# INTEROPERABILITY TESTING OF THE CCSDS FILE DELIVERY PROTOCOL

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## ABSTRACT

The CCSDS recently developed the CCSDS File Delivery Protocol which can operate in configurations from simple point-to-point space/ground systems to complex arrangements of orbiters, landers, relaying spacecraft, and multiple ground facilities. An international interoperability test program has been developed in support of the development and fielding of the protocol. The first phase was successfully completed in the Fall of 2002. The second phase is to be completed about the time of the presentation of this paper.

First phase testing involved five independent implementations of the Core Procedures of the protocol. Since these Procedures are for point-to-point file transfers, only two protocol "entities" were involved in each executed test. The second phase tests other Procedures, which involve multi-hop transferring of files. This phase will involve two separate, independent implementations, with one implementation being hosted on multiple hardware/OS platforms. Each test will involve three or more entities.

## KEYWORDS

File Delivery Protocol, CSDS, interoperability testing.

# OVERVIEW OF THE CFDP

The CCSDS File Delivery Protocol (CFDP) was developed to provide the using community with an efficient and effective file transfer protocol containing design features making it especially effective in the space environment in both performance and operational characteristics.

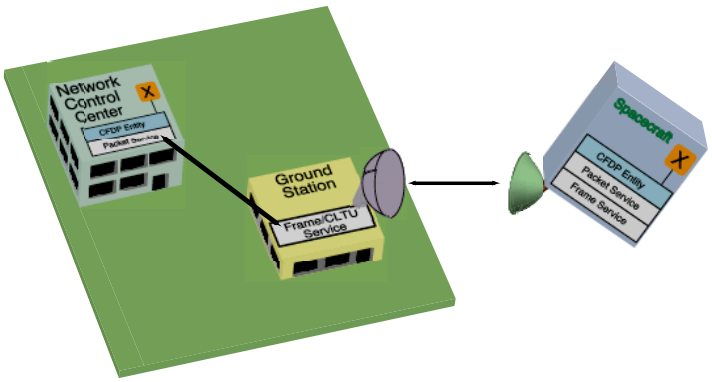
The CFDP provides the capability to transfer files to and from a spacecraft, or among spacecraft. It has the following characteristics:

- Files can be transferred reliably, where it is guaranteed that all data will be delivered without error, or unreliably where a 'best effort' delivery capability is provided
- Files can be transmitted with a unidirectional link, a half duplex link, a full duplex link
- File transfer can be triggered automatically or manually
- File transfer can be point to point between ground and a single spacecraft, or between ground and a destination spacecraft via single or multiple 'relay spacecraft' to a destination spacecraft, or between spacecraft, with or without intermediate 'relay spacecraft'.

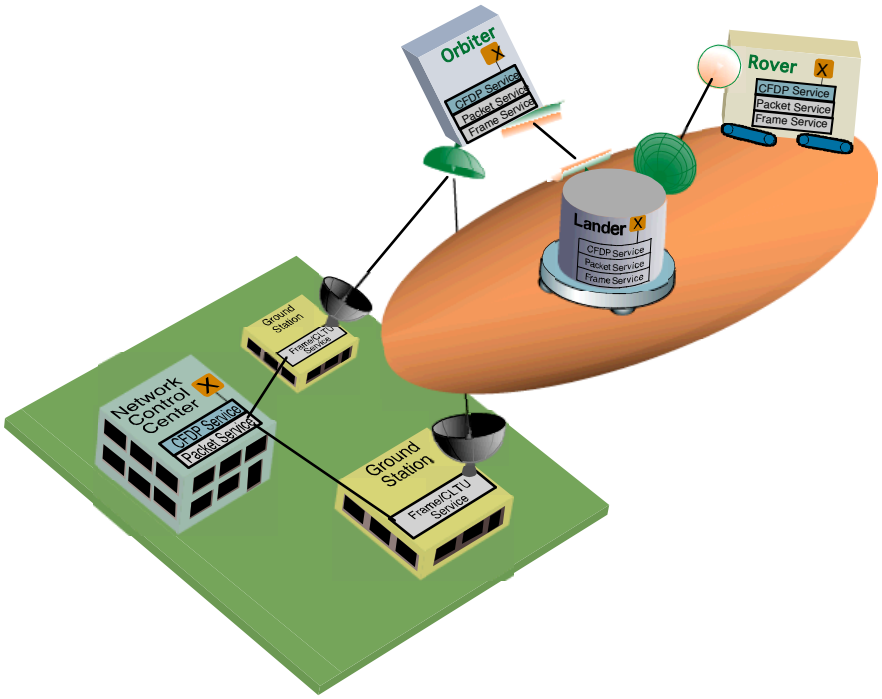
Compared to the common terrestrial file transfer protocols, the CFDP has many distinctive features, including:

- Transfers which can span ground station contacts (time disjoint connectivity)
- Transfers which can span multiple ground stations
- Effectiveness over highly unbalanced link bandwidths
- Minimization of link traffic
- Effectiveness spanning low earth orbit and deep space speed-of-light delays
- End-to-End accountability even through multiple store and forward intermediaries
- Automatic store and forward operation
- Store and forward initiation before the file is completely received at the forwarding entity
- Data availability to the user as the file is received
- Minimization of on-board memory requirements through buffer sharing.

In order to accomplish the above wide variation in tasks while at the same time minimizing the complexity of the required implementation for any particular mission requirements set, the CFDP has a modularized architecture. For simple point-to-point needs, as for a near-earth orbiting spacecraft which directly contacts ground stations, the Core Procedures are sufficient.




In more complex situations where relaying through intermediate spacecraft is required, as, for example, in the case of a Mars rover communicating with an earth station via a Mars lander and Mars orbiter, two options are provided. First, the Extended Procedures may be implemented. These procedures enhance the capabilities of the Core Procedures and provide the capability to deliver files in situations where the source of the file has no direct communication with the file destination and therefore must send the file through intermediate “waypoints”, Alternatively, the Store-and-Forward Overlay (SFO) Procedures may be used. These Procedures operate at the Application layer and utilize only the Core Procedures and do not require the Extended Procedures.

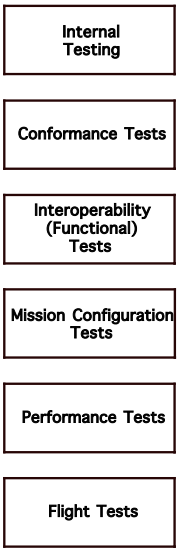



The decision as to whether to use the Extended Procedures or the SFO is strictly implementation specific and rests on many factors. Simplistically speaking and viewing from outside implementation specifics, the most obvious difference between the two methods is that the Extended Procedures provide the option of having Waypoints begin forwarding a file even before the file is completely received by that Waypoint.

Conversely, using the SFO, a Waypoint can begin forwarding a file only after receiving the complete file. Thus, in some but not all mission configurations the Extended Procedures may provide faster end-to-end file transfers. On the other hand, if that feature is not needed, the SFO provides a more detailed reporting capability as to the status and location of in-transit files.

## OVERALL CFDP TESTING

As with any protocol development, there are several parts to a comprehensive and effective testing philosophy. In general, for CCSDS space/ground and space/space communications protocols, testing steps as shown in the figure below are needed. The interoperability testing which is the subject of this paper is only one part of such a testing program, specifically the third block from the top in the diagram.




## INTEROPERABILITY TESTING

The purpose of interoperability testing is to provide a high level of confidence that independent, separately developed implementations operate correctly with one another. This not only increases confidence in the ability to provide cross-support among the implementations, but is a very powerful method of evaluating and improving the readability and precision of the protocol specification document. Interoperability testing among independent implementations quickly pinpoints statements in the protocol definition which are subject to different interpretations, which are unclear, which are or appear to be in conflict with another part of the specification, or which are simply incorrect. It also finds areas which need to be but are not in the specification. Of all of these, perhaps identifying statements in the protocol definition which are subject to different interpretations is the most important, and is also the most difficult to achieve by any other kind of testing. It is of particular importance for international standards, where the nuances of language can be and often are a serious problem.

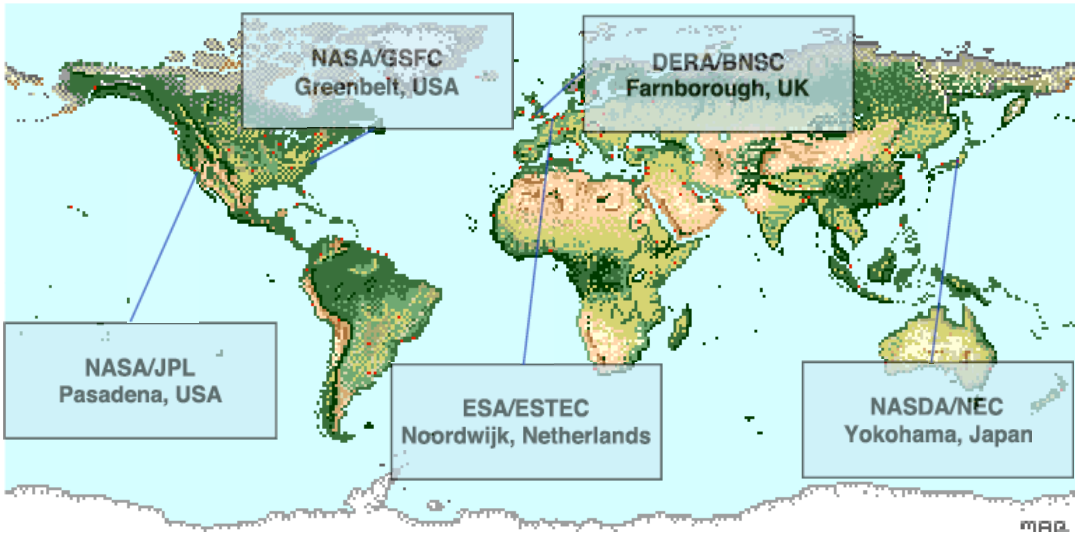
## *CORE PROCEDURES TESTING*

To aid in the finalization of the protocol specification and to increase the confidence of potential users in the CFDP Core Procedures, a series of interoperability tests was designed, documented, and executed among the several different CCSDS member Agencies' implementations of the Core Procedures. Development of the Core Procedures benefited greatly from the inter-agency, interoperability testing program. The program began with face-to-face workshops and over time developed into a worldwide distributed configuration utilizing the Internet. Testing tools and test procedure documents were developed and a great deal was learned not only about the CFDP but also about the processes of such inter-agency testing.

The first Workshop was held in May, 2000, at the Applied Physics Laboratory (APL) of the Johns Hopkins University, and was so productive that it resulted in a series of Workshops. Workshops were held at DERA, Farnborough, UK, in November 2000, and then at JPL, Pasadena, USA, in May, 2001.

Although the face-to-face workshops were very beneficial, they involved extensive travel and therefore were necessarily infrequent, they required that the host organization provide significant amount of equipment, working space, and technical and administrative support and thus were expensive. These were strong motives for developing an arrangement in which the various implementers could test with one another while remaining at their home sites. The Internet was the obvious technology to use to create such a distributed testing capability. It is free, available 24 hours per day, 365 days per year, provides almost unlimited connectivity (i.e., no limit on number of parties involved in tests), and all of the implementers were already connected.

Following the Pasadena Workshop the testing configuration migrated to what has become a worldwide Distributed Inter-Agency Testbed, operating over the Internet. The resulting configuration is shown below. It is especially interesting that the implementers are distributed in a truly worldwide manner, from the Netherlands to the United Kingdom to the east coast of the U.S. to the west coast of the U.S. to Japan, and back to the Netherlands.




Several support items were developed and contributed by various participants to assist in the testing and to place the tests on a common basis so that valid test comparisons could be made and progress assessed. An ESA provided Relay Module tester provides for the insertion of known errors in the protocol stream (either inbound or outbound), including dropping of specific PDU types, insertion of duplicate PDUs, insertion of random noise type errors, insertion of link delays for simulation of deep space environment, etc. The NASDA NEC Conformance Tester provides both the software system and the attendant (software) scripts which allow an implementer to perform true CFDP Conformance tests on his/her implementation of the Core Procedures.

As the culmination of the testing of the CFDP Core Procedures, a series of proctored tests were held as a "Final Exam Week" before requesting that the CFDP go from Red (draft) to Blue (final) status. In most (but not all) cases, the proctor was not one of the implementers, and was located separately from the implementers, Fifteen Test Sessions of approximately four hours each were held with implementers and a proctor. Four hundred ninety tests were conducted, of which four hundred sixty two were successful. Of the unsuccessful tests, areas of the specification which were subject to different interpretations were found, but no true errors in the protocol. While all of the tests were functional, four (all successful) simulated an inter-entity range of 2.7 million miles (mission configuration tests).

## *EXTENDED PROCEDURES TESTING*

Additional CFDP "Extended Procedures", which add the capabilities of store-and-forward file transfers through multiple waypoints in series are now a part of the fully approved (Blue Book) CCSDS Recommendation. The interoperability testing approach was so successful with the CFDP Core Procedures that it has been determined to extend such testing to the Extended Procedures and to the Store and Forward Overlay Procedures. However, at this time there are only two independent implementations of the Extended Procedures (and also the SFO), those by ESA/ESTEC and NASA/JPL. Particularly in the case of the Extended Procedures in which each participating entity,

whether original sender, Waypoint, or final destination, must have the Extended Procedures, and in which each test requires at least three entities, the testing configuration is necessarily more limited than it was for the Core Procedures. To provide the greatest practical diversity among the entities in the tests the JPL implementation will be operated on significantly different host operating systems and platforms. It is planned to have versions of the JPL implementation operating under Linux, Unix, and Apple Macintosh OS X operating systems, on platforms at least including PCs, Macintosh, and a Power Computing PowerTower.

The physical configuration of participants will include the ESA/ESTEC at Noordwijk, Netherlands, NASA/JPL at Pasadena, CA, USA, and the author's facility in Corvallis, OR, USA.

The Test Series for the Extended Procedures are documented in CFDP Notebook Of Common Inter-Agency Tests for Extended Procedures as Test Series F6 through F9, a continuation of the numbering of the tests for the Core Procedures described in CCSDS File Delivery Protocol (CFDP) Notebook Of Common Inter-Agency Tests. It is necessary that those Core Procedure tests be performed on the entities before attempting the Extended Procedure tests.

Test Series F6 demonstrates the basic functioning of the Extended procedures in order to establish a confidence baseline for Series F7 tests, which will initiate thorough checking of the Extended procedures. Test Series F6 utilizes one Waypoint. Demonstrations are made of Unacknowledged and Acknowledged modes, of canceling an ongoing transaction, and of user messages.

Test Series F7 initiates thorough checking of the Extended procedures (utilizing one Waypoint) in Acknowledged mode, including automatic recovery from dropping of the metadata PDU, of each of the positively acknowledged PDUs (EOF and Finished), of the positive acknowledgements to those PDUs, and also simulation of an extremely noisy link in which every PDU except the EOF in each direction is dropped once. The Deferred Transmission Procedure operation, and handling of a fault are demonstrated.

Test Series F8 checks the functioning of the forwarding methods (*Incremental and Immediate* and *In Total Upon Custody Acquisition*) of the Waypoint. Test Series F8 utilizes one Waypoint.

Test Series F9 demonstrates the functioning of a Waypoint that is positioned between two other Waypoints. Test Series F9 utilizes three Waypoints.

**Extended Procedures Test Series**

| CFDP Functional Test Series | Features Exercised |
|---|---|
| F6 | Unreliable Transfer via One Waypoint, and Reliable Transfer via One Waypoint |
| F7 | Reliable Transfer via One Waypoint |
| F8 | Checks the functioning of the forwarding methods (*Incremental and Immediate* and *In Total Upon Custody Acquisition*) of the Waypoint. Utilizes one Waypoint. |
| F9 | Transfer via Multiple Waypoints in Series, and Currently Undefined-Reliable Transfer via Multiple Waypoints in Series |

## *STORE AND FORWARD OVERLAY TESTING*

An alternative method of store-and-forward file transfers through multiple waypoints in series, called the Store-and-Forward Overlay, is also now a part of the fully approved (Blue Book) CCSDS Recommendation.

As mentioned above, at this time there are only two independent implementations of the SFO, one by ESA/ESTEC and one by NASA/JPL. However, in the case of the SFO, the final destination may optionally have only the Core Procedures. This allows more flexibility in the test configuration, since the "Core only" implementers can participate as a final destination. As with the Extended Procedures, each test requires at least three entities. Also as with the Extended Procedures, to provide the greatest practical diversity among the entities in the tests it is planned that the JPL implementation will be operated on significantly different host operating systems and platforms. At this time it is planned to have versions of the JPL implementation operating under Linux, Unix, and Apple Macintosh OS X operating systems, on platforms at least including PCs, Macintosh's, and Power Computing PowerTower.

The physical configuration of participants will include the ESA/ESTEC at Noordwijk, Netherlands, NASA/JPL at Pasadena, CA, USA, NASDA/NEC in Yokohama, Japan, and the author's facility in Corvallis, OR, USA.

Documentation of the test plans for the SFO are still in draft form. However, the plan is based on the matrix shown following.

| | ***Start-up*** | | ***Trace*** | | | | ***Msg Types*** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SFO Interoperability Tests** | *One-way (Unreliable)* | *Two-way (Reliable)* | *Trace to original source* | *Trace to final destination* | *Trace to both* | *No trace, report failure* | *Msg to user* | *Flow Label* | *Fault Handler Override* | *Filestore request and response* | *Segmentation control* |
| **Things to be tested** | Test Number 1 | Test Number 2 | Test Number 3 | Test Number 4 | Test Number 5 | Test Number 6 | 7 | 8 | Test Number 9 | Test Number 10 | Test Number 11 |
| **SFO Msg Types** | | | | | | | | | | | |
| SFO Request | x | x | x | x | x | x | x | x | x | x | x |
| SFO Message to User | | | | | | | x | | | | |
| SFO Flow Label | | | | | | | | x | | | |
| SFO Fault Handler Override | | | | | | | | | x | | |
| SFO Filestore Request | | | | | | | | | | x | |
| SFO Report | | | x | x | x | x | x | x | x | x | x |
| SFO Filestore Response | | | | | | | | | | x | |
| **Options** | | | | | | | | | | | |
| Trace control flag | | | | | | | | | | | |
| No trace | x | x | | | | x | | | | | |
| Trace toward source only | | | x | | | | | | | | |
| Trace toward destination only | | | | x | | | | | | | |
| Trace in both directions | | | | | x | | x | x | x | x | x |
| Transmission mode | | | | | | | | | | | |
| Acknowledged | | x | x | x | x | x | x | x | x | x | x |
| Unacknowledged | x | | | | | | | | | | |
| Segmentation control | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Record boundaries respected | | | | | | | | | | | | x |
| Record boundaries not respected | x | x | x | x | x | x | x | x | x | x | | |
| **Reports to Original Source** | | | | | | | | | | | | |
| Relay transaction success | | | x | | x | | x | x | | x | x | |
| Relay transaction failure | | | | | | x | | | x | | | |
| **Reports to Final Destination** | | | | | | | | | | | | |
| Relay transaction success | | | | x | x | | x | x | | x | x | |
| Relay transaction failure | | | | | | x | | | x | | | |
| **Error Conditions** | | | | | | | | | | | | |
| Max number of Waypoints exceeded | | | | | | x | | | | | | |
| **Transaction to succeed/fail** | succeed | succeed | succeed | succeed | succeed | fail | succeed | succeed | fail | succeed | succeed | |