

Extending the International Space Station Life and Operability

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The International Space Station (ISS) is in an operational configuration with final assembly complete. To fully utilize ISS and extend the operational life, it became necessary to upgrade and extend the onboard systems with the Obsolescence Driven Avionics Redesign (ODAR) project. ODAR enabled a joint project between the Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) focused on upgrading the onboard payload and Ku-Band systems, expanding the voice and video capabilities, and including more modern protocols allowing unprecedented access for payload investigators to their on-orbit payloads. The MSFC Huntsville Operations Support Center (HOSC) was tasked with developing a high-rate enhanced Functionally Distributed Processor (eFDP) to handle 300Mbps Return Link data, double the legacy rate, and incorporate a Line Outage Recorder (LOR). The eFDP also provides a 25Mbps uplink transmission rate with a Space Link Extension (SLE) interface. HOSC also updated the Payload Data Services System (PDSS) to incorporate the latest Consultative Committee for Space Data Systems (CCSDS) protocols, most notably the use of the Internet Protocol (IP) Encapsulation, in addition to the legacy capabilities. The Central Command Processor was also updated to interact with the new onboard and ground capabilities of Mission Control Center – Houston (MCC-H) for the uplink functionality. The architecture, implementation, and lessons learned, including integration and incorporation of Commercial Off The Shelf (COTS) hardware and software into the operational mission of the ISS, is described herein. The applicability of this new technology provides new benefits to ISS payload users and ensures better utilization of the ISS by the science community.

I. Introduction

THE International Space Station (ISS) Program, in order to fully utilize and extend the operational life of ISS, embarked upon the Obsolescence Driven Architecture Redesign (ODAR) project. ODAR is a joint Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) activity focused on upgrading the payload and Ku-Band systems. The upgrades increase the voice and video capabilities, expanding the voice by two Space-to-Ground loops and adding two more video channels in the Return Link. The Ku-Band Return Link is doubled to 300Mbps and the Forward Link is increased to 25Mbps. ODAR also provided the opportunity to include more modern protocols such as the Internet Protocol (IP) Encapsulation (CCSDS 133.1-B-2) standard provided by the

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Consultative Committee for Space Data Systems (CCSDS). The sum of this work provides the payload investigators unprecedented access to their payloads on-orbit.

The Huntsville Operations Support Center (HOSC), home to the ISS Payload Operations Integration Center (POIC), located at MSFC, was tasked with bringing new capabilities to the payload community for minimal cost. To accomplish this, the HOSC personnel developed a high-rate space data “router”. The enhanced Functionally Distributed Processor (eFDP) is designed to manage a 300 Mbps Return Link data stream. The eFDPs are configurable to forward, by Virtual Channel (VC), Ku-Band Return Link to both Mission Control Center – Houston (MCC-H) and the HOSC. The eFDP also provides a Line Outage Recorder (LOR). When not configured for real-time forwarding, the eFDP can be configured to record raw data as it is received in an engineering support mode. Engineering support mode is used to record the raw data stream being received from the Radio Frequency (RF) system. The data is used to investigate processing issues. In addition to the Return Link processing, the eFDP provides a 25 Mbps Forward Link transmission with a loopback capability to support troubleshooting if necessary.

The HOSC also updated the Payload Data Services System (PDSS) servers to incorporate the latest CCSDS protocols (IP Encapsulation) while maintaining the legacy capability. PDSS is the payload community’s broker to the new on-board and ground capabilities provided by ODAR. It distributes Return Link data to the payload investigator by Application Process Identifier (APID), or in the case of the IP Encapsulated frames, data will be distinguished by the embedded packet source IP address.

The Central Command Processor (CCP) will communicate with the Communications Data Processor (CDP) at MCC-H to submit the commands, data and files for Ku-Band Forward Link. The CCP is also central to the Transmission Control Protocol (TCP) IP Encapsulation as it will provide the mapping and translations of addresses between the ground systems and the on-board systems.

This paper presents the architecture, implementation, and lessons learned for the eFDP, PDSS and CCP enhancements. It also includes the integration and incorporation of Commercial Off The Shelf (COTS) hardware and software into the operational mission of the ISS and discusses the applicability of the technology to ISS payload users.

II. International Space Station Ku-Band Architecture

Figure 1 below illustrates the data links between the ISS and the Ku-Band ground systems. A typical payload, using the S-Band Forward Link path, traverses the HOSC Virtual Private Network (VPN) tunnel to external Private (ePVT) servers. An ePVT server allows remote users access to POIC remote services. From ePVTs, the uplink data is sent through the CCP to MCC-H for inclusion in the S-Band Forward Link to the ISS. The Ku-Band Forward Link is handled differently. The CDP is used to multiplex the data for forwarding.

Data on the Return Link is first processed at the White Sands Complex (WSC) by the eFDP. For payload data, the eFDP sends the Return Link data to the POIC for processing by the PDSS. Data from the PDSS is forwarded to the payload user.

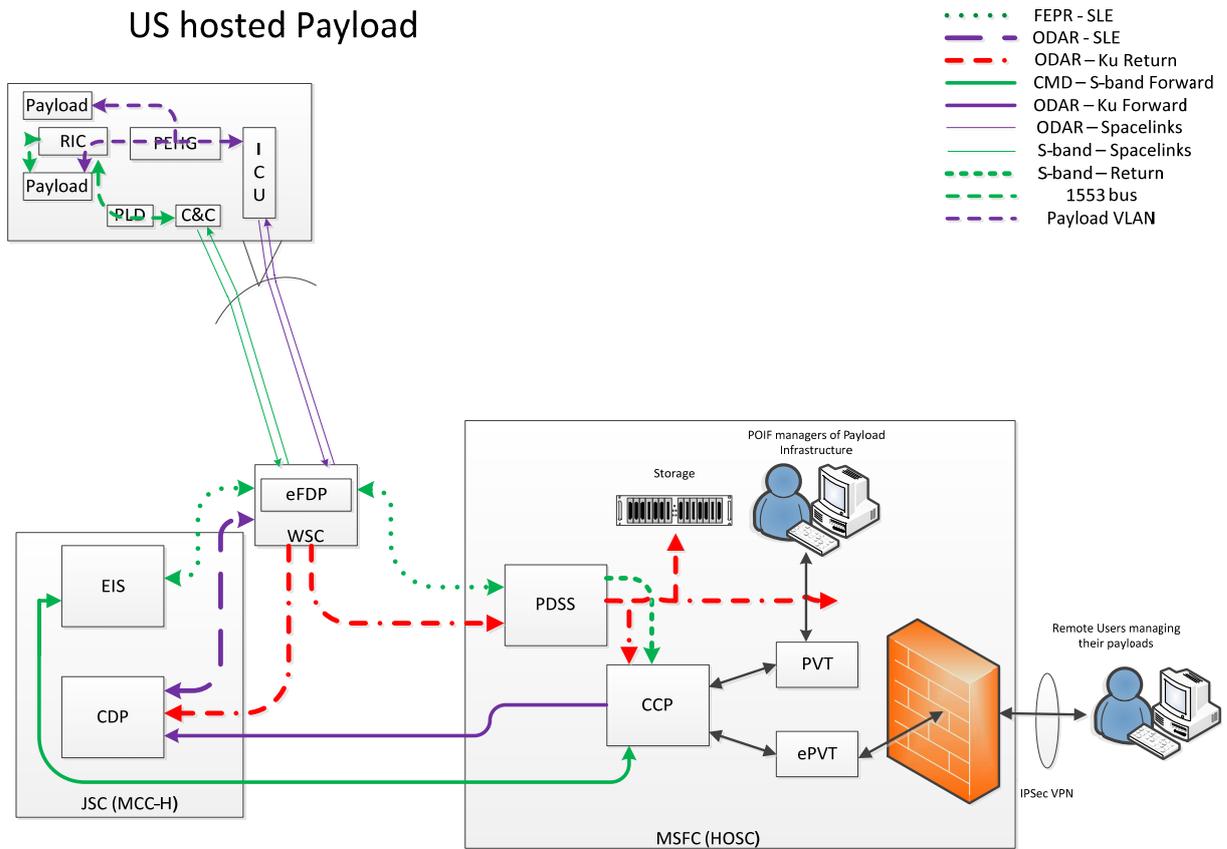


Figure 1. Overview of the ISS to POIC Links

III. Payload User Benefits

Substantial benefits are realized with the incorporation of updated standards, as depicted below:

1. Increased bandwidth for payloads.

On the Forward Link, payload users will have access to bandwidth that is greater than two orders of magnitude. This significantly reduces the time to upload configuration files for repurposing payloads and thus increases the scientific and technology utilization of ISS. It also reduces the time and effort of the payload developer and principal investigator configuring their payload.

2. More direct control of payloads and Payload Local Area Network (LAN) devices.

The Forward Link also allows direct access to the devices located on the Payload LAN. This enables the flight controllers to have command line access to the on-board network devices for configuration and monitoring. It also allows the payload teams to have direct, command line access to their payload as if it was sitting in their local laboratory.

3. Minimizes infrastructure management and attendant costs for ground based payload control.

As mentioned above, there is a reduction in the amount of special hardware and personnel managing the systems. By including the IP Encapsulation and other CCSDS protocols, COTS products can be used to monitor the on-board and ground systems and alert personnel when problems exist. It also provides payloads with simpler interfaces.

4. Enables the use of new technology.

The system will allow for the use of IP cameras and Disruption Tolerant Networking (DTN) without the need to create special builds or configurations.

The capabilities and the changes the HOSC had to make to enable payload user access to the interface and technology ODAR provides are discussed below.

IV. enhanced Functionally Distributed Processor

The Functionally Distributed Processor (FDP), in use prior to ODAR, was a vendor provided turnkey system designed to process the Ku-Band Return Link at up to 150 Mbps; it cost approximately \$75,000 US Dollars (USD). There was no capability to perform Ku-Band Forward Link dispensation. ODAR requirements were to support Ku-Band Return Link at up to 300 Mbps and Forward Link up to 25 Mbps using CCSDS Space Link Extension (SLE). The HOSC solution is packaged in the cleverly named “enhanced Functionally Distributed Processor” (eFDP). It uses a COTS Dell R710 server with 12 GB RAM, 8 CPU cores and one Engineering Design Team, Inc. (EDT) serial communication board. The eFDP cost is around \$9,000 USD providing approximately 88% cost reduction from the legacy system.

A. Architecture

The eFDP performs what can be considered Tier 1 processing of the Return Link. It searches for synchronization patterns within the data stream and then performs the Pseudo-Noise decoding and a five (5) interleave Reed-Solomon decoding to extract each frame from the stream. The stream is then de-multiplexed into individual VCs for LOR storage and distribution to the PDSS Servers for additional processing.

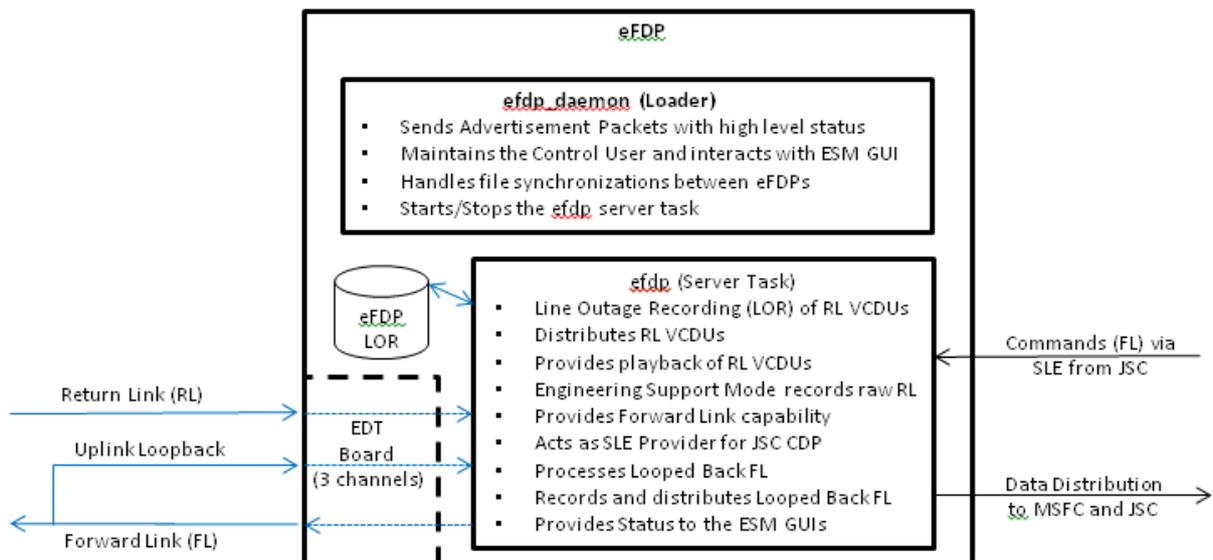


Figure 2. eFDP Software Processes

The eFDP loader (efdp_daemon) process runs during system boot. It reads the eFDP configuration file to determine the destinations to advertise that this eFDP is operational. That advertisement is received by the eFDP System Manager (ESM) Graphical User Interface (GUI) to inform the operators the eFDP is available. The loader also receives instructions from the ESM console to affect changes to the eFDP server task (start and stop, taking control, edits to VC list, etc.) as well as keeping the mission configuration files between the eFDPs synchronized.

The server task (efdp process) handles the majority of the processing. It configures the Engineering Design Team, Inc. (EDT) Emitter-Coupled Logic (ECL) board and performs the Return Link and Forward Link processing. Return Link data is written to the LOR by VC and transmitted to all configured servers. The server task also incorporates an SLE provider for the CDP binds to forward commands and data on the Ku-Band Forward Link. Forward Link data is written to the EDT ECL board for transmit to the RF system. The Forward Link is also looped back into the EDT board where it is processed similar to the Return Link and shipped to the configured recipients.

The EDT ECL board does the bulk of processing of the data streams. It provides Synchronization, Pseudo-Noise (P-N) Encoding and Decoding and Reed-Solomon Encoding and Decoding. There are three channels: two for input and one for output. Typical configuration is one input channel for the Return Link, the other input channel for the Forward Link loopback and the output channel is used for the Forward Link transmission.

The LOR is 3 Terabytes (TB) of disk storage, which is capable of maintaining a minimum of 8 hours of data. By default, the files are compressed after they are written, so the system can store more than the minimum. The LOR playback feature allows operators to retransmit a selected time slice. This feature allowed the eFDP to augment the current operational flight system. The current system experienced network interruptions where data was lost in transit. The eFDP LOR was able to playback the data to fill in the gaps. When the LOR storage usage reaches a high watermark (95%) level, a “Garbage Collection” function is invoked to delete the oldest files until LOR storage usage is back down to the low watermark (90%) level.

The ESM allows the operator to monitor and control the eFDPs. It can run on the eFDP itself, but it is normally run on a separate Operator’s Workstation. The ESM is written in JAVA and runs on both Windows and Linux machines.

B. Lessons Learned

The computation intensive portion of the Return Link stream processing is the Reed-Solomon decoding. A software only solution was explored. Using a dedicated CPU core and thread to process each interleave, the maximum achieved sustained throughput was about 170 Mbps. After extensive research, a hardware solution was discovered. A high rate serial board available from EDT met the specification to achieve the throughput needed. The board has 3 channels, two for receiving and one for transmitting. It is capable of processing a 300+ Mbps stream and contained a built-in Reed-Solomon processor. The EDT card, with some custom programming, suits the needs for both the Return Link and the Forward Link processing with a bonus channel available to provide a loopback of the Forward Link.

EDT was tasked to write the Field Programmable Gate Array (FPGA) code needed to perform the stream processing. The HOSC personnel worked with EDT to integrate the card into the eFDP. The board performs the compute intensive data stream encoding and decoding. The HOSC developed the efdp server task and efdp loader software to achieve the additional required frame processing, storage and distribution.

The support for the new 25 Mbps Ku-Band Forward Link capability required the use of the SLE - Forward Command Link Transmission Unit (CLTU) Service Specification. Testing with several versions of the Blue Book implementation revealed that the required throughput was not satisfactory especially when network delays were included in the mix. Based on test results from tuning the SLE Forward CLTU Service Specification (Table 1 below), setting the Protocol Data Unit (PDU) to six provides the largest throughput capable. The result of the testing along with the recommendation to include multiple PDUs per CLTU was supplied to the SLE-Enhanced Forward CLTU Service Specification Orange Book (CCSDS 912.1-O-101.8) for inclusion in the standard. The eFDP utilizes the Orange Book version for SLE.

Number of PDUs per CLTU (220 Bytes)	Simulated Roundtrip Network Delay (milliseconds)	Throughput Achieved (Mbps)	Result
1	80	25.0	Right on the edge
1	200	10.1	Does not meet Requirement
2	200	20.1	Does not meet Requirement
3	200	30.1	Meets Requirement
6	200	60.0	Sweet Spot
7	200	20.0	Diminishing Returns

Table 1. Test Results from Tuning the SLE Forward CLTU Service Specification

The implementation of the SLE was a joint venture between Amergint and the HOSC. Amergint provided the SLE libraries, which handle the communication of the uplink frames from JSC to the eFDP at the White Sands Ground Terminal. The HOSC software was developed to process the frames for delivery to the EDT board for transmission.

V. Payload Data Services System

The primary purpose of the PDSS is to receive, process, store and distribute ISS Ku-Band data and payload health and status data (a subset of Ku-Band data) to the user community, which includes the International Partners (IPs), the User Operations Facilities (UOFs), the United States Operations Center (USOC), the HOSC User Operations Area (UOA) and investigator sites. The PDSS supports the following activities: Return Link support, data record and replay, simulation and test, and data storage. It also receives and stores ground ancillary data, such as status, from the POIC and distributes it to the user community. In addition, the PDSS provides ISS core systems data to the POIC. All data is stored and distributed within a custom method, the Enhanced HOSC System (EHS) protocol.

The PDSS receives the ISS CCSDS formatted S-Band and Ku-Band Return Link data broadcast from the WSC. Core systems data is contained in the S-Band stream. Payload data is contained in the Ku-Band stream. PDSS routes the EHS protocol encapsulated core systems data in real time to the POIC. EHS protocol encapsulated payload data (includes both Ku-Band and Ground Support Equipment (GSE) packets) is routed to the POIC and to the user community in real time. Stored EHS protocol payload data is accessible for two years.

A. Architecture

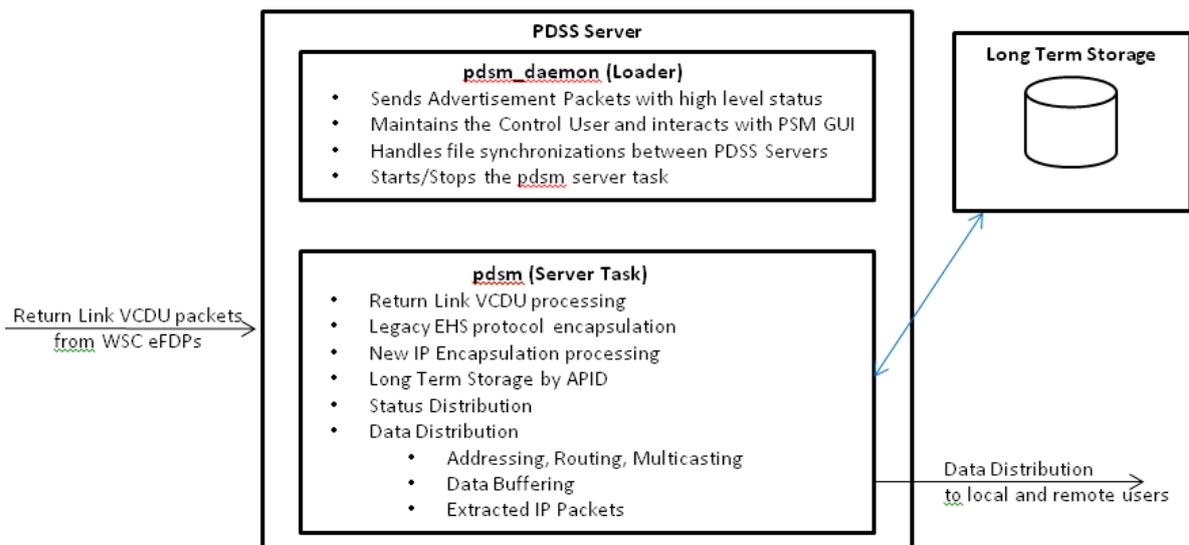


Figure 3. PDSS Software Processes

The PDSS Server performs Tier 2 processing of the Return Link data received from the eFDP. It delves deeper into the frame data as it checks the CCSDS Header information to determine its protocol type (Advanced Orbiting Systems (AOS) Space Data Link, Bitstream and now IP Encapsulation) and tracks sequence counters within each VC. PDSS recombines the data in each VC into telemetry packets by APID, formats into EHS packets and then stores and distributes packets. Initial testing of the PDSS servers indicated that they will have enough processing capacity to be able to handle the increased data rate from 150 Mbps to 300 Mbps.

A new requirement associated with ODAR is the necessity to support CCSDS IP Encapsulation (CCSDS 133.1-B-2). The implementation will be accomplished in phases. The first phase will support encapsulated User Datagram Protocol (UDP) packets which the PDSS server simply transmits to the destination or set of destinations. The second phase is the routing of the encapsulated TCP packet, which results from a telnet or similar session, back to the originator of the session.

CCSDS IP Encapsulation processing for UDP packets consists of detecting the protocol type; extracting the encapsulated packet; assigning a pseudo-APIID for storage based on the destination of the packet; storing the packet in long term storage; and transmitting the packet to either the original destination, a translated destination or fanning a list of destinations as designated. Encapsulated TCP packets are extracted and transmitted to the CCP for further processing.

VI. Central Command Processor

The Central Command Processor (CCP) is the focal point for the uplink processing at the HOSC. It accepts commands from multiple users, authenticates and validates the user, formats the commands with CSSDS headers, and transmits the commands to MCC-H for inclusion in the Forward Link stream. The addition of the Ku-Band Forward Link greatly expands the throughput and potential for the CCP. The CCP is being updated to allow file uplinks and TCP-based sessions to provide the Payload Investigators a command line interface to their on-board systems.

A. Architecture

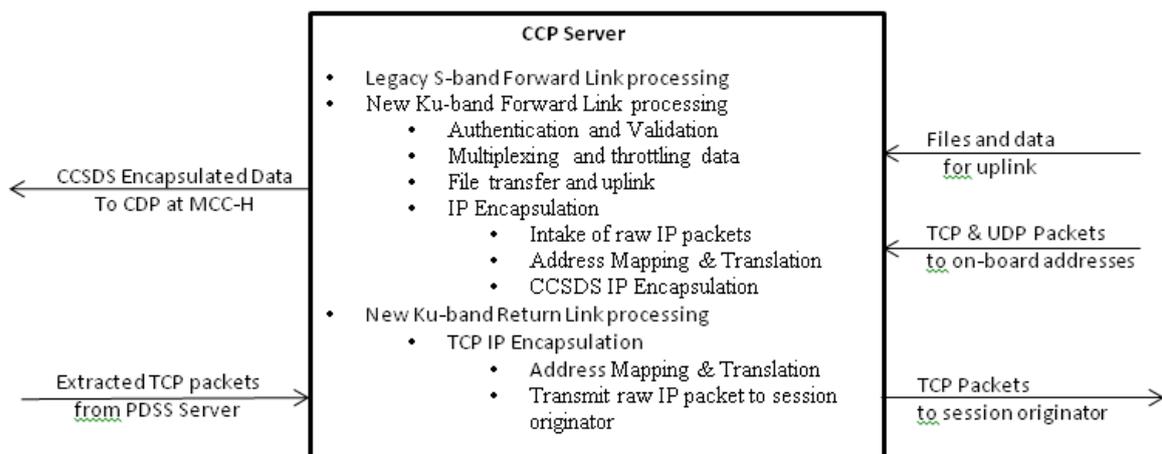


Figure 4. CCP Software Processes

The CCP handles all processing that feeds commands and data into the Forward Link stream. It authenticates and authorizes command users for uplink, consolidates and throttles data from multiple users, and formats and forwards the data to the MCC-H for uplink. It also provides status and statistics to the HOSC Integrated Support Team (IST).

The CCP will utilize the CCSDS File Delivery Protocol (CFDP) for file transfers and uplink. The files may be either streamed during contact with ISS or preloaded in the CCP. The files will be scanned for viruses before being passed on to the CDP for inclusion in the Forward Link stream.

A new requirement associated with ODAR is the necessity to support CCSDS IP Encapsulation (CCSDS 133.1-B-2) for Forward Link as well as the Return Link. The CCP will perform the encapsulation of IP traffic to be included in the Forward Link. It will read raw packets from the network, translate the IP addresses from ground-based to on-board compatible addresses, encapsulate the packets and multiplex them into the transmission to the CDP.

The CCP will maintain a mapping of the address translations so that it can reverse the process for TCP encapsulated packets returned from on-board in the Return Link. TCP packets will actually be extracted by the PDSS Server and then forwarded to the CCP to be processed. The CCP will translate IP addresses from the on-board addresses to the corresponding ground-based addresses and then transmit raw packets on the network.

The processing and CCSDS IP encapsulation of the TCP packets will enable a Payload Investigator to establish a telnet session from the ground system to the on-board payload. This will make available new operational possibilities for running and reconfiguring the payload directly by the Payload Investigator.

VII. Conclusion

The ODAR implementation significantly improves the payload investigator's ability to access and maintain their payloads onboard the ISS. The eFDP, PDSS and CCP provide a direct link connecting the science teams to their payload. All three systems map the data between the ground and on-board systems. This is accomplished through the use of CCSDS and networking standards, making the user interface simpler. Collectively, this gives investigators unprecedented access to their payloads allowing greater ease to repurpose the payload. ISS is poised to provide many more years of considerable scientific discovery.

Appendix A Acronym List

AOS	Advanced Orbiting Systems
APID	Application Process Identifier
BPDU	Bitstream Protocol Data Unit
CCP	Central Command Processor
CCSDS	Consultative Committee for Space Data Systems
CDP	Communications Data Processor
CFDP	CCSDS File Delivery Protocol
CLTU	Communications Link Transmission Unit
COTS	Commercial Off The Shelf
CPU	Central Processing Unit
DTN	Disruption Tolerant Networking
ECL	Emitter-Coupled Logic
eFDP	enhanced Functionally Distributed Processor
EHS	Enhanced HOSC System
ePVT	external Private (LAN)
ESM	eFDP System Manager
FDP	Functionally Distributed Processor
FPGA	Field Programmable Gate Array
GB	Gigabytes
GSE	Ground Support Equipment
GUI	Graphical User Interface
HOSC	Huntsville Operations Support Center
IP	International Partners
IP	Internet Protocol
ISS	International Space Station
JSC	Johnson Space Center
Ku-Band	12-18 gigahertz range in the electromagnetic spectrum
LAN	Local Area Network
LOR	Line Outage Recorder
Mbps	Megabits per second
MCC-H	Mission Control Center – Houston
MSFC	Marshall Space Flight Center
ODAR	Obsolescence Driven Avionics Redesign
P-N	Pseudo-Noise
PDSS	Payload Data Services System
PDU	Protocol Data Unit
POIC	Payload Operations and Integration Center
PVT	Private (LAN)
RAM	Random Access Memory
S-Band	2-4 gigahertz range in the electromagnetic spectrum
SLE	Space Link Extension
TB	Terabytes

TCP	Transmission Control Protocol
UDP	User Datagram Protocol
UOA	User Operations Area
UOF	User Operations Facility
USOC	United States Operations Center
VC	Virtual Channel
VCDU	Virtual Channel Data Unit
VPN	Virtual Private Network
WSC	White Sands Complex

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