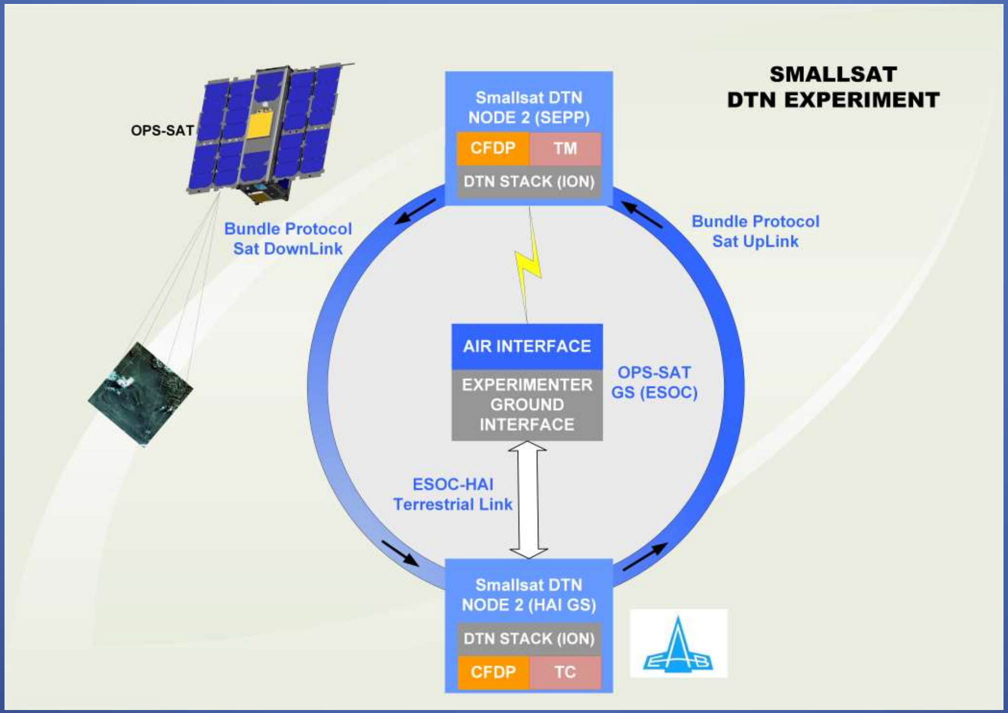
Smallsat DTN
ESA OSIP project for OPS-SAT campaign



27-04-2023

PRESENTATION OUTLINE

- Introduction
- Project Objectives
- System Architecture
- Ground Testing
- Flight Demo Scenarios & Results

Introduction

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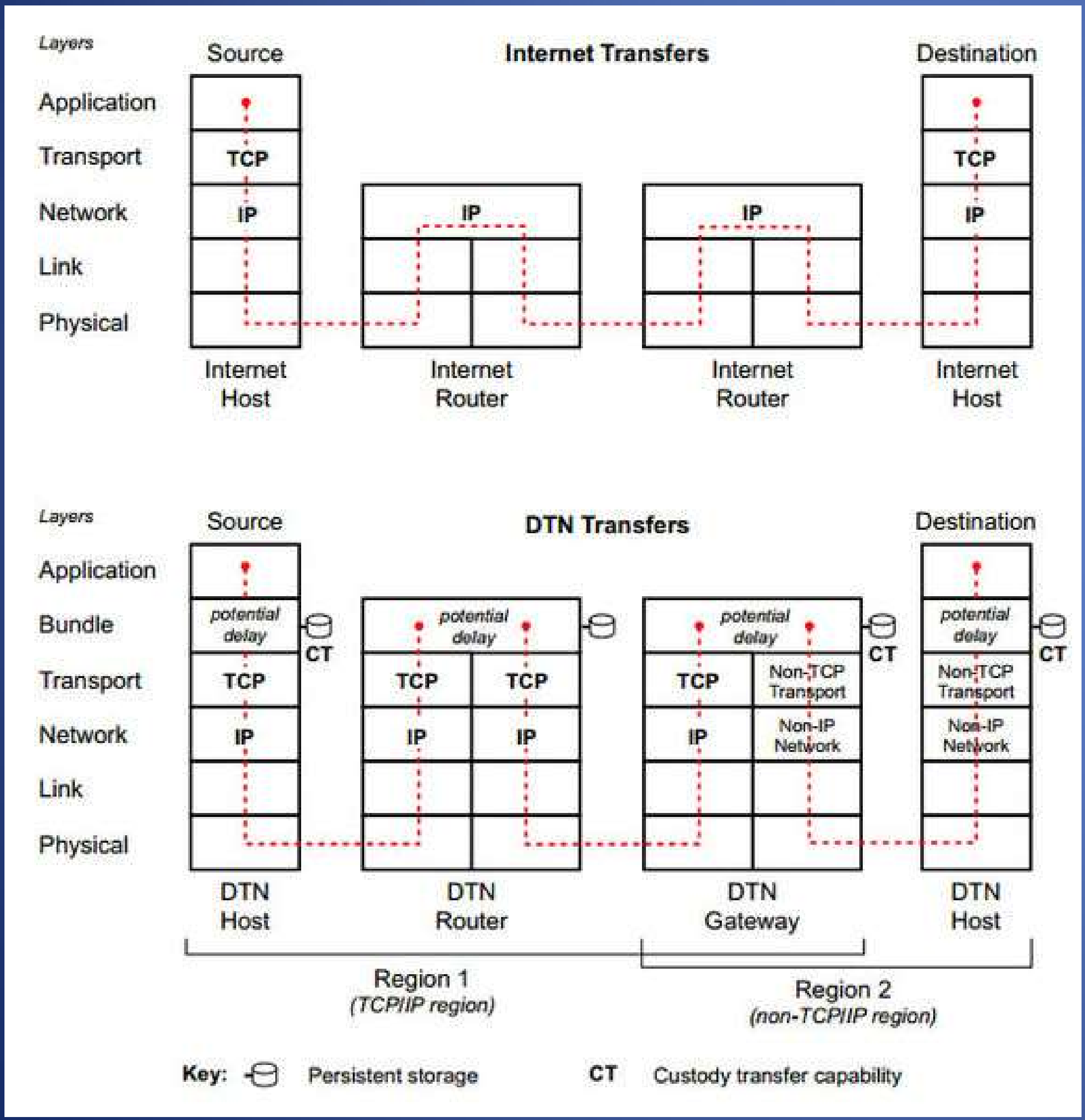
DTN Networking Overview – Bundle Protocol



SPACE ENVIRONMENT

- Potentially Long Delays
- Frequent Disruptions
- Highly Asymmetric Links
- Links maybe unidirectional
- High Error Rates

DTN ARCHITECTURE

- Overlay Network
- Store & Forward
- Retransmission schemes(Custody Transfer, LTP)

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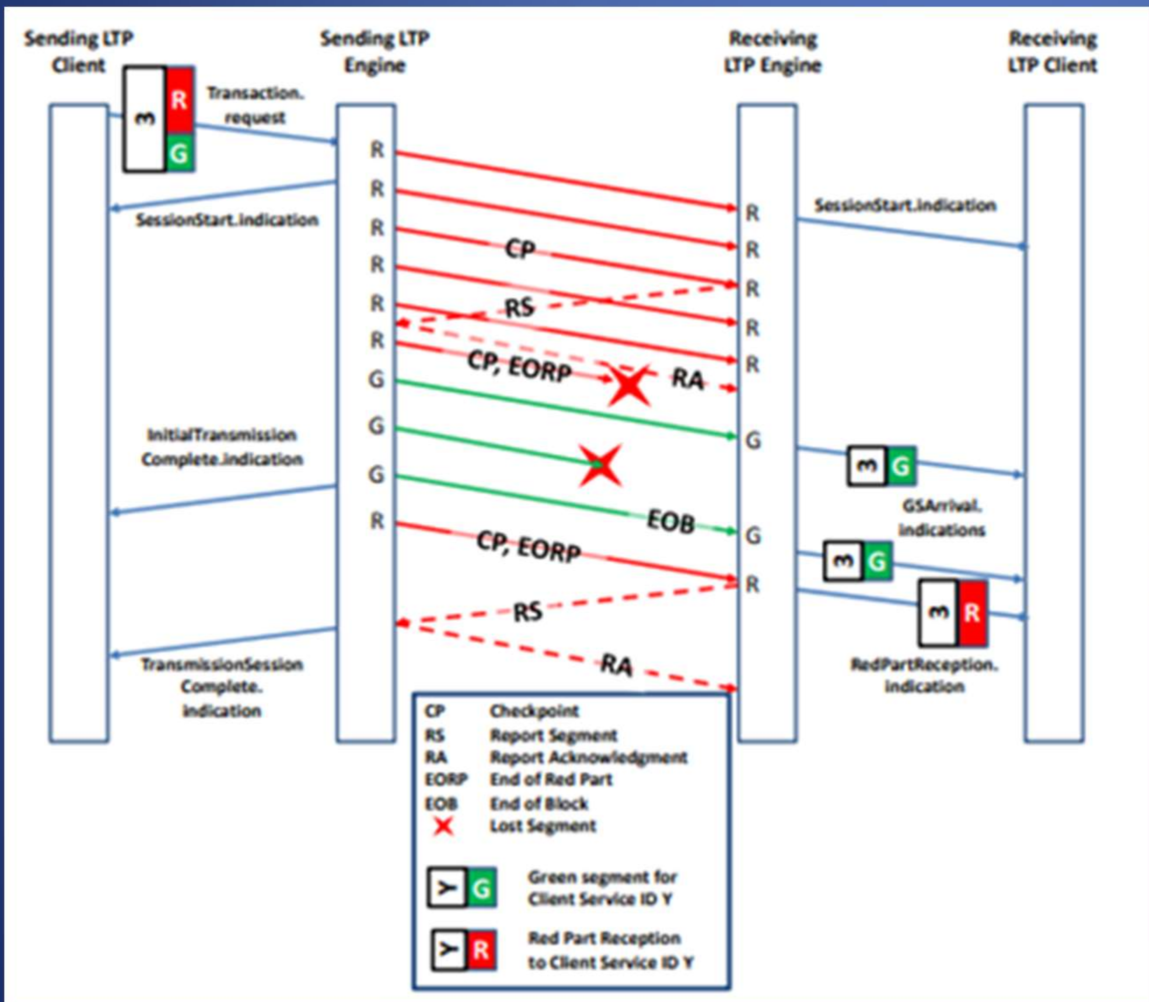
DTN Networking Overview – Convergence Layers



Convergence Layers

- Encapsulate Bundle Protocol over IP and non-IP networks
- Example CL in ION DTN
    - TCP (BP over TCP)
    - UDP (BP over UDP)
    - LTP over UDP (BP over LTP over UDP)

LTP CL

- Bundles -> LTP Blocks -> LTP Segments
- Red part (acknowledged transmission)
- Green Part (un-acknowledged transmission)

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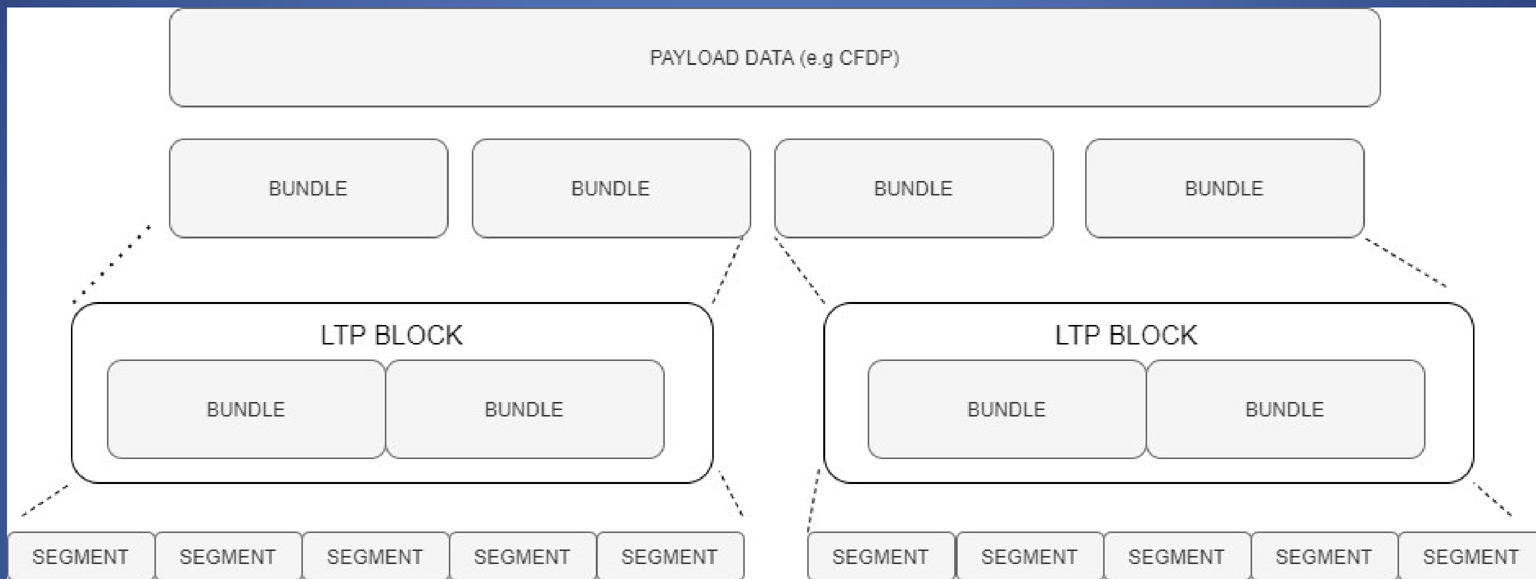
DTN Networking Overview – CFDP over BP/LTP



CFDP Service Classes

- Class I : Unreliable Transfers
- Class II : Reliable Transfers

ION CFDP Implementation (CFDP over BP)

- Class I
- Reliability (retransmission scheme) offered by Convergence Layer, e.g. LTP Red Part

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ION DTN - CFDP, BP, LTP

- ION DTN software distribution is an implementation of Delay Tolerant Networking architecture as described in RFC 4838 (Store and Forward Architecture, EIDs , URIs, priorities)
- Implements Bundle protocol (BP) v6 (RFC 5050) and in latest version BP v7(RFC 9171)
- Implements LTP (RFC 5326) over UDP as a Convergence Layer and
- CFDP Class1 ([RD-3]) over Bundle Protocol.

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OPS-SAT

OPS-SAT is ESA's flying laboratory, the first of its kind, with the sole purpose of testing and validating new techniques in mission control and on-board satellite systems. ESA has allowed entities(companies, universities) throughout Europe to submit experiments involving OPS-SAT.

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Objectives & Architecture

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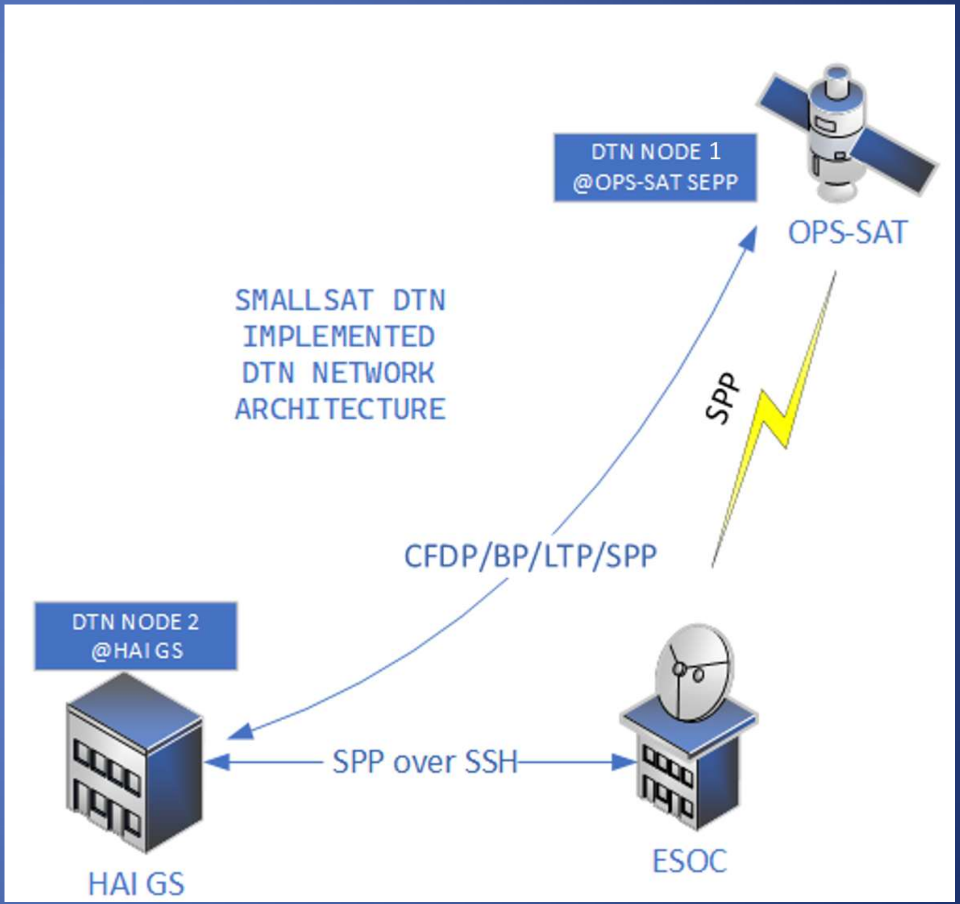
Smallsat DTN High-Level Architecture

- Two node network.
  - Node 1 on OPS-SAT
  - Node 2 on Ground Segment

- Simple Topology (but matches OPS-SAT architecture)

- Permits the investigation of a number of interesting DTN Flight Scenarios



Smallsat DTN High Level Objectives (I)

Implement a DTN network on OPS-SAT (Space – GS) to demonstrate:

- Data Distribution using ION CFDP over BP/LTP
- Tolerance of DTN network in small and large disruptions of challenging Satellite RF Link
- Satellite (DTN Network) and Payload (OPS-SAT camera) operations and automation over BP + CFDP
- Continuous operations of a DTN network in real operational environment.
- Mix of BP & SPP based TC/TM for reliable, continuous operations, of DTN Network

Smallsat DTN High Level Objectives (II)

The following additional objectives complemented the original project ones, after discussions with ESA DTN Team. The additional objectives were inspired by OPS-SAT 2 mission objectives:

- Disruption in Optical Communications (Cloud Coverage & Complete miss of a pass)
- Variable Data Rates (VDR) on downlink
- New generation Consultative Committee for Space Data Systems (CCSDS) protocol stack (DTN)

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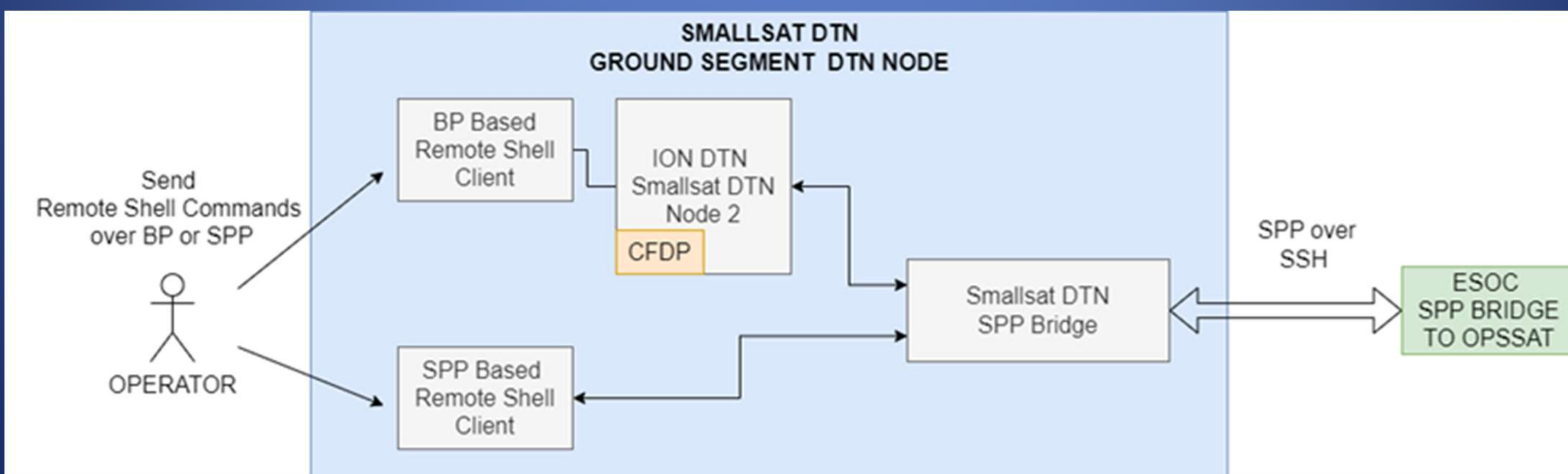
Smallsat DTN System Architecture (I)– Ground Segment

Smallsat DTN GS

- Implements ION DTN Node 2 with LTP CL to ION DTN Node 1 on OPS-SAT
- Support CFDP Class I File transfers over BP/LTP using ION implementation
- SEPP Remote Operations over BP (BP Remote Shell Client)
- SEPP Remote operations over SPP (SPP Remote Shell Client)



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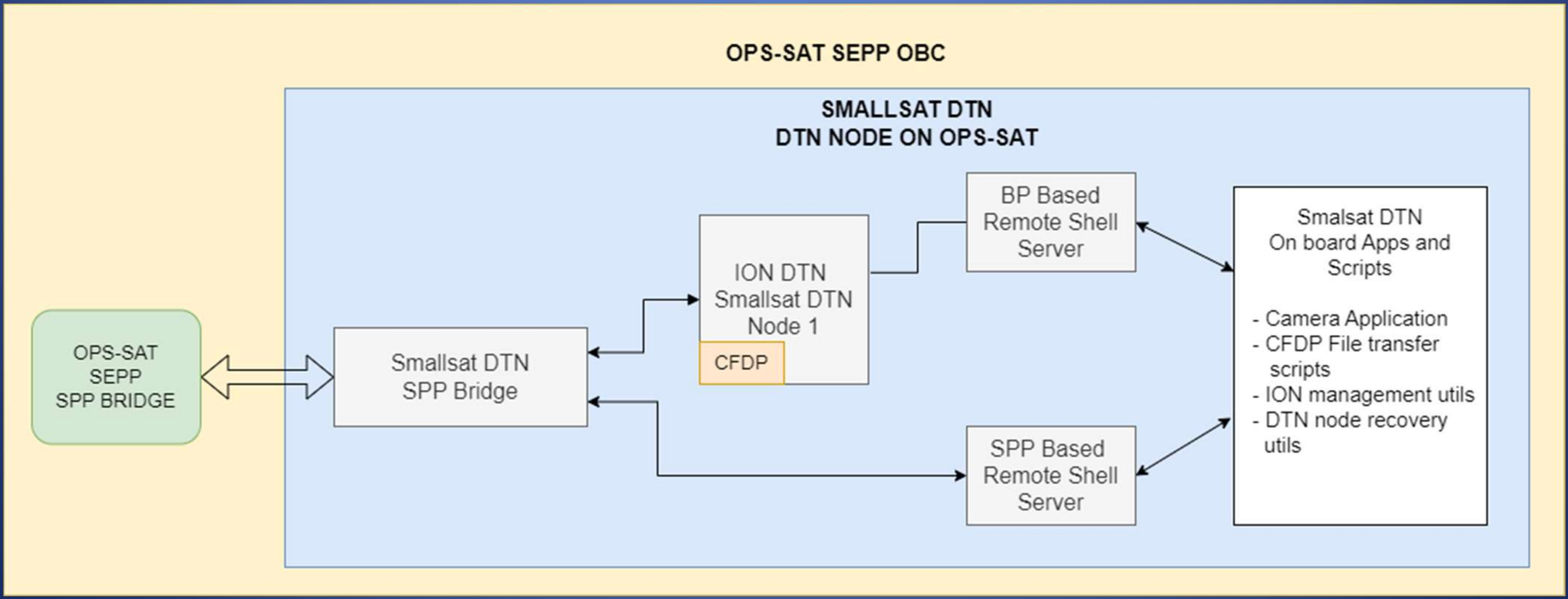
Smallsat DTN System Architecture (II) – Space Segment

Smallsat DTN Space Segment

- Implements ION DTN Node 1 with LTP CL to ION DTN Node 2 on HAI GS
- Support CFDP Class I File transfers over BP (and LTP) using ION implementation
- SEPP Remote Operations over BP (BP Remote Shell Server)
- SEPP Remote Operations over BP (SPP Remote Shell Server)
- Smallsat DTN On Board Apps and Scripts



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Ground Testing

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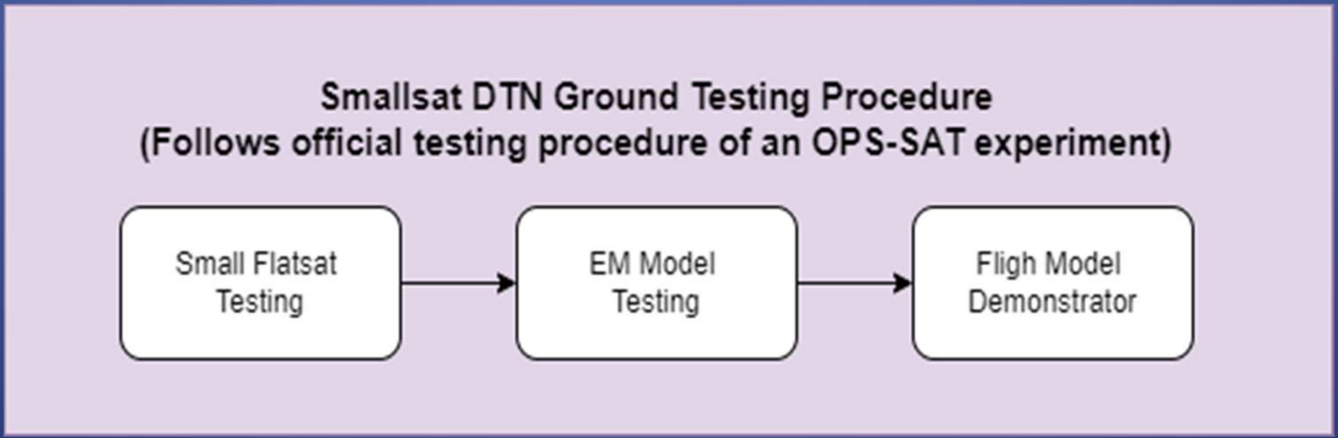
Smallsat DTN Ground Tests

OPS-SAT Ground Testing Facilities

- **Small Flat-Sat:** Simplified model of OPS-SAT (based around OPS-SAT SEPP computer)
- **Engineering Model:** A (almost) Complete Duplicate of Flying OPS-SAT

Smallsat DTN Ground Tests

- **Phase 1 (Small Flat-Sat):** Performed 5 test session on Small Flat-sat for functional testing
- **Phase 2 (EM):** Performed 5 test sessions on Engineering Model of OPS-SAT for final tuning and pre-flight tests



Smallsat DTN Flight Demo

(Five Demonstration Scenarios)

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Smallsat DTN Flight Demo - Scenario 1
CFDP File transfer – BP automation

Scenario Objectives

- Sent command over BP Shell from Ground, to capture 8 images from OPS-SAT camera and download Images via CFDP automatically over multiple passes
- Start CFDP upload of a large file form GS to OPS-SAT. Expect to complete over multiple passes

Scenario Results

- 4 of the 8 images captured, downloaded completely via ION CFDP during available passes.
- The multi-pass CFDP upload, did not manage to finish during the available passes. Post analysis showed that the largest part of the file was uploaded.
- Demonstrated CFDP file transfer automation and BP automation operation (decoupling TM/TC generation and transmission from satellite pass times)

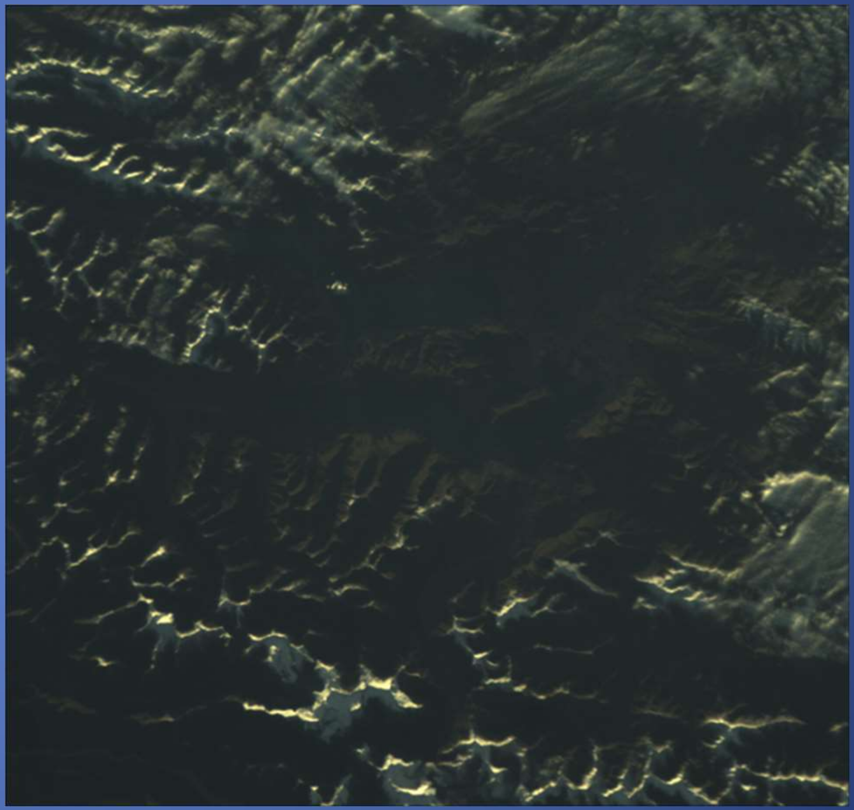

Image of Mountains in New Zealand. Captured via remote command (over BP) from Smallsat DTN GS. Downloaded over Multiple Passes (5, 6, 7, 8, 9) automatically via CFDP/BP/LTP. The CFDP file transfer survived, RF link interruptions, a complete miss of a pass (pass Nr. 7), unattended passes (5, 6) and Variable Data Rates scenario on pass 8.

Smallsat DTN Flight Demo - Scenario 2.

Optical link blockage due to cloud coverage in part of a pass (OPS-SAT 2 scenario)

Scenario Objectives

- Emulate cloud blockage of satellite link for several seconds, by breaking the connection of project to ESOC for 1 Minute.
- Verify that on-going CFDP file transfers survive link loss

Scenario Results

- The emulation of scenario was more realistic, since there is an orientation of the GS antenna, where the signal is actually blocked by a near-by obstacle.
- CFDP file transfers survived link loss of this scenario. (See image of previous slide)

Smallsat DTN Flight Demo –Scenario 3.

Full miss of a pass in space-to-ground optical links (OPS-SAT 2 scenario)

Scenario Objectives

- Emulate complete miss of a pass, by breaking the connection of Smallsat DTN GS to ESOC for the complete duration of a pass.
- Verify that on-going CFDP file transfers survive the unexpected complete miss of a pass.

Scenario Results

- The emulation of scenario was more realistic and we did not need to brake the ground connection to ESOC since, in pass Nr. 7 RF link could not be established with the satellite and the complete pass was missed.
- CFDP file transfers survived the complete miss of this pass (See comments on downloaded image of first scenario).
- No reconfiguration of DTN network was performed to handle the unexpected event.

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Smallsat DTN Flight Demo –Scenario 4.

Variable Data Rates during a pass (OPS-SAT 2 scenario)

Scenario Objectives

- Send commands from Smallsat DTN Ground Segment, to modify (on the fly and in real-time), the preconfigured LTP Link TX rate of the DTN node on Satellite, while there are active CFDP File Transfers
- Verify the change of changed data rates on Ground Segment.

Scenario Results

- During the 8th pass of the demonstrator, in parallel to active CFDP uploads and downloads, the transmission rate of ION DTN on spacecraft, was remotely modified on the fly three times with commands sent from the ground segment.

- The remote configuration was applied successfully and the modification of data rate on the downlink was immediately visible in the real time TM/TC console of Smallsat DTN Ground Segment.

- CFDP File Transfers Continued normally during changes of TX speed

Smallsat DTN Flight Demo –Scenario 5.

Continuous operation and remote configuration of the DTN network

Scenario Objectives

- Operate a live LEO DTN network in a continuous way
- This scenario is practically part of all other scenario since most of the operations were performed over BP (CFDP File transfers, VDR scenario).
- One special operation in an ION DTN network, is the update of ION's contact plan of its nodes. The plan was to send this update at the last contact and verify that the new configuration is applied at the satellite.
- Implement procedures to recover functionality in case of errors.

Scenario Results

- New contact plans were uploaded with CFDP at the 3rd and 4th pass.
- Failing to upload contact plan at the 4th pass meant that DTN LTP connectivity would be lost, due to an unconfigured (regarding future contacts) DTN node on Space Segment
- New contacts fortunately were applied with commands sent from GS at 4th pass.
- Recovery procedures have been developed to overcome the failure of updating the contact plan in time.
- The recovery procedures were not needed during Flight Demo, but were demonstrated successfully during ground tests.

Smallsat DTN Flight Demo – Conclusions I

- The scope of this project covered many DTN operational scenarios and its original goals were accomplished.

- Benefits of DTN and CFDP concepts (reliability, tolerance in disruptions, network automation, reliable multi-pass file transfers) were demonstrated in an operational environment.

- Three DTN scenarios relevant to a future ESA mission (OPS-SAT 2) were demonstrated

- Bumped into a limitation of the ION CFDP implementation. ION CFDP sometimes, may not complete file transfers, in the case of late arrival of CFDP metadata. ION Development team was contacted and used workarounds based on their suggestions.

- Bundle traffic priorities did not work well during parallel CFDP traffic and high priority bundles experienced large delays, making "real-time" operations over BP difficult. As a workaround the SPP based shell was used in these cases.

- Some useful tools are missing from the ION distribution, e.g. a monitoring tool to show status of CFDP file transfers.

Smallsat DTN Flight Demo – Conclusions II

- One thing that its value became obvious is the combination of Linux + ION on space hardware. Practically in this project ION provided BP, LTP and CFDP and Linux provided everything else.

- ION proved to be an invaluable implementation of the DTN architecture even offering concepts like the support of Variable Bit Rates. ION proved also light on resource usage (memory and CPU) since it is written in C.

- Smallsat DTN project operated, the Flight Demonstrator LEO DTN network, continuously for the duration of three days, handling the unexpected events of real operations (without restarting any of its software components in space or ground segment) and successfully completed the project's demonstration scenarios.

Smallsat DTN Flight Demo – Future Work

- As a next step following this demonstrator, Smallsat DTN team will Investigate the issues of ION CFDP and ION behavior of bundle priorities.

- There is also an ongoing common experiment on OPS-SAT with ESA DTN team. For this joint OPS-SAT experiment, there will be an upcoming demonstrator, where HAI will provide the ION node on OPS-SAT and ESA the DTN Node on ground segment, with its brand new ESA DTN implementation called DTNA. The goal of this demonstrator will be to showcase besides DTN concepts, interoperability between the used BP implementations.

- Smallsat DTN team plans to implement 'service point' DTN applications like MQTT bridges for ION DTN.

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Thank You