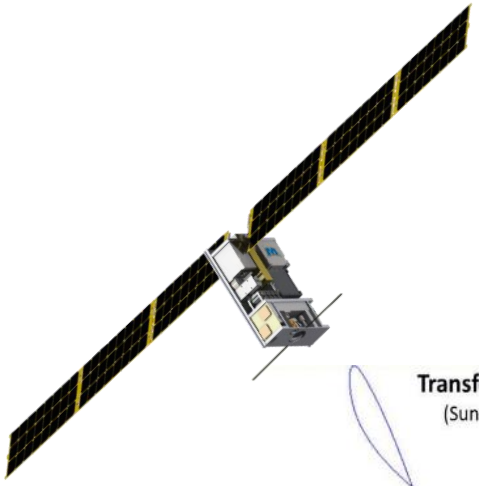
Future Work

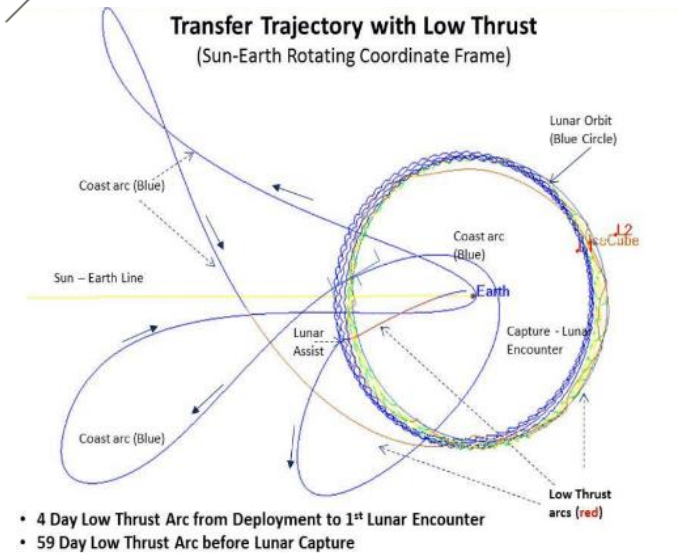
Stability Test

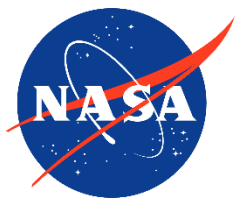
- Impacted by pandemic, originally planned for July
- Longer than previous demonstrations
- Simulate an actual pass
- Verify stability of entire network
- Better understand performance of whole system

In-Flight Experiment

- DTN LIC Experiment is set to take place four months after launch during LIC cruise phase
- With four months of operations before the experiment we'll be able to compare the exact impact DTN could have on LIC's mission operations
- In addition to the previously ascribed benefits, CFDP demonstration with DTN is planned to show that it can support LIC's use of CFDP
- Planned ESA cross-support demonstration
- Create a Flight Validation Report







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