CCSDS Ground Software Testing Using Onboard Telecommand-Telemetry Simulator

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Abstract— **The Consultative Committee for Space Data Systems (CCSDS) is an organization established by the member space agencies. ISRO involves as an observer agency for CCSDS. CCSDS defines a standard set of protocols to be followed. CCSDS promotes interoperability and cross-support among cooperating space agencies. CCSDS Telecommand (TC) and Telemetry (TM) protocols are uniform standard across globe.**

Telemetry gives the overall health of all the subsystems onboard along with measurement/experimental data. For effective control of various satellite subsystems, under all conditions, a highly efficient and responsive telecommand system is absolutely essential, as telecommands are used to control spacecraft operations remotely through ground checkout (during testing) or ground stations (during mission). Any wrong generation of command can be catastrophic and can lead to mission failure.

In order to support robust command operations, CCSDS complied telecommand management and processing {Command Operation and Frame Operation Procedure (COP/FOP)} was developed. Command Operation and Frame Operation Procedure (COP/FOP) form an integral software for the Telemetry and Telecommand Processor(TTCP) which was designed by Spacecraft Checkout Group (SCG) of U. R. Rao Satellite Centre, Indian Space Research Organization (ISRO) as a part of 'Make in India' campaign .

TC Processing and Management Software must be deployed for all CCSDS and CCSDS-like satellites including Indian communication satellites and Indian Remote Sensing satellites. Keeping in mind the high reliability requirements and risk involved in a spacecraft mission, any instrument which is interfaced with it (in this case, TTCP) needs to undergo detailed testing, proper verifications and validations. Towards the same, an "onboard Telecommand and Telemetry" Simulator is designed to act as a stub to the COP/FOP software modules during testing. This paper briefs about features of telecommand management and processing for TTCP, design approach used for the onboard TC-TM simulator. It also briefs about the test cases designed and the testing approach taken.

Keywords—CCSDS, TTCP, COP, FOP

I.   INTRODUCTION

Spacecraft Checkout Group has developed CCSDS complied Telemetry and Telecommand Processor (TTCP) to support Checkout requirements of ISROs Communication and Remote Sensing Satellites. The uplink communication to a spacecraft consists mainly of Telecommands, which are
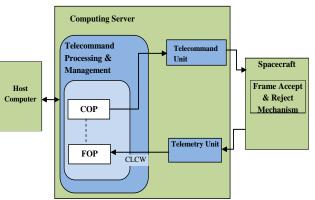
TTCP

Figure 1: The TTCP ground system with COP, FOP and its interfaces.

executed onboard to perform desired tasks, the TM downlink provides spacecraft health data, payload data and feedback for the Telecommands received. The TTCP is an inhouse developed system which controls the TM and TC links to the spacecraft. In particular, it establishes the links to the spacecraft complying with the PHY(physical), the channel coding and synchronization and packet data standards suggested by CCSDS.

The system comprises of separate telemetry and telecommand hardware units which are interfaced to the external world through a computing server as shown in figure 1 . The COP/FOP is the software implementations of the Telecommand packetization, randomization, processing of feedback (which comes in TM) and ARQ (Automatic

Repeat Request) protocols for CCSDS. This module can be modelled as a state machine which transits based on the feedback received or directive requests as defined in CCSDS standards. The main objective of this paper is to discuss testing of this software. Note that as this software interfaces with the spacecraft, it is required to design a stub which can mimic the spacecraft to facilitate testing. This stub, which will be called as CCSDS TMTC simulator henceforth, should be intelligent enough to modify TM to bring out the state changes in the COP. In the following sections, we elaborate on this simulator and more importantly the design and execution of test cases for ascertaining proper functional testing of the COP/FOP module. In section II brief description of the CCSDS standards, the ground system, and a state machine view of the same, a precise design description of the TMTC simulator is provided. In section III testing approach is outlined. The paper is closed with concluding remarks in the final section.

II. PRELIMINAIRES

A. Consultative Committee for Space Data Systems (CCSDS)

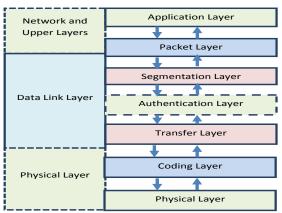CCSDS defines the layered architecture as shown in figure 2.

Figure 2. CCSDS Layered Architecture

CCSDS supports three ways of commanding [3], which are described below.

1. BD frames: BD stands for ByPass Acceptance Check and Data. BD frames will get transmitted only once. This is a best effort delivery mechanism.

2. AD frames: AD stands for Acceptance Check and Data. In AD frames, retransmission of commands will happen if the response received from Communication Link Control Word (CLCW : from Telemetry) is not as expected. This is analogous to a ARQ which retransmits frames based on feedback, the feedback being piggybacked with TM as CLCW. This ensures higher reliability but suffers for greater delay.

3. BC frames: BC frames involves transmission of control commands which causes a defined control action onboard, which is then reflected in CLCW.

In addition to these, Directive Requests are defined in CCSDS protocols which can be used for configuring the COP.

B. Ground System

TTCP Telecommand Processing and Management Software implements COP and FOP segment where COP is the telecommand protocol which generates, packetizes and transmits the commands to Telecommand Hardware Unit which in turn channel codes, randomizes, adds synchronization structures (e.g., preamble, idle patern etc.), modulates the command and sends it to spacecraft.

Onboard, the frames are managed by Frame Accept Reject Mechanism (FARM). Based on Communication Link Control Word (CLCW) received from the FARM and the current state of COP, FOP will judge the command transmission and decide on a retransmission if the need be so. The CLCW, as mentioned earlier acts as a composite ACK/NACK for command reception; it is embedded in the TM. The details of CLCW have been listed here; can be found in CCSDS standards.

CLCW consists of following information:

- Control Word Type – 1 bit
- CLCW Version Number – 2 bits
- Status field – 3 bits
- COP in effect – 2 bits
- VCID – 6 bits
- Reserved Space – 2 bits
- No RF Available – 1 bit
- No bit lock – 1 bit
- Lockout – 1 bit
- Wait – 1 bit
- Retransmit – 1 bit
- FARM-B Counter – 2 bits
- Reserved Space – 1 bit
- Report Value – 8 bits

A modular approach is taken in architecting Telecommand Processing and Management Software to support pipelining and parallelism which processing TC and TM. The software is decomposed into five major functional blocks [4]:

➢ TC Processing and Management Control
➢ TC Processing and Management Monitor
➢ TC Frame Generator & Transmitter
➢ Bypass CLTU generation
➢ CLCW processing
➢ Log & Display
➢ TC Echo

C. States of TC Pocessing and Management Software

TTCP TC Processing and Management software can be modelled as a state machine 6 states. Note that this state machine description is again in compliance with CCSDS. Each request from host will be validated, processed as per state of TC Processor[3]

- **Active (S1) :** This is a normal state where there are no recent errors and flow control problems.
- **Retransmit Without Wait (S2):** This state describes that 'Retransmit' flag is `on` in CLCW but there are no exceptional circumstances.
- **Retransmit with Wait (S3):** Software enters in this state if 'wait' flag is `on` in CLCW.
- **Initializing without BC Frame (S4):** TC Processing and Management software is in S4 state after receiving Initiate AD Service (with CLCW check) directive while in Initial state. A successful CLCW check will result in a transition to S1.
- **Initializing with BC Frame (S5):** The software is in S5 state after receiving BC directives. A successful transmission of BC request and a clean CLCW will result in transition of S1.
- **Initial (S6):** Initial state is the first state of TC Processor.

The state transition occurs based on the telemetry reception from Telemetry Unit and Directives received from the Automatic Checkout Software system (ACSS). The CLCW is extracted from the received telemetry frames and handed over to FOP by the TM unit. FOP and subsequently COP, process these CLTU extracting Sequence number, retransmit and lockout or lockout flags etc. The value of these flags initiates a state transition. A sample state transition diagram is shown below.
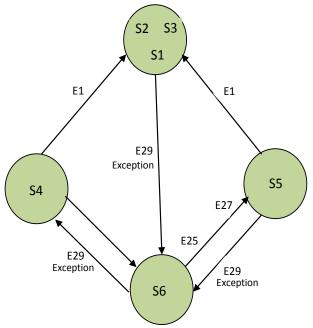

Figure 3. Example of a State Transition Diagram

TABLE I.   EVENT DESCRIPTION

Event Number	Event Details
E1	CLCW arrives in form of valid COP-1 Pattern as: Lockout Flag = 0, N(R) = V(S), Retransmit Flag = 0, Wait Flag = 0, N(R) = NN(R)
E25	Receive Directive From Management Function Initiate AD Service (with CLCW check) Directive, BC_Out_Flag = Ready
E27	Receive Directive From Management Function Initiate AD Service (with Set V(R) Directive), BC_Out_Flag = Ready
E29	Receive Directive From Management Function Terminate AD Service Directive

N(R) = Frame Sequence Number in CLCW
NN(R) =Next expected frame sequence number
V(S) =Transfer frame sequence Number
Table I describes the state transitions as shown in figure 3. For a precise view of the COP as a state machine encompassing almost all possible state transitions refer section III.

D. CCSDS TM-TC Simulator

CCSDS TM-TC Simulator is a software package designed to test and evaluate TC Processing and Management Software. The software allows the user to configure and simulate CCSDS/ CCSDS like Telemetry Frames . The software has the intelligence to execute onboard FARM (Frame Accept and Reject Mechanism) and supports close loop operations with respect to Telecommand and Telemetry.

Salient Features of CCSDS TM-TC Simulator with respect to Telecommand includes:

- Reception of command packets from COP .
- Depacketization and extraction of CLTU(Command link transfer unit)
- Extraction of decoder information
- Extraction of frame type (BD,BC, AD)
- BCH Parity Removal
- Derandomization of data.
- CLCW formation based on received Communication Link Transfer Unit(CLTU).
- Display of CLTU
- Display and log of command codes with respect to time
- Display of Frame type

- Acknowledgment Handling between COP and Simulator.

Besides processing TC and formation of CLCW the software also needs to form TM packets which conform to the syntax and semantics decided for the communication from the particular spacecraft it is trying to mimic. Towards this the simulator does the following.

- Configuration of Primary Header Information
- Multiplexing of CLCW if needed for decoders.(Note nominally a Spacecraft has 2 decoders thus there are two redundant links present for commanding, these CLCW for each of these links are different and need to be multiplexed if required)
- Configuration of Master Frame information and sub-frame information (no. of sub-frames, Frame Sync Code, Frame Sync Code Length, Frame Length, Frame ID, OBT)
- Configuration of sub frame information (spacecraft id , frame length)
- Provision for fixed pattern, incremental pattern, variable pattern and user defined pattern for TM frames.
- Cyclic Redundancy Check (CRC) computation for each sub-frame
- Master frame formation (which includes HouseKeeping and Playback data).
- Dissemination of data to clients and COP.

III. TESTING THE GROUND SYSTEM

The ground system needs to be tested in order to identify any, errors or omissions against the actual requirement, Before communicating with the spacecraft thorough testing is carried out to clear ground software and its interface to the spacecraft. In this section the test design and plan for the Telecommand processing and management software is briefed.

A. Test Setup

Spacecraft Checkout Computers(SCC) are loaded with Automatic Checkout Software System(ACSS). ACSS is a collection of programs used for final TM and TC processing and data analysis in Checkout. During testing phase, ACSS is used to select the required mode of commanding, and send directives to configure the COP before sending a command. A telecommand sent through ACSS is received via COP, which is then converted to a CLTU and sent to the CCSDS TMTC Simulator. The simulator will acquire the CLTU, depacketize , remove parity byte, derandomize and display the command code. It will also provide the information whether command sent is BD, BC and AD frame. It will send the acknowledgment of command received to COP which inturn will provide

acknowledgement to ACSS. Note that acceptancing the CLTU and acknowlegding the same is a function of the ground Telecommand unit. Thus, the CCSDS TMTC Simualtor not only simulates the TM/TC processing on board, it simulates the TC hardware unit too, enabling the testing of the TTCP software bypassing channel coding and modulation as performed by the TC hardware. Consequently, the simulator will form CLCW based on the type of frame received from COP. CLCW will be further embedded in the TM frames. In case of AD mode commanding the simulator will imitate a closed loop and assist in testing of the ground segment for the same. While forming the CLCW the simulator takes on the functions of onboard FARM. It might be required to manually form the CLCW while testing to create anomalous test cases, the simulator facilitates that too. Figure 4, illustrates this test setup and the scope of the CCSDS TM TC simulator.
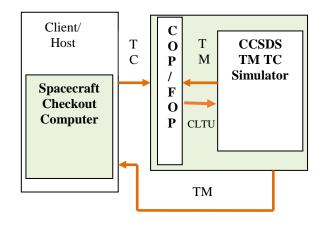

Figure. 4 Test Setup

B. Test Case Design

As indicated earlier , COP implemented in TC processing and management software can be understood as a state machine where transitions are governed by either "Directives" or "CLCW" extracted from TM. Figure 5, depicts the evolution of the software in response to CLCW. The effect of directives is shown in figure 6. Note that, for ease of comprehension the effect of directives and CLCW on COP has been shown seperately. However, it is impossible to partition the test cases in such a fashion. In other words, while designing test cases the test vectors include a sequence of CLCWs and Directives which bring about a desired state change for complete exploration of all its states.. The figures tend to illustrate an abstract view of the COP, for details of CLCW and Directives refer [3]. An exhaustive test of this software as a state machine, though possible with the developed tools, is impratical and unneccesary. From the figures it is evident that in some cases multiple input scenarios can influence same transitions. Also same input scenario can have similar effects in different states. Observing the same, test vector sequences of directives(issued from ACSS) and CLCW settings(configured at the simulator) were reduced which avoided traversing a single path more than once (with few

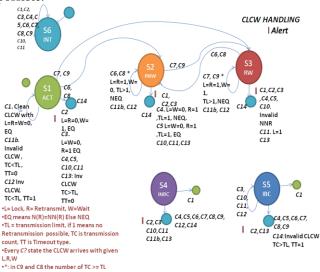exceptions) and restricting the repetation of inputs wherever possible.

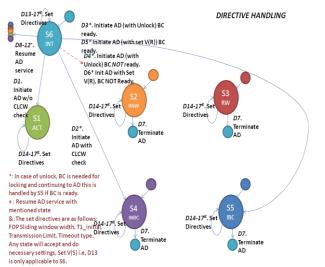**Fig. 5 State transitions based on CLCW reception**

Fig. 6 State transitions based on Directive reception

An example test sequence is enumerated below. This test sequence also happens to be one of the nominal commanding sequences for Spacecraft.

TABLE II.   TEST CASE

Focus	From	To	Events to be simulated (Sample)
S6	S6	S6	C1,C2,C3, D16,C4,C5, D16,C6,C7,C9, C10,C11

The test is being carried out state wise. The test cases are generated and seggregated based on state information. In the example shown in Table II, colum Focus indiates that all the

tests corresponding to state 6 will be tested. The various events that can occur in state 6 will be simulated and the events are listed in the column 'Events to be simulated' in Table II. The affect of event execution may change the COP state from initial state to other state which is defined in Column 'From' and 'To' respectively of Table II.

For Example if Case1 is simulated in state 6, no action will be taken resulting in unchanged COP state.

In addition to above tests, other functional and performance tests such as variable length commanding, continuous commanding, verification of frame transmission to multiple clients, abrupt disconnection of clients, abrupt closure of application, abrupt network failures etc., were also performed.

IV. CONCLUSION

The successful implementation and testing of CCSDS based Telecommand Processing and management software for in-house developed TTCP has resulted in significant cost reduction for checkout operations.Even, the development of onboard Telemetry and Telecommand Simulator has provided a lot of options for simulation and testing of ground equipments/softwares prior to interface them with spacecraft.The intense testing of CCSDS Telecommand Processing and Management Software has given the confidence to replace costly procured TTC Processor Units with high Annual Maintenance cost.

Having the TTCP units and corresponding simulators, designed and developed in-house, the required expertise and resources are readily available for future requirements and maintenance.Moreover, with thorough testing of this ground software using simulator has given lot of confidence to even deploy the system to various ground stations as well. In future, the software will be upgraded for commanding in both CCSDS and Non-CCSDS based projects.

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