A COMMERCIAL CCSDS TELECOMMAND PROCESSOR

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ABSTRACT

After a slow start, the CCSDS Telecommand Recommendation is finally being embraced by a large number of NASA, ESA and NASDA space missions. Even some commercial satellites are exploring the possibility of using this advanced protocol. The CCSDS Telecommand is a closed-loop space communication protocol that offers its users a guaranteed data delivery service, which is essential for the satellite control operations. This paper describes a commercial product that supports the CCSDS Telecommand protocol. This product provides Telecommand uplink segmentation, transfer, coding and physical layer services and Command Operations Procedures (COP). Optionally, it provides corresponding functions at the receiving end for command link verification.

KEY WORDS

CCSDS, Telecommand, satellite commanding, uplink, COP-1.

INTRODUCTION

The Consultative Committee for Space Data Systems (CCSDS) is an international committee dedicated to the development and implementation of space systems communication protocols. Through a set of common protocols, the same ground data processing equipment is able to support not only multiple satellites of different types, but also satellites by different space agencies such as National Aeronautics and Space Administration (NASA), Department of Defense, European Space Agency and National Space Development Agency of Japan, plus more commercial satellites. An important part of the CCSDS protocol recommendations is Telecommand ([1]-[5]), a space communication protocol for sending control commands to satellites reliably and efficiently.

Since its first debut in 1987, CCSDS Telecommand (TC) recommendation was slowly embraced by the space community. However its popularity gained momentum in recent years, with the estimated number of space missions using the TC jumping from three in 1994 to thirteen in 1998 and sixteen in 1999. A part of this surge is due to the availability of commercial support in products and services for this complex communication protocol.

CCSDS TC protocol provides a guaranteed data delivery service between ground data systems and satellites. In order to guarantee the data integrity, the Telecommand protocol employs a retransmission scheme to ensure that the data is delivered 1) without errors; 2) without loss; 3) in sequence; and 4) without duplicates.

TSI TelSys, Inc. of Columbia, Maryland has developed a commercial-off-the-shelf product supporting CCSDS TC service. This CCSDS Telecommand Processor (CTP) receives user command directives for setting up service sessions, formats user command packets into TC frames and Command Link Transmission Units (CLTUs), and outputs the CLTUs through its serial port for modulation and uplink. The CTP also receives the Command Link Control Word (CLCW) extracted from return link data, and performs error checking. If an error is found, a retransmission of affected data will be automatically initiated. Optionally the CTP can perform the receiving end of the TC protocol, receiving the CLTUs, extracting packets and checking errors. This option is useful for system self-testing and satellite integration and test applications.

This paper begins with a quick overview of CCSDS TC protocol and its services. It then describes the CTP architecture and its functional features, followed by implementation issues and practical considerations. Some potential CTP applications are discussed before the conclusion.

CCSDS TELECOMMAND OVERVIEW

The CCSDS TC protocol is designed for a wide range of missions. Its architecture defines a comprehensive set of layered and standardized command delivery services (Figure 1). Each layer relies upon a well defined set of services provided by the underlying layer, and provides similarly well defined services to the layer above. These layers are functionally grouped into a "Data Management Service" (DMS), a "Data Routing Service" (DRS), and a "Channel Service" (CS). The DMS layer intends to define the process from TC users entering command requests to an end-to-end transport data unit called a TC Packet carrying the command. The definition of this layer is vague and left for future specification. The rest of this paper is focused on the two well specified layers, the DRS and CS.

The DRS consists of two layers: Segmentation and Transfer. The Segmentation Layer receives TC packets and formats them into TC segments. The segmentation is a flow control technique that allows large data units to be transported across the space link without blocking off data units from other users. The Transfer layer wraps TC segments into TC frames, which are the data units designed for reliable space link transportation. It supports data multiplexing and prioritization through Virtual Channels (VC). More importantly, the Transfer layer contains retransmission procedures required for guaranteed data delivery.

The CS also consists of two layers: Coding and Physical. The Coding layer encodes TC frames from the Transfer layer into TC codeblocks. Multiple TC codeblocks representing a TC frame are encapsulated into a CLTU. Errors induced during physical transmission of these codeblocks will be detected and optionally corrected at the receiving end of the Coding Layer. The Physical layer serializes and modulates the CLTUs on to the RF carrier for space link transmission.
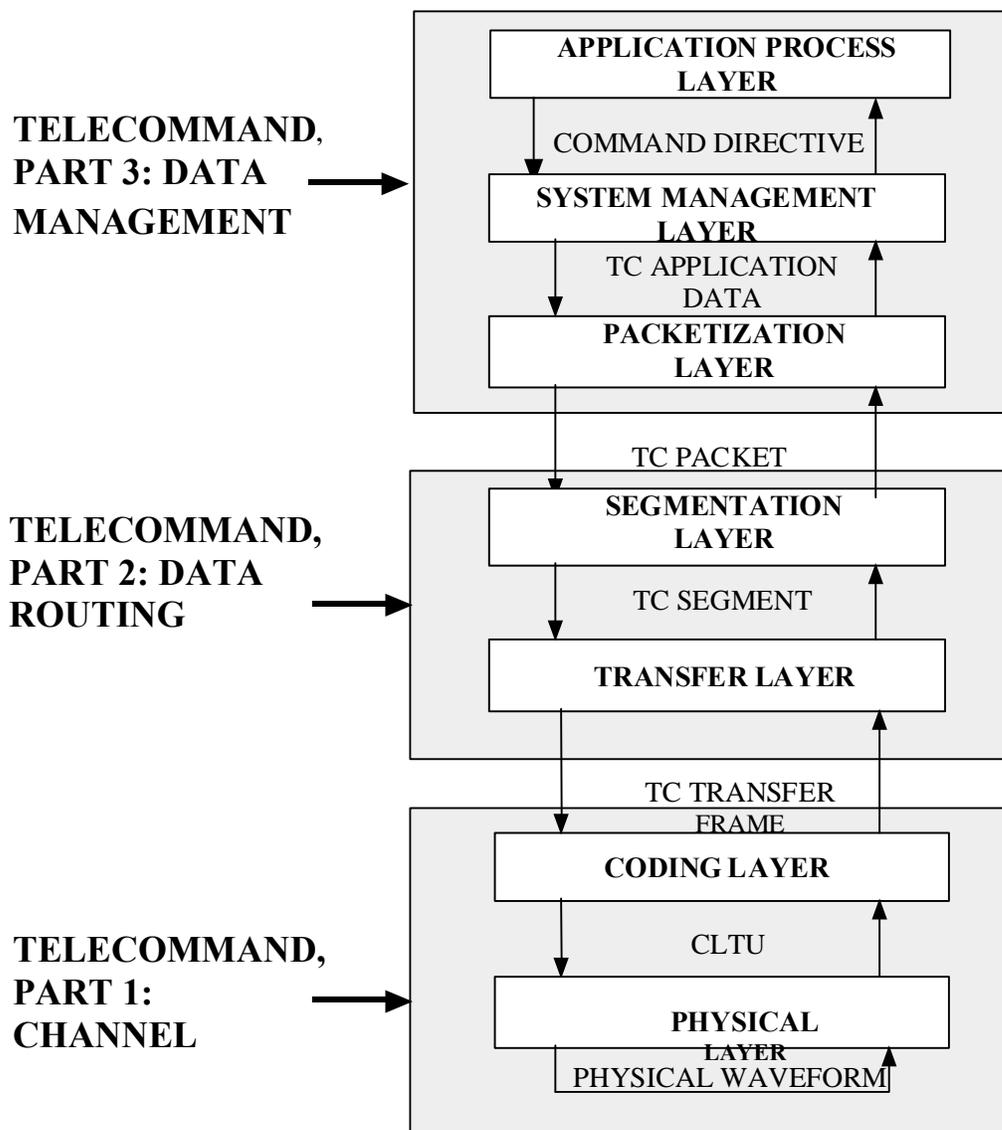
Figure 1.   CCSDS Telecommand Service Model

The Channel Service also consists of two layers: Coding and Physical. The Coding layer encodes TC frames from the Transfer layer into TC codeblocks. Multiple TC codeblocks representing a TC frame are encapsulated into a CLTU. Errors induced during physical transmission of these codeblocks will be detected and optionally corrected at the receiving end of the Coding Layer. The Physical layer serializes and modulates the CLTUs on to the RF carrier for space link transmission.

The Command Operations Procedure-1, commonly known as COP-1, is the protocol responsible for error-free data deliveries. As a closed-loop communication protocol, COP-1 uses a sequential "go-back-n" retransmission technique to correct TC frames rejected by the satellite because of errors. The errors can be either corrupted bit information, as indicated by BCH decoding, or out of sequence TC frames, as indicated by frame sequence count verification. The acknowledgement returned from the satellite is carried through downlink telemetry in CLCWs that are appended to telemetry transfer frames.

For better transmission efficiency, COP-1 allows continued transmission of TC frames within a preset window before acknowledgements for their successful receipt are received. The actual window size varies from mission to mission depending on uplink rate, frame size, and channel noise level. COP-1 also supports a flow control mechanism that prevents the on-board data system from overflow.

In addition to this sequence-controlled service, COP-1 also provides an expedited data service that transfers data without sequence checking and retransmission. While the data will be delivered immediately after their receipt on-board, there is no guarantee for data integrity. Therefore this service should be used only in exceptional operational circumstances with great caution, or where upper layer software is responsible for sequence checking and retransmission.
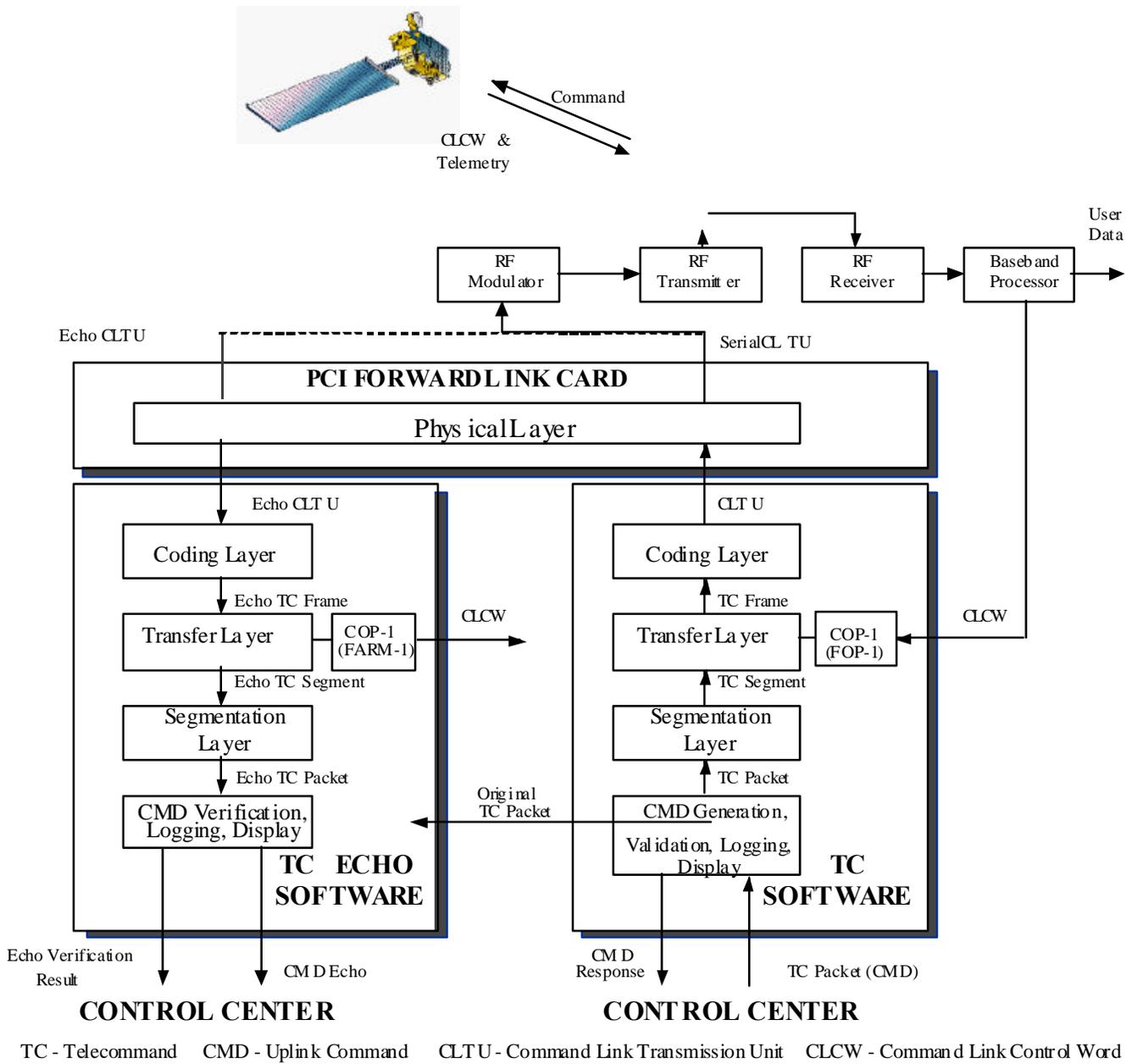

CCSDS TELECOMMAND PROCESSOR

In response to growing demands for CCSDS TC support, TSI TelSys, Inc. has developed a CCSDS Telecommand Processor (CTP) to provide CCSDS Telecommand formatting, protocol processing, and serial transmission for satellite command uplink. In addition, an Echo option to the CTP can acquire transmitted CCSDS telecommands, perform the TC protocol processing on the space receiving side, and extract the commands and verify them against the original commands.

Figure 2 shows a block diagram of the CTP. It consists of three components: TC Software, a PCI Forward Link (FL) Card, and optional TC Echo software. The TC Software is responsible for the ground sending side of CCSDS TC Data Routing Service, including the Segmentation and Transfer Layers, as well as the Coding Layer of Channel Service. The PCI FL Card provides functions for both the ground sending side and space receiving side of the Physical Layer in the Channel Service. The TC Echo Software supports the space receiving side of CCSDS TC Data Routing Service, including the Segmentation and Transfer Layer, and the Coding Layer of Channel Service. Similarly, the TC Software supports the ground sending side of the COP-1, while the TC Echo software supports the space receiving side of COP.

The CTP software is written in Java and C, and can be run on a Sun Solaris and SGI Irix environment. The PCI FL Card can be integrated in Sun UltraSparc workstations with PCI bus and SGI O-200 workstations.

Command Transmission

Once initialized and enabled, the TC software receives commands in TC packets from users via an Ethernet connection using the TCP/IP protocol. The received commands are validated against a set of user-defined parameters. If any errors are found, such as invalid spacecraft ID or wrong data length, the command will be rejected and users informed. Optionally the received commands can be echoed back directly for link verification. The validated commands are logged and then processed. Each input TC

Figure 2.   CCSDS Telecommand Processor Block Diagram

packet provides a specific Multiplexing Access Point (MAP) ID and VC ID for routing. Based on the MAP ID, the TC packet is segmented and tagged with the MAP ID for multiplexing with TC segments of other MAPs on the same VC. Next the TC segments are formatted into TC frames with the assigned VC ID. CRC parity is calculated for and appended to the end of each frame. The TC frames of one VC will be multiplexed with TC frames of other VCs in a queue for transmission. Up to 64 MAPs and 64 VCs can be supported.

To meet a wide range of mission requirements, the Segmentation Layer processing can be optionally bypassed. In this case, each TC packet will be formatted into one TC frame without a segmentation header. It is the user's responsibility to ensure that the TC packet size is not larger than the maximum TC frame size specified. Another option is packet aggregation. When the aggregation is turned on, multiple small TC packets may be aggregated into one TC segment and then one TC frame, provided their total length is within the limit of maximum frame length. There are several parameters that users can specify to affect packet aggregation. The maximum number of aggregation packets tells the TC software to wrap up the TC segment in process when the number of TC packets aggregated has reached this limit. In order to avoid undesired delay in the aggregation process, the TC software uses the aggregation timeout value to determine when to close out a TC segment for transmission even though its length is still smaller than the maximum frame length and the number of TC packets in the segment is still less than the maximum specified.

Once a TC frame is released for transmission, it is encoded with Bose-Chaudhuri-Hocquenghem (BCH) code. Each of 56 information bits are accompanied by 7 parity check bits and a filler bit to form a 64 bit code block. A TC frame is encoded into multiple BCH code blocks with possible filler bits at the last block. If a sufficient bit transition density is not guaranteed for the physical channel, then the encoded data can be randomized (with randomization option ON). Finally the TC software encapsulates the encoded and randomized data with a start sequence and a tail sequence to form a Command Link Transmission Unit (CLTU), which is the data structure that carries the TC data as a contiguous series of encoded TC codeblocks across the TC Channel Service. Before passing this CLTU to the PCI FL Card for actual transmission through the space link, the TC software can log it into a file for later verification.

The Forward Link (FL) Card is a full-length PCI card integrated in a Sun or SGI workstation with a PCI bus. It receives the CLTU from the TC Software, serializes it, and transmits it through an RS-422 serial port. Both Physical Layer Operations Procedures, PLOP-1 and PLOP-2, are supported. The FL Card generates acquisition sequence, and the pattern of which is specified by users, prior to CLTU transmission. All tail patterns specified in the past and current CCSDS recommendations are selectable by the user. Idle sequence, the pattern of which is also specified by users, can be optionally inserted before the first CLTU, after the last CLTU and between the CLTUs. The output clock may come from either an internal or an external source.

The TC product implements CCSDS TC COP-1. The main purpose of COP-1 is to provide a sequence-controlled transmission, known as the AD service, which ensures a high probability of success. The TC software is responsible for the ground sending part of COP-1; called the Frame Operation Procedure (FOP-1), and the TC Echo software for the spacecraft receiving end of COP-1, called the Frame Acceptance and Reporting Mechanism, or FARM-1.

The service is based on an automatic request for retransmission procedure of the "go-back-n" type. The procedure consists of sequence-control mechanism both on the ground and on the spacecraft. It also uses a standard report returned in the telemetry downlink, the CLCW. The TC software receives CLCWs from the return link baseband processor and uses it to verify the acceptance of previously transferred TC frames. Retransmission is initiated if one or more frames are determined to be lost. The CLCWs can also be logged and displayed. In addition to the AD service, the BD service that provides an expedited but not guaranteed delivery is also supported.

Command Echo

Complementary to the telecommand formatting and uplink transmission functions, the command echo function can be used for the verification of telecommand formatting and transmission. As shown in (Figure 2), the command echo function is implemented through the PCI FL Card, the TC software and an optional TC Echo software.

In addition to sending out the serialized CLTUs, the TC FL Card can also receive the serial bitstream through a separate input port. Detection circuitry on the card looks for the acquisition; start and tail sequences to delineate and capture echo CLTUs. The captured echo CLTUs are transferred back to the TC Software for CLTU level echo verification. If enabled, the TC software can compare the captured echo CLTU with its original copy logged before the transmission. Any errors will be flagged and reported. All echo CLTUs will be time tagged and logged in files in the order they are received. The echo CLTU can also be displayed on a local terminal.

The echo verification at TC packet level will require further TC processing. The optional TC Echo Software receives the echo CLTUs from the TC software. It first performs BCH decoding on the echo CLTUs. The CLTUs detected with BCH errors are deleted. TC frames are extracted only from the CLTUs with good quality. Next validation check is performed for each TC frame, including the verification of version number, spacecraft ID, frame length, CRC and other header patterns. TC frames that fail any of these tests will be discarded. If in AD service, the TC frames are routed to the assigned VCs for sequence check. Only the frames bearing absolute Frame Sequence numbers that are in the proper up-counting sequential order are accepted. All other frames are discarded. The segments in accepted frames are routed to MAP for TC packet extraction and reassembly. The extracted TC packets can be logged and displayed. At last the echo packets are verified by comparing them to the originals. Any verification error will be reported. The echo packets themselves can be transferred to their originating users. TC Echo software performs FARM-1 functions and generates CLCWs.

Operational Modes

In order to support a wide range of applications, three operational modes are provided: Real-time, Store and Forward, and Test. Command processing functions are the same in all three modes. The only difference is the source of command. The Real-Time mode is used to transmit real-time commands that are initiated from the user. The Store and Forward mode is used to transmit pre-generated commands from a pre-loaded command file. The Test mode is designed for system integration and test. In this mode, the operator can select and transmit commands from a set of commands displayed on a control console in real-time.

Control Interfaces

The CTP operation can be controlled and monitored through Gem™, a TSI TelSys telemetry system management software. Under Gem™, the users can configure the CTP through a local Graphical User Interface (GUI) with a specific set of operational parameters, including operational mode, uplink spacecraft ID, TC processing options, command verification parameters, log file names, etc. TC

processing status at different layers is collected and displayed on a local control console. As an example, (Figure 3) shows the TC Echo software operations main window display.
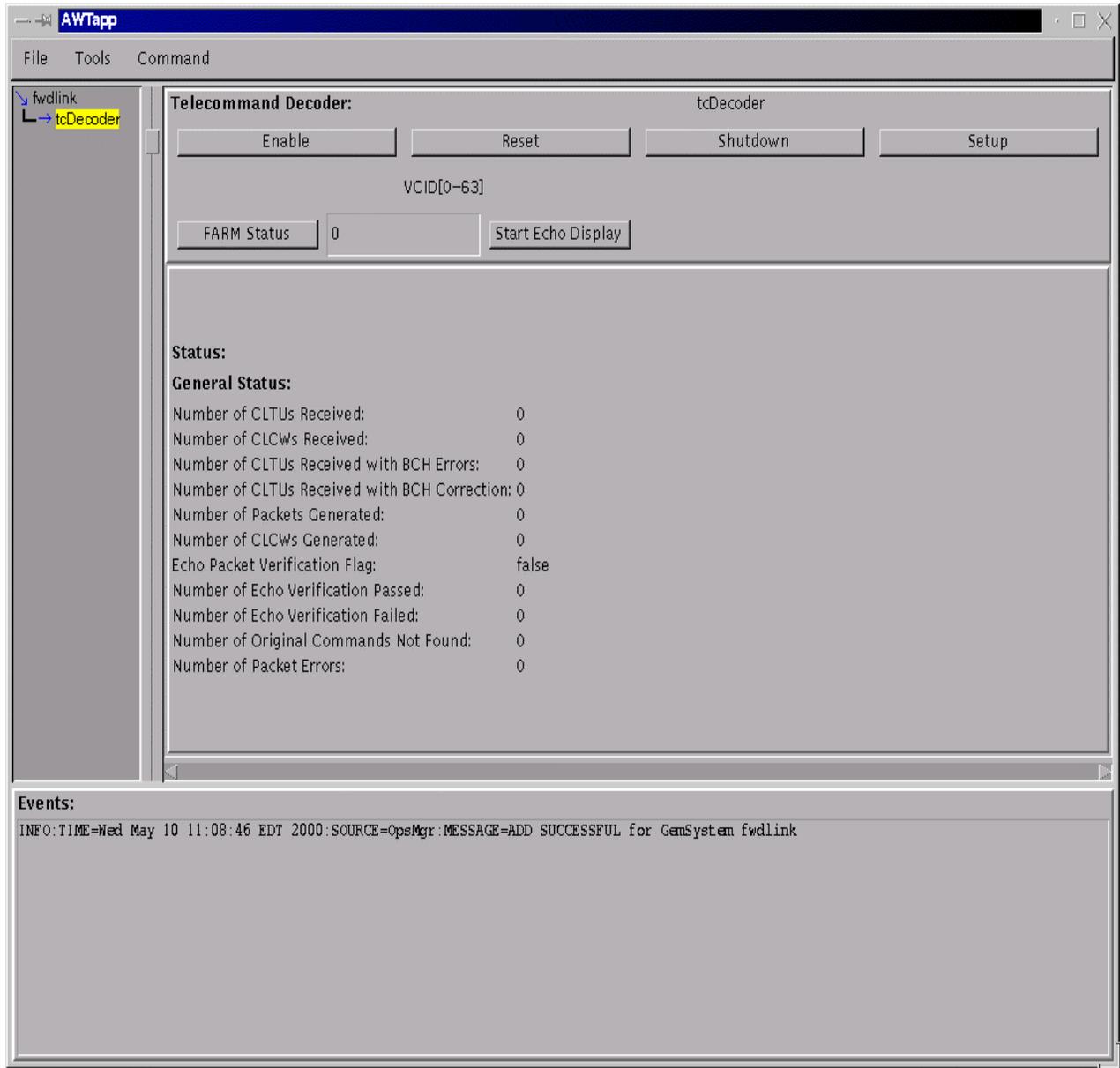
Figure 3.   CTP Echo Software Operations Main Window Display

In addition to the local GUI control, the CTP can be remotely controlled through an Application Programming Interface (API). Through the API, all control functions can be exercised; and all status information can be reported to the remote host. The API allows the CTP to be integrated easily into a user's own operations management.

IMPLEMENTATION ISSUES

Many design issues were encountered during the development of the CCSDS Telecommand Processor. Several interesting ones are briefly discussed in the following paragraphs:

Isochronous Commanding

Support of isochronous commanding was considered in the CTP design. The isochronous commanding requires the CTP to process and transmit user's commands at a programmable fixed time interval. Because the isochronous commanding scenario is not supported by the CCSDS telecommand recommendations, many special considerations have to be given to its implementation. First, the AD service cannot be used since the automatic retransmission will defy all timing requirements of isochronous operations. This means only the unreliable BD service can be used for isochronous commanding support, hopefully on a rather reliable link. Second the timing is complex when a stream of isochronous commands is multiplexed with other commands to be transmitted over the same physical link to the satellite. Different queues need to be set up to buffer and process these commands separately so a large normal command will not prevent an isochronous command from being transmitted on time.

The CTP software, written in Java, is designed to run on a Unix environment. Since the Unix environment provides poor real-time response at best, it can not be relied on to guarantee the isochronous timing. Therefore, the CTP design allocates this function to a dedicated hardware queuing and timing control on the PCI Forward Link (FL) Card. Based on the programmed time interval, the PCI FL Card will transmit each isochronous CLTU at equally spaced times. Sophisticated logic allows other CLTUs to be transmitted if there is enough time for its transmission before the next isochronous CLTU transmission begins.

Command Buffering and Priority Handling

The CTP provides multi-stage buffering for user commands before they are processed and transmitted. The CTP also supports two-levels of priority. Because of the priority handling requirement, multiple queues have to be implemented in order to process high-priority commands ahead of low-priority ones. More priority levels will require more buffering queues, the management of which becomes a significant burden on the CTP software.

Number of Command Paths to be Supported

The CCSDS TC recommendation allows a mission to use up to 64 Virtual Channels (VCs) and up to 64 MAPs for each VC. Each VC/MAP combination should be treated as a command path independent of others. Theoretically there could be 64 x 64, or 4096 command paths to be supported. As within the COP-1 engine, each path will require a dedicated queue in order to support the multiplexing of TC frames from different paths. Again the management of all 4096 possible paths is non-trivial and potentially the biggest drain on system resources and the drag on system real-time performance.

Buffer Clearing

As mentioned above, the CTP provides internal buffers at different stages for user commands to be temporarily queued prior to their process and transmission. In real-life applications, there is a need to discard all queued commands and start with new commands. One option is to maintain the current processes and only clear all commands from the buffers. However, further analysis shows that there are potentially too many queues in the telecommand process, especially in the core Transfer Layer. With a potential 4096 command paths in operation, and each one may be in a different stage of processing, there is too high a risk for an error to occur even with rigorous testing. The best option is to kill and restart the core process so it can be assured that the process is in a known state with clean buffers.

Command User Interface Standard

Like its counterpart in the CCSDS return link, currently there is no standard for the contents and formats through which command information is delivered to the uplink system. The CTP defines a 26-byte header format for each command. The header includes the information relevant to the command such as version, a unique command ID, data type, length, spacecraft ID, and station ID, etc. However, little has been done to standardize this layer of interface. As such, more often than not, a customer would want to have a different format for his system even with just the same set of information. As result, the code has to be customized and a different version has to be maintained. It would be much more efficient if CCSDS can define this interface as part of its recommendation so the time and efforts for providing such systems can be significantly reduced.

POTENTIAL APPLICATIONS

The CTP is a very versatile product built for many types of applications. It can be used at ground stations for supporting CCSDS satellite uplink. Its TC echo software can be used in the same configuration for closed-loop testing at different levels at the station. Moreover, the CTP is an ideal tool for the satellite integration and testing groups to use as an effective tool to test satellite on-board data systems. Its testing mode can be used for step-by-step debugging and trouble shooting. Its command echo verification automatically detects anomalies and reports errors. Its extensive logging and display capability enables the user to examine data at every stage for format and content errors.

CONCLUSIONS

A commercial CCSDS Telecommand Processor (CTP) has been added to TSI TelSys Inc.s' telemetry processing product family, along with the Front-End Procecssor, Service Processor, Data Simulator and other CCSDS processing modules. The CTP supports both the TC uplink processing for sending-end functions as well as the echo processing for receiving-end functions. Because the CTP provides multiple operational modes and extensive data logging and display functions, it is a good tool for ground station mission support, and also a powerful tool for satellite integration and test.

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