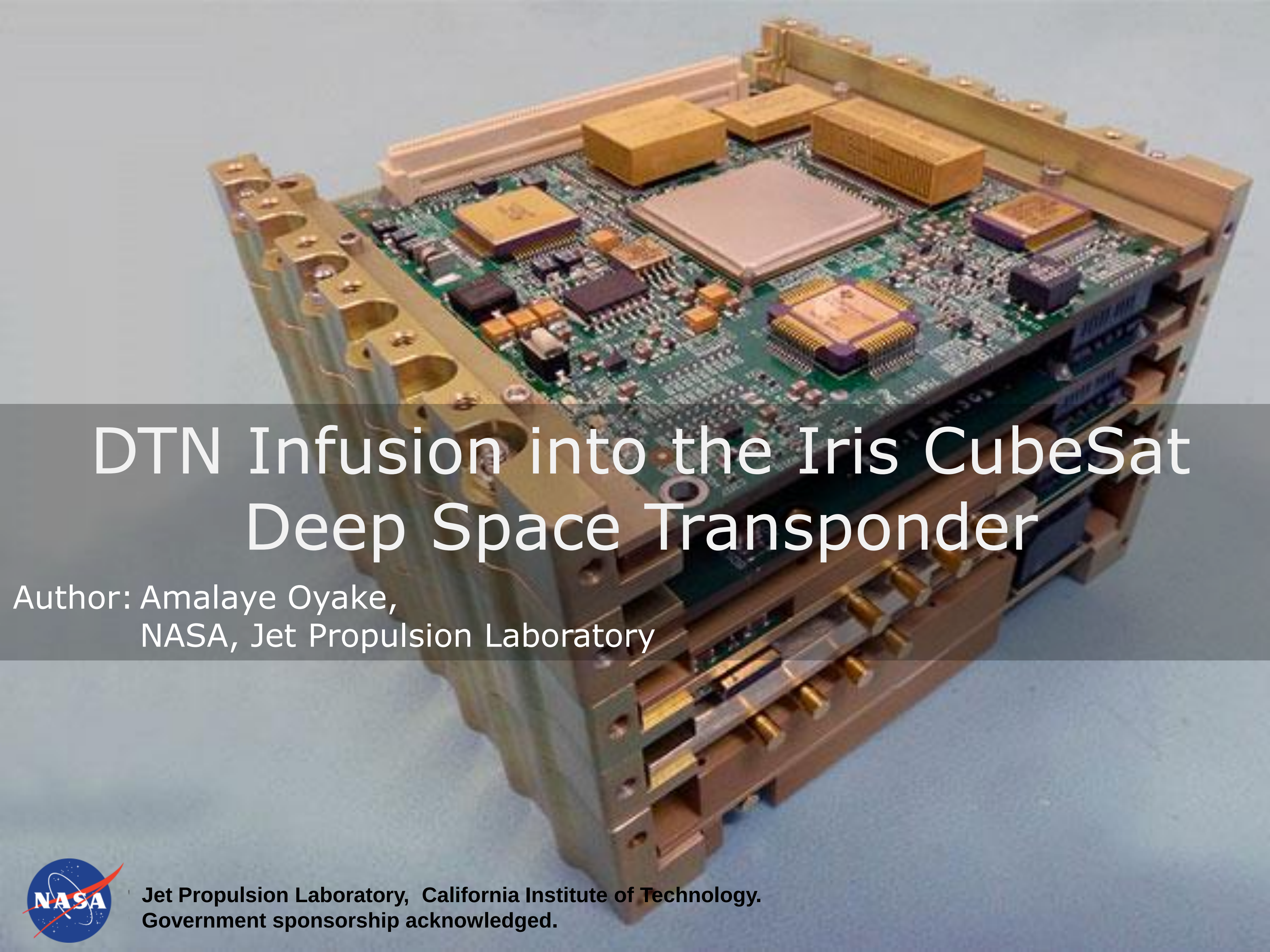

DTN Infusion into the Iris CubeSat Deep Space Transponder

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Government sponsorship acknowledged.

Introduction

- The Jet Propulsion Laboratory has developed the small-form-factor deep space transponder known as Iris, for use in CubeSats, thus enabling CubeSats to operate from deep space.[1]

- The Iris transponder is a 0.4 U, 0.4 kg, consumes 12.8 W, and interoperates with NASA's Deep Space Network (DSN) on X-Band frequencies (7.2 GHz uplink, 8.4 GHz downlink) for command, telemetry, and navigation [1].

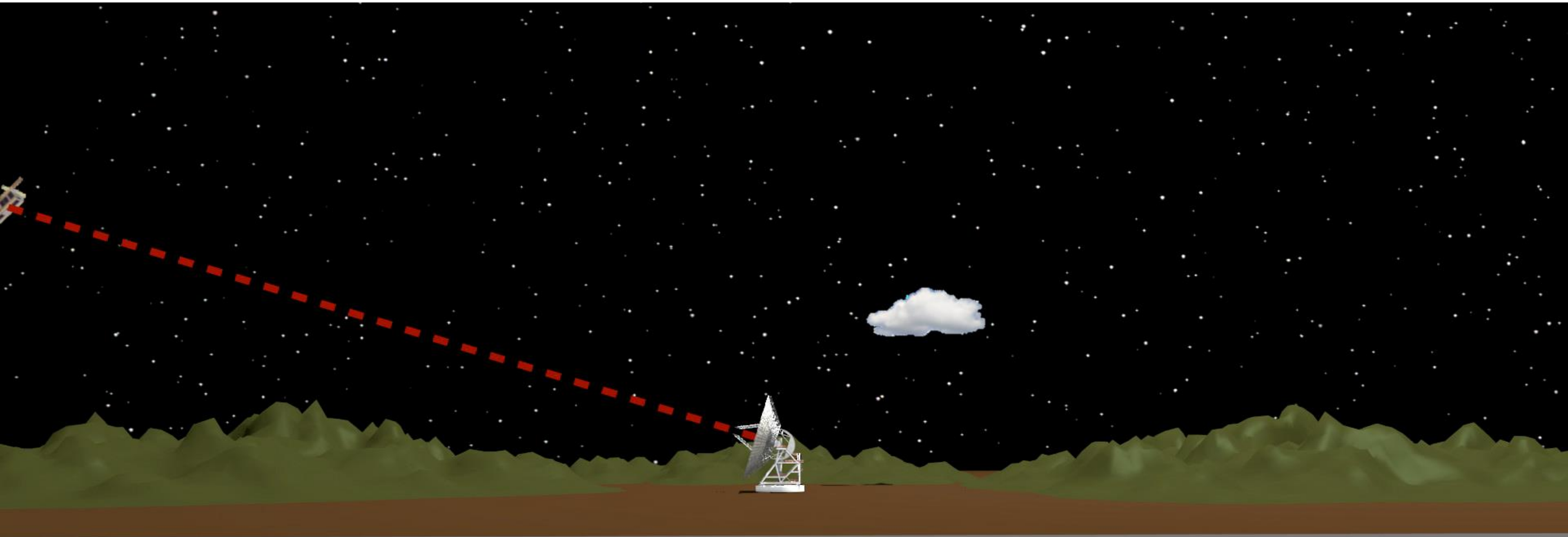
- The Iris transponder is designed as a low (cubic) volume and low mass, lower power and low cost, software/firmware defined telecommunications subsystem for deep space communications.[1]

Source: "Iris Transponder-Communications and Navigation for Deep Space", Courtney Duncan, et al, 04/08/2014

Introduction

- The goal of this work is to extend the capabilities of the Iris transponder by running the Disruption Tolerant Networking (DTN) protocol stack on the onboard processer contained within the Iris transponder hardware.
- This will enable small deep space assets like CubeSats to form networks. The work will be performed in two phases, spanning two years.
- The plan will involve infusing the JPL ION DTN implementation into the Iris transponder radio and run as an application on the Space Telecommunications Radio System (STRS) architecture.
- The STRS architecture provides a generic software defined radio environment, which creates radio interfaces for transmitting and receiving data, and allows for software applications to interface with the radio modem.

Communication Example



Data recovered with link errors and legacy telemetry

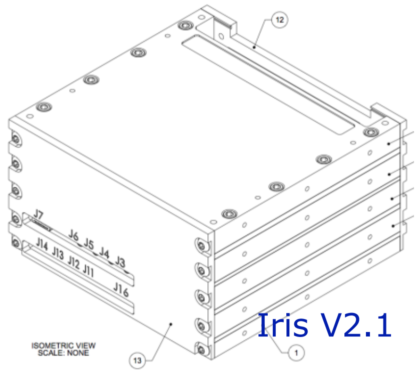
Data recovered with DTN LTP reliability

Iris Radio At-a-Glance

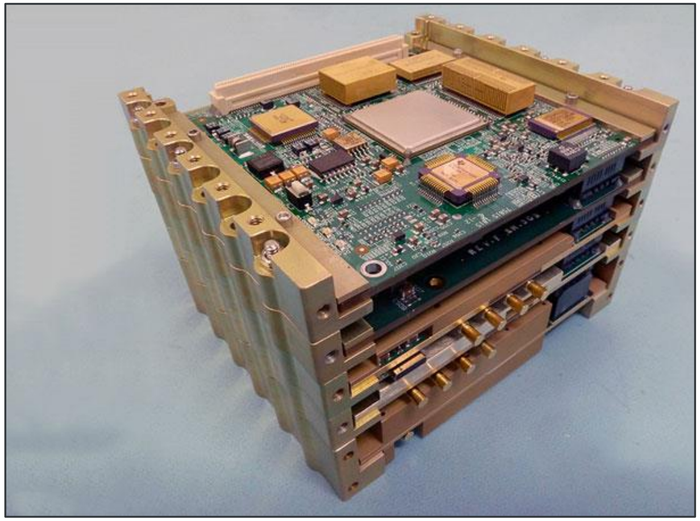
- CubeSat/SmallSat compatible deep-space transponder
- ~0.5U volume (100.5 x 101.0 x 56.0 mm; transponder only)
- DSN/NEN-compatible at X-band (7.2GHz/8.4GHz)
- Provides navigational support (Doppler, SRA, DDOR)
- Iris V1.0 for INSPIRE, and Iris V2.0 for MarCO
- Iris V2.1 baselined for six EM-1 CubeSat missions
  - Lunar Flashlight (JPL)
  - NEA Scout (MSFC)
  - BioSentinel (ARC)
  - CubeSat for Solar Particles (SwRI)
  - Lunar IceCube (MSU)
  - LunaH-Map (ASU)

Iris Specification	Iris V2.1 Specification Value
Digital Processor	Xilinx Virtex-6 w/ 32-bit LEON3-FT @ 50 MHz
DC/RF Power*	30.0W DC w/ 5.0W RF output
Uplink Rates†	62.5 – 8,000 bps at 2^n multiples
Downlink Rates†	62.5 – 256,000 bps at 2^n multiples
Channel Coding Types	Conv(1/2,7), RS(255,223), Turbo(1/2, 1/3, 1/6)
Memory (RAM)	2MB SRAM + 4Mbit EDAC SRAM
Memory (NVM)	32MB NOR Flash, segmented 4x8MB
S/C Interface	1.0 MHz SPI

Nominal at ambient; †Subject to link margin



DTN Infusion into Iris Transponder Goals



- Extend the capabilities of the Iris transponder by running the Disruption Tolerant Networking (DTN) protocol stack on the onboard processer contained within the Iris transponder hardware.
  - The JPL ION DTN implementation will be infused into the Iris transponder radio and run as an application on the Space Telecommunications Radio System (STRS) architecture.
  - The STRS architecture provides a generic software defined radio environment, which creates radio interfaces for transmitting and receiving data, and allows for software applications to interface with the radio modem

- Provide an operational capability for the EM-1 CubeSat missions using the Iris transponder
  - Iris transponder is baselined to be used on 6 (out of 13) CubeSats on SLS EM-1 Secondary Payloads
  - Lunar IceCube has agreed to utilize DTN at some point during the mission

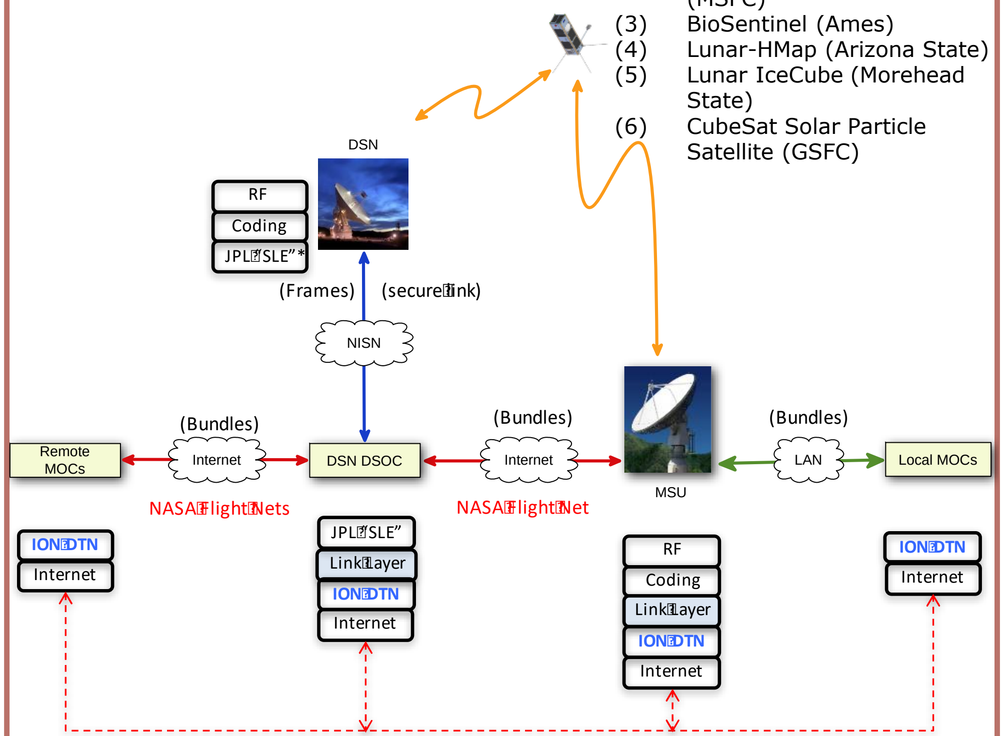
- Motivate infusion of DTN into NASA tracking networks
  - Development of a DTN node for use at the Morehead State University 21m antenna is in progress
  - Plan for infusing DTN into DSN operations by 2018 has been developed and submitted to SCaN for funding consideration

– Put in place new capabilities for missions
  - Improve downlink efficiency and reduce the cost of downlink planning for single missions.
  - 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

DTN Heritage on Flight Systems

- **DTN Core protocols have been fully standardized as Blue Book CCSDS Standards**
- **Protocols are flight-ready and have been flight tested**
  - Deep Impact/EPOXI Deep Space Flight Validation
  - EO-1 flight test
  - LCRD proof-of-concept test during operations
  - **<u>Fully operational on the ISS Payload LAN as a service for ISS payloads</u>**
  - *See next slide for additional DTN tasks*
- **DTN is being incorporated into AES projects**
  - Baselined for AES avionics developments
  - **<u>Infusing DTN into the Iris transponder provides DTN functionality to all AES CubeSats on EM-1 with *no recurring cost* to each mission</u>**
  - Morehead State antenna 21m upgrade and Lunar IceCube MOC will include a DTN node

(1) Lunar Flashlight (JPL)
(2) Near Earth Asteroid Scout (MSFC)
(3) BioSentinel (Ames)
(4) Lunar-HMap (Arizona State)
(5) Lunar IceCube (Morehead State)
(6) CubeSat Solar Particle Satellite (GSFC)

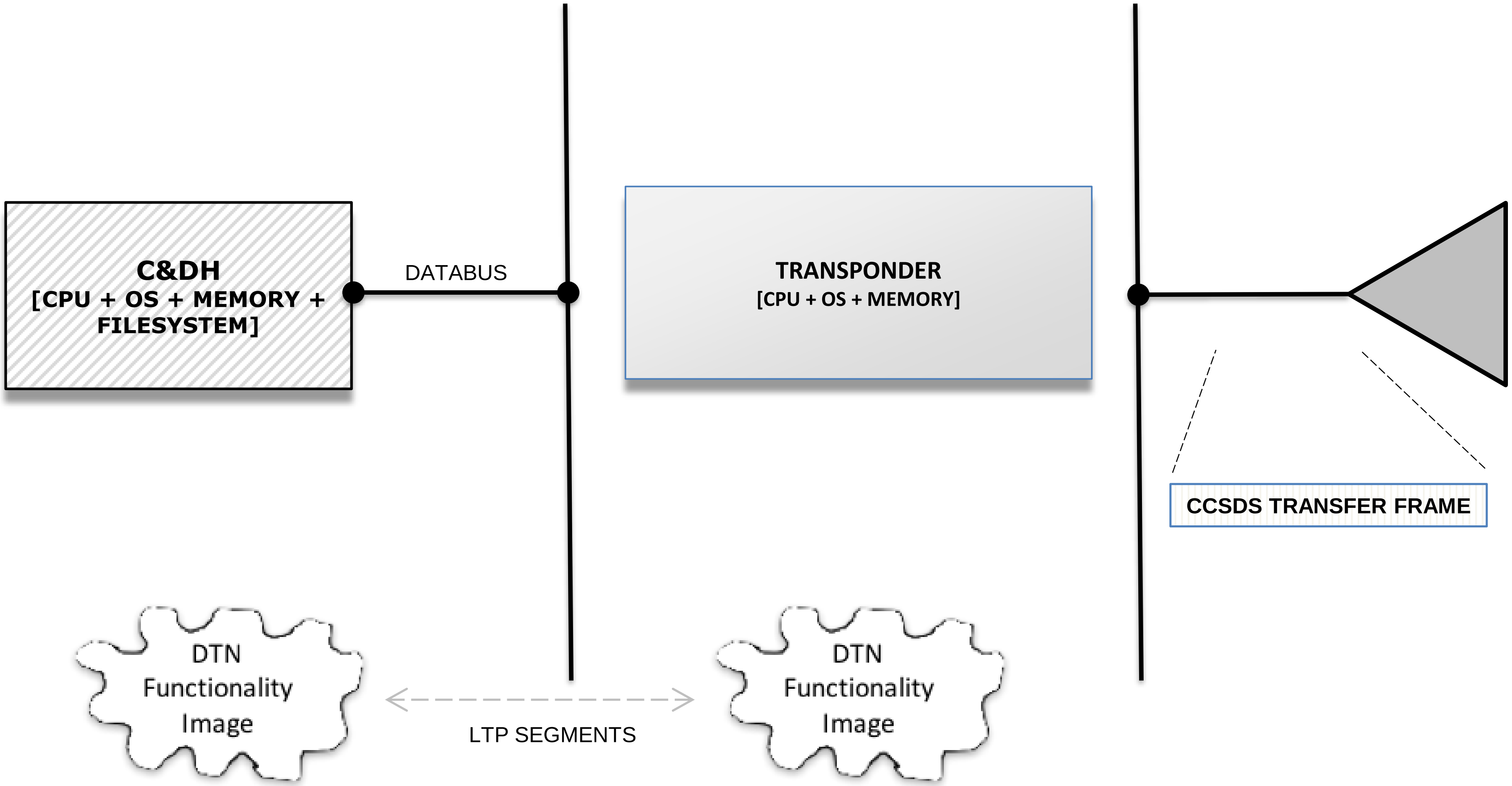


MSU DTN node will become integrated into the DSN Service as it comes online and can be operated as a standalone capability.

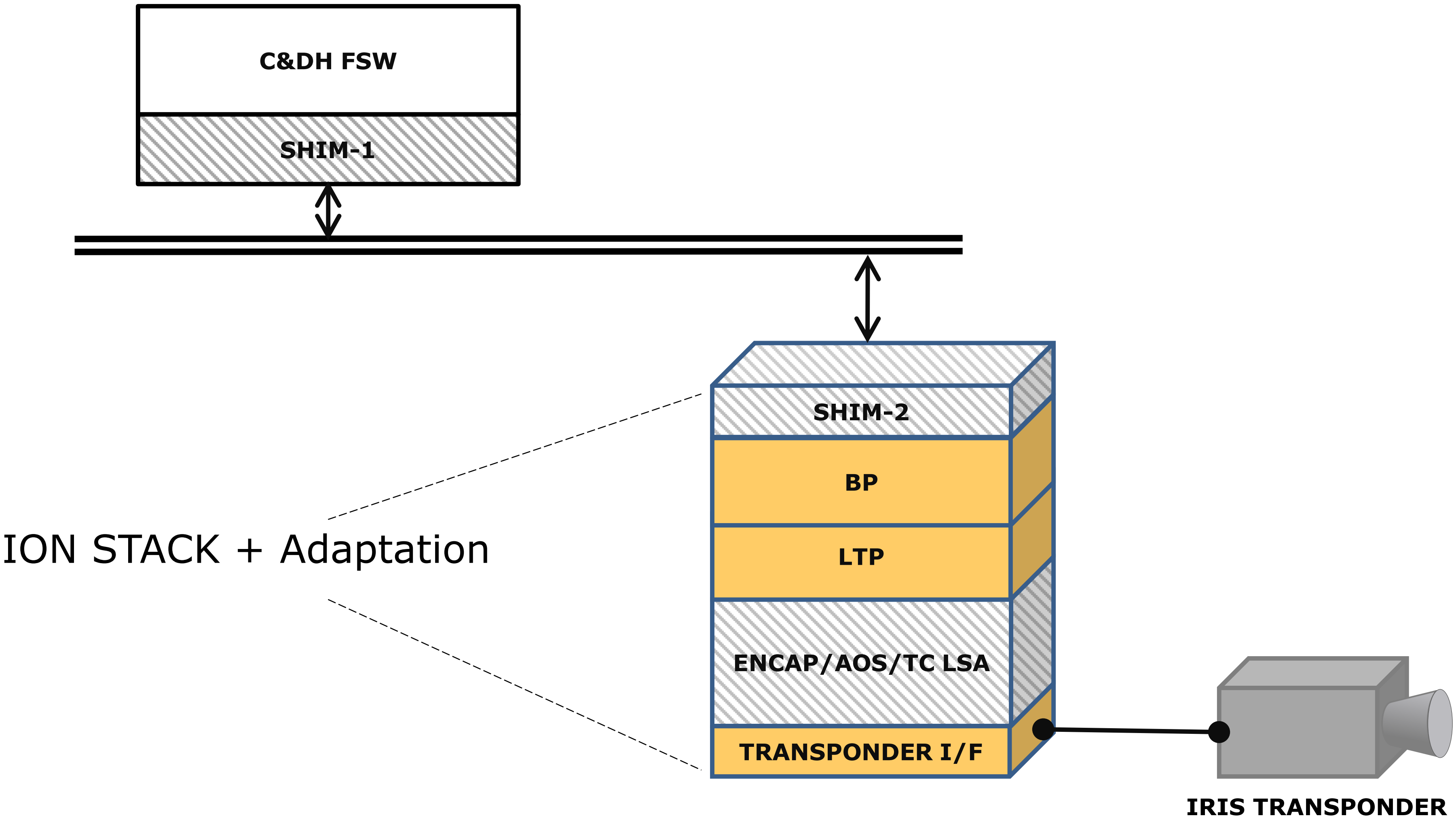
Constraints on DTN implementations for space

	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.

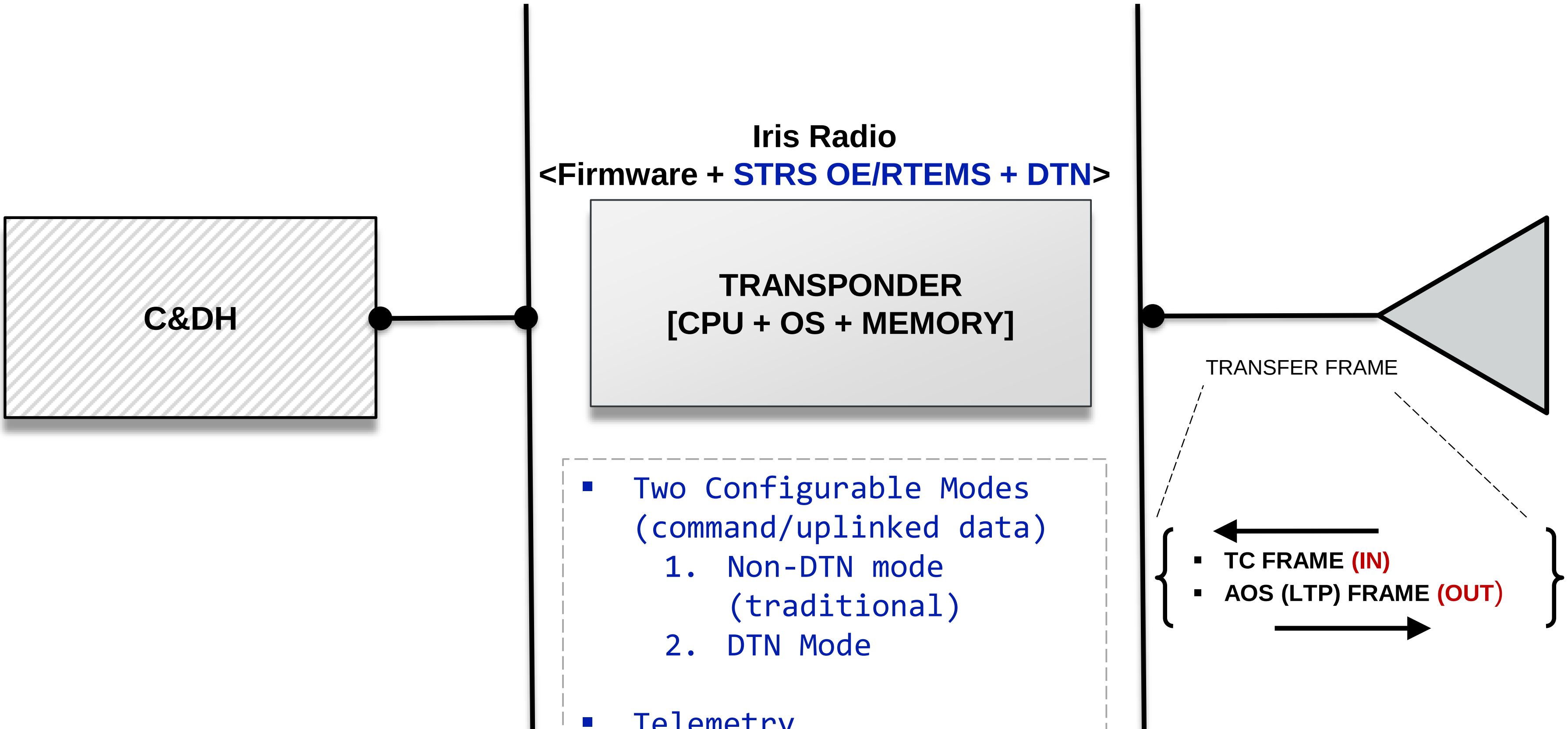
DTN-Iris Architecture



DTN-Iris Architecture



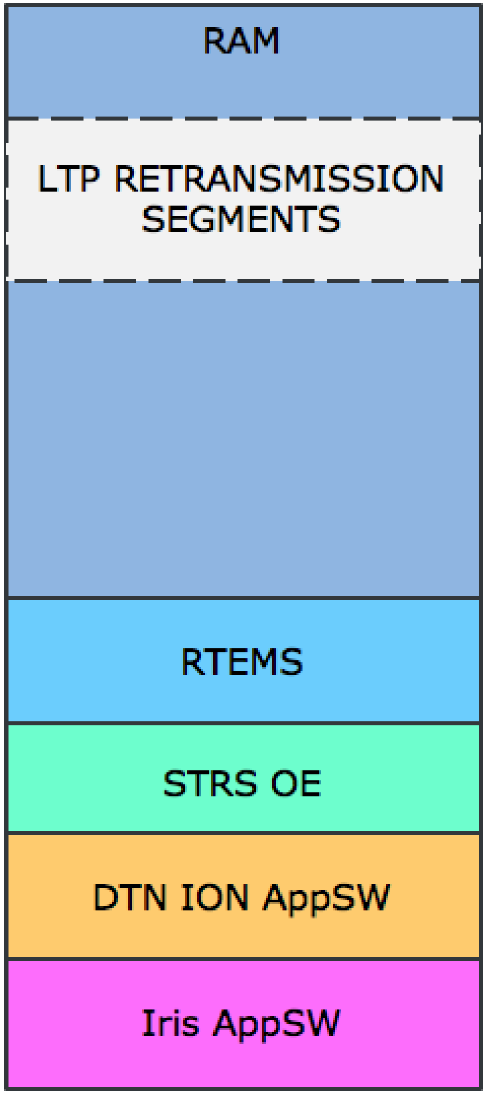
DTN-Iris Architecture



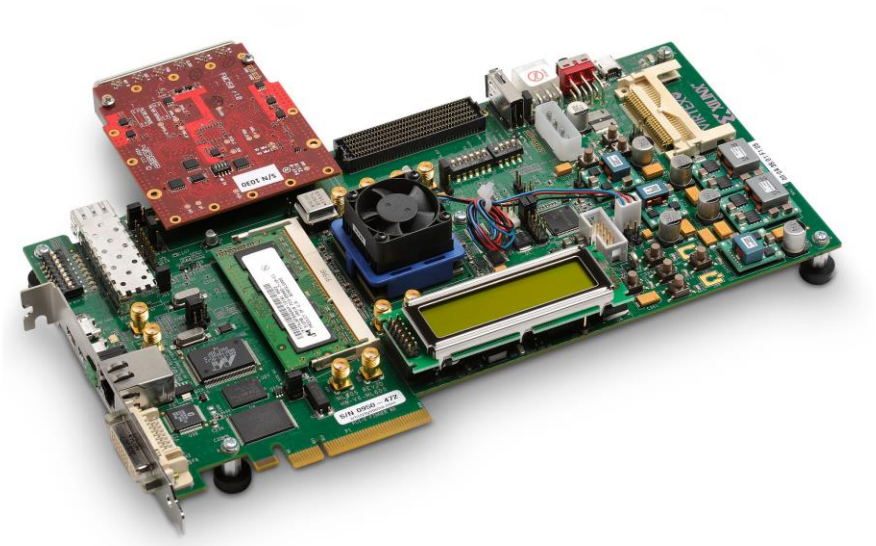
- Two Configurable Modes (command/uplinked data)
  1. Non-DTN mode (traditional)
  2. DTN Mode
- Telemetry
  - Traditional TM frames (Non-DTN)
  - DTN PDUs encapsulated in AOS frames.

Iris Resource Usage and Margins

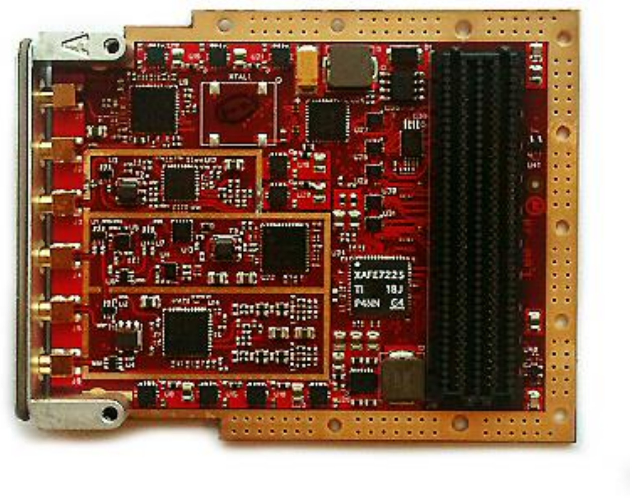
Use 5% of RAM for LTP segment storage



Design – Key Tools



Xilinx ML605



4DSP/Abaco FMC30RF

USRP 2900

Requirements

PERFORMANCE METRIC	REQUIREMENT/AVAILABLE RESOURCES	GOAL	PLAN FOR VALIDATION
CPU Loading	> 50% CPU Max usage		Analysis based on DHFR from memory through RTEMS to spacewire to the spacecraft host at several megabits/second, and we’re not using all the processor
Real-time performance requirement for frame extraction	Capable of generating 256kbps	Generate no more than N fill frames.	Test
Meet Storage requirement for LTP retransmission due to lunar round-trip acknowledgement time	~ 90 AOS Frames after 3 seconds	Allocate storage necessary for LTP segments.	Test

Requirements

PERFORMANCE METRIC	REQUIREMENT/ AVAILABLE RESOURCES	GOAL		ESTIMATE/MAR GIN	PLAN FOR VALIDATION
Software Images Size for entire software image (ION/STRS-OE/ RTEMS)	XXXXX	XXXXX	XXXXX	XXXXX	Test
In-Memory Margin (Heap, Data, Storage)	XXXXX	XXXXX	XXXXX	XXXXX	Test

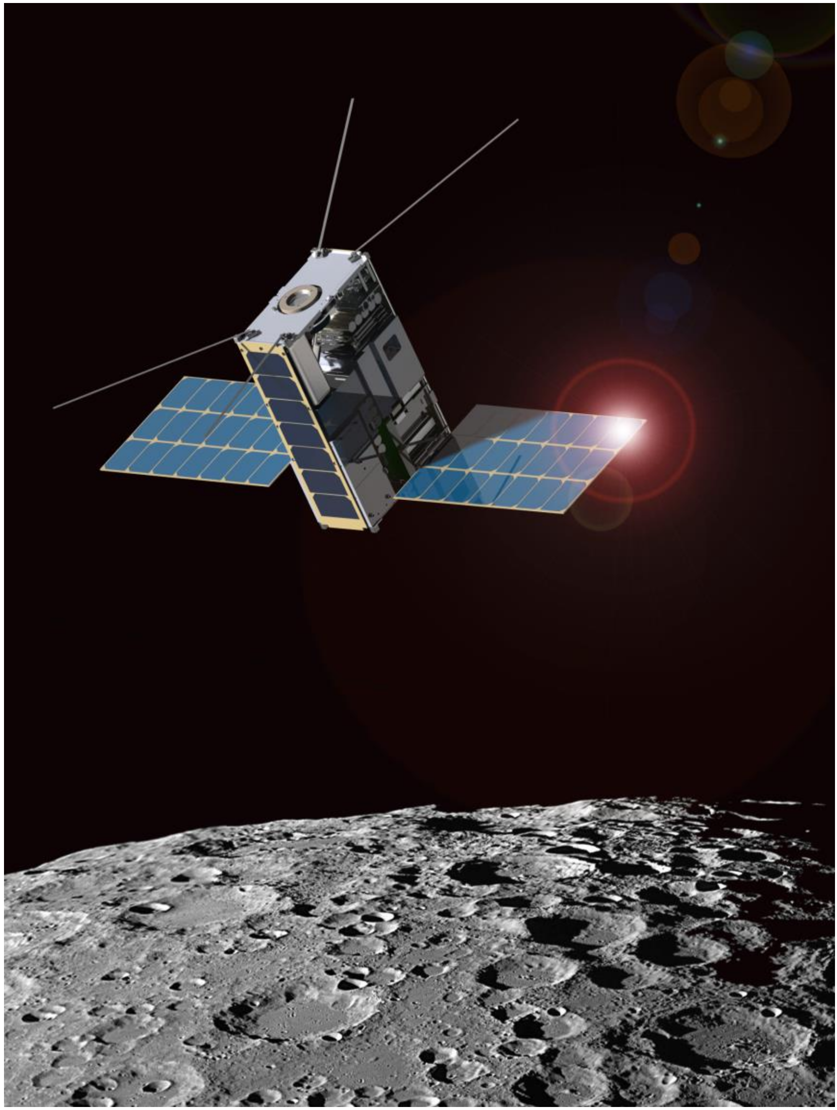
Candidate Mission

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

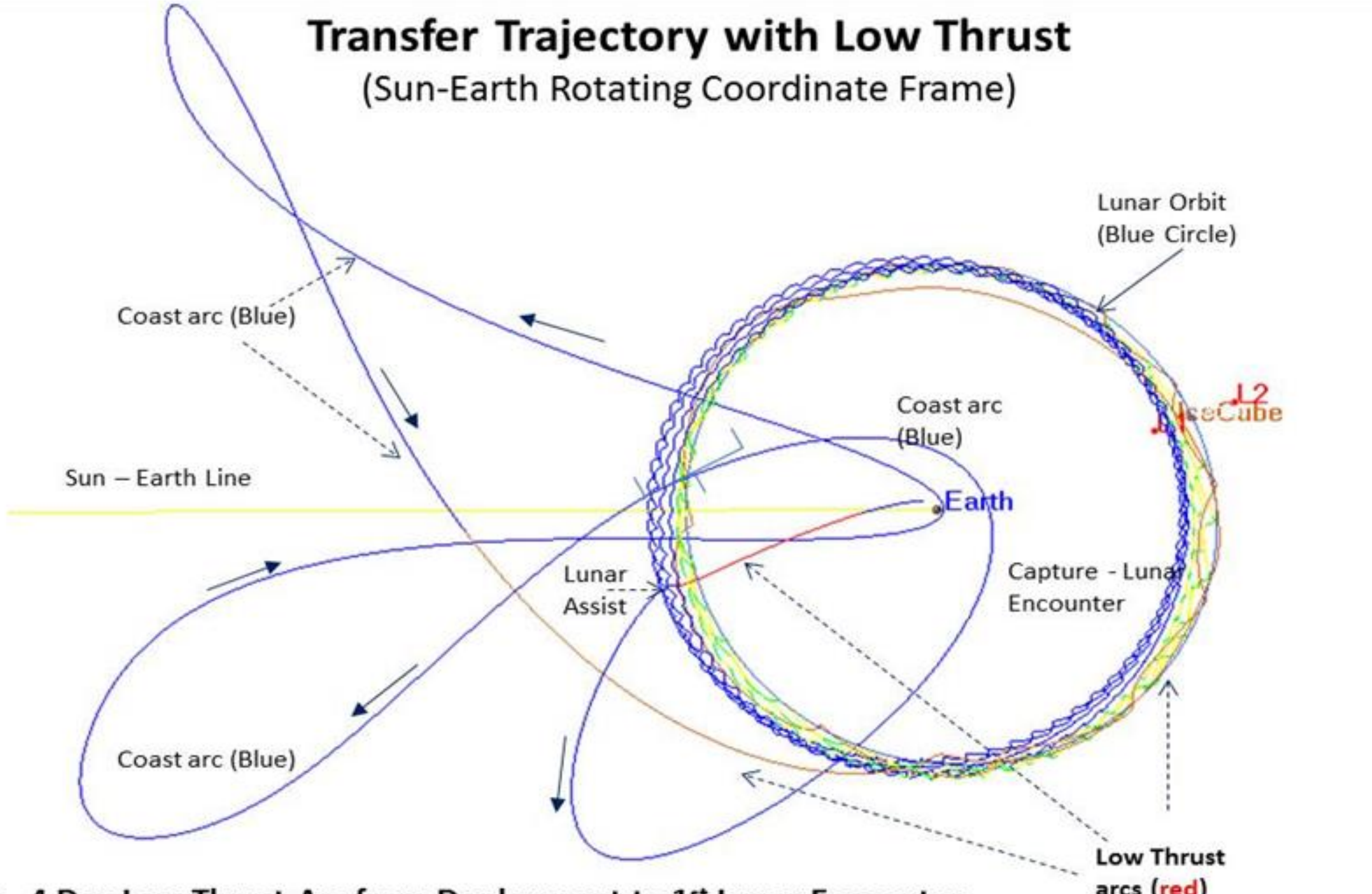
Morehead State University Age of Deep-Space Exploration with CubeSats Heralded In what scientists say signals a paradigm shift in interplanetary science, NASA has selected a shoebox-size mission to search for water ice and other resources from above the surface of the moon.

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



Mission Profile

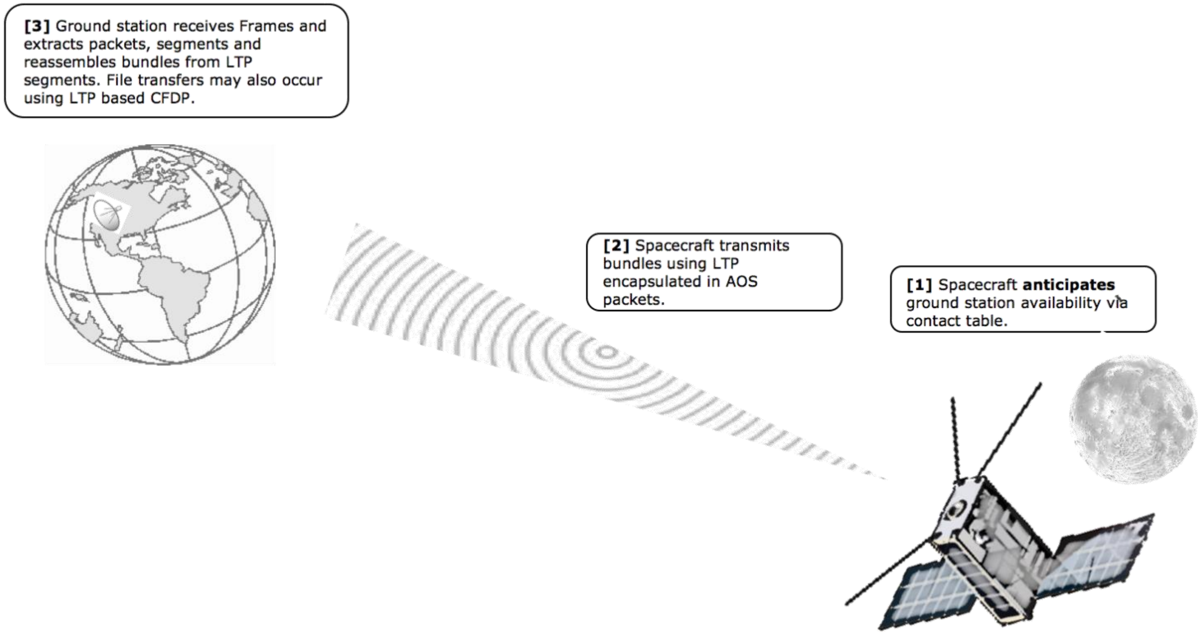


- 4 Day Low Thrust Arc from Deployment to 1st Lunar Encounter
- 59 Day Low Thrust Arc before Lunar Capture

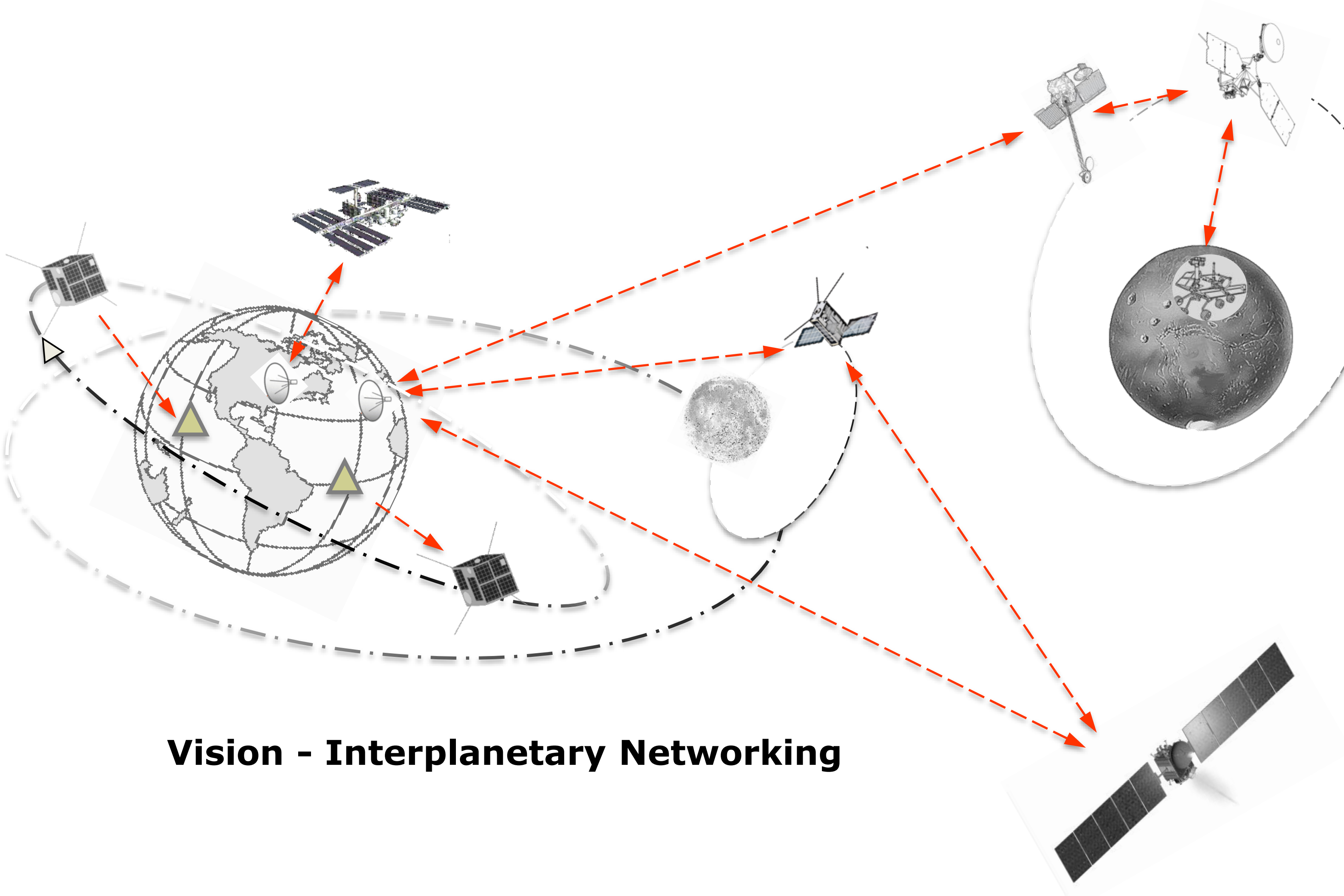
Conclusion

- By combining DTN technology with CubeSats, scientists will be able to create dynamic bi-directional networks that can be used to monitor and control remote assets in deep space.

- The Iris transponder is a novel development and will allow for the creation of a first-of-a-kind network in space that will provide a capability set for future NASA deep space missions, where networking will be a requirement.



Conclusion



Vision - Interplanetary Networking

BACKUP

Iris Specifications

Iris V2

General Specifications	
Network Compatibility	DSN[1], NEN[3], SN[3]
Redundancy	Single string
Design Lifetime	3 years
Frequency Bands	X-band[1], UHF receive[1], Ka-[3], S-[2], UHF transmit[3]
Envelope	104 x 118.5 x 65 mm
LNA Envelope	75.5 x 43 x 13 mm
SSPA Envelope	87.5 x 43 x 23 mm
Flight Operating Temperature	–20 to +50°C
Solid State Power Amplifier	3 RF paths, dedicated to 3 antennas, path selectable via power switching
Low Noise Receive Amplifier	3 RF paths, dedicated to 3 antennas, path selectable via power switching
VCO	Internal TCXO[1], external 10 MHz[3]
TCXO Allan Deviation	10^{-9} at 1 sec (non-coherent operation)
Ranging Delay Variation	< ±30 nsec
Telemetry Symbol Rates (downlink)	62.5 bps[1], 125[2], 250[1], 500[2], 1 k[1], 2 k[2], 4 k[1] 8 k[1], 16 k[1], 32 k[2], 64 k[1], 128 k[2], 256 k[1], 512 k[3] 1.024 M[3], 2.048 M[3], 4.046 M[3], 8.192 M[3], semaphores — (< 62.5 bps)[3], Other arbitrary rates[4]
Subcarriers, Downlink	25 kHz[1] 281.25 kHz[1] Arbitrary subcarriers to 10 MHz[4] Direct carrier modulation[2]

Iris Specifications

FPGA	Virtex 6 (–130[2], –240[3])
CPU	Gaisler LEON3-FT softcore (on Virtex 6)
Memory	32 Mbit non-volatile NOR-Flash (radiation tolerant) 16 Mbit volatile SRAM (radiation tolerant) 4 Mbit volatile EDAC SRAM (radiation tolerant)
Interface	Point-to-point SPI
Launch Capability	Non-operational at launch
Radiation, SEE Levels (100 mil (Al))	LET >37 MeV–cm^2/mg (Virtex 6), 20 krad (ELDRS to 5 krad)
Telemetry Encoder	Firmware encoder
Command Detector	Firmware decode with FireCode (spacecraft reset direct command)
Mounting	CubeSat stack in chassis with separate SSPA and LNA modules
Carrier Loop BW	Configurable (20 Hz typical)
Command uplink rates (bps)	62.5[1] PM/PSK/NRZ 125[2] 250[2] 500[2] 1000[1] 2000[2] 4000[2] 8000[1] Arbitrary rates[4]
Command uplink subcarriers	16 kHz[1] Arbitrary subcarriers[4] Direct Carrier modulation[2]
Command/Telemetry Interface	Command and Telemetry Dictionary[1], configurable[4]

[1]Compatibility verified in Version 1 and/or Version 2.
[2]Compatibility supported in Version 2 but not yet verified.
[3]Capability under development or planned.
[4]Capability supportable due to software/firmware reconfigurability.