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The Coming of the Internet Age to Spaceflight Mission Operations

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ABSTRACT

This paper is to explore a new space flight operations concept of using the off-the-shelf internet tools, combined with gateway servers, space link standards, and on-board file system.

INTRODUCTION

The technology available to the project for ground operations and planning has taken giant steps forward. Small personal computers now have the capacity to perform the complex processes required to plan mission activities and to formulate these plans in terms of sequence products to control the spacecraft's operational activities. These ground computers are also integrated into the Internet allowing users like Principle Investigators to collect requested activities from a science team and formulate a sequence file to instruct the spacecraft's instrument(s), all from their own facility using the Internet's standard tools.

A typical ground system for space mission consists of the following elements:
a) Tracking Stations that perform tracking and communications services with spacecraft,
b) Asset Management such as the DSN that manage the NASA Deep Space Tracking Network schedule usage of its tracking stations and controlling its provided services;
c) Payload Operations Control Center (POCC) or Mission Support Area (MSA) that performs S/C monitor and control by providing the level zero processing of the telemetry data, command generation, and data staging;
d) the project users, such as flight operations team, the science team and principal investigator(s), and mission operations team, etc, who utilize the POCC (or MSA) for data and operations services.

This paper describes a method that allows the project personnel to utilize the Internet tools that come standard with all desktop computing systems. The typical tools are web browser for scheduling and data retrieval, E-mail for correspondence and event notification, and FTP for product transfer between cooperating personnel, the POCC and the mission data product store. Browser and file transfer operations will most likely require the use of a secure communications link upon which the standard Internet protocols would operate.

While the ground operations concept is taking a new shape, a paradigm shift is also in the making for the way mission data are stored, managed and transported. The spacecraft operating system will provide file service support functions and the system executive will operate/interpret uplinked files to perform the onboard sequencing and control activities. Spacecraft will also store the vast majority of their onboard generated mission data as files (products) within their random access mass storage system. Thus the scene has changed for telemetry and command activities where the focus will now be on the transfer of file products between the spacecraft and the users on the ground. The ground users (e.g. PIs, Operations Controllers) will transfer their files to the mass storage units provided within the POCC for buffering files until the appropriate time to deliver them across the spacelink. The space users (e.g. instruments, system controller) will deposit their data products in the spacecraft's mass store to await delivery across the spacelink at the appropriate time. Both space and ground user could use standard internet file transfer protocols (e.g. FTP) for the transfer of their data files to the respective mass store units; the environment in which TCP/IP and FTP operates effectively. These files could be stored within priority folders within the mass store units until selected for transfer. The instrument data files and/or ground generated files could utilize a COTs file encryption tool to satisfy privacy requirements. Ground users (e.g. PIs) that are not located within the POCC will be required to send their data to the POCC. The POCC will provide the functionality required to control the uplink data channel and insure that the operational data transfer priorities are satisfied. The POCC provides the gateway to route the uplink data via the scheduled station proving the required tracking station security needed to control access to the spacelink application processes. The gateway service will create logs of the data sent to the S/C for historical analysis. The gateway services may also be called upon to control the stations radiation of the uplink data using application processes like the CCSDS SLE CLTU service to meet uplink time of radiation requirements which can not be guaranteed using the NISN (or Internet) ground communications services.

The transfer of data across the spacelink would most likely utilize frame data units (e.g. CCSDS Telecommand Frames) carrying data gram packets (i.e. source packets, IPv4, etc). During a tracking pass the respective spacelink controllers within the S/C and/or the POCC would prioritize data for radiation across the spacelink. The controllers will need to accommodate real time stream oriented data as well as the stored data products contained within the local mass storage units. Since spacelink communications may be disjoint and reliable transfer of data products will require some store and forward features and responsive reporting. The process may need to also accommodate the delayed transfer of these reports when the respective link (a communication channel back to the source of the data) is not available in real time.

CCSDS FILE DELIVERY PROTOCOL

Before we describe operational aspects in the various space environments, lets put forth the functionality of CFDP so that the basic operational aspects hinted to in the introduction of this paper and further exploited in the mission type scenarios are understood.

CFDP is a file transfer and/or message delivery protocol designed for the space link environment. CFDP provides the capability to move files, manipulate files, and deliver messages either reliably or on a best effort basis. A file and/or message transfer is conducted as a transaction composed of one or more protocol data units.

Moving files with CFDP is a point-to-point process that transports a file from one file storage to another file storage. The metadata associated with a file is also transported in the move file transaction. The file manipulation process of CFDP performs the load file, replace file, patch file, and append file functions according to the directives contained within the transaction's metadata. Message delivery is an application-to-application function. An application message when included within the metadata, is delivered to the destined application at the time and condition specified in relation to the file transfer. These three elements: moving files, manipulate files, and deliver messages, play important roles in supporting flight operation.

CFDP minimizes handshaking required to start, continue, and complete file transfer. The protocol uses byte offset to identify data location within a file (or serialized object), thus it is insensitive to communications artifacts that deliver duplicate or out of order data units within a transaction. Each data transfer unit has a unique transaction ID which is used to associate the file transfer attributes (source/destination, etc.). The CFDP supports hop by hop custody transfer. It also supports incomplete file delivery and incremental file delivery. Using CFDP, file transfer can span multiple contacts and multiple stations. It provides efficient operation when utilized on simplex, half duplex, and full duplex links.

Telemetry Data Management And Delivery

Spacecraft collect instrument and engineering data sets and then downlink these data sets during a tracking session. Spacecraft can generate a glut of data. Since tracking sessions are time-bandwidth limited, it will most likely be required for the spacecraft to prioritize its data for return.

Science data collected for a specific activity are stored as a product (file) in the on-board storage system. For instance, image and instrument calibration data has inherent natural boundaries. Fields and particle experiment data have well defined instrument cycles that also can be used to define processing data set. One way of organizing the stored data is to assign a science activity to a subdirectory; the acquired data for that activity are stored as files within an allocated subdirectory. The operations team could define delivery priorities for the return of data from the activities providing the S/C controller with the prioritization controls to order the files for transfer. It is also reasonable to expect that selected data sets would require complete (reliable) delivery while others could tolerate some loss. Since the data are all accounted for in files, the ground could use the directory listing to account for the delivery of all acquired and delivered data.

Real time engineering telemetry is normally acquired and transferred to the ground in a continuous stream of engineering measurements. These measurements are carried in engineering packets and transferred to the ground using the "TDM like method" during a communications pass. These engineering data can also be collected and stored in the on-board storage as a file, which may contain the original TDM engineering packets or reorganized as data summaries when required. The real-time engineering data usually has the highest priority for downlinking while the stored engineering files will have a diversity of priorities. The down link data management process will need to meter the data from the various sources for telemetering to the earth.

Telemetry data accountability is a significantly important and effort consuming activity. Real time data streams are typically accounted for by percentage of delivery. The accounting for file transfer data is performed at the file level not the packet level, both simplifying the data management task in the S/C and on the ground and improving the data accountability in user terms rather than communications percentage terms.

Command and Sequence Data Transfer

Ground operations personnel and Instrument Principle Investagators create an operational scenario which they transform into a collection of directives that tell the spacecraft what to do and how to do it. This collection of directives is typically assembled into one or more files and uplinked to the spacecraft during the tracking pass.

There occasionally will be sequence updates. The magnitude of these updates will vary. The update could be a tweak, which is accomplished by a file patch; an expansion, which may be accomplished by a file append; or a complete re-vamp, which requires replacement of the original file.

The actions required to patch, append, and replace, all use the same three steps: (1) perform a move file, (2) trigger the file manipulation process, (3) inform the application that a modification of the file has occurred. Using the CFDP, these three steps can be accomplished with one file delivery transaction.

FLIGHT OPERATIONS MODEL

The flight operation model contains a space segment and ground segment, as depicted in the following figure.

On the space segment, the Space Link function is performed by the Radio Frequency Subsystem (RFS); the Transport

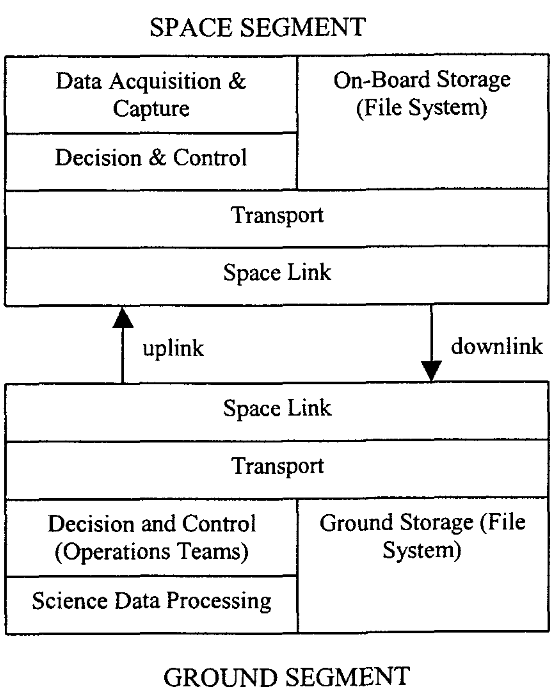

Figure 1 Flight Operations Model

function, the Decision & Control function, and the On-board Storage function are performed by the C&DH; while the on-board science and engineering data acquisition and capture functions are performed by the science instruments and spacecraft subsystems.

On the ground segment, the Space Link function is performed by the tracking station; the Transport function and the Ground Storage function are performed by the POCC; the Decision & Control function are performed by the flight team, the mission ops team, and the science ops team; the Science Data Processing function is performed by the PIs (or their designated agents).

In this architecture, the POCC serves as the Space Link Terminus between the Operational teams and the Space Link.

GROUND SYSTEM FRONT END ARCHITECURE

SLE service is used between tracking station and the POCC

CCSDS Space Link Extension (SLE) transfer services, augment the space to ground transfer protocols (transferring telemetry data from the tracking station to the POCC and/or directly to users; and spacecraft command data from the POCC to the tracking station.

POCC uses CFDP & Stream protocol over the SLE to communicate with the S/C

As we described above, most of the temenetry data from spacecraft and command data to spacecarft can tolerate time delay thus can be constructed in files and handled with CFDP service, with the exception of real time telemetry that need to be transmitted as soon as possible. In this case, the real time telemetery data are handled as a stream data. Although the CFDP has provision to handle stream data as unbounded file, it is more involved.

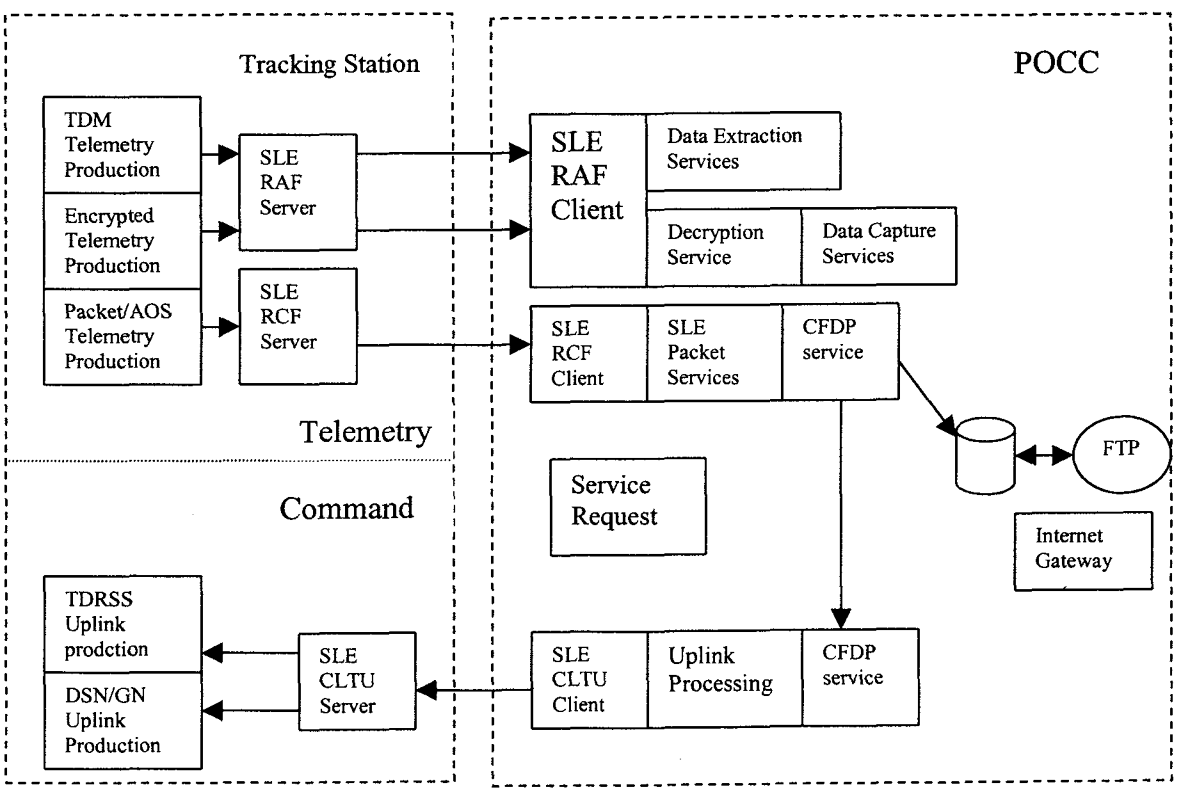

Figure 2 Ground system Front End

As an illustration, we are showing the CFDP over SLE RCF for downlink and close the loop with SLE CLTU service for acknowledgement and retransmission request.

In a near earth orbiting Satellite with direct to earth link, the disparity between uplink and downlink rates effects the performance efficiency of standard TCP/IP. The downlink data rates can be very high while the uplink rates are limited. The use of CFDP allows the files to be downlinked with virtually no handshaking. The use of transfer performance reports provides the handshaking necessary to acknowledge data received while reporting any missed portions of a file. This provides the means to accomplish a reliable transfer of a file and to provide the control to manage the transfer of custody of that file either from the spacecraft to the receiving ground terminus or vice versa. The telemetry data are collected and staged on the spacecraft as products awaiting delivery to the user. This allows the spacecraft to make last minute decisions on the order of product delivery and when necessary the level of editing or compression that should be applied to the product based on the available bandwidth capacity of the link.

The operations team interfaces with the POCC and the Space-Ground Network Asset Management Systems by E-mail, web browser, and FTP

The operations team schedule the SLE service using E-mail or web browser. The real time telemery data can be displayed and viewed by the operations team with web browser. DSN's Mission Management Office (MMO) has developed a web application called Rampage that allows the remote user to view the real time channel data display and to retrieve the stream data with a web browser. MMO's File Interchange System (FIS) automatically generated e-mail to notify the users when a new file is added, modified, or deleted on the FIS. The FIS also support the automatic sequence generation (ASP) process. The operations team will FTP a command request file to the FIS, which then E-mail a notification to the ASP process. The ASP retrieves the command request file, performs the command generation, translation, and formatting necessary for transfer to the tracking stations and eventual radiation to the spacecraft.

The currently planned usage of the CFDP is only to provide the file delivery service to handle the distinct space link characteristics. However, as we described in the previous section, the CFDP is a protocol that transfers a file with attached message. An E-mail message with attached file can be delivered from a PI to the instrument on the spacecraft using the FTP protocol on the ground segment and then using the CFDP protocol on the space segment.

CONCLUSION

As we have explained above and showed in the diagram (Figure 3), using the SLE services as glueware on the ground between tracking station and POCC and off-the-shelf internet tools such as e-mail, web browser, and FTP for data transfer on the ground between POCC and operations teams, we can efficiently and effectively provide the communications necessary for project operations accordance with present agency security and project management policies.

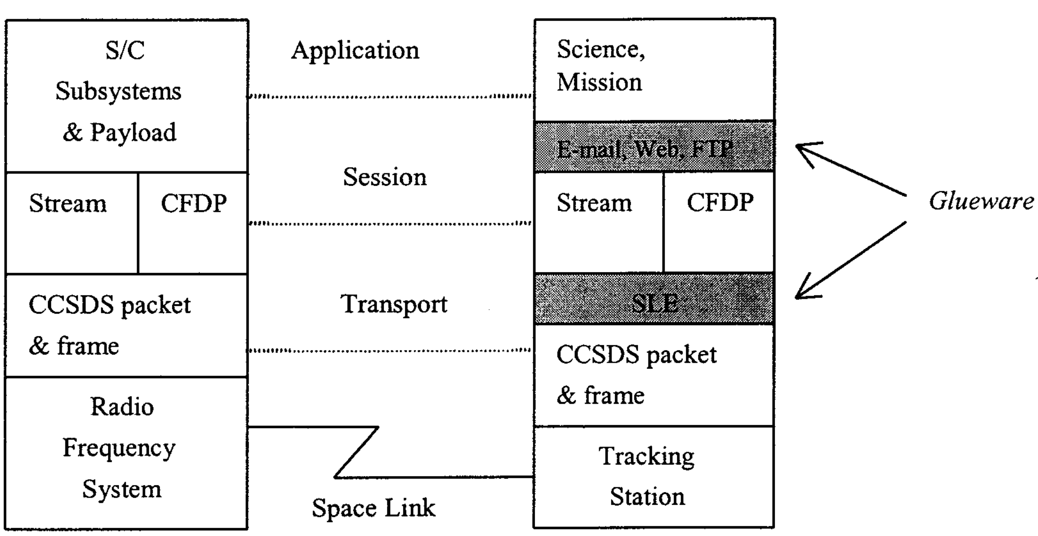

Figure 3 Protocol Suite

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