THE CFDP INTER-AGENCY TEST PROGRAM

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1. THE CCSDS FILE DELIVERY PROTOCOL (CFDP)

In recent years, CCSDS has concentrated on providing flexible and efficient transfer protocols for various data over space links.

The basic CCSDS suite solves the data transfer problems for current missions in which the manipulation of onboard storage tends to be handled manually, or by ad hoc protocols developed privately. While this is an acceptable way of managing a limited amount of memory, with the rapid development and take-up of solid state mass memory this is no longer the case.

The availability of gigabytes of solid state memory leads to a new era of spacecraft operation, where much of the routine traffic to and from the spacecraft will be in the form of files. Furthermore, due to the random access nature of the onboard storage medium, it becomes possible to repeat transmission of data lost on the link and thus guarantee delivery of critical information.

Drivers Toward CFDP

• Spacecraft now use mass memory with very large data files

• For cost reasons, the trend is towards more autonomous operation whereby the spacecraft 'decides' (for example) when it should download stored data and when it should upload new operational plans

• Some of the new deep space missions do not have direct line of sight between earth and final destination, rather data must be relayed between a series of spacecraft, each providing a store and forward capability, until the final destination is reached

• Spacecraft constellations (e.g. fixed or formation flying) require efficient and reliable data file transfer, possibly through multi paths

• Inter-operability within and among Agencies, and between space-ground networks (e.g. towards interoperability with Internet on-ground) is becoming increasingly important as economic considerations require consolidation of networks.

While the onboard storage medium has rapidly evolved, the essential constraints of space missions remain.

Mission Constraints

• Systems resources which may be restricted in one or both of the entities involved in an end-to-end data transfer may include computational power and memory capacities, driven by the need for expensive parts qualification and also the need to limit power, weight and volume in the remote end system

• Environmental restrictions may include noisy, bandwidth limited, asymmetrical, and interrupted communications links with very long propagation delays, and a consequent reliance on a 'store-and-forward' mode of operation

• User needs often include a requirement for early access to transferred data regardless of its quality, and for a method of providing progressively increasing quality of the data.

In response to these factors, the CCSDS File Delivery Protocol (CFDP) has been developed to complement the existing CCSDS packet standards.

What is CFDP?

• CFDP provides the capability to transfer 'files' to and from a spacecraft mass memory

• The content of the files may be anything from a conventional timeline update to an unbounded SAR image

• 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, with near earth and deep space delays

• File transfer can be triggered automatically or manually

• File transfer can be point to point between ground and a single spacecraft or between ground via multiple 'relay satellites' to a destination satellite or vehicle.

The CFDP has many unique characteristics compared to terrestrial file transfer protocols.

Distinctive Features of CFDP Compared to Terrestrial File Transfer Protocols

- Efficient operation over simplex, half duplex, and full duplex links
- 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
- Operation through multiple intermediaries (multiple hops)
- 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
- Effectiveness spanning low earth orbit and deep space.

The protocol is independent of the technology used to implement data storage and requires only a few fundamental filestore capabilities in order to operate. It assumes a minimum of two filestores, typically one within the spacecraft and one on the ground, and operates by copying data between the two adjacent filestore locations.

A more complete description of the CFDP can be found in Operating CFDP in the Interplanetary Internet, Scott Burleigh, NASA/JPL, in these proceedings.

2. DEVELOPMENT OF THE CFDP TESTBED

Development of the CCSDS File Delivery Protocol (CFDP) has benefited greatly from an inter-agency protocol testing program. The program began with a face-to-face mutual testing workshop 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 program was so successful that it may serve as a model for similar testing in other areas of the CCSDS domain.

The CFDP Inter-Agency Testing Program was begun on the initiative of Eric Bornschlagel of ESA ESTEC. As a result of that initiative, the first Testing Workshop was hosted in May, 2000, by Ben Ballard at the Applied Physics Laboratory (APL) of the Johns Hopkins University, in Columbia, Maryland.

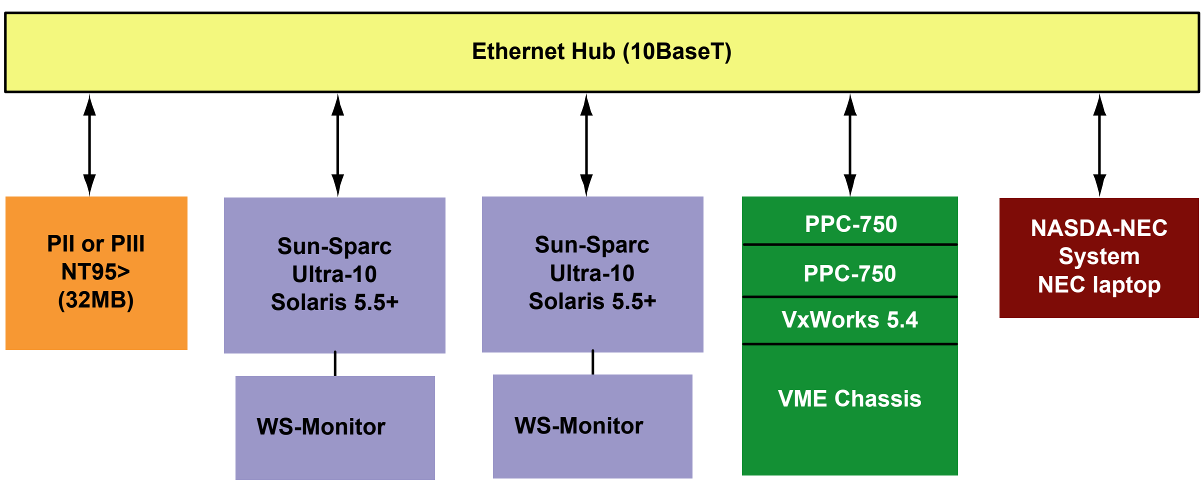
The first Workshop was sufficiently productive that it resulted in a series of Workshops. Workshops were held at DERA, Farnborough, UK, in November 2000, and then at JPL, Pasadena, USA, in May, 2001. Following the Pasadena Workshop the testing configuration migrated to what has become a worldwide Distributed Inter-Agency Testbed, operating over the Internet.

The initial, face-to-face, Workshops were primarily mutual software debugging and development sessions among the various protocol implementers. These were very productive in that role, and also established mutual confidence and respect among the implementers - a "team building" process. As the implementations (and the process) matured, testing began to focus less on software development and more on testing the protocol.

3. TESTBED CONFIGURATIOPNS

3.1 Face-To-Face Workshops

Each of the face-to-face testing workshops had somewhat different configurations, primarily in the number of implementations at the workshop. However, the configurations were basically as shown below. Especially note the wide range of hosting systems among the implementations.



Configuration - CFDP Face-to-face Workshops

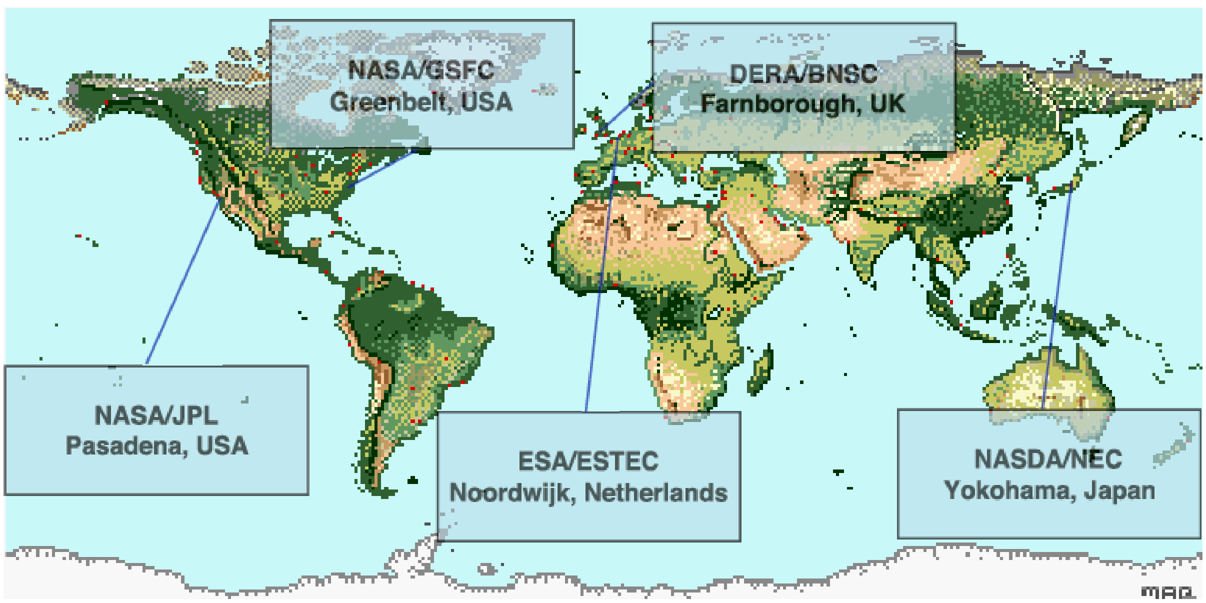
3.2 Distributed Testbed

Although the face-to-face workshops were very beneficial, they had several disadvantages. Since they involved extensive travel they were necessarily infrequent, and since they involved arranging for a significant amount of equipment and working space and miscellaneous technical and administrative support they required a considerable investment of resources by the host. For both these reasons they were expensive. There were therefore 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.

Initially the implementers were reluctant to move to the Internet because (the author believes) it reduced their ability to assist one another in debugging, and because of the difficulty of establishing parallel communications for coordination. The first problem diminished as the maturity of the implementations increased. The latter problem was solved by the simple solution of using the AOL Instant Messenger service. It is multi-party, interactive, realtime, and provides for a permanent record ("save as a file") and is *free*.

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.



Configuration – CFDP Distributed Testbed

Below is a short example of an actual AIM log from one test.

Example of AIM log
CFDPHiro: I got f3_2 **CFDPHiro**: .out **rjks2000**: Right **rjks2000**: Do you have the files for F3.3? **rjks2000**: ./cfdprob_2/f3_3.old **CFDPHiro**: Yes. **rjks2000**: Ready?

CFDPHiro: Ready.
rjks2000: Success again
CFDPHiro: f3_3.out has disappeared! Success.
rjks2000: 3.7?
CFDPHiro: Yes.
rjks2000: Sent. Success
CFDPHiro: f3_7.dir has appeared! Success.
CFDPHiro: F3.8?
rjks2000: Do you have a f3_8.dir directory?
CFDPHiro: Yes.
CFDPHiro: Ready.
rjks2000: Sent. Success
CFDPHiro: f3_8.dir has disappered! Success.
CFDPHiro: We did F3.
rjks2000: Hooray!

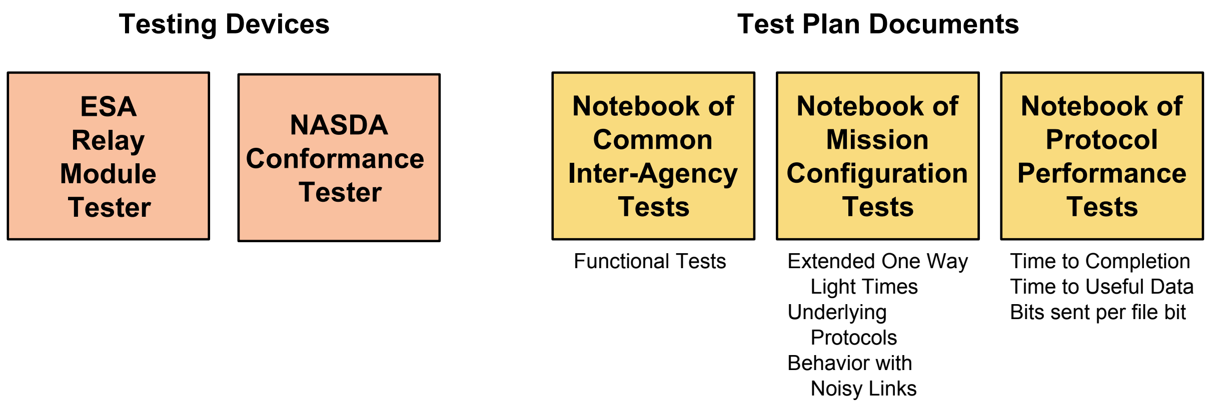
4. SUPPORT ITEMS

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.

The ESA Relay Module tester is a software device developed and contributed by ESA/ESTEC. It 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. It, and similar devices patterned on it, provided the basic testing capability for functional and mission configuration testing.

The NASDA Conformance Tester was developed and contributed by NASDA/NEC. This 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. Performance of these conformance tests demonstrates that the implementation under test meets the specified interface and procedural requirements of the CFDP. Successful completion of these conformance tests provides a very high level of confidence that the implementation is ready for testing with other independent implementations.

A series of three Testing Notebooks were developed and contributed by NASA/JPL. The *Notebook of Common Inter-Agency Tests* has been the primary document of the testing to date. It contains test descriptions and procedures for five different Test Series between two or three separate CFDP entities (implementations). The tests are strictly functional interoperability tests. The *Notebook of Mission Configuration Tests* contains tests which emulate deep space mission configurations. And finally, the *Notebook of Protocol Performance Tests* contains tests designed to measure the speed and efficiency of the protocol operation in various configurations.

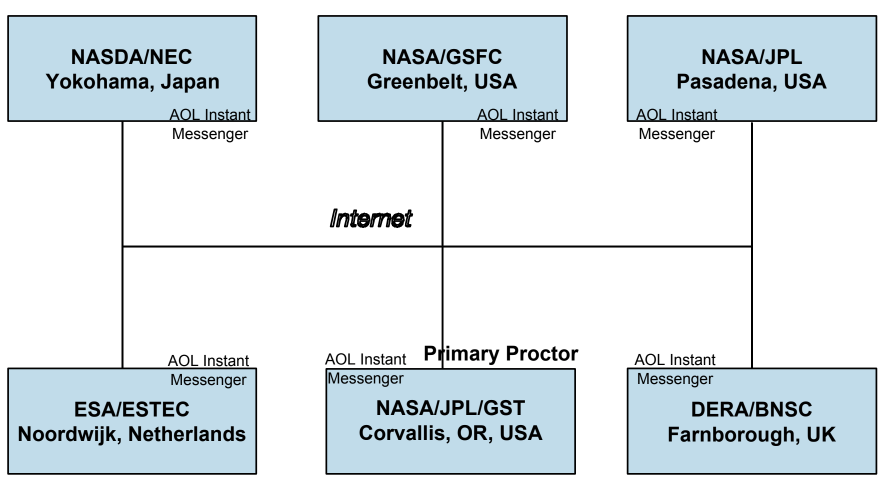


Test Support Items

5. "FINALS WEEK"

As a major benchmark, 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, as shown below

Fifteen Test Sessions of approximately 4 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).



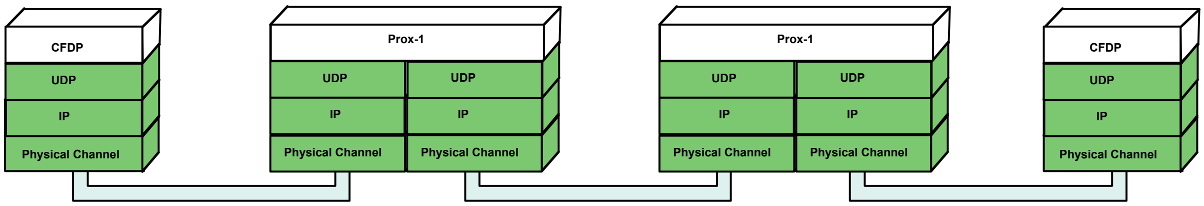
Configuration - CFDP "Finals Week"

6. LESSONS LEARNED

Testing of an in-design protocol by using independently created implementations greatly improves both the protocol and confidence in it

6.1 Limitations Of Distributed Testing Via The Internet

Testing vertically (i.e., up and down the protocol stack, rather than peer-to-peer) over the Internet provides a low fidelity model, since UDP and other Internet lower layer protocols are between the protocol-under-test layers, as shown below. Because of the Internet layers and the unknown delays in the Internet, accurate performance measurements of the CCSDS protocols cannot be made.



Internet Layers Between CCSDS Layers

6.2 Place In An Overall Test Program

There are several types of testing to be done in a good testing program.

- conformance testing
- implementation testing
- protocol testing
- interoperability testing
- performance testing
- mission model testing

They need to be planned, documented, and executed separately. They often conflict, either in content or method of execution. It should be noted that all of these except performance testing can be accomplished using a distributed testbed. Both face-to-face testing workshops and distributed testing are valuable and complimentary.

An ideal test program would begin with face-to-face workshops and migrate to distributed testing

6.3 Test Discipline

To keep testing focused and organized, it is essential to have a set of common test plans and test set descriptions for all to use in inter-implementation testing ("Notebook of Common Inter-Agency Tests for Protocol XXX", etc.). To maintain their usefulness, these tests sets must be periodically updated from implementers' inputs

Test discipline needs to be loose during the first couple of face-to-face workshops. These will be primarily mutual debugging and team building exercises

When test discipline is needed to achieve a coherent set of test records, use of a proctor is desirable.

7. THE FUTURE

The CFDP "Core Procedures", which provide point-to-point (single hop) file transfer capabilities, are a fully approved (Blue Book) CCSDS Recommendation.

Additional CFDP "Extended Procedures", which add the capabilities of store-and-forward file transfers through multiple waypoints in series are expected to move from draft status to become a part of the fully approved (Blue Book) CCSDS Recommendation in the Spring of 2003.

An alternative method of store-and-forward file transfers through multiple waypoints in series, called the Store-and-Forward Overlay, is also expected to move from draft status to become a part of the fully approved (Blue Book) CCSDS Recommendation in the Spring of 2003.

Capabilities to transfer files via waypoints in parallel, as well as in series, will be added in two ways. First, a description of a "user level" technique, called "Data Product Manager" (DPM) will be added to a supporting CFDP document (Green Book) in the immediate future. Since the DPM is a description of a method, and is not a protocol, it will not be included in the Blue Book.

Work is in progress on the generalization and development of the above kinds of capabilities in the context of "delay-tolerant" networking; various components being "bundling", and the Licklider Transmission Protocol" (LTP).

As the above evolution of CFDP takes place, the distributed testbed will continue in its "proofing" role. In the immediate future the testbed will be used to verify the multi-hop capabilities being added to the CFDP. These tests will again culminate in a "Finals Week" before formal approval of the added capabilities is given.

A weakness of the current CFDP testing is that it has all been over UDP. It is very desirable to have a distributed testbed which provides access to other lower layers, allowing functional testing of protocols both peer-to-peer and vertically, including the CCSDS Packet Telemetry, Telecommand, AOS, SCPS, and Proximity-1 lower layer protocols. Adding such a vertical testing capability is being investigated.

In addition, it may be feasible to create such a testbed in which various implementations are left on-line all of the time. This would provide support to developers whenever needed, wherever their location, and at their convenience. Such a capability would be a first step toward a cross-program CCSDS distributed testbed perhaps incorporating other Peer-to-Peer Distributed Testbeds