OPERATIONAL VALIDATION OF CFDP ON PACKET TELEMETRY AND TELECOMMAND LINKS

Marjorie de Lande Long
(marjorie@delandelong.com)
Ian de Lande Long
(ian@delandelong.com)
I B + M A de Lande Long Software + Consultancy
Seeheim, Germany
www.delandelong.com

Gian Paolo Calzolari
(Gian.Paolo.Calzolari@esa.int)
European Space Agency, ESOC D/TOS
Darmstadt, Germany

ABSTRACT

The Consultative Committee for Space Data Systems (CCSDS) is defining a CCSDS File Delivery Protocol (CFDP) capable of use between systems of multiple endpoints. A number of prototype CFDP implementations have been developed and some interoperability tests performed over UDP links. This paper reports on a study of CFDP running over more realistic packet telecommand and packet telemetry links. An integrated test system was constructed by adapting existing commercial and prototype software. This was used to study a number of scenarios which are likely to be important in early operational use of CFDP in space. This approach has been found to be useful both for testing a protocol during its development and specification and for verifying the impact of new approaches to Space Missions.

KEY WORDS

CFDP, Packet Telecommand, Packet Telemetry, CCSDS, File Delivery Protocol

INTRODUCTION

The Consultative Committee for Space Data Systems (CCSDS) has been working to define a CCSDS File Delivery Protocol (CFDP) capable of use between systems of multiple endpoints (for example spacecraft, ground control systems, planetary rovers). The protocol supports configurations of varying complexity ranging from simple systems with a single ground station and spacecraft up to systems with many spacecraft, multiple hops and multiple pathways using both reliable and unreliable underlying links. The links may suffer long periods of non-availability due to occlusion. CFDP has been designed and specified by CCSDS Subpanel 1F. The specification (see reference 1) currently has Red Book status which means there is enough detail for implementations to be built but that the specification has not yet been approved by the CCSDS member agencies.

A number of prototype implementations are being developed for ground and space use. Some interoperability tests have been run between the different implementations to check for possible weak points and to improve both CFDP definition and implementations.

Most of the testing so far has used Internet protocols, specifically UDP, for the underlying communications layer. However, in operational use, CFDP will generally run over space link protocols, which have many different characteristics compared to UDP. Tests of CFDP in the space environment are planned for 2001 using the STRV 1d spacecraft.

Meanwhile, it was decided that it would be useful to study the behaviour of the CFDP protocol when it is running over one of the space link protocols. The purpose of the study was to validate CFDP over simulated packet telecommand and telemetry links.

The study contained a number of areas of work:

- construction of the Integrated Test System
- definition of the test scenarios
- execution of the test scenarios
- evaluation of results
- production of a set of recommendations and warnings on CFDP.

The work was performed during the period March to November 2000. This paper describes the CFDP Integrated Test System, looks at some of the scenarios studied, discusses some of the recommendations which emerged from the study, particularly on the subject of flow control, and concludes that the testing of higher layer protocols over simulated links is a valuable tool.

The test system is available for free licensing to CCSDS Member Agencies wishing to simulate the space link and to examine the effect of using CFDP on their spacecraft operations and monitoring. This is important given that CFDP can be considered a major step towards advanced data links and new Telemetry and Telecommand Architectures.

INTEGRATED TEST SYSTEM

The Integrated Test System was built from two existing software elements. These are the:

- Packet Telecommand and Telemetry Simulator of I B + M A de Lande Long Software + Consultancy
- CFDP implementation of the European Space Technology Centre (ESTEC).

The simulator is described in reference 2. The telecommand components of the simulator are also used in operational spacecraft control systems.

The structure of the Integrated Test System is shown in figure 1.

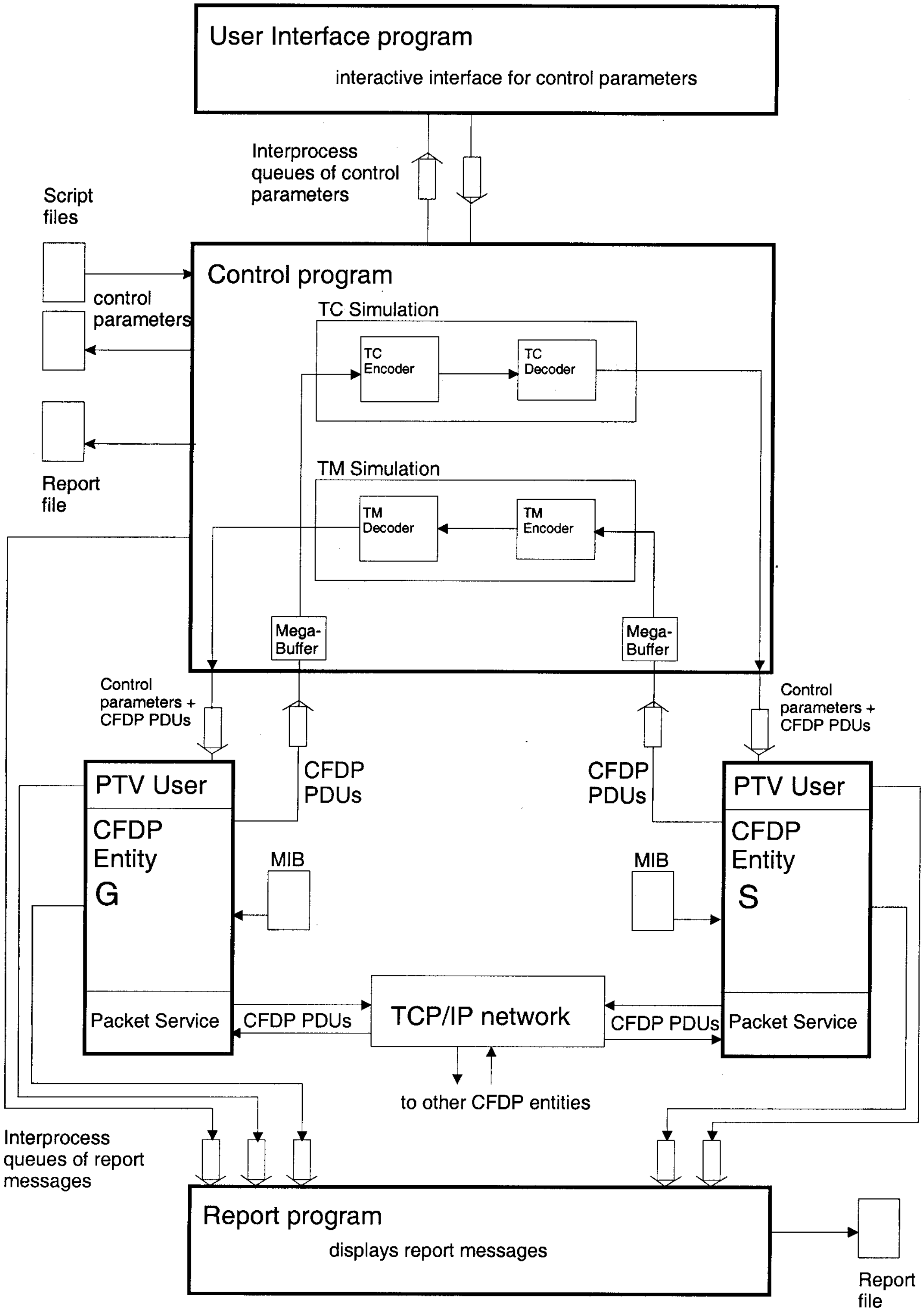

Figure 1: Structure of the Integrated Test System

The running of the system is controlled by a modified version of the Packet Telecommand and Telemetry Simulator, called the Control program. In total, the test system uses five processes:

- the Control program
- two instances of the CFDP entity: G (ground) and S (space)
- the User Interface program
- the Report program.

The Control program has two pairs of interprocess message queues for sending and receiving CFDP protocol data units (PDUs). One pair is used for communicating with the G entity and the other for the S entity.

When PDUs arrive from the G entity, they are (optionally) queued in a mega-buffer and then “uplinked” as TC packets via the TC Encoder. A mega-buffer is a buffering system in main memory which can accept megabytes of data. When a packet is delivered by the TC Decoder, it is sent via the other interprocess message queue to the S entity. Similarly, PDUs received from the S entity are queued and then “downlinked” through the TM Encoder and TM Decoder and delivered to the G entity.

The Control program starts and stops the other processes in a run. It takes parameters from a script file and from the interactive user interface. Parameters input interactively during the run are saved to another script file so that the run can be repeated if required. Also, the Control program can use the interprocess message queues for sending control messages to the CFDP entities.

Each CFDP entity has its own Management Information Base (MIB) file. The MIB file can include the addresses of further CFDP entities running on other machines. This permits the execution of tests which require more than two entities.

TEST SCENARIOS

The European Space Agency (ESA) are primarily interested in the use of CFDP in simple scenarios with two CFDP entities, representing a spacecraft and a ground system. ESA expect that their use o CFDP in the medium term will be for this kind of application.

The main aim of the study is to validate the combination of CFDP with Packet Telecommand. Therefore, the test scenarios were chosen to concentrate on this combination. For example, how should the telecommand link be configured for a particular kind of CFDP transfer? What is the effect of the mission type - for example, Near Earth or Deep Space?

There are a number of issues to be addressed by the tests:

- Choice of values for Packet Telecommand parameters
- Short or long loop delay (near Earth or Deep Space)
- Interruption of connectivity
- Simplex connection (“blind” transmission)
- Highly unbalanced bandwidth (slow uplink, fast downlink)
- Multiple simultaneous file transfers
- Link errors
- Concurrent non-CFDP traffic on telecominand and telemetry links
- Concurrent CFDP traffic to additional CFDP entities

- Choice of values for CFDP timers
- Choice of CFDP acknowledgement options

The defined test scenarios were implemented as script files and executed on the Integrated Test System and the results were analysed.

Checkout scenario: to demonstrate that the integrated test system is working.

The single test in the checkout scenario has been run successfully.

Loop delay scenario: compares long loop delay against short loop delay.

Three tests have been run for the loop delay scenario. The first two compare a short loop delay (2 seconds each way) against a long loop delay (50 minutes each way). A third test has the long loop delay and introduces errors on the uplink.

All three tests have been run successfully. The CFDP timers were set to very long values to allow for the loop delay, and the CFDP transactions ran well in these conditions. In test with errors on the uplink, there were 17 data packets sent in response to the NAKs from the receiving end.

Unbalanced bandwidth scenario: to compare highly unbalanced bandwidth against more equal bandwidth.

Two tests have been run for the unbalanced bandwidth scenario. They compare a more unbalanced bandwidth (downlink 500 times faster than uplink) with a less unbalanced bandwidth (downlink 12.5 times faster than uplink).

Both tests have been run successfully. The highly unbalanced bandwidth did not have any effect on the CFDP behaviour. Differences between the two tests were caused by the different uplink rates.

Multiple transaction scenario: to study behaviour when multiple file transfer transactions are running simultaneously.

Five tests have been run for the multiple transaction scenario, using different combinations of multiple transactions running simultaneously.

All five tests have been run successfully. Simultaneous transactions running in opposite directions are genuinely simultaneous. The total time for three uplink and two downlink transactions in one test was the same as the three uplink transactions alone in another test.

One-way communication scenario: to study behaviour when there is no downlink communication.

One test has been run for the one-way communication scenario. It uses CFDP Unacknowledged mode. It uses the Packet Telecommand B Service, because the A Service is not suitable for one-way communication. The test has been run successfully.

Interrupted transfer scenario: to study behaviour when the connectivity is interrupted part way through a file transfer. This is intended to examine the case where file transfer begins, the pass ends, and the file transfer is resumed in the next pass. For example, the next pass might not be until the following day.

One test has been run for the interrupted transfer scenario. It uses the Packet Telecommand A Service. One file, size 60K, is uplinked. When part of the file has been transferred, the CFDP transaction is suspended at the source entity. The packet telecommand session is terminated and the uplink and downlink signals are stopped. Later, the signals are restarted, a new packet telecommand session is started and the CFDP transaction is resumed.

The test has been run successfully. There was a CFDP problem: the Suspend PDU did not reach the destination entity, so the transaction was not suspended at the destination entity. This happened because the Suspend PDU was at the end of the queue behind other PDUs for the file.

Link error scenario: to study behaviour in the presence of link errors.

Six tests, divided into two groups, have been run for the link error scenario.

In the first group, various combinations of link errors are tested. All four tests have been run successfully. As expected, the transactions subjected to link errors took slightly longer to execute. One of the tests showed some problems with CFDP Acknowledged (immediate) mode.

In both tests in the second group, a large file (size 2MB) is uplinked with link errors. In one test, the losses are recovered by the Packet Telecommand A Service (COP- 1 protocol) and in the other, the losses are recovered by the CFDP protocol. Both tests have been run successfully. The loop delay was short (0.25 seconds each way), so there was no significant difference in the time taken.

Concurrent traffic scenario: to study behaviour in the presence of concurrent non-CFDP traffic on the telecommand and telemetry links.

There are four tests for the concurrent traffic scenario, which have various combinations of concurrent telemetry and telecommand traffic. All the tests have been run successfully. As expected, the transactions took longer when there was competing traffic. The competing telecommand traffic had proportionately more effect:

Uplink times:

No concurrent traffic	54 seconds
Concurrent 50% of uplink capacity	113 seconds

Downlink times:

No concurrent traffic	22 seconds
Concurrent 80% of downlink capacity	36 seconds

Difficult scenario: to study behaviour in the presence of multiple negative factors.

File transfers are executed in difficult conditions: highly unbalanced bandwidth, long loop delay, uplink and downlink link errors, and two files uplinked simultaneously.

Two tests have been run for the difficult scenario, with multiple negative factors. In one test, the losses are recovered by the Packet Telecominand A Service (COP- 1 protocol) and in the other, the losses are recovered by the CFDP protocol.

Both tests have been run successfully. The loop delay was long (60 seconds each way), so the test with the A Service took slightly longer (17 minutes against 14 minutes). In these conditions, the COP-1 go-back-n protocol has to retransmit many frames each time a frame is lost.

Additional CFDP entity scenario: to study behaviour in the presence of additional CFDP traffic with other CFDP entities.

One main test has been run for the additional CFDP entity scenario. The test requires two machines connected by a network capable of running UDP. The second machine runs two additional CFDP entities.

In the main test, there are transactions to uplink and downlink some files. Simultaneous transactions send files to and from the additional entities. The test has been run successfully.

A test without the additional entities was run as a comparison. The time for the uplink and downlink transactions was the same in both tests. The CFDP traffic with the additional entities had no noticeable effect on the transactions.

CFDP RECOMMENDATIONS AND WARNINGS

The issues arising from the analysis of the test results were written into a report of CFDP recommendations and warnings. The report was presented at the CCSDS Subpanel 1 F meeting, 9-1 0 November 2000. It was agreed that the next version of the CFDP Red Book or Green Books would be amended to take account of most of the issues raised.

The list below shows the titles of the issues. The most important one is the question of flow control. Many of the other points concern parts of the Red Book where the necessary detail is missing or unclear.

- Flow control on interface to underlying communications layer
- Queues of File Data PDUs inside a CFDP entity
- Definition of Keep Alive PDU
- Use Keep Alive PDU after EOF (End of File)
- Simultaneous transactions with same source and destination
- Additional communications channel
- Errors while executing filestore requests
- Cancelling the NAK timer
- Immediate mode
- Timing of responses to NAKs
- Gap to end of file
- Finished PDU positive acknowledgement
- Deferred transmission
- Aggregate entities
- Waypoint to a member
- Handover message traffic
- Unacknowledged mode
- State tables
- MIB definition
- Blue status for Red Book
- Put.request and Transaction.indication

CONCLUSIONS

The CFDP protocol has been run in a set of test scenarios, representing a range of different types of space missions and operating conditions. The tests have demonstrated that CFDP can successfully transfer files over realistic space links, with constraints such as low bandwidth, long loop delays and competing traffic.

The study has also highlighted areas where the CFDP specification needs expansion and clarification, particularly in the area of flow control.

Overall, the study has shown that simulations are a useful tool both for testing a protocol during its development and specification and for verifying the impact of new approaches to Space Missions.

ACKNOWLEDGEMENTS

We would like to thank the developers of the ESTEC CFDP implementation for allowing us access to the source code. Without their co-operation, it would not have been possible to build the test system used in the study.

The paper includes material, including diagrams and tables, extracted from the Final Report of the study "Operational Validation of CFDP (on a Packet Telecommand Link)" under ESOC Contract Reference 14131/00/D/SW.

REFERENCES

1. Consultative Committee for Space Data Systems, CCSDS File Delivery Protocol (CFDP), Red Book, CCSDS 727.0-R-3.2, August 2000 (The latest version of this document is available at *http://www.ccsds.org/red_books.html* and once formally adopted by CCSDS will appear at *http://www.ccsds.org/blue_books.html*

2. Packet Telecommand and Telemetry Simulator *http://www.delandelong.com/tcsim.htm*