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OFF THE EARTH FOR THE EARTH

DTN Leads the International Space Station Payload Operation in Advanced Exploration

July 2016

INTERNATIONAL SPACE STATION

DTN on ISS is LIVE

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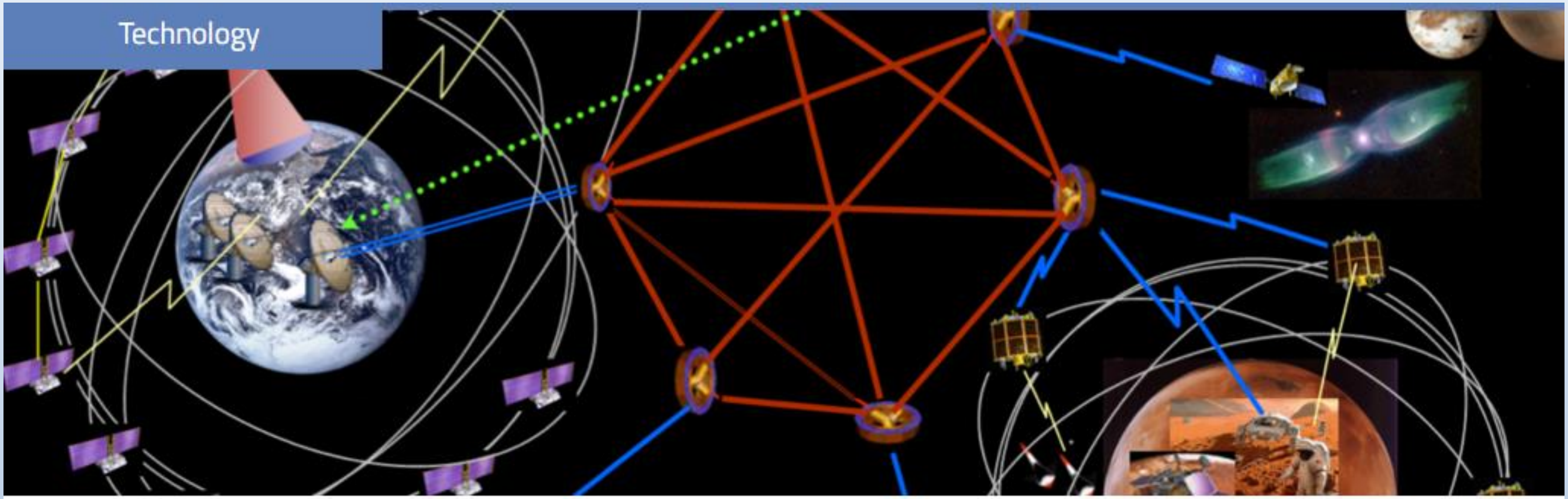
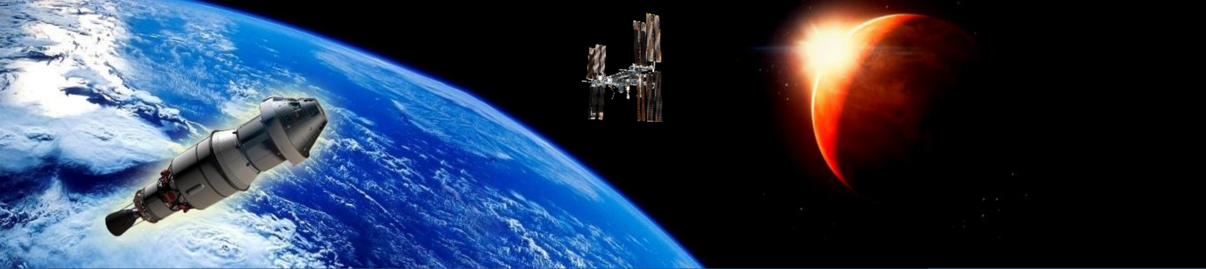


June 21, 2016

New Solar System Internet Technology Debuts on the International Space Station

This month, NASA took a major step toward creating a Solar System Internet by establishing operational Delay/Disruption Tolerant Networking (DTN) service on the International Space Station. The DTN service will help automate and improve data availability for space station experimenters and will result in more efficient bandwidth utilization and more data return.

https://www.nasa.gov/feature/new-solar-system-internet-technology-debuts-on-the-international-space-station



Use of ISS to Prepare for Exploration | Maturing Critical Systems

- Radiation Environment Monitor - (NASA) demonstration of first generation of operational active personal space radiation dosimeters
- Amine Swingbed - (NASA) provide for environmental control of the habitable volume for human-rated spacecraft by removing metabolically-produced carbon dioxide, and minimizing losses of ullage air and humidity
- Air Quality Monitor (AQM) – (NASA) volatile organic compound analyzer to be used to monitor the ISS environment
- **Disruption Tolerant Networking for Space Operations (DTN) - (NASA) *long-term, readily accessible communications test-bed, DTN is the comm. standard for future spacecraft***
- DOSIS-3D – (ESA) Determination of the radiation field parameters absorbed dose and dose equivalent inside the ISS with various active and passive radiation detector devices provided by ESA, JAXA and Russia. Aiming for a concise three dimensional dose distribution (3D) map of all the segments of the ISS.
- Exploration EVA Suit – (NASA) Could fly exploration suit as early as 2019. Will demonstrate and mature suit on ISS prior to use beyond LEO
- NASA Docking System - (NASA) Based on International specs agreed to by partners for exploration ISS will utilize and mature the system on ISS starting in 2015 with arrival of passive port.

ISS Institutional DTN

ISS DTN Project provides the following:

- ISS Disruption Tolerant Networking (DTN) Architecture for flight, ground, and test/simulation systems (includes MSFC-HOSC, MCC-H, and SCTF/SDIL)
- Increased reliability of payload data transfers between ISS and remote payload control centers during communication outages
    - MSFC-HOSC, MCC-H, and ISS DTN nodes will store user file uplinks/downlinks and forward bundles as Ku-band becomes available
- Increased automation of Payload Developer (PD) requests for data transfers
    - Reduce PD real-time support to access and downlink science data
    - Reduces need for duplicate storage and extra retrieval actions
- Mechanism to alleviate extensive support to plan payload transfers around loss of communications.
- Mechanism to use standard, publicly available protocols, avoiding the use of costly custom protocol implementations
- Opportunity to gain valuable experience using DTN, which is the expected communication protocol of choice for future space exploration

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Delay Tolerant Networking (DTN) Implementation on (JSL)

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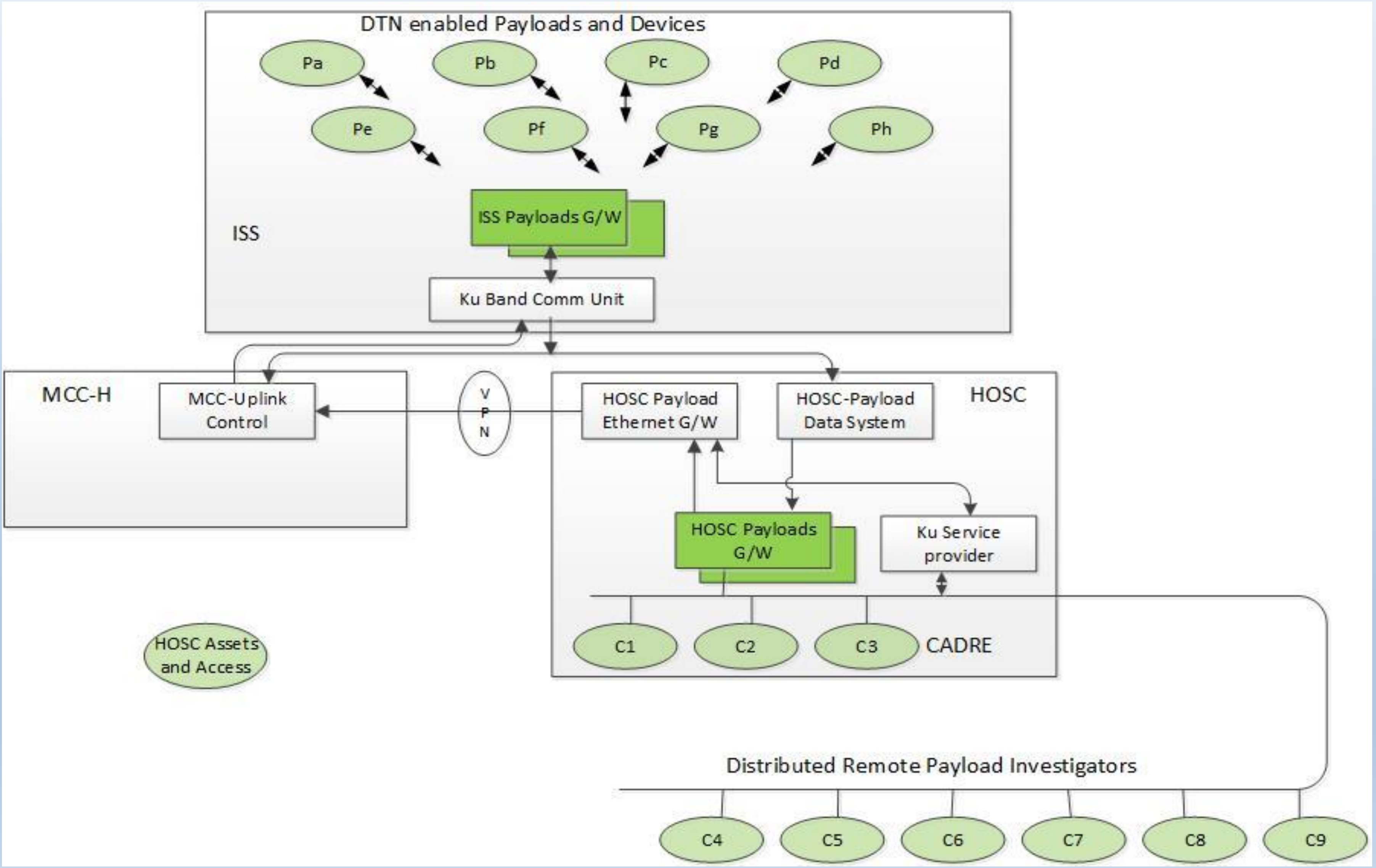

Testing Methodology

- Completed numerous successful engineering and integration tests
  - Nominal payload communication
  - Loss of communication
  - CFDP File Transfers
  - Characterization Testing
- Environment
  - WAN emulator used to simulate ISS 600 ms RT delay
  - Nominal Downlink: 20 Mbps LTP
  - Nominal Uplink: 4 Mbps LTP
  - Network outages simulated via modem power off on ISS Ku Communications Unit.
- Test tools:
  - Bping and Bpecho
  - Bpdriver and bpcounter
  - CFDPtest
  - TReK CFDP GUI and TReK CFDP Console

Testing Methodology

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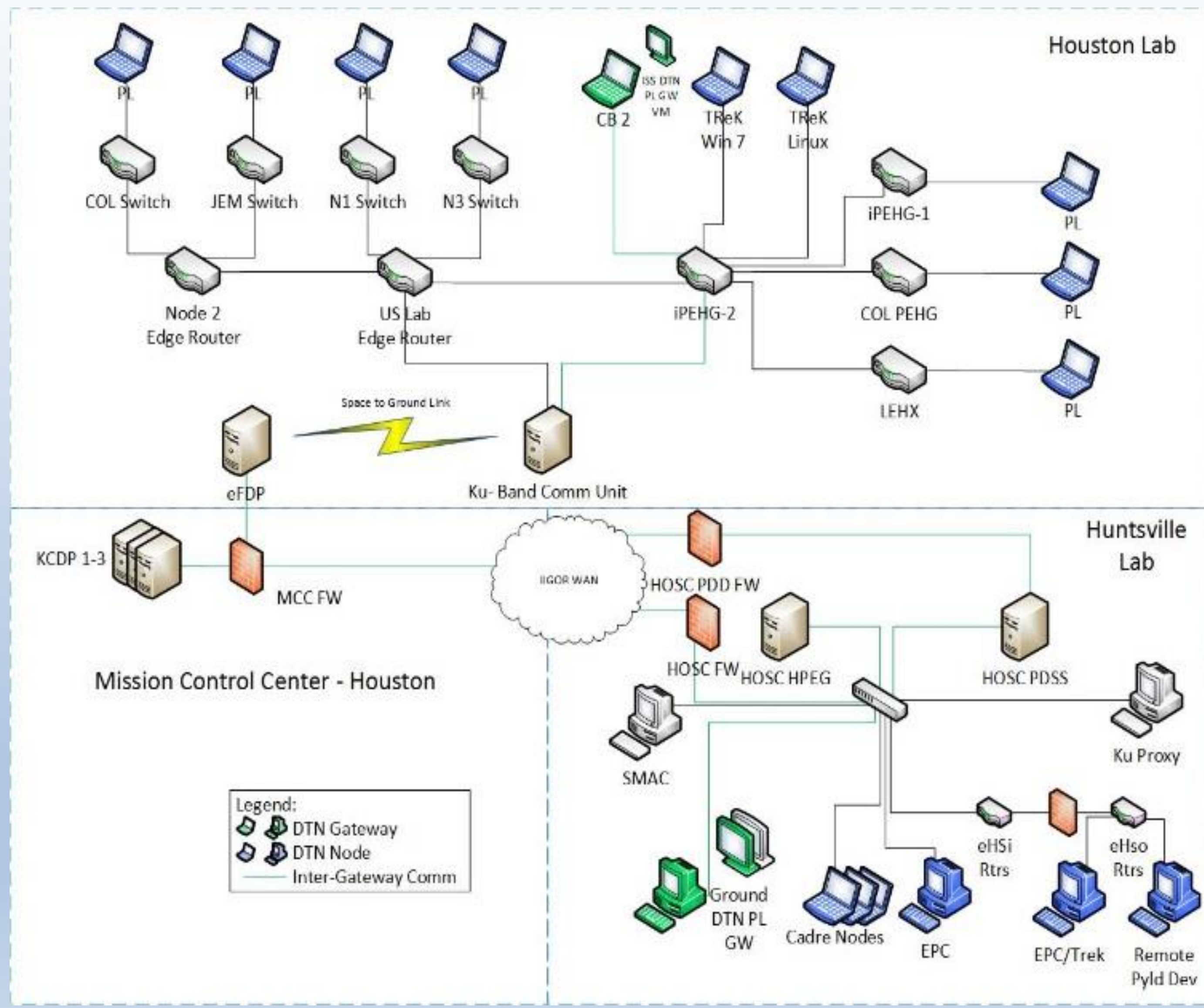

Nominal Payload Testing

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- First Test (Single Node)
  - Simple two node configuration using TReK Windows and Linux ISS nodes tested independently
  - 100kB bundle size x 1000 bundles = 100 MB per node

SOURCE NODE	DESTINATION NODE	DIRECTION	BUNDLES SENT	BUNDLES RECEIVED	TIME (sec)	TOTAL BYTES	THROUGHPUT (Mbps)	DATA SEGMENTS (Total/Rexmit)	REPORT SEGMENTS (Total/Rexmit)
TReK Win7	HOSC Cadre B	Downlink	500	500	23.987	50 MB	16.675	3501/0	501/0
TReK Linux	HOSC Cadre C	Downlink	500	500	24.165	50 MB	16.533	3501/0	501/0
HOSC Cadre B	TReK Win7	Uplink	500	500	100.792	50 MB	3.969	36002/0	502/0
HOSC Cadre C	TReK Linux	Uplink	500	500	100.811	50 MB	3.960	36003/0	501/0

- All bundles transferred successfully
- Downlink rates ~15 Mbps
- Uplink rates ~4Mbps
- Zero retransmissions

Nominal Payload Testing

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- Second Test (Multiple Node)
  - Six node configuration using TReK Windows/Linux and EXPRESS Laptop nodes on ISS
  - 100kB bundle size x 100 bundles = 10 MB per node

SOURCE NODE	DESTINATION NODE	DIRECTION	BUNDLES SENT	BUNDLES RECEIVED	TIME (sec)	TOTAL BYTES	THROUGHPUT (Mbps)
ELC-1	HOSC Cadre A	Downlink	100	100	17.188	10 M	4.694
ELC-2	HOSC Cadre B	Downlink	100	100	12.988	9900003 *	6.098
ELC-3	HOSC Cadre C	Downlink	100	100	14.57	9900003 *	5.436
ELC-4	HOSC Cadre A	Downlink	100	100	12.876	10 M	6.213
TReK Win7	HOSC Cadre B	Uplink	100	100	24.75	9900003 *	3.21
TReK Linux	HOSC Cadre C	Uplink	100	100	13.463	10 M	5.942
HOSC Cadre A	ELC-1	Uplink	100	100	54.35	10 M	1.472
HOSC Cadre B	ELC-2	Uplink	100	100	33.025	10 M	2.422
HOSC Cadre C	ELC-3	Uplink	100	100	36.27	10 M	2.206
HOSC Cadre A	ELC-4	Uplink	100	100	89.965	10 M	0.889
HOSC Cadre B	TReK Win7	Uplink	100	100	20.873	10 M	3.833
HOSC Cadre C	TReK Linux		100	100	66.135	9900003 *	1.198

* Due to initial first packet received out of order

  - All bundles transferred successfully
  - Throughput is reduced due to simultaneous transfers of multiple nodes and was calculated from first to last packet, so the data rate appears skewed when a sender is idle waiting to send bundles.
  - Cumulative data rates are consistent with single node testing.

Nominal Payload Testing

- The third and fourth tests exercised the DTN Management Daemon to reconfigure the bandwidths during DTN operations.
- Third Test (Reduced Downlink)
  - Data rate reconfigured to 10 Mbps using daemon
  - Same as the second multiple node test
  - All bundles transferred successfully
  - Downlink rates for nodes ~0.5 – 4Mbps
  - Uplink rates for nodes ~0.75 – 2.6 Mbps
  - As expected downlink rates are near half the rate.
- Fourth Test (Increased Downlink)
  - Data rate configured back to 20 Mbps and performed Second Test again.
  - All bundles transferred successfully
  - Downlink rates for nodes ~3 – 7Mbps
  - Uplink rates for nodes ~0.75 – 3.9 Mbps

Loss of Communication Testing

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- Eight simultaneous transfers (4 up and 4 down) between four nodes on ISS and four nodes at Huntsville
- LOS was created by powering off the modem on the ISS Ku Communication Unit for 10 minutes.

SOURCE NODE	DESTINATION NODE	BUNDLES SENT	BUNDLES RECEIVED	TIME (sec)	TOTAL BYTES	THROUGH-PUT (Mbps)
ELC-1	HOSC Cadre A	200	200	403.593	19900003 (1)	3.945
ELC-2	HOSC Cadre B	200	200	1018.707	20 M	1.571
TReK Win 7	HOSC Cadre B	200	200	1039.147	20 M	1.54
TReK Linux	HOSC Cadre C	200	200	927.65	20 M	1.725
HOSC Cadre A	ELC-1	500	500	1011.31	50 M	0.396
HOSC Cadre B	ELC-2	500	500	226.152	50 M	1.769
HOSC Cadre B	TReK Win 7	500	500	739.067	50 M	0.541
HOSC Cadre C	TReK Linux	500	500	282.307	50 M	1.417

(1) Due to initial first packet received out of order

- All data was stored and successfully retransmitted when signal was reacquired.
- Large number of retransmits (not shown) but to be expected due to the LOS

File Transfer Testing

- First Test (Single Node Transfers)
  - Two different mechanism were used for file transfers: CFDPTest and TReK Toolkit CFDP GUI
  - Single file transfers were used for the first test.
  - File sizes tested were 1 MB, 50 MB, 175 MB, and 1 GB.
  - File types included TXT, DOC, MPEG, and IMG.
  - Files were verified as successfully transferred when their checksums matched pre and post transfer.

File Transfer Testing

- First Test (Single Node Transfers)

SRC	DEST	Data Segment (Total/# Rexmit)	Report Segment (Total/# Rexmit)	Canceled by Sender (Total/# Rexmit)	Canceled By Rcvr (Total/# Rexmit)	Filesize
Cadre C	TReK Win7	757/4	10/0	0/0	0/0	1 MB
TReK Win7	Cadre B	73/0	9/0	0/0	0/0	1 MB
Cadre C	TReK Win7	37582/0	405/0	0/0	0/0	50 MB
TReK Win7	Cadre B	3642/0	410/0	0/0	0/0	50 MB
Cadre C	TReK Win7	131128/2	1413/0	0/0	0/0	175 MB
TReK Win7	Cadre B	12707/0	1428/0	0/0	0/0	175 MB
Cadre C	TReK Linux	37595/13	407/0	0/0	0/0	50 MB
TReK Linux	Cadre A	3648/0	416/0	0/0	0/0	50 MB
Cadre C	TReK Linux	131128/2	1413/0	0/0	0/0	175MB
TReK Linux	Cadre A	12716/0	1437/0	0/0	0/0	175 MB
TReK Win7	Cadre B	69336/28	7785/6	0/0	0/0	1 GB

File Transfer Testing

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- Second Test (Multiple Node Transfers)
  - Two different mechanism were used for file transfers: CFDPTest and TReK Toolkit GUI
  - Simultaneous file transfers were used for the second test.
  - File sizes tested were 1 MB, 50 MB and 175 MB.
  - File types included TXT and MPEG.
  - Files were verified as successfully transferred when their checksums matched pre and post transfer.

File Transfer Testing

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- Second Test (Multiple Node Transfers)
  - No LOS

SRC/DEST	Data Segment (Total/# Rexmit)	Report Segment (Total/# Rexmit)	Canceled by Sender	Canceled By Rcvr	Filesize
Cadre C -> TReK Linux	79144/3397	1101/0	0/0	134/0	50 MB
Cadre B -> TReK Win7					50 MB
TReK Linux -> Cadre C	25407/30	2895/47	0/0	1/0	175 MB
TReK Win7 -> Cadre A					175 MB

  - With 10 min LOS

SRC/DEST	Data Segment (Total/# Rexmit)	Report Segment (Total/# Rexmit)	Canceled by Sender	Canceled By Rcvr	Filesize
Statistics During LOS					
Cadre C -> TReK Linux	12918/999	196/0	0/0	0/0	50 MB
Cadre B -> TReK Win 7					50 MB
TReK Linux -> Cadre C	3880/4	453/10	0/0	0/0	175 MB
TReK Win7 -> Cadre A					175 MB
Final Statistics					
Cadre C -> TReK Linux	77093/1249	929/0	0/0	18/0	50 MB
Cadre B -> TReK Win7					50 MB
TReK Linux -> Cadre C	26193/495	3273/208	16/0	66/198	175 MB
TReK Win7 -> Cadre A					175 MB

Characterization Testing

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1. Reboot of on board gateway during a CFDP transfer resulted in successful file transfers.
   - Bundles were queued on the ground gateway during the reboot period. Those bundles were successfully sent and received by the destination node after the reboot had completed.
   - Conversely, the bundles that were queued on the on board gateway were successfully transmitted and received by the ground node after the completion of the reboot.
2. Full Load Testing
   - Simulated ISS environment to attempt to maximize the bandwidth through the ISS laptops
   - Maximum downlink and uplink data rate achieved approximately 50 Mbps
     - 50 Mbps uplink is unrealistic due to Ku-band data rate limit.

ISS DTN Evolution

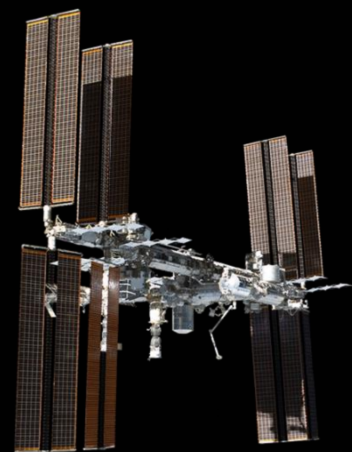
- First long-term operational implementation of DTN in Space
- 12 ISS Payloads in-work for DTN integration via ISS Payload Office
  - Telescience Resource Kit (TReK) – First demo payload in Spring 2016
  - Plant Habitat is the first non demo user targeting early 2017 deployment
- Planned platform upgrade from Lenovo T61P Laptop to HP ZBook
  - Support for higher bandwidth and storage capability
- Support currently is for DTN-enabled Payloads only
  - Future support will include capability to gateway TCP and UDP payload applications
  - ECOSTRESS Payload will utilize direct TCP data transfer over External WiFi system.
- Upgrades for Aggregate Custody Signaling and Delay Tolerant Payload Conditioning
  - Better uplink bandwidth efficiency and in-order data delivery as necessary
- Potential DTN Security upgrades which would include Bundle Protocol Security (BPSec) and Secure Key Distribution and Management
- DTN Management Daemon upgrades or potential integration of the Asynchronous Management Protocol (AMP)
- System expansion to operations applications

Coordination and Appreciation

- **Brett Willman – ISS DTN Project Manager**
- **Suzanne Davidson – Boeing JSL DTN Technical Lead**
- **Adam Schlesinger – AES DTN Project Technical Lead**
- **Lee Pitts – MSFC Lead DTN Architect**
- **Bill Pohlchuck – ISS DTN Lead Developer**
- **Kelvin Nichols – MSFC Lead DTN Integrator**
- **Jeff Lippincott – TReK DTN Integrator**
- **David Zoller – HOSC ISS DTN2 Gateway Developer**
- **Joanne Towne – HOSC ISS DTN Test Lead**
- **Dennis Botts – HOSC Customer Support Lead**
- **Tyler Doubrava – SWRDFSH DTN Integrator**
- **Jim Wiehoff – ISS DTN Project Lead**

Delay/Disruption Tolerant Networking for the International Space Station (ISS)

Brett Willman – NASA ISS DTN Manager
Bill Pohlchuck – Boeing ISS DTN Lead Developer



BACKUP

DTN Management Daemon

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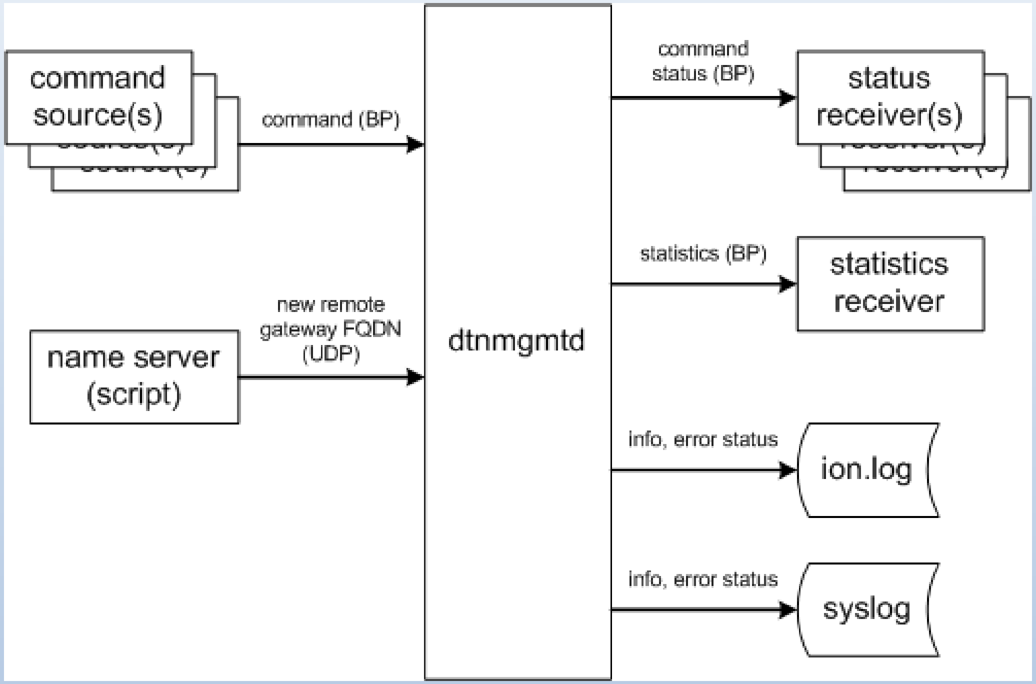
- The DTN Node Management Daemon was developed to handle management of the ISS Payload DTN Node.
- Providing a DTN management daemon avoided the reliance on applications such as SSH to send commands/status.
- Run as a service on the node similar to ION bpecho. BP is used for sending command, command status, and statistics information (messages).
- DTN Management Daemon Capabilities:
  - Ability to control output rates between the on-orbit and ground DTN Gateway nodes
  - Ability to control the flow of the file I/O between the on-orbit and ground DTN Gateway nodes, i.e. suspending, resuming, and cancelling flow of bundles related to designated file I/O “jobs” (CFDP).
  - Route selection to newly designated active remote DTN gateway nodes via DNS reconfiguration and command
  - Support enabling/disabling I/O with neighboring nodes, especially output control
  - Gathering and reporting of basic level DTN node statistics. This feature provides the configurability to provide the statistics receiver identity, reporting interval, and enable/disable statistics reporting state

DTN Management Daemon



Command Source(s)

- Send command message via BP
- Provide EID of command status message receiver, if desired, for the current command message

Status Receiver(s)

- Receive command status messages via BP

Statistics Receiver

- Receives DTN node statistics sent from dtnmgmtd
- dtnmgmtd sends node statistics to *only one* designated receiver

Name Server

- A script is run manually to change IP address associated with logical G/W hostname (FQDN)
- Script sends UDP message to dtnmgmtd to indicate new remote G/W host

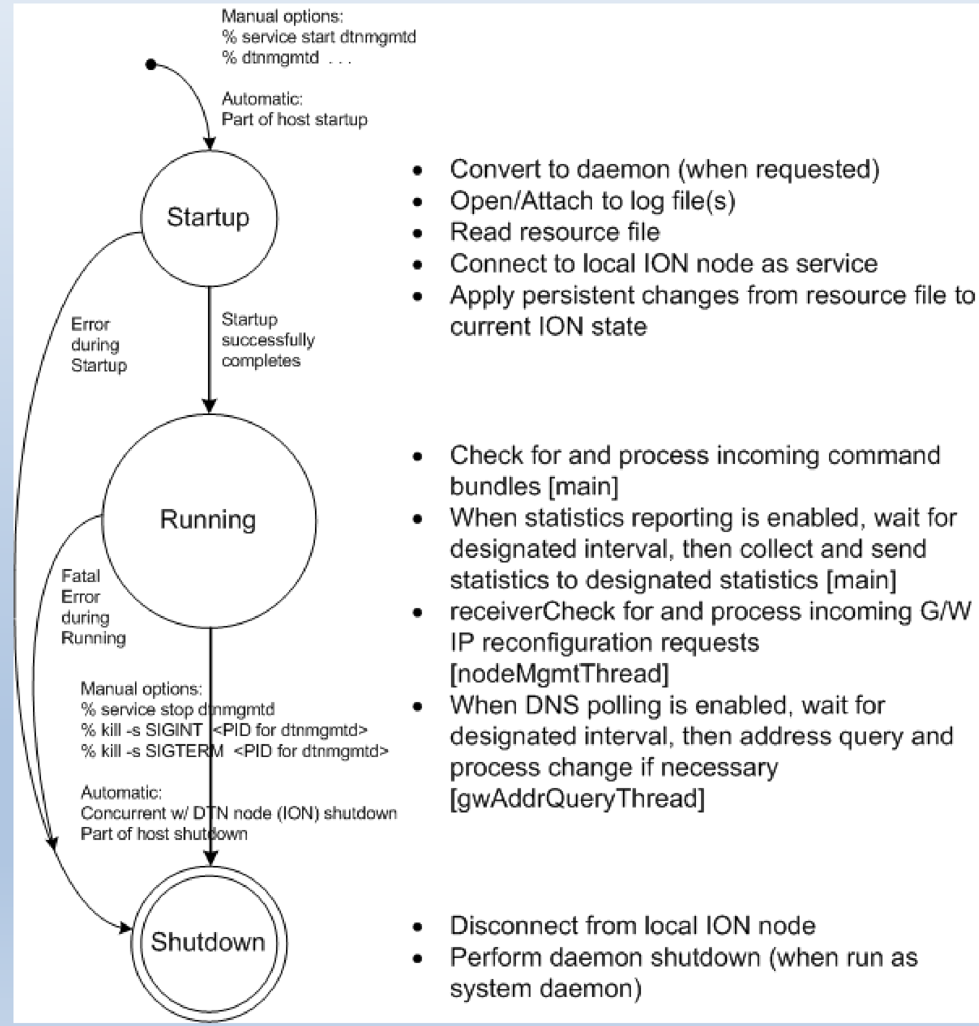
"ion.log", "syslog"

- Informational and error status written to ion.log
- syslog is used for error messages when dtnmgmtd is run as a daemon

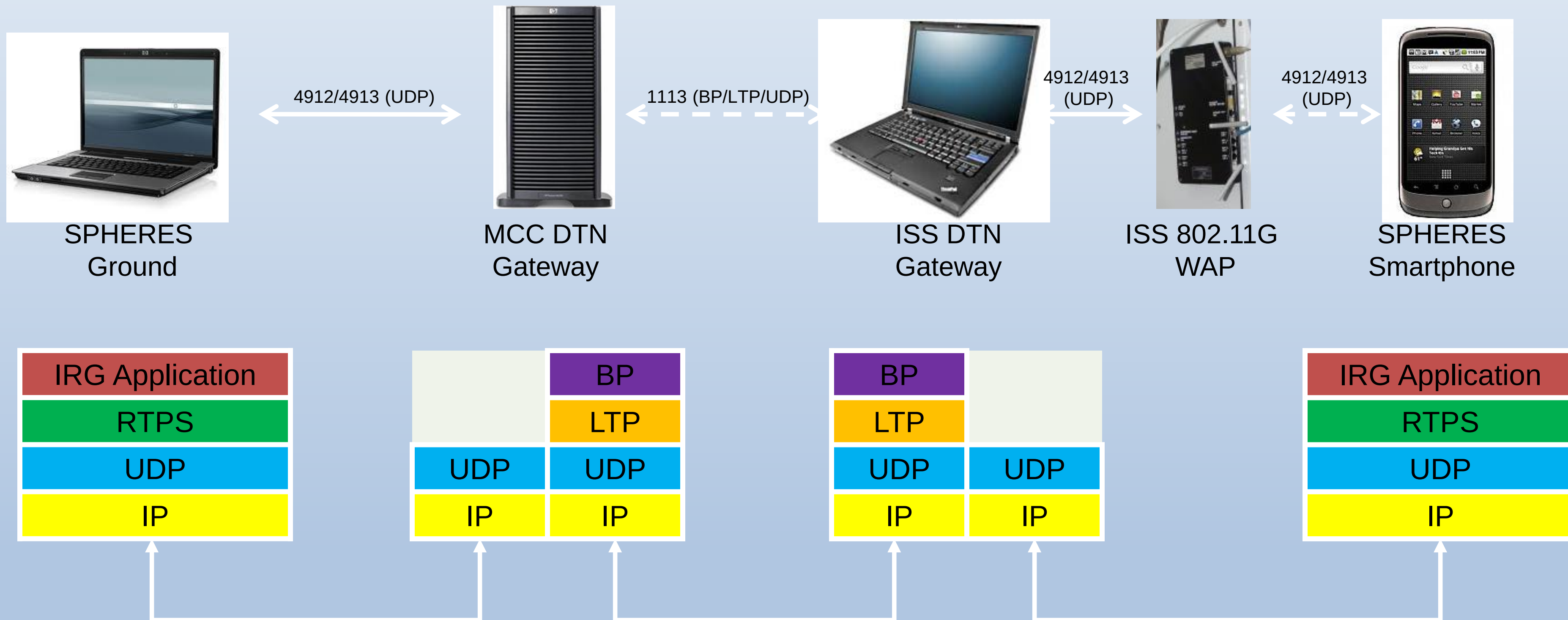
DTN Management Daemon

dtnmgmtd:

- **Support being run as a system service (daemon), after DTN node service has started**
  - Service "dtnmgmtd"
  - Run via special user account (ion)
  - Error output to syslog; other output to ion.log
- **Support being run as a non-daemon**
  - Error output to stdout and stderr; other output to ion.log
- **Uses a special DTN network configuration file**
  - Contains neighbor nodes (of interest), gateway nodes (if defined)
  - Contains persistent information outside of ION node start-up files
  - Content (output rates) overrides ION node startup values upon daemon startup
- **Designed to be runnable on any ION-based node, given an appropriate DTN network configuration file**

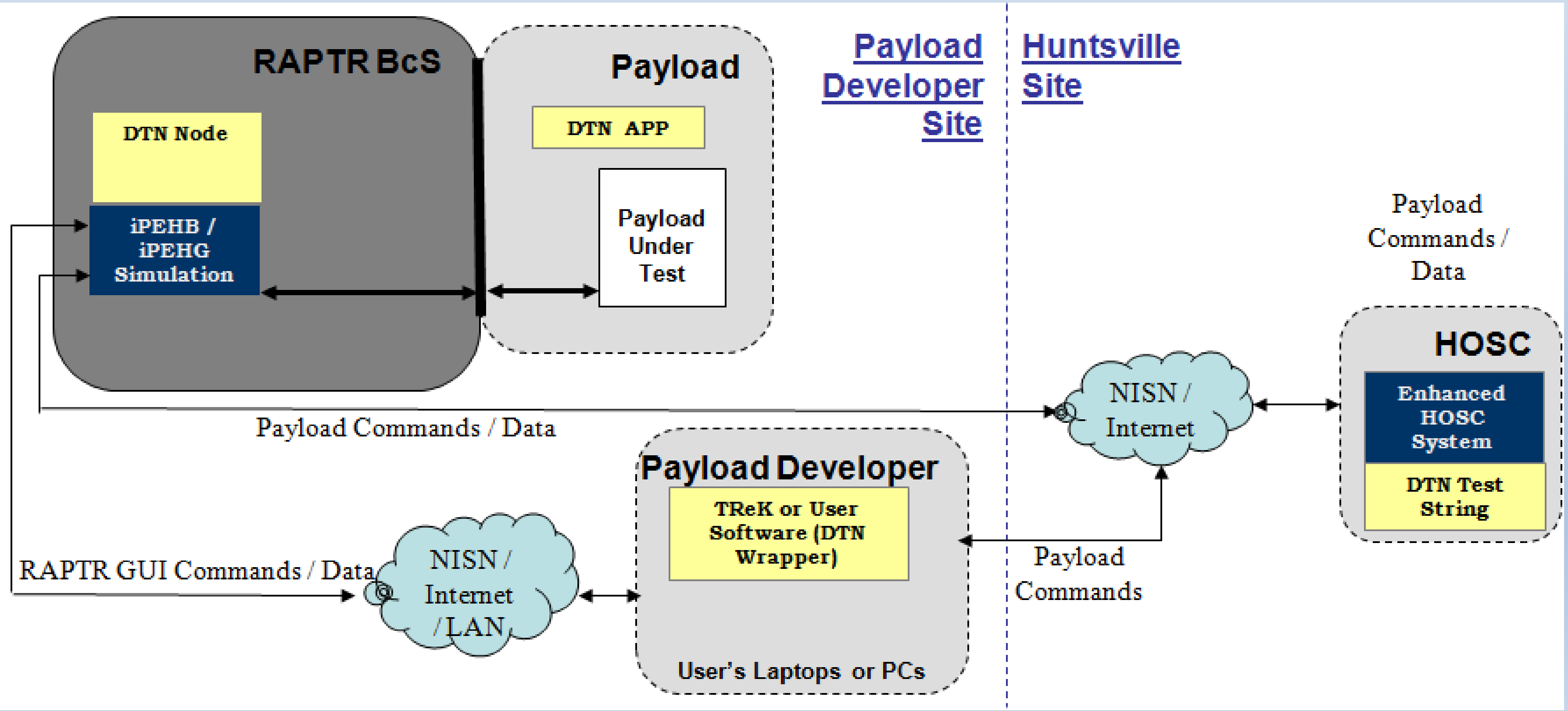


SPHERES Smartphone



DTN Remote Payload Testing w/ RAPTR

- Addition of DTN Node in Remote Advanced Payload Test Rig (RAPTR) allows PD to test DTN at remote facilities:
  - Incorporate DTN VM node into RAPTR for payload testing.
  - Covers all Payload Rack Checkout Units (PRCU) at Marshall Space Flight Center (MSFC) as well



- TReK is one of the Huntsville Operations Support Center (HOSC) remote operations solutions
  - Used to monitor and control International Space Station payloads from anywhere in the world.
  - Don't have to be DTN expert to get your data
- The ISS program is providing the TReK Toolkit software as a generic flight software capability offered as a standard service to payloads
- TReK Demo on an ISS provided T61p laptop. Installed on May 27, 2016
- ISS DTN Capabilities:
  - Transfer files (send and receive) using CFDP.
  - Configure and Manage (start, stop, monitor) ION DTN node.
- Ground DTN Capabilities:
  - Transfer files (send and receive) using CCSDS File Delivery Protocol (CFDP)
  - Configure and Manage (start, stop, monitor) ION DTN node.
- Software:
  - IONconfig Application - Provides the capability to generate ION configuration files and scripts. The scripts (Windows batch files and Linux shell scripts) can be used to start and stop ION. This application has a graphical user interface.
  - IONizer Application - Provides capabilities to start, stop, and monitor ION. This application has a graphical user interface.
  - IONizer Library - Provides an application programming interface to start, stop, and monitor ION.

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Payload Test Services

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Testing Services for Payloads

- Test services are provided at both HOSC and SDIL
- These facilities support:
  - Link emulation
  - Simulates onboard systems and utilizes images or actual hardware for specific systems
  - Provides high fidelity interoperability testing between MCC-H, SDIL, and HOSC
  - Currently available and configurable against current and future ground systems
  - Both facilities also support stand-alone testing leveraging a high degree of virtualization:
    - Simulates onboard systems and utilizes images for specific systems
    - Provides the ability to exercise uplink and downlink protocols through the use of flight software packages executing on virtual servers
    - Available for development systems now and moving integration testing in the last half of ‘15
- HOSC also hosts the TReK Demonstration Payload Image within HOSC On-Demand Test environment to support payload team familiarization with DTN capabilities.
- SDIL provides access to the flight-like ISS High Rate Communication and JSL Hardware