The Consultative Committee for Space Data Systems

# Report Concerning Space Data System Standards

## CCSDS FILE DELIVERY PROTOCOL (CFDP)—

# PART 1:

# INTRODUCTION AND OVERVIEW

## INFORMATIONAL REPORT

## CCSDS 720.1-G-3

## GREEN BOOK

**April 2007**

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# FOREWORD

This document is a CCSDS Report, which contains background and explanatory material to support the CCSDS Recommended Standard, *CCSDS File Delivery Protocol* (reference [1]).

Through the process of normal evolution, it is expected that expansion, deletion, or modification to this Report may occur. This Report is therefore subject to CCSDS document management and change control procedures, which are defined in reference [2]. Current versions of CCSDS documents are maintained at the CCSDS Web site:

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# DOCUMENT CONTROL

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# 1 INTRODUCTION

## 1.1 PURPOSE

This Report is an adjunct document to the Consultative Committee for Space Data Systems (CCSDS) Recommended Standard for File Delivery Protocol (reference [1]), and it contains material that will be helpful in understanding the primary document. This Report will assist decision-makers and implementers with evaluating the applicability of the protocol to mission needs, as well as with making implementation, option selection, and configuration decisions related to the protocol.

## 1.2 SCOPE

This Report provides supporting descriptive and tutorial material**. This document is not part of the Recommended Standard.** In the event of conflicts between this Report and the Recommended Standard, the Recommended Standard shall prevail.

## 1.3 ORGANIZATION OF THIS REPORT

This Report is divided into two parts. The first part (this document) provides an introduction to the concepts, features, and characteristics of the CCSDS File Delivery Protocol (CFDP). It is intended for an audience of persons unfamiliar with the CFDP or related protocols. This Report contains three sections and three annexes, as follows:

a) section 1, Introduction;

b) section 2, Summary and Overview (of the CFDP);

c) section 3, Example Configurations (i.e., possible configurations using the protocol);

d) annex A, The CFDP Inter-Agency Test Program, which proved to be a valuable tool in the development of the CFDP;

e) annex B, Abbreviations and Acronyms.

The second part of this Report (reference [3]) is an implementers guide. It provides information to assist implementers in understanding the details of the protocol and in the selection of appropriate options, and contains suggestions and recommendations about implementation-specific subjects. The second part also contains implementation reports from various member Agencies, and the requirements upon which the CFDP is based.

## 1.4 CONVENTIONS AND DEFINITIONS

### 1.4.1 BIT NUMBERING CONVENTION AND NOMENCLATURE

In this document, the following convention is used to identify each bit in an N-bit field. The first bit in the field to be transmitted (i.e., the most left-justified when drawing a figure) is defined to be 'Bit 0'; the following bit is defined to be 'Bit 1' and so on, up to 'Bit N-1'. When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., 'Bit 0', as shown in figure 1-1.

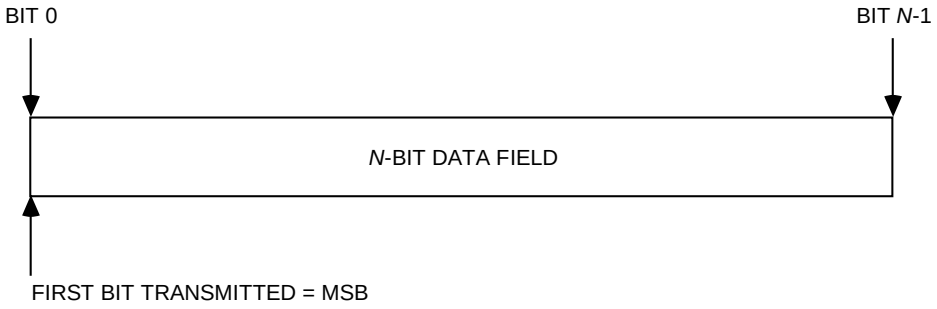



**Figure 1-1: Bit Numbering Convention**

In accordance with modern data communications practice, spacecraft data fields are often grouped into 8-bit 'words' that conform to the above convention. Throughout this Report, the nomenclature shown in figure 1-2 is used to describe this grouping.

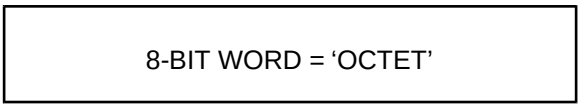



**Figure 1-2: Octet Convention**

By CCSDS convention, all 'spare' bits shall be permanently set to value 'zero'.

### 1.4.2 DEFINITIONS

Within the context of this document the following definitions apply:

A *file* is a bounded or unbounded named string of octets that resides on a storage medium.

A *filestore* is a system used to store files; CFDP defines a standard *virtual filestore* interface through which CFDP accesses a filestore and its contents.

A *CFDP protocol entity* (or *CFDP entity*) is a functioning instance of an implementation of the CFDP protocol, roughly analogous to an Internet protocol 'host'. Each CFDP entity has

access to exactly one filestore. Each entity also maintains a *Management Information Base* (MIB), which contains such information as default values for user communications requirements, e.g., for address mapping, and for communication timer settings.

The functional concatenation of a file and related *metadata* is termed a *File Delivery Unit* (FDU); in this context the term 'metadata' is used to refer to any data exchanged between CFDP protocol entities in addition to file content, typically either additional application data (such as a 'message to user') or data that aid the recipient entity in effectively utilizing the file (such as file name). Note that an FDU may consist of metadata only. Note also that the term 'file' is frequently used in this document as an abbreviation for 'file delivery unit'; only when the context clearly indicates that only actual files are being discussed should the term 'file' not be read as 'file delivery unit'.

The individual, bounded, self-identifying items of CFDP data transmitted between CFDP entities are termed *CFDP Protocol Data Units* or *CFDP PDU*s. Unless otherwise noted, in this document the term 'PDU' always means 'CFDP PDU'. CFDP PDUs are of two general types: *File Data PDUs* convey the contents of the files being delivered, while *File Directive PDUs* convey only metadata and other non-file information that advances the operation of the protocol.

A *transaction* is the end-to-end transmission of a single FDU between two CFDP entities. A single transaction normally entails the transmission and reception of multiple PDUs.

Any single end-to-end file transmission task has two associated entities: the entity that has the file at the beginning of the task (the *source*), and the entity that has a copy of the file when the task is completed (the *destination*).

Each end-to-end file transmission task includes a point-to-point file copy operation. Any single file copy operation has two associated entities: the entity that has a copy of the file at the beginning of the operation (the *sender*) and the entity that has a copy of the file when the operation is completed (the *receiver*). Each end-to-end file transmission task includes one or more point-to-point file copy operations. Any single point-to-point file copy operation has two associated entities: the *sender* and the *receiver*. The sender is the entity that has a (possibly temporary) copy of the file at the beginning of the operation. The receiver is the entity that has a (possibly temporary) copy of the file when the operation is completed.

In the simplest case, the only sender of the file is the source, and the only receiver is the destination. In more complex cases (the general case), there are additional '*waypoint*' entities that receive and send copies of the file; the source is the first sender and the destination is the last receiver.

The term *CFDP user* is used to refer to the software task that causes the local entity to initiate a transaction or the software task that is notified by the local entity of the progress or completion of a transaction. The CFDP user local to the source entity is referred to as the *source CFDP user*. The CFDP user local to the destination entity is referred to as the *destination CFDP user*. The CFDP user may be operated by a human or by another software process. Unless otherwise noted, the term *user* always refers to the CFDP user.

A *message to user* (or *user message*) allows information related to a transaction to be delivered to the destination user, in synchronization with the transaction.

A *filestore request* is a request to the remote filestore for service (such as creating a directory, deleting a file, etc.) at the successful completion of a transaction.

*Service primitives* form the software interface between the CFDP user and its local entity. The user issues *request* service primitives to the local entity to request protocol services, and the local entity issues *indication* service primitives to the user to notify it of the occurrence of significant protocol events.

## 1.5 REFERENCES

The following documents are referenced in the text of this Report. At the time of publication, the editions indicated were valid. All documents are subject to revision, and users of this Report are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below. The CCSDS Secretariat maintains a register of currently valid CCSDS Recommended Standards.

[1] *CCSDS File Delivery Protocol (CFDP).* Recommendation for Space Data System Standards, CCSDS 727.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, June 2005.

[2] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-9. Yellow Book. Issue 9. Washington, D.C.: CCSDS, November 2003.

[3] *CCSDS File Delivery Protocol (CFDP)—Part 2: Implementers Guide*. Report Concerning Space Data System Standards, CCSDS 720.2-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, January 2007.

# 2 SUMMARY AND OVERVIEW

## 2.1 BACKGROUND

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, because of 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 toward more autonomous operation whereby the spacecraft 'decides' (for example) when it should download stored data and when it should upload new operational plans.

– Interoperability within and among Agencies, and between space-ground networks (e.g., toward interoperability with the ground-based Internet) is becoming increasingly important as economic considerations require consolidation of networks.

– 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.

– The increasing onboard use of real-time operating systems (such as VxWorks and RTEM), which assume the presence of a 'file system', make onboard data handling increasingly file-oriented.

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

**Mission Constraints**

– Systems resources that 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, as well as 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.

– User needs often include a requirement for early access to transferred data regardless of its quality, as well as a method of providing data of progressively increased quality.

In response to these factors, the 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, or a full-duplex link, with near-Earth and deep space delays.

– File transfer can be triggered automatically or manually.

NOTE – CFDP was designed to support the transfer of true files stored in a true file system. However, because CFDP is based on the concept of an abstract 'virtual filestore' (which in practice might be implemented in ways that are wholly unlike conventional 'file systems'), and because the CFDP specification does not define exactly what a 'file' is, the protocol can in practice be used to convey blocks of data between repositories that may not look like file systems. Such use, however, is a private matter within the using organization and should be defined by a local technical note or agreement among the using parties.

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 that can span ground station contacts (time disjoint connectivity).

– Transfers that can span multiple ground stations.

– Effectiveness over highly unbalanced link bandwidths.

– Minimization of link traffic.

– Data availability to the user as the file is received.

– Minimization of onboard memory requirements through buffer sharing.

– 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.

– Effectiveness spanning low Earth orbit and deep space.

## 2.2 OPERATIONAL CONTEXT

The CFDP enables the moving of a file from one filestore to another, where the two filestores are in general resident in separate data systems and often with an intervening space link. In addition to the purely file delivery-related functions, the protocol also includes file management services to allow control over the storage medium.

In its simplest form, the protocol provides a *Core* file delivery capability operating across a single link. For more complex mission scenarios, the protocol offers *Extended* operation providing store-and-forward functionality across an arbitrary network, containing multiple links with disparate availability, as well as subnetworks with heterogeneous protocols. See figure 2-1.

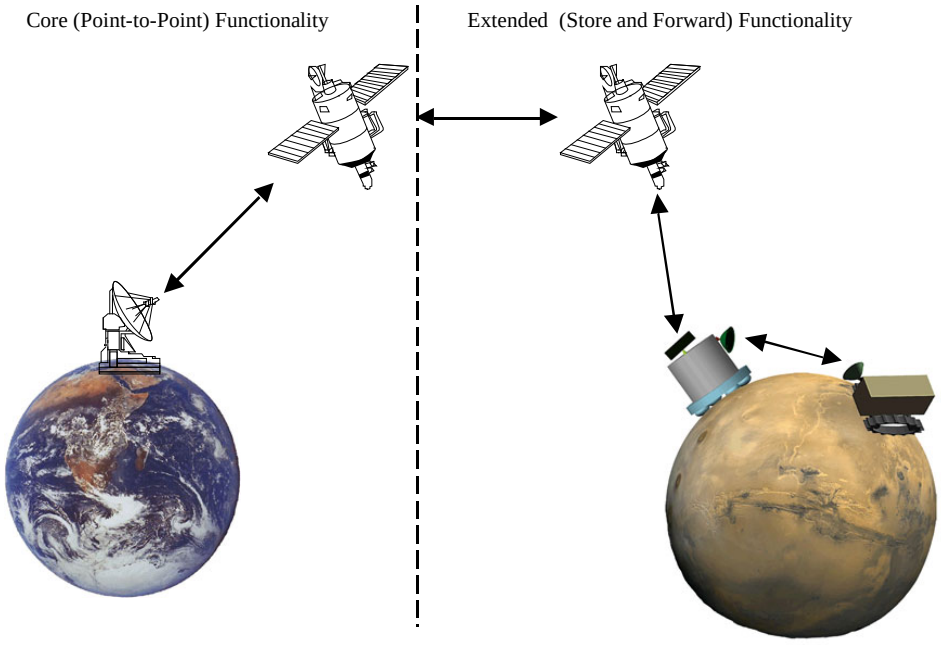



**Figure 2-1: Core and Extended Capabilities**

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.

The protocol makes no assumptions about the information being transferred and can be utilized for a wide range of applications involving the loading, dumping, and control of spacecraft storage.

The protocol has been specifically designed to minimize the resources required for operation. It is also scaleable, so that only those elements required to fulfill the selected options need be implemented.

The protocol can operate over a wide range of underlying communication services, specifically including CCSDS packet services. See figure 2-2.

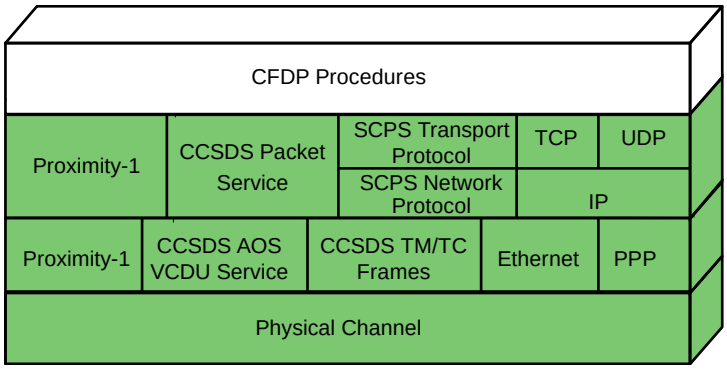



**Figure 2-2: The CFDP Operates over a Wide Range of Underlying Protocols**

## 2.3 DESIGN CONCEPT

As depicted in figure 2-3, the protocol consists of Core procedures and Extended procedures. The Core procedures constitute the interaction between two protocol entities with a direct network path between them. The sending entity is the entity from which the file is copied in a file copy operation. The receiving entity is the entity to which the file is copied in a file copy operation.

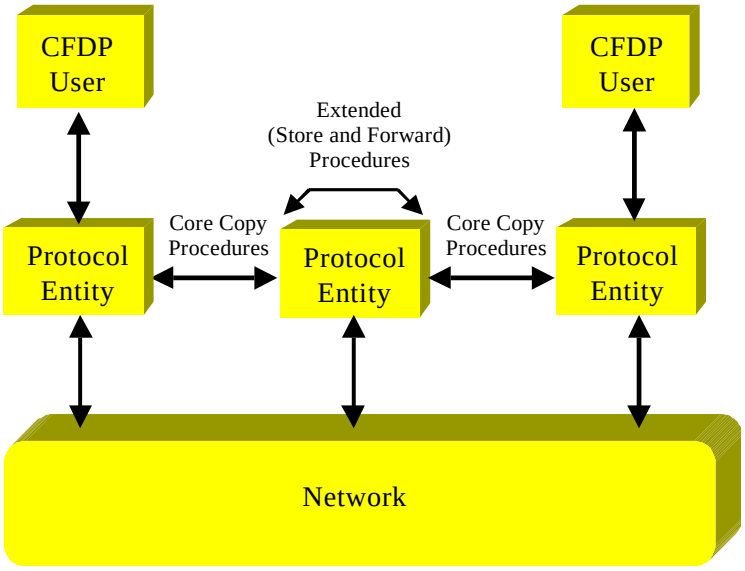



**Figure 2-3: Core and Extended Interactions**

Where direct network connectivity between the source and destination is impossible, the Extended procedures automatically build an end-to-end file copy transaction by executing multiple file copy operations, as follows: one file copy operation between the source and the first waypoint; others between successive waypoints as necessary; and a final file copy operation between the last waypoint and the destination. Each of these is simply another instance of the Core file copy operation. The reliability of a transaction is determined by whether the transaction is chosen to operate in unacknowledged mode or in one of the

acknowledged modes. In unacknowledged mode data delivery failures are not reported to the sender and, therefore, cannot be repaired, although errors will be detected and erroneous data discarded. Reception of the complete file is therefore not guaranteed. In acknowledged mode, the receiver informs the sender of any undelivered file segments or ancillary data. These are then retransmitted, guaranteeing complete file delivery. Each transaction results in the copying of a single file from source to destination.

When the Extended procedures are operating, the sender or receiver of a given PDU may be a 'waypoint' CFDP entity. Extended procedures are used when the original source of the PDU has no direct connectivity to the PDU's final destination, but only to some intermediate entity. The waypoint entity in turn may have direct connectivity either to the PDU's final destination or only to some further intermediate entity; the last waypoint entity in such a chain must have direct connectivity to the final destination of the PDU.

All such scenarios as described above force each end-to-end transmission to entail a series of two or more point-to-point exchanges of data. For this purpose, the CFDP architecture is extended as follows:

- A *Store-and-Forward Overlay* (SFO) system is added to user applications as a standard user operation. The user application at each relay point examines each incoming file and, if the accompanying metadata indicates that the file's final destination is elsewhere, initiates another point-to-point file transmission either to the final destination or to another relay point that is farther along the route.

- *Extended procedures* are added to CFDP itself. The CFDP entity at each relay point checks the final destination of each incoming file and, if necessary, initiates another point-to-point transmission toward that destination; the file is never delivered to the user application at any relay point.

The Extended Procedures and the store-and-forward overlay are alternatives, and it is not necessary that both be implemented, although such implementation is acceptable. Extended Procedures might be selected, for example, if it is desirable that portions of a file be forwarded by a waypoint immediately upon receipt, rather than only upon receipt of the entire file. This can get the initial parts of a file delivered to the final destination sooner than under SFO, even though final reception of the entire file at the final destination should take about the same length of time either way. Conversely, if detailed reporting on transaction status is required and there is more than one waypoint in the transaction path, then the store-and-forward overlay system might be preferred.

It is expected that in deep space use, a pair of CFDP entities that have files to exchange may at any given moment be unable to communicate; for example, a spacecraft orbiting Mars may be on the far side of the planet, unable to transmit to Earth. For this reason CFDP, when using store-and-forward overlay or Extended procedures, is built entirely on a *store and forward* communication model. If transmission of a file from Earth to a Mars-orbiting spacecraft is interrupted when the spacecraft passes behind the planet, the CFDP entities at both ends of the transmission simply store their outbound Protocol Data Units (PDUs)—possibly in non-volatile memory, to assure continued service even in the event of an unplanned system reset—until the spacecraft re-emerges and transmission can resume. A

collateral benefit of this model is that it largely insulates user applications from the state of the communication system: an instrument can record an observation in a file and 'transmit' it (that is, submit it to CFDP for transmission) to Earth immediately without considering whether or not physical transmission is currently possible. By sequestering outbound data management and transmission planning functions within CFDP, this *deferred transmission* can simplify flight and ground software and thereby reduce mission costs.

Using powerful forward error correction coding can minimize data loss in communication across deep space but cannot eliminate it altogether. Consequently CFDP supports optional 'acknowledged' modes of operation in which data loss is automatically detected and retransmission of the lost data is automatically requested. However, the large signal propagation delays that characterize interplanetary transmission limit the usefulness of the retransmission strategies commonly used in terrestrial protocols. For example, delaying the transmission of PDU *N* until an acknowledgment that PDU *N - 1* (or even PDU *N - 100*) has been received would significantly retard data flow if the round trip time on the link exceeded the time required to radiate the PDU(s) for which acknowledgment is required. For this reason, CFDP's retransmission model is one of *concurrent transmission*: data PDUs for multiple files may be transmitted as rapidly as possible, one after another, without waiting for acknowledgment, and requests for retransmission are handled asynchronously as they are received. As a result, portions of multiple files may be in transit concurrently.

The determination of how and when a waypoint entity forwards a PDU toward its target entity is an implementation matter. In general it is desirable to forward each PDU as soon as possible, rather than wait until custody of an entire FDU has been taken before forwarding any part of it; this approach minimizes the time required for complete end-to-end transmission of the data. In practice, however, immediate forwarding will frequently be impossible, because radio contact among CFDP entities is typically discontinuous. The waypoint entity in such cases must store PDUs in some persistent medium, such as an intermediate copy of the transmitted file, until forwarding is practical.

## 2.4 ARCHITECTURE ELEMENTS

### 2.4.1 GENERAL

The architectural elements involved in the file delivery protocol are depicted in figure 2-4 and described in subsections 2.4.2 through 2.4.6.

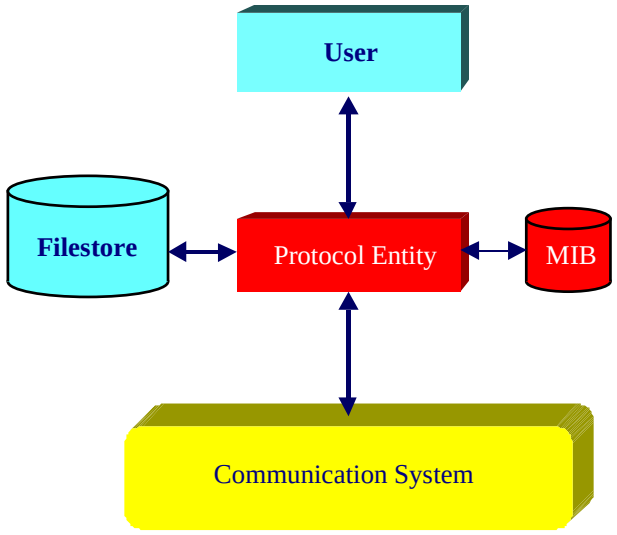



**Figure 2-4: Architectural Elements of the File Delivery Protocol**

As the figure indicates, each protocol entity has access to exactly one filestore and is accessed by exactly one user.

### 2.4.2 USER

The protocol operates at the request of the CFDP user. The user interacts with the protocol using the service primitives. A CFDP user is always a software task, which may or may not be operated by a human. Each CFDP protocol entity has at most one user. In some instances a user may not be present; in particular, any entity that always functions solely as an Extended procedures waypoint (performing store-and-forward operations) need not have a user.

### 2.4.3 PROTOCOL ENTITY

The protocol entity consists of implementations of the *Core delivery procedures*, which allow immediate file delivery and manipulation over a single network hop, and optionally the *Extended procedures*, which allow for time-disjunct or immediate delivery over a number of network hops with appropriate facilities for onward routing. A single service interface is presented to the user; the addition of the Extended procedures is evident in the quality of service and the multi-hop capability.

### 2.4.4 FILESTORE

The protocol operates by copying files from storage medium to storage medium, and it is therefore assumed that all CFDP entities have access to a local storage capability. As the ways in which the storage capability is provided will vary, the protocol is built on the premise that any file or organized set of files (i.e., a filestore) can be described in terms of a single standard representation. This representation, called a '*Virtual Filestore*', is assigned a standard set of attributes with which the protocol manages the file delivery process. This approach allows complete independence from the technology used to implement the filestore.

In an implementation, the virtual filestore must be mapped to and from the actual hardware and software that constitute the real filestore. The virtual filestore has been defined to be as universal as possible while still resembling the interface provided to most real filestores. Therefore, the convergence function required to adapt real filestores to this model is easily realizable. Figure 2-5 shows an example of such a possible implementation structure.

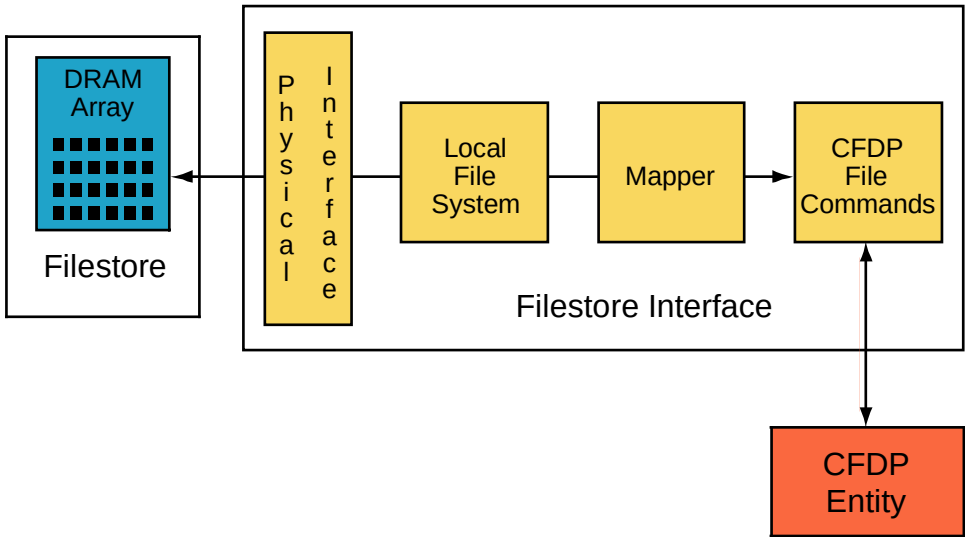



**Figure 2-5: Possible Virtual Filestore Structure**

To enable interoperability, the protocol assumes a minimum set of capabilities from the Virtual Filestore, but also provides an extensibility mechanism to support use of additional capabilities. The minimum required filestore capabilities are:

- create file;
- delete file;
- deny file;
- rename file;
- append file;
- replace file;

- create directory;
- remove directory;
- deny directory;
- list directory.

In some circumstances, it is advantageous for the CFDP protocol to be able to recognize record boundaries within the file. If this option is to be used, the filestore must have the capability to make the distinction between such files and those that are to be treated as a stream of octets.

### 2.4.5 MANAGEMENT INFORMATION BASE

To perform a file delivery, a significant amount of information must be passed by the local user to its local CFDP entity, and by the local CFDP entity to the remote CFDP entity. Typically, this data is static and is maintained by the CFDP entities as system tables, referred to as the Management Information Base (MIB). The MIB contains such information as default values for user communications requirements, e.g., for address mapping, and for communication timer settings. The MIB is formally defined as part of the protocol specification.

### 2.4.6 UNDERLYING COMMUNICATION SYSTEM

The protocol assumes the availability of an underlying communication system to which all CFDP entities in a given CFDP addressing domain have access. In order that the protocol may operate over a wide range of implementations including CCSDS, Internet and Open Systems Interconnection (OSI) networks, the services required by the protocol have intentionally been kept as simple as possible. This underlying conceptual communication system is referred to as the Unitdata Transfer (UT) layer. Since only minimal network capabilities are assumed, services sometimes provided by the UT layer (such as transaction multiplexing, sequence auditing, and error detection) are provided by CFDP.

It should be noted that although the CFDP protocol can operate over a service where data errors, data loss, and out-of-sequence delivery occur, it is not intended to compensate for networks where these effects are prevalent. Severe performance reductions will result if such an approach is taken.

## 2.5 PROTOCOL OPERATIONS

### 2.5.1 SERVICE INTERFACE

#### 2.5.1.1 Service Primitives

The software interface between the CFDP user and its local entity consists of two types of service primitives: 'request' primitives and 'indication' primitives. The user issues 'request' service primitives to the local entity to request protocol services, and the local entity issues 'indication' service primitives to the user to notify it of the occurrence of significant protocol events. Each primitive has parameters that convey related information.

Table 2-1 lists the five 'request' primitives and twelve 'indication' primitives that make up the CFDP user interface.

**Table 2-1: CFDP Service Primitives**

| Request Primitives | Indication Primitives |
|---|---|
| Put | Transaction |
| Cancel | Metadata-Recv |
| Suspend | File-Segment-Recv |
| Resume | Suspended |
| Report | Resumed |
| | EOF-Sent |
| | Transaction-Finished |
| | Transfer-Consigned |
| | Report |
| | Fault |
| | Abandoned |
| | EOF-Recv |

When the Extended procedures are implemented, the sender and/or receiver of a given PDU may be a 'waypoint' CFDP entity. Extended procedures are used when the original source of the PDU has no direct connectivity to the PDU's final destination, but only to some intermediate entity. That waypoint entity in turn may have direct connectivity either to the PDU's final destination, or only to some further intermediate entity; the last waypoint entity in such a chain must have direct connectivity to the final destination of the PDU.

The end-to-end execution of a transaction may therefore comprise multiple successive executions of Core procedures between adjacent entities, some of which may be initiated by the Extended procedures themselves rather than by a CFDP user's invocation of services; when this is the case, the Extended procedures essentially take on the role of the CFDP user. However, this variation is invisible to the Core procedures, which operate in the same way at all times.

When the sender for a Copy File procedure is the file's source entity, but the receiver is a waypoint rather than the file's destination entity, the sender issues a Transfer-Consigned.indication primitive when the file has been successfully copied to the adjacent

waypoint's filestore. This notifies the sending application that custody of the file has been transferred to the first waypoint; if the original file itself is being used as the sender's retransmission buffer, and is therefore protected from deletion or modification, it is now safe to end that protection. The Sender will then issue a Transaction-Finished.indication primitive as it receives notification of the entire end-to-end file transfer from the final destination entity.

When the receiver of a Copy File procedure is a waypoint, it may or may not wait until the entire procedure is complete before beginning to copy the file to the destination (or next waypoint). Immediate (incremental) forwarding of the file has the desirable effect of minimizing delay in getting at least part of the file to the destination.

The protocol specification contained in reference [1] formally defines the service primitives in detail; the remainder of this subsection 2.5.1 gives a brief overview of the operation of the request primitives and their relation to the indication primitives that the protocol entities generate as a result.

#### 2.5.1.2 The CFDP Transaction

The *transaction* is the fundamental operation that the protocol performs to transfer user data between CFDP entities. Each transaction is the end-to-end transmission of a single FDU from a single *source* CFDP entity to a single *destination* CFDP entity. The entities communicate with each other using the PDU messages and procedures defined in the protocol specification.

Each CFDP entity is identified by a unique *entity ID*. Each transaction is identified by a unique *transaction ID* that consists of the ID of the transaction's source entity and a transaction sequence number that the source entity assigns when it initiates the transaction.

A transaction may transfer a file from the local filestore, and/or one or more user messages, and/or one or more filestore requests to the destination entity.

User messages allow delivery of information related to a transaction in synchronization with the transaction; they are not intended for general-purpose messaging. CFDP defines a small number of reserved user messages to implement user operations transactions. Except for these reserved messages, the contents and meanings of user messages are not defined or constrained by the CFDP.

There is an inactivity timer that, if there is a cessation of PDU reception for a given Transaction for the specified time period, causes the issuance of a Fault.indication to the local user. It takes no other action. That is, any further resulting action is not specified by the protocol, but is taken by the user in an implementation-specific manner. The user might try to restart or otherwise salvage the Transaction, abandon it, or take some other action appropriate to the implementation and operational configuration. The basic purpose of the timer is to handle situations that are outside of the protocol itself. Examples might be the crashing of the operating system in the other entity party to the ongoing Transaction, the extended failure of an intermediate communication link, etc.

#### 2.5.1.3 Put Request

The 'Put' request is issued by the source entity to initiate a CFDP transaction; in fact, every transaction is the result of a Put request. The parameters of the request may contain all the information needed to specify the transaction, including destination entity ID, source and destination file names, messages to user and filestore requests to accompany the file transfer operation, and protocol options. If optional parameters are omitted, the entity supplies default values from the MIB.

As a pure file delivery request, 'Put' only allows the source user to send a file from its local filestore to a remote filestore. However, the ability to include user messages and filestore requests in a Put request enables the requesting user to initiate more complex operations, such as getting a file from the destination entity and then deleting it from the remote filestore. These capabilities are described in more detail in subsection 2.5.2.

When the source user issues a 'Put' request, the local entity uses the request's parameters to build a *metadata* PDU that describes the transaction, and it assigns a unique transaction ID to be used in later service requests and indications related to the transaction. Since concurrent transactions may be active, the entity issues a 'Transaction' indication to pass the ID back to the user. It then initiates transmission procedures to the destination entity.

#### 2.5.1.4 Put Operations

In CFDP procedures, the source entity sends the metadata (which contains any user messages and filestore requests) followed by any file data to the destination entity. Upon receipt of the metadata PDU, the destination entity creates and initializes the data structures it will use to track and control the transaction, retains any filestore requests for later use, and issues the Metadata-Recv indication to its user. The user then retrieves any user messages contained in the metadata, including Proxy and List Directory messages, acts on any of these two message types, and passes on any others in an implementation-specific manner.

Upon receipt of each PDU containing file data, the destination entity optionally issues the File-Segment-Recv indication to its user. (When the source entity sends the EOF PDU for the file, it may optionally notify its user via an EOF-Sent indication. Likewise, when the destination entity receives the EOF PDU for the file, it may optionally notify its user via an EOF-Recv indication). If transfer of the entire FDU completes successfully, the destination entity then executes any filestore requests it originally saved from the metadata.

Upon successful completion of the FDU transfer or, if there were any filestore requests, at the completion of any filestore requests, the destination entity sends a Finished PDU to the source entity, and may optionally issue a 'Transaction-Finished' indication to its user. Upon receipt of the Finished PDU, the source entity issues a 'Transaction-Finished' indication to its user. In both cases, the 'Transaction-Finished' indication contains a condition code indicating completion status:

– successful transfer of the complete FDU;

– cancellation by the source or destination CFDP user;

– fault, including protocol error, filestore error, or inactivity.

The ‘Transaction-Finished’ indication also contains a completion status for each of the transaction’s filestore requests, if any.

NOTE – It is possible for the source and destination CFDP entities of a transaction to be unable to communicate directly; in this case the transaction may entail a series of point-to-point (sender-to-receiver) PDU exchange sessions between the source and destination CFDP entities and one or more waypoint CFDP entities.

#### 2.5.1.5 Cancel Request

A ‘cancel’ request may be issued at any time by either the source or destination entity of an ongoing transaction, or by any waypoint if extended procedures are in effect. The request propagates throughout all CFDP entities participating in the designated transaction, causing the immediate and unconditional cessation of all activities involved in the designated transaction, and eliminating it as an activity. The source and destination entities notify their users of the cancellation by issuing the ‘Transaction-Finished’ indication with a condition code indicating cancellation.

#### 2.5.1.6 Suspend Request

A ‘suspend’ request may be issued at any time by either the source or destination entity of an ongoing transaction, or by any waypoint if extended procedures are in effect. The suspend originating entity, if it is the FDU source entity, notifies its user of the suspension by issuing the ‘Suspended’ indication.

#### 2.5.1.7 Resume Request

A ‘resume’ request may be issued at any time by the entity that suspended the transaction, or by any waypoint if extended procedures are in effect. The resume originating entity, if it is the FDU source entity, notifies its user of the resumption by issuing the ‘Resumed’ indication. When the resume responding entity is the FDU destination entity, it may optionally notify its user of the resumption by issuing the ‘Resumed’ indication.

#### 2.5.1.8 Report Request

A ‘report’ request about an ongoing transaction may be issued at any time by either the source or destination entity user; it causes the local CFDP entity to return a status report about the designated transaction in a ‘report’ indication.

### 2.5.2 USER OPERATIONS

#### 2.5.2.1 Definition

The term ‘user operations’ refers to the use of the CFDP services offered by the local CFDP entity to cause the CFDP user of a remote CFDP entity to initiate additional CFDP transactions. User operations are implemented using the ‘Message to User’ capability of the protocol to forward an ‘order’ to the remote CFDP user, which will in turn initiate a transaction with its local CFDP entity.

Six standard user operations are defined:

a) proxy operations;

b) remote status report operations;

c) remote suspend operations;

d) remote resume operations;

e) directory operations;

f) store-and-forward overlay operations.

#### 2.5.2.2 Proxy Operations

Proxy operations are used to initiate the delivery of a file from a remote CFDP entity to some other user, either to the local user itself (in which case the proxy operation functions as a ‘Get’) or to the user of some third CFDP entity. The FDU transmitted in a proxy operation normally contains a file but may contain only metadata, such as filestore directives or a Message to User containing an order to another remote CFDP user.

#### 2.5.2.3 Remote Status Report Operations

Remote status report operations are used to request a report of the status of a specified CFDP transaction at the remote entity.

#### 2.5.2.4 Remote Suspend Operations

Remote suspend operations are used to request the suspension of a specified transaction at the remote entity.

#### 2.5.2.5 Remote Resume Operations

Remote resume operations are used to request the resumption of a specified transaction at the remote entity.

#### 2.5.2.6 Directory Operations

Directory operations are used to request a listing of the contents of a specified directory in the remote user's local filestore.

#### 2.5.2.7 Store-and-Forward Overlay Operations

Store-and forward operations provide an alternative mechanism for transmitting files between users of CFDP entities that may never be in direct communication; this mechanism does not rely on implementation of the Extended Procedures. Each transmitted file is received, stored, and forwarded in a hop-by-hop manner by intermediate *waypoint users* (rather than intermediate waypoint CFDP entities, as in the Extended Procedures) until it finally reaches a user termed the *agent*, whose CFDP entity can directly communicate with that of the *destination* user.

## 2.6 PROTOCOL RELIABILITY OPTIONS

### 2.6.1 GENERAL

The quality of service offered by the protocol is selectable, according to mission requirements and transmission capability, and ranges from an unacknowledged option, whereby a file is transmitted with no attempt at completeness should errors occur (errors will be detected and data discarded), to a fully acknowledged option providing error recovery through retransmission. For the acknowledged mode of operation, several sub-options may be selected by the receiver. These sub-options relate to release time of any Negative Acknowledgments (NAK) and range from immediate release to deferred release (whereby any NAKs are stored until the assumed end of the transmission). The unacknowledged option is appropriate where two-way communication is not possible, where incomplete transmission is acceptable, or where the underlying communication mechanism already ensures reliable data transfer. The acknowledged sub-options share a common acknowledgment mechanism but use different strategies in making retransmission requests to optimize for different scenarios.

For the acknowledged mode of operation, in the Extended Procedures, only the Deferred mode is allowed, whereby any necessary NAKs are transmitted only after the assumed end of the initial reception. See figure 2-6.

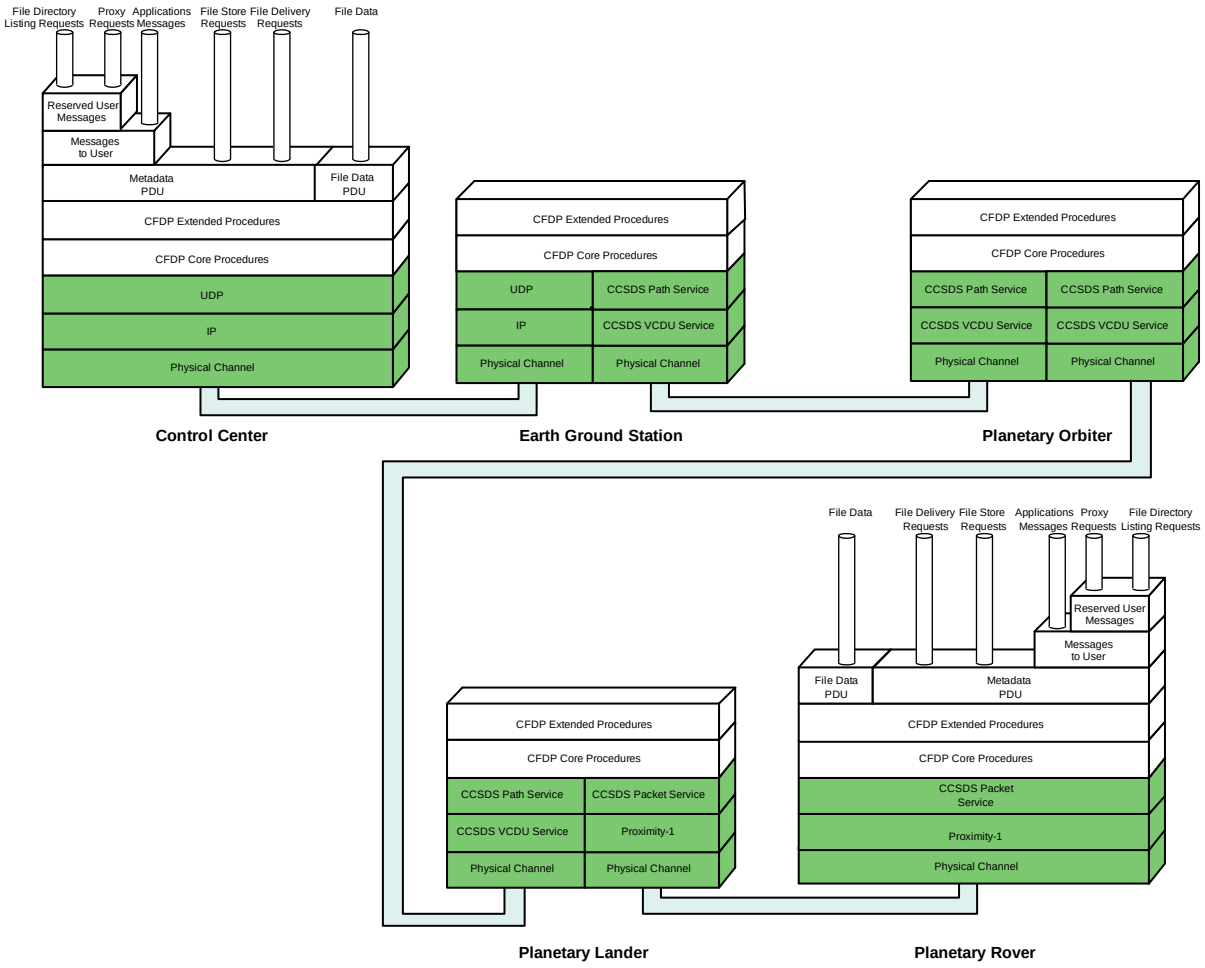



**Figure 2-6: Pipe Diagram—Extended Procedure**

This subsection contains sequence diagrams that illustrate how the protocol uses data transmission and protocol control PDUs to implement the various options available in the unreliable and reliable services. Table 2-2 defines the abbreviations used in the figures for various PDU types; the protocol definition in reference [1] defines the meaning and format of these PDUs in detail. In each file delivery operation, the sequence of events between the file *sender* and the file *receiver* is as shown.

**Table 2-2: Abbreviations**

| Abbr. | PDU Type |
|---|---|
| M | metadata |
| FD(n) | file data segment |
| NAK | retransmission request |
| EOF | end of file (sender to receiver) |
| FIN | finished (receiver to sender) |
| ACK | acknowledgment |
| PRMPT | prompt |

### 2.6.2 UNRELIABLE SERVICE

When unreliable service has been selected, the receiving entity makes no attempt to improve the quality (completeness) of the received file by transmitting information about missing data to the sending entity. That is, the file is sent in what amounts to a simplex mode in that there is only one-way communication, from the sender to the receiver. Figure 2-7 illustrates this mode. A file completion map identifying any missing portions of the file can optionally be delivered to the receiving user. If a CFDP implementation includes this option, it will provide the file completion map as part of the status message returned with the Transaction-Finished indication.

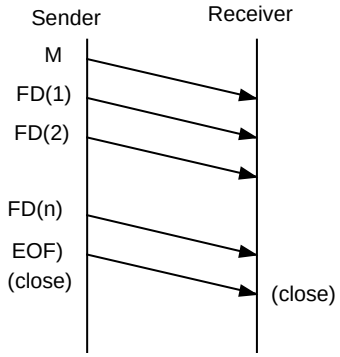



**Figure 2-7: Unreliable Service Mode**

### 2.6.3 RELIABLE SERVICE

#### 2.6.3.1 Negative Acknowledgments and Acknowledgments

When reliable service has been selected, the CFDP uses both Negative Acknowledgments (NAK) and Acknowledgments (ACK). NAKs are used to request retransmission of lost data. ACKs are used to ensure the receipt of EOF and Finished PDUs.

Since lost data may still be outstanding after the EOF sequence, a Finished PDU is sent by the receiving entity when all file data has been successfully assembled. Delivery is ensured by requiring an ACK for the Finished PDU.

NAK procedures are utilized throughout the transmission. There are four user selectable options associated with the issuance of NAKs:

- Deferred;
- Immediate;
- Prompted;
- Asynchronous.

In the Deferred NAK mode, the receiving entity saves all information about missing data until the EOF is received. It then issues a NAK to request the missing data. An example is shown in figure 2-8. The deferred NAK mode may be appropriate where communicating entities are very loosely coupled, such as when interplanetary distances introduce very long light time delays.

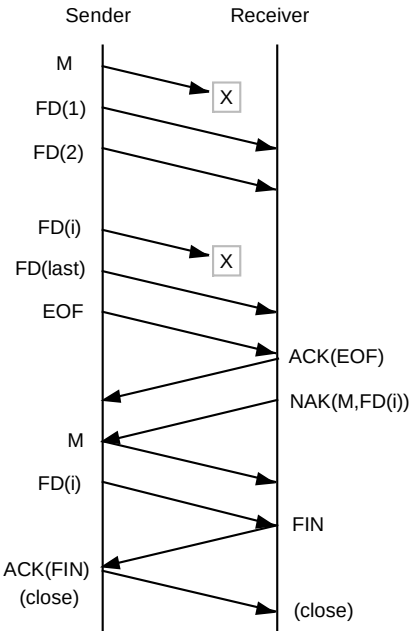



**Figure 2-8: Deferred NAK Mode**

In the Immediate NAK mode, each discontinuity in the data detected at the receiving entity results in the immediate transmission of a NAK to the sending entity. Examples of this mode are shown in figure 2-9. The Immediate NAK mode is useful, for example, where the communicating entities are tightly coupled; it makes no attempt to control the number of NAK messages it uses, in return for maximizing completeness of the received portion of a file as the transfer progresses.

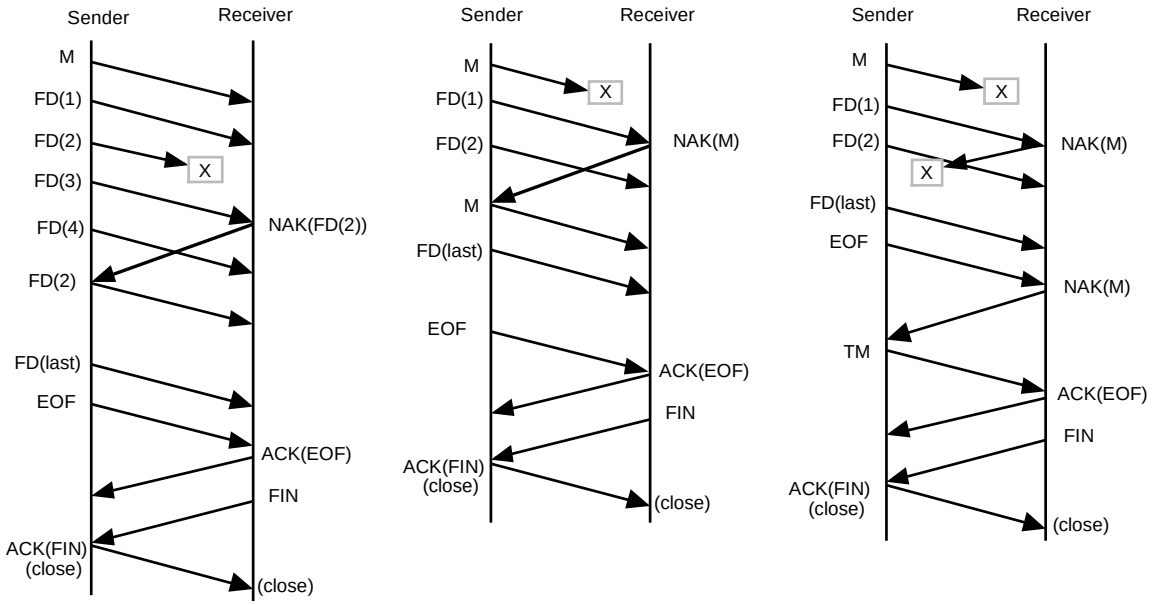



**Figure 2-9: Immediate NAK Mode**

In the Prompted NAK mode, the sending entity transmits a Prompt (NAK) message to the receiving entity telling it to send its NAK. When the receiving entity receives the Prompt (NAK), it sends any outstanding NAK. In response to a Prompt (NAK) when no data is missing, a CFDP NAK may be empty (that is, request the retransmission of no data). The EOF is treated as an inherent prompt and results in the receiving entity's sending a NAK if any data is missing. This mode is illustrated in figure 2-10. The Prompted NAK mode allows the sending entity to control the frequency of NAK messages, which may be useful, for example, when the return link for sending NAKs is only occasionally available, or is very bandwidth-limited.

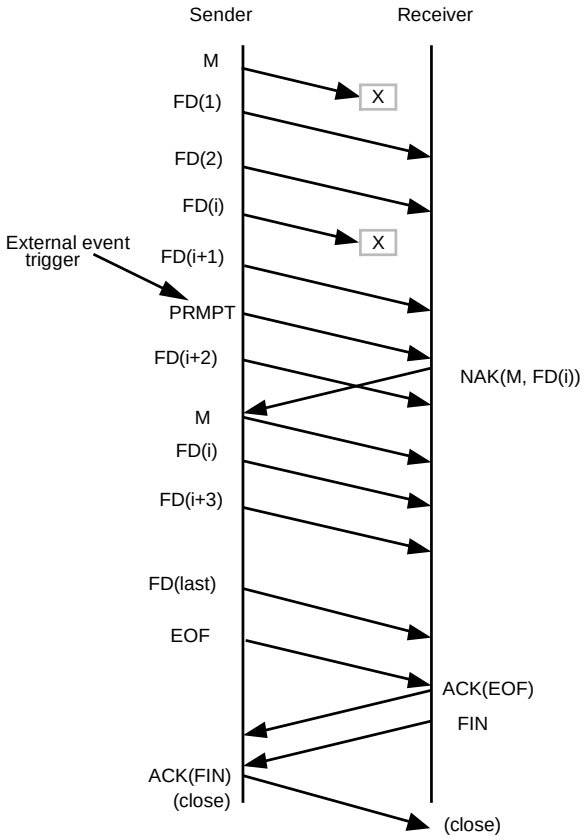



**Figure 2-10: Prompted NAK Mode**

In the Asynchronous NAK mode the receiving entity issues a NAK (if any data is missing) in response to some outside event; that is, the receiving entity is triggered by something outside of the CFDP to send any necessary NAK. Such an external event might for instance be the impending loss of the space-to-ground link. An example of this mode is shown in figure 2-11. Like the Prompted NAK mode, the Asynchronous NAK mode also limits the frequency of NAK messages, but in this case the receiving entity has control.

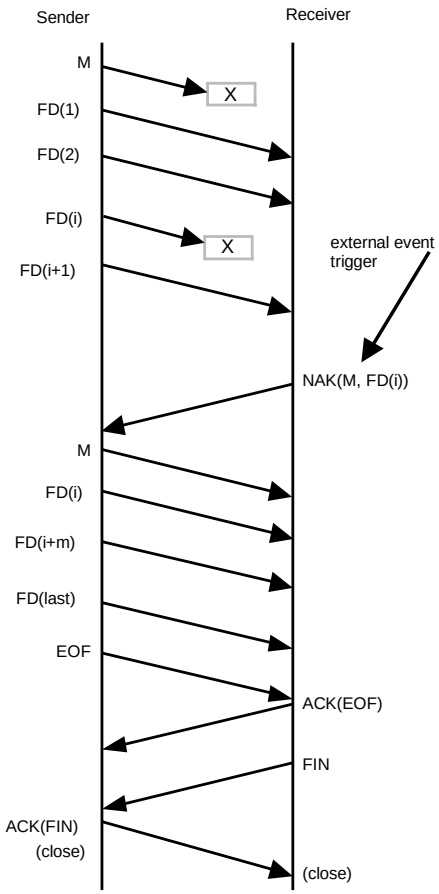



**Figure 2-11: Asynchronous NAK Mode**

### 2.6.3.2 Timers

Several timers are used in the reliable service processes. In each case in which a time-out capability is required, a timer is started upon issuance of the item. Upon receipt of the required response, the timer is disabled. If the required response is not received before the timer expires, the item is reissued. A count of the number of retransmissions is kept. If the preset limit of retransmissions is exceeded, a fault is declared.

In reliable service, within the file copying process timers are invoked for the EOF, the EOF-triggered NAK, and finished (FIN) transmissions.

The operation of the NAK time-out is illustrated in figure 2-12. A NAK timer is started upon the issuance of the EOF-triggered NAK (which requests (re)transmission of all file data not yet received). Note that previous individual NAKs are not acknowledged. When the timer expires, the receiving entity again determines whether or not any of the transaction's file data or metadata have yet to be received. If any file data gaps or missing metadata remain, normally a NAK is issued and the timer is reset.

The operation of the end-of-file and finished time-outs is shown in figure 2-13, parts (a) and (b), respectively.

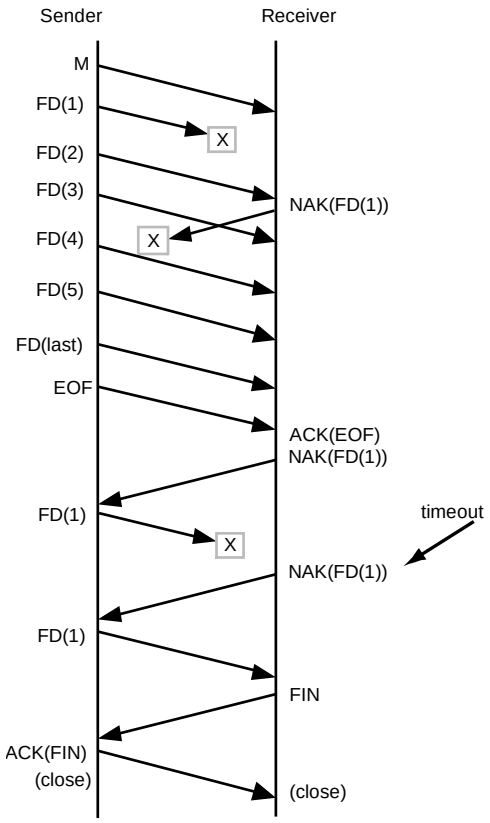



**Figure 2-12: Time-out Triggered NAK Retransmission**

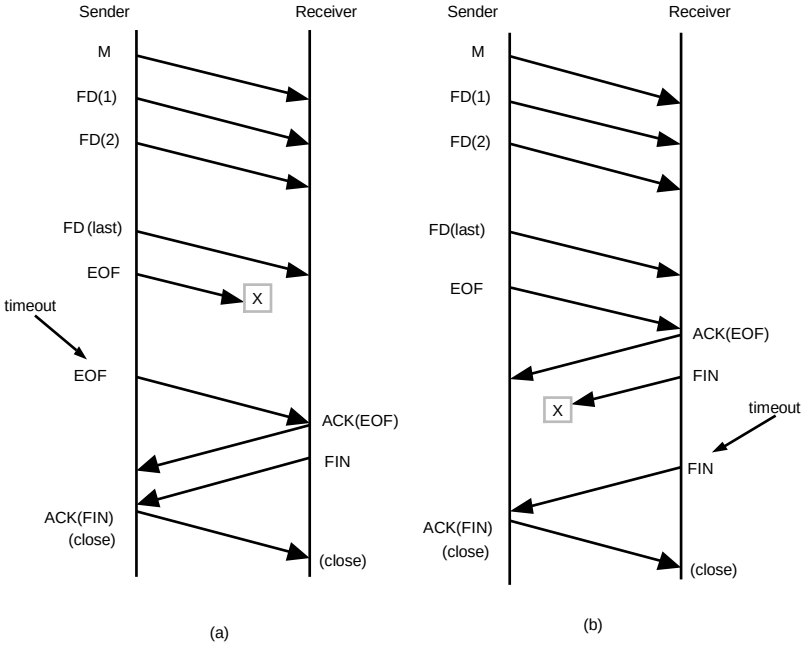



**Figure 2-13: Time-out Triggered EOF and Finished Retransmissions**

In addition to the time-outs just described, there is an overall inactivity timer. If there is a cessation of PDU reception for a given Transaction for the specified time period, this timer causes the issuance of a Fault indication, with a condition code identifying the condition 'Inactivity' to the local user. It takes no other action. That is, any further resulting action is not specified by the protocol, but is taken by the user in an implementation-specific manner. The user might try to restart or otherwise salvage the Transaction, abandon it, or take some other action appropriate to the implementation and operational configuration. The basic purpose of the timer is to handle situations that are outside the protocol itself. Examples might be the crashing of the operating system in the other entity party to the ongoing Transaction, the extended failure of an intermediate communication link, etc. This timer is mandatory, except that it is not used at the Source end of an unacknowledged mode transfer.

## 2.7 PRIMITIVES, PDUS, AND PIPES

The 'spawning' relationships between Request Primitives and PDUs, and between PDUs and Indication Primitives in the operational process from initiation through termination, is shown in figure 2-14. Figure 2-15 is a 'pipe' diagram of the CFDP showing several of the possible lower layers. The examples of lower layers shown in the figure are just that, examples, and are not intended to be all-inclusive. Figure 2-16 shows a possible example implementation involving a spacecraft, a ground station and a control center. (Refer also to 3.2.1.3 and 3.2.1.4.)

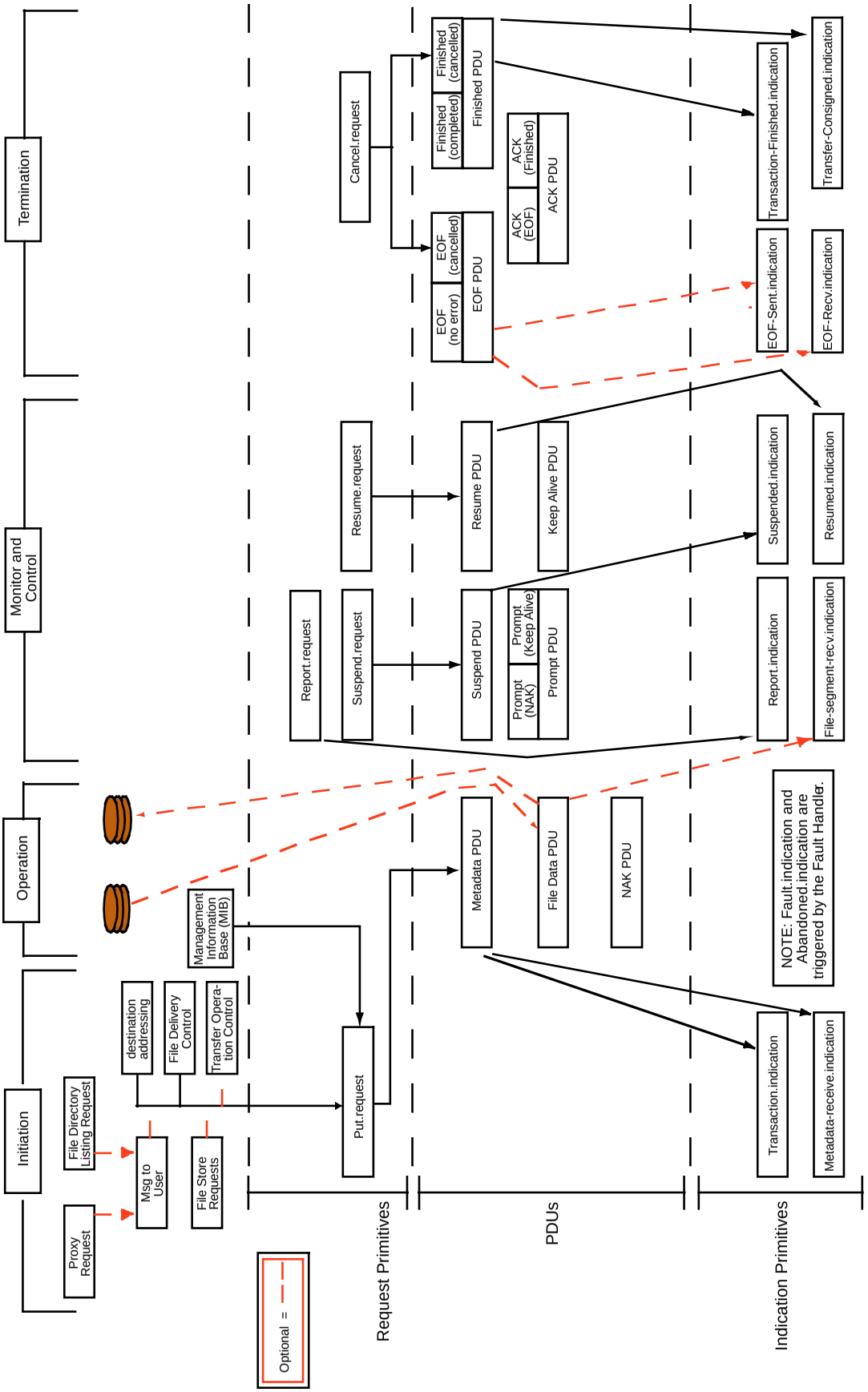



**Figure 2-14: Request Primitives, PDUs, and Indication Primitives—Operational View**

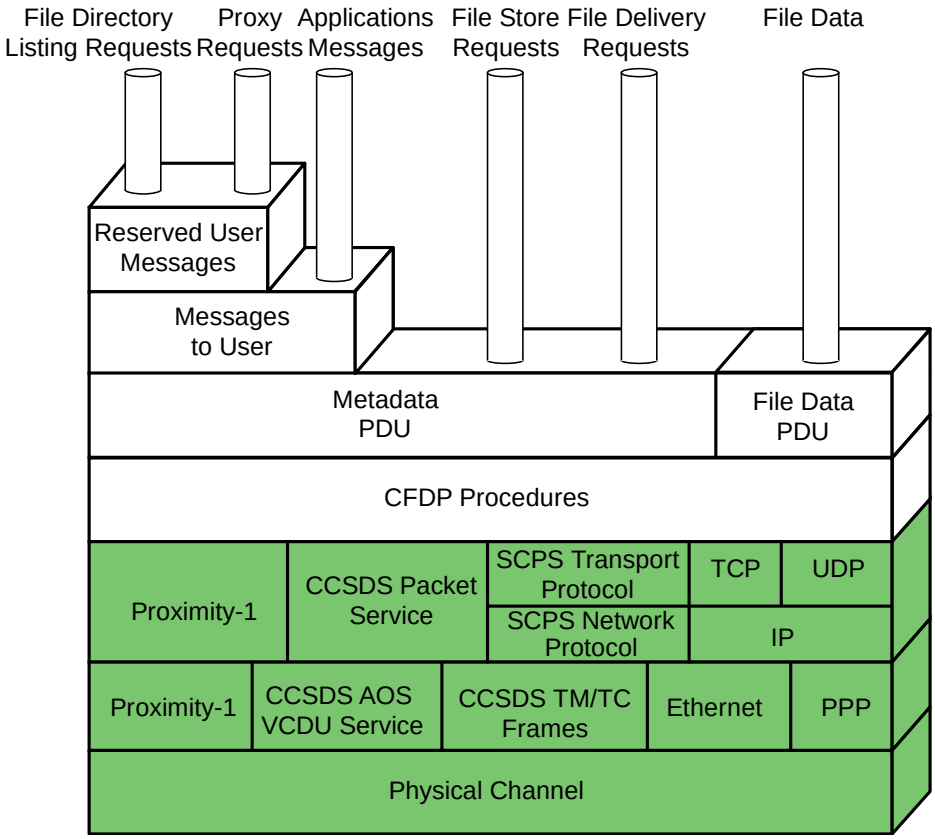



**Figure 2-15: CFDP Pipe Diagram**

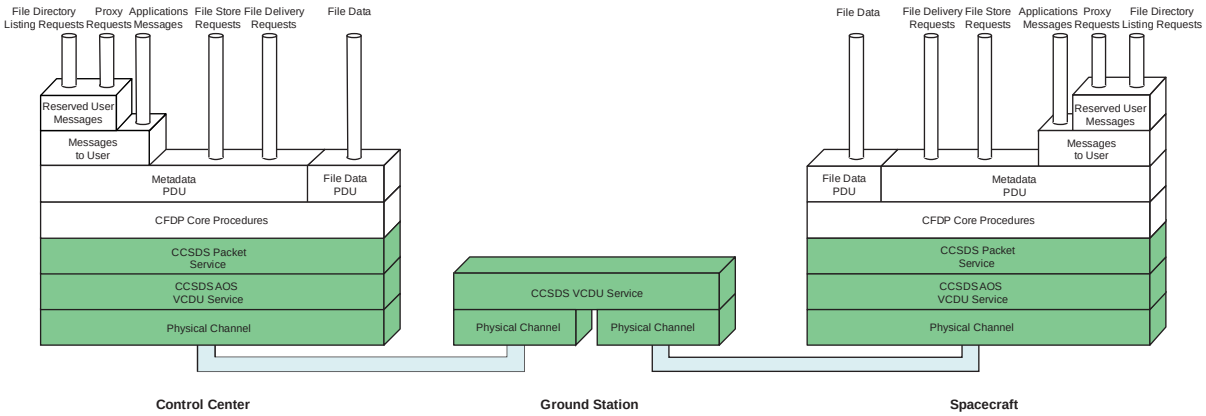



**Figure 2-16: Pipe Diagram—Example of Relay**

# 3 EXAMPLE CONFIGURATIONS

## 3.1 OVERVIEW

This section provides examples that illustrate some of the widely varying network topologies over which the CFDP will operate, and the use of some of the CFDP options.

The entire purpose of the CFDP is to perform a file transfer between two end points. These end points may be located in Earth-orbiting spacecraft, mission control centers, or interplanetary spacecraft. The end points may often not have direct connection to one another. The CFDP overcomes such blocking conditions by utilizing intermediate entities (waypoints) and/or with multi-pass connections in time, either disjoint or with overlap.

The following example mission configurations are included:

– file deliveries using no waypoints;

– file deliveries using three party proxy;

– file deliveries using one waypoint.

NOTE – Annex B contains the following example mission configurations:

– file deliveries via waypoints in parallel;

– file deliveries via waypoints in series and parallel.

It is important to note that a facility located between CFDP end points does not necessarily constitute a ‘waypoint’. If such a facility (often a ground station or relaying spacecraft) does not contain a CFDP entity and provides only lower layer services, it is simply a ‘relay’; in the context of the CFDP, a point-to-point connection exists through such a relay between two CFDP entities. Example Mission Configurations 1, 2, and 3 include ground stations configured as relays rather than waypoints.

Ground station handover management is required any time a file transfer cannot be completed within a single pass and must be resumed later over the same or a different ground station. CFDP contains basic concepts (transaction ID) and services (Suspend/Resume and Link Lost/Link Acquired) to meet handover requirements in many situations. Although handover management is not a part of the protocol, and no specific handover management signaling takes place between CFDP entities, CFDP is well adapted to the automation of this process and, therefore, it strongly supports station operations automation. System functions outside the CFDP may be used to implement fully autonomous handover operations.

## 3.2 FILE DELIVERIES

### 3.2.1 EXAMPLE CONFIGURATION 1: FILE DELIVERIES WITH NO WAYPOINTS

#### 3.2.1.1 General

In Example Configuration 1, a file transfer takes place between two CFDP entities, a spacecraft and an NCC. One or more ground stations handle frames and route data between the spacecraft and NCC. The ground stations do not contain CFDP entities and therefore are relays, and there is a (functional) point-to-point connection between the two CFDP entities. Examples are given for unreliable space-to-ground, reliable space-to-ground, reliable ground-to-space, and two party proxy (Get). Three party proxy file deliveries are shown in Example Configuration 2.

When only one ground station is used (figure 3-1) and the file being delivered is large, multiple space-to-ground contacts (passes) with the ground station may be required in order to complete the delivery of the subject file.

If more than one ground station is used (figure 3-2) there may be redundant data (if multiple space-to-ground contacts are required, the ground station contacts may overlap in time.) The CFDP service at each endpoint deletes any duplicate data that it received because of overlapping contacts.

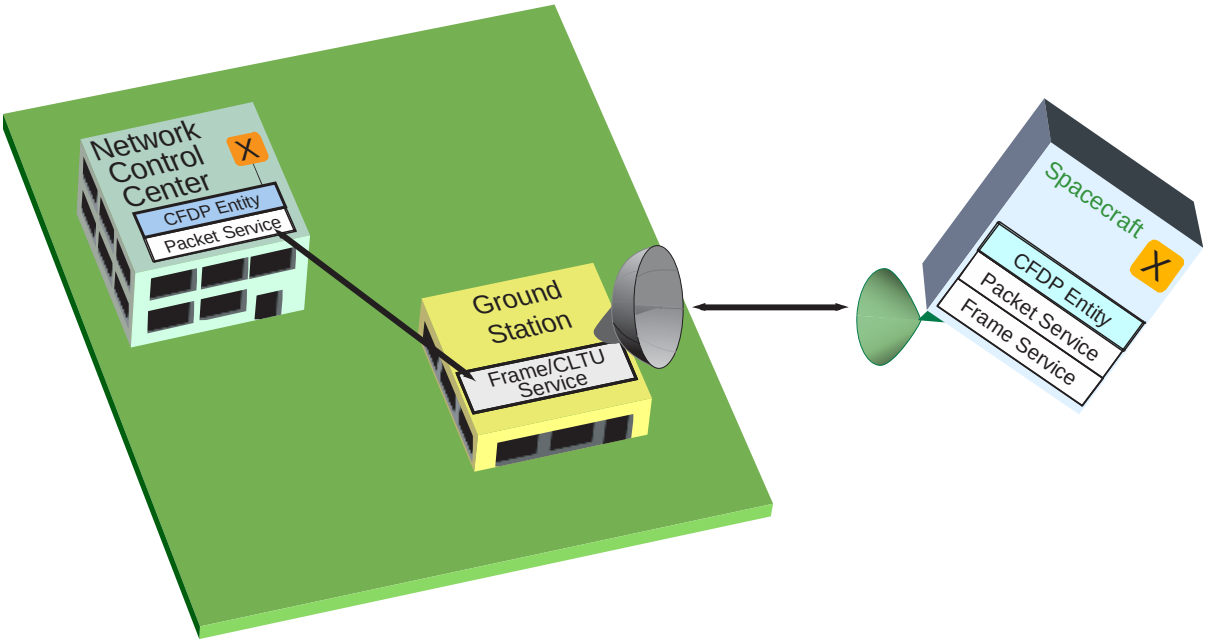



**Figure 3-1: Example Configuration 1**

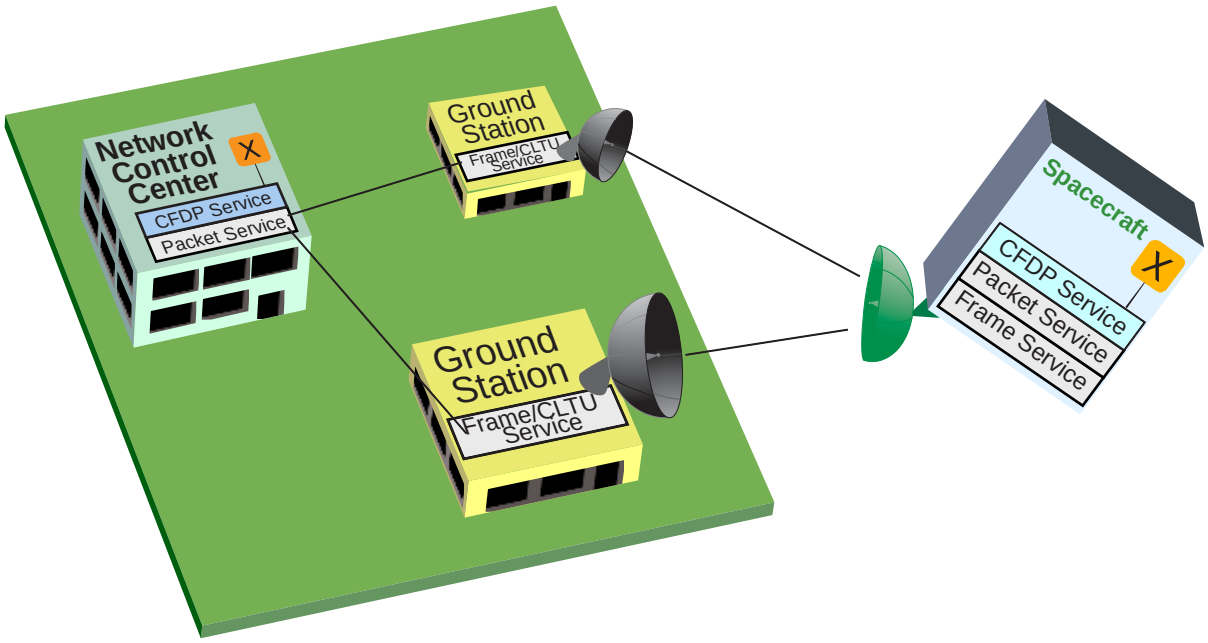



**Figure 3-2: Example Configuration 1a**

### 3.2.1.2 Unreliable Download

Example 1 of Configuration 1 is of an unreliable file delivery from a spacecraft to an NCC. The network configuration is directly from the spacecraft through ground stations to the NCC, as shown in figures 3-1 and 3-2. The file size may be large enough to require more than one ground/spacecraft contact period. The ground station contacts may overlap in time, or may be time disjoint.

A user (human or automated) on the spacecraft initiates the transaction by causing a Put request to be sent to the local spacecraft CFDP entity.

Upon receipt of the Put request, the spacecraft CFDP entity initiates the transaction. It configures the protocol options (e.g., quality of service) according to the information contained in the MIB, unless overridden by information in the Put request. The CFDP entity places the required information in the file metadata and begins the file delivery operation. Each item that the CFDP entity wishes transmitted is placed in a PDU and passed to the lower layer network. In this example the interface is to CCSDS Path Service. The Path Service places the PDUs within CCSDS packets, virtual channels, and frames and transmits them to the ground station(s). The ground station(s) synchronizes on the frames, optionally performs error correction, and routes them to the NCC. At the NCC, the NCC CCSDS packet service extracts the packets from the frames, the PDUs from the packets, and passes the PDUs to the NCC CFDP service for action and file assembly. (Alternatively, the packet extraction process could be accomplished by CCSDS services at the ground stations, with the extracted packets being sent to the NCC CFDP entity via CCSDS Path Service.) Any duplicate PDUs caused by overlapping ground station contacts are removed by the CFDP entity. Because unreliable service has been selected, there is no CFDP traffic from the NCC

to the spacecraft. Details of the CFDP PDUs, their contents and formats, and the manner in which they operate are detailed in reference [1].

The sequence of events is shown in figure 3-3. Note that since this example is for unreliable quality of service, the loss of File Data PDU 'N+1' is irrecoverable. Also note that an optional File Completion Map, which shows the size and exact location within the file of the missing data, is available to the NCC User. (In all the sequence diagrams, optional items are shown in red.) This mode may be particularly useful for the transmission of image data, etc., where file sizes tend to be large and absolute completeness may not be necessary.

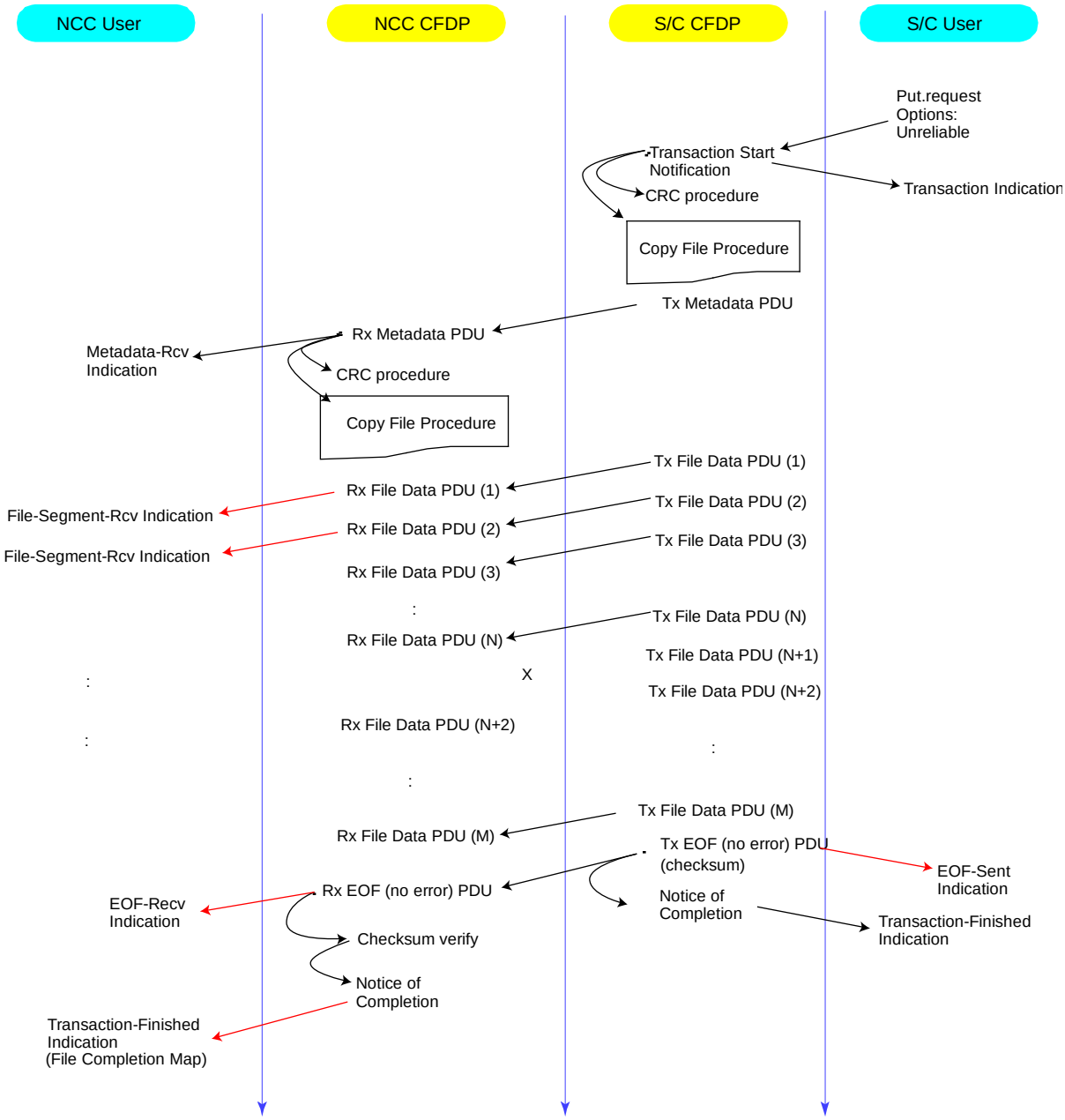



**Figure 3-3: Unreliable Download**

### 3.2.1.3 Reliable Download

Example 2 of Configuration 1 is of a reliable delivery of a file from a spacecraft to an NCC. The network configuration is directly from the spacecraft through ground stations to the NCC, as shown in figures 3-1 and 3-2. The spacecraft is in low Earth orbit, and the contact will have simultaneous uplink and downlink. The file size may be large enough to require more than one ground/spacecraft contact period. The ground station contacts may overlap in time or may be time disjoint. The following options could be selected to meet the requirements:

- quality of service—reliable;
- NAK mode—immediate.

A user (human or automated) on the spacecraft initiates the transaction by causing a Put request to be sent to the local spacecraft CFDP entity.

Upon receipt of the Put request, the spacecraft CFDP entity initiates the transaction. It configures the protocol options (e.g., quality of service, NAK mode) according to the information contained in the MIB, unless overridden by information in the Put request. It places the required information in the file metadata and begins the file delivery operation. Each item that the spacecraft entity wishes transmitted is placed in a PDU and passed to the lower layer network. In this case, the interface is to CCSDS Path Service. The operation through the Path Service has been described previously (3.2.1.2).

The sequence of events is shown in figure 3-4. Note that since this example is for reliable quality of service, the lost File Data PDU ‘N+1’ is recovered. Also note that as the NAK mode is Immediate, when File Data PDU ‘N+2’ is received and it is therefore known that N+1 was missed, the NAK requesting retransmission of N+1 is sent immediately. Finally, note that an optional File Completion Map, which shows the size and exact location within the file of any missing data, is still available to the NCC User even though, since this is a reliable transfer, there should be no missing data. This is because in the event of a protocol error that causes cancellation of the remaining file delivery operation, it may be desirable to retain that portion of the file that has been received. In that situation the file completion map can be important. If a CFDP implementation includes this option, it will provide the file completion map as part of the status message returned with the Transaction-Finished indication.

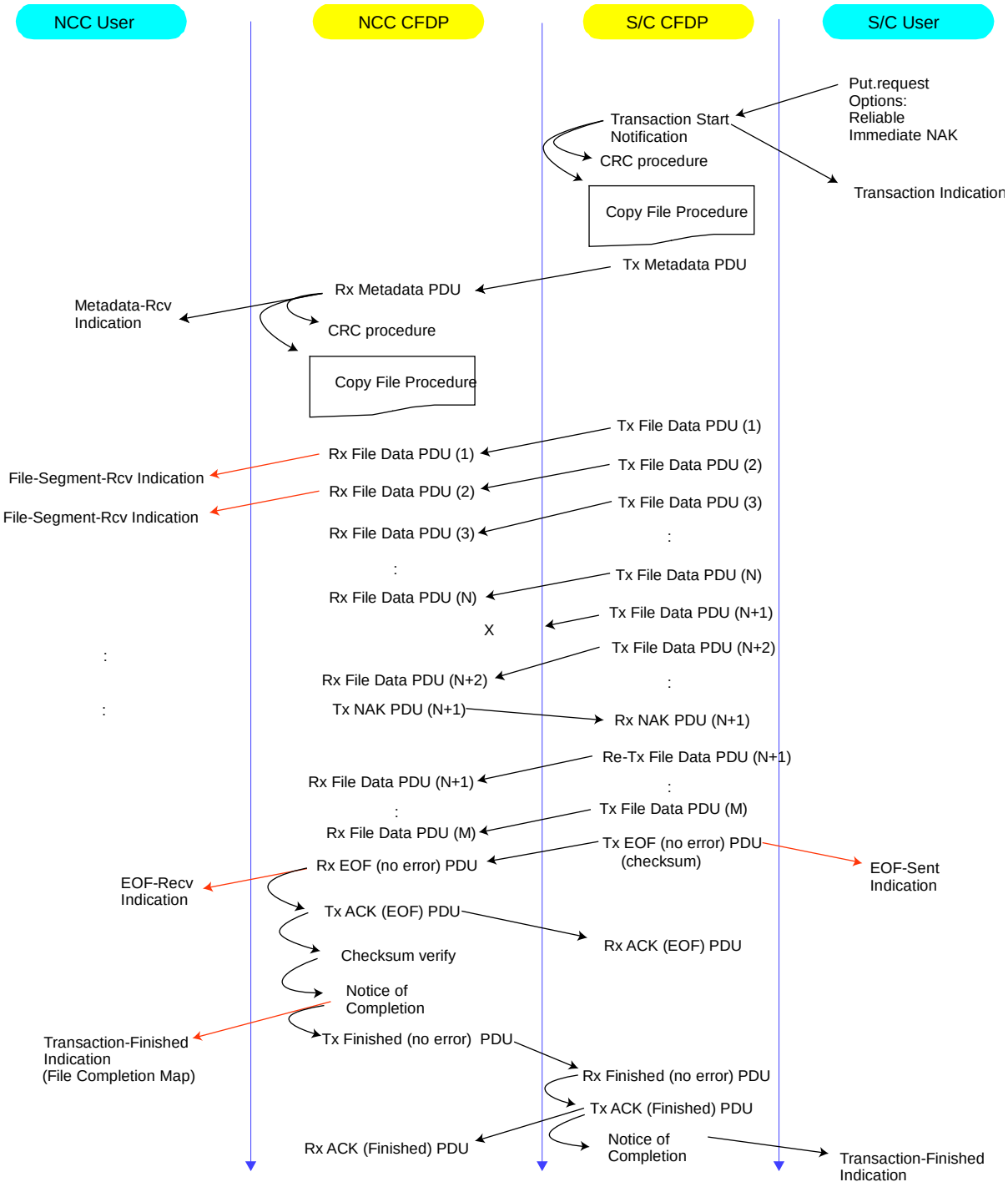



**Figure 3-4: Reliable Download**

### 3.2.1.4 Reliable Upload

The third example of Configuration 1 is of an NCC-initiated reliable delivery, from the control center to a spacecraft, of a file constituting a new star catalogue for use by star trackers of the onboard navigation system. The network configuration is directly from the NCC through ground stations to the spacecraft as shown in figures 3-1 and 3-2. The spacecraft is in cruise configuration in an interplanetary transfer trajectory and, because of power restrictions in cruise mode, the downlink transmitter will not be turned on until late in the contact period. The file size is small enough to require only a single ground/spacecraft contact period. It is desired to include a message to the onboard navigation system to switch from the old to the new star catalogue during the first slew maneuver, after successful receipt of the new star catalogue.

NOTE – The main purpose of the CFDP's including the ability to carry a 'message to user' in the metadata of the file being transferred is to synchronize utilization of that message with delivery of the file. In this example, if the command to switch to the new star catalogue was sent in a separate transmission, it might arrive either before or long after the map itself, depending on packet loss and retransmission effects. However, if the message is attached to the file itself, then synchronized receipt of the message is implicit. Also, the CFDP has the capability of carrying file store directives in specially marked versions of message to users, thus assuring that the file store directives will be synchronized with the file to which they are related, if so desired.

The following options could be selected to meet the requirements:

- message to user—transmitted in the Put request;
- quality of service—reliable;
- NAK mode—asynchronous.

The asynchronous NAK mode is selected, since a downlink will not be available until late in the contact period. By using the asynchronous mode, the bulk of the file can be delivered before the downlink is available. Then when the downlink transmitter is turned on, only the transmission of any necessary NAK and the resulting data retransmissions, as well as the transaction close-out actions, remain to be accomplished. (The deferred NAK mode might be a better solution, but this example is used to illustrate the function of the Asynchronous NAK mode.)

A user (human or automated) in the NCC initiates the transaction by causing a Put request to be sent to the local NCC CFDP entity. The message to user to be sent with the file is contained within the request.

Upon receipt of the Put request, the NCC CFDP entity initiates the transaction. It configures the protocol options (e.g., quality of service, NAK mode) according to the information contained in the MIB, unless overridden by information in the Put request. It places the message to user described above in the file metadata and begins the file delivery operation.

Each item that the CFDP entity wishes transmitted is placed in a PDU and passed to the lower layer network. In this case, the interface is to CCSDS Path Service. The operation through the Path Service has been described previously (3.2.1.2).

The sequence of events is shown in figure 3-5. Note that since this example is for reliable quality of service, the lost File Data PDU 'N+1' is recovered. Also note that as the NAK mode is Asynchronous, when File Data PDU 'N+2' is received and it is therefore known that N+1 was missed, the NAK requesting retransmission of N+1 is not sent immediately, but is held until an external event (establishment of downlink connectivity) triggers its transmission. Finally, note that an optional File Completion Map, which shows the size and exact location within the file of any missing data, is available to the Spacecraft User even though, since this is a reliable transfer, there should be no missing data. This is because in the event of a protocol error that causes cancellation of the remaining file delivery operation, it may be desirable to retain that portion of the file that has been received. In that situation the file completion map can be important. If a CFDP implementation includes this option, it will provide the file completion map as part of the status message returned with the Transaction-Finished indication.

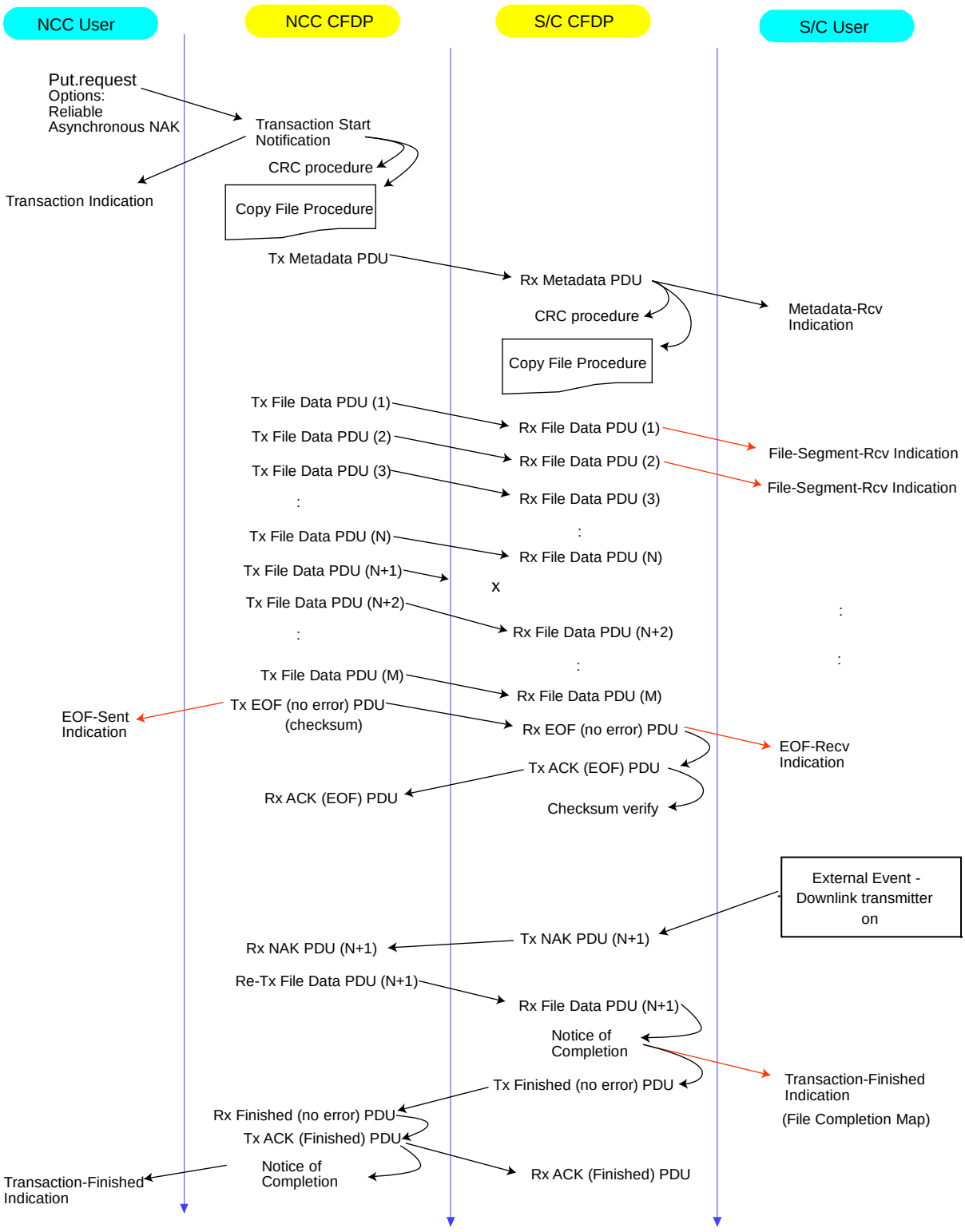



**Figure 3-5: Reliable Upload**

#### 3.2.1.5 Two Party Proxy (Get)

The CFDP provides a functional 'Get' capability through the use of a proxy operation. It effects this through the use of a 'Proxy Put Request'. This example is that of an NCC initiating a reliable delivery of a file from a spacecraft to the NCC (a functional 'Get'). The network configuration is directly from the spacecraft through ground stations to the NCC, as shown in figures 3-1 and 3-2. The spacecraft is in low Earth orbit, and the contact will have simultaneous uplink and downlink. The following options could be selected to meet the requirements:

- transaction type—Proxy Put;
- quality of service—reliable;
- NAK mode—immediate.

The sequence of events is shown in figure 3-6. The user at the NCC initiates the transaction by inputting a Put.request primitive to the local NCC CFDP entity. The Put.request primitive contains a Proxy Put Request message, and the options selection shown above. The resulting Put.request PDU is sent to the spacecraft CFDP entity as a single transaction, called Transaction 'X' in figure 3-6. This transaction contains only metadata (containing the specially marked message to user that in turn contains the Proxy Put Request), and no file data. Upon receipt of the Proxy Put Request, the spacecraft CFDP entity user initiates a Put file delivery transaction from itself to the NCC (Transaction 'Y'), using the parameters sent by the NCC. The spacecraft/NCC transaction is a normal Put transaction, except that when the Transaction-Finished indication for Transaction 'Y' is received by the spacecraft user, it causes a completion notification to be sent (as Transaction 'Z') back to the NCC CFDP entity, informing it that the proxy file delivery it requested in Transaction 'X' has been completed.

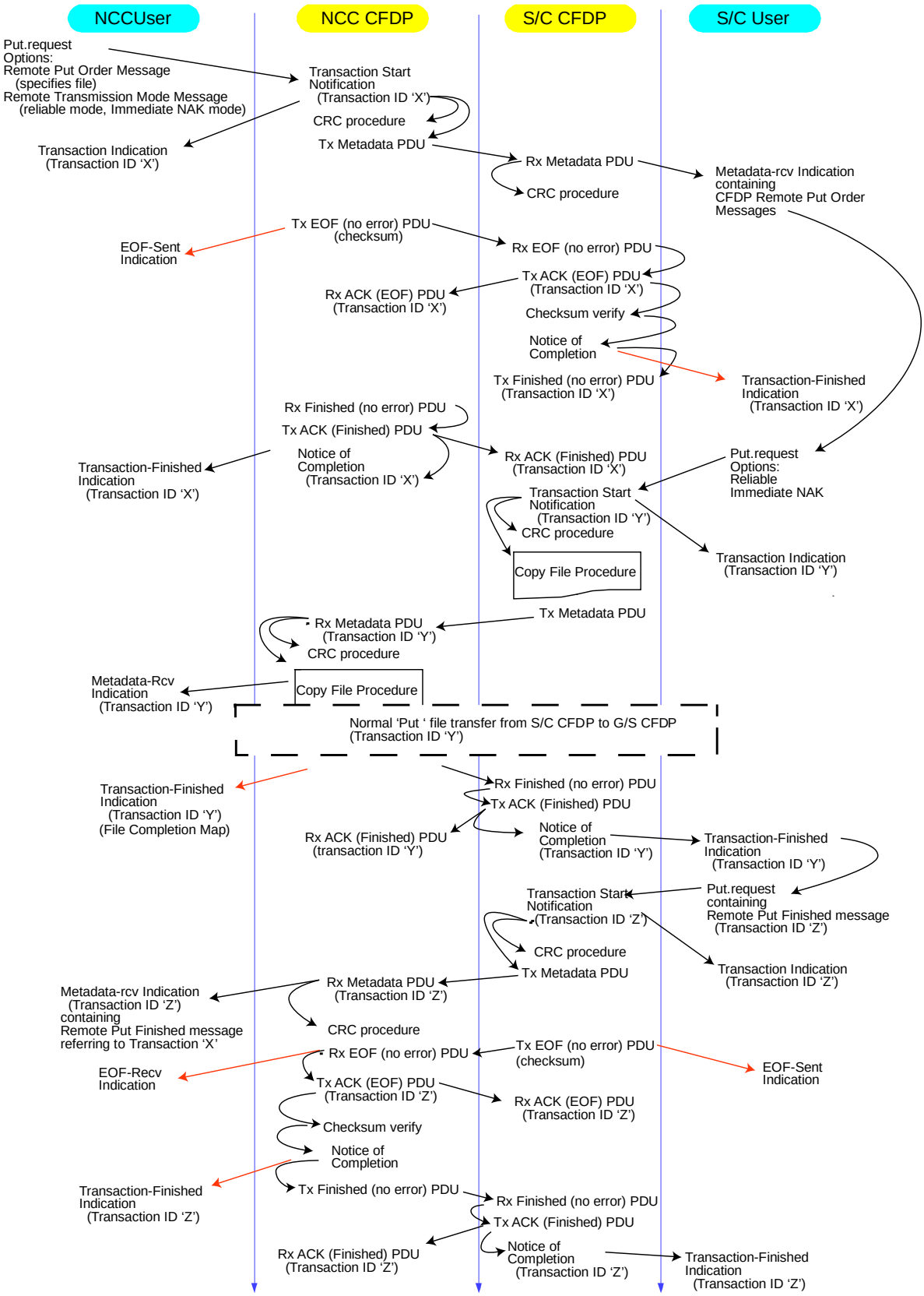



**Figure 3-6: Two Party Proxy (Get)**

### 3.2.2 EXAMPLE CONFIGURATION 2: THREE PARTY PROXY

The next example is that of a user (perhaps notified by telephone of a spacecraft emergency) requesting an NCC to initiate reliable delivery of an instrument contingency operations file *resident at the NCC* to a spacecraft. The user is remote from his/her home facility and uses a laptop computer, which contains a CFDP entity. The network configuration is from the user's laptop (via the Internet), to the NCC, to a ground station, to the spacecraft, as shown in figure 3-7. The spacecraft is in low Earth orbit and the NCC/spacecraft contact will have simultaneous uplink and downlink. The file size is small enough that it can be completely delivered within one ground/spacecraft contact period.

The following options could be selected to meet the requirements:

- transaction type—Proxy Put;
- quality of service—reliable;
- NAK mode—immediate.

The sequence of events is shown in figure 3-8. The remote user initiates the transaction by inputting a Put.request primitive to his/her local laptop CFDP entity. The Put.request primitive contains the address of the NCC CFDP entity, a Proxy Put Request message, and the options selection shown above. The resulting Put.request PDU is sent to the NCC CFDP entity, via the Internet, as a single transaction, called Transaction 'X' in figure 3-8. This transaction contains only metadata (containing the specially marked message to user that in turn contains the Proxy Put Request), and no file data. Upon receipt of the Proxy Put Request, the NCC CFDP entity user initiates a Put file delivery transaction from itself to the spacecraft (Transaction 'Y'), using the parameters sent by the remote User. The NCC/spacecraft transaction is a normal Put transaction, except that when the Transaction-Finished indication for Transaction 'Y' is received by the NCC user, it causes a completion notification to be sent (as Transaction 'Z') back to the Remote User's CFDP entity, informing it that the proxy file delivery it requested in Transaction 'X' has been completed.

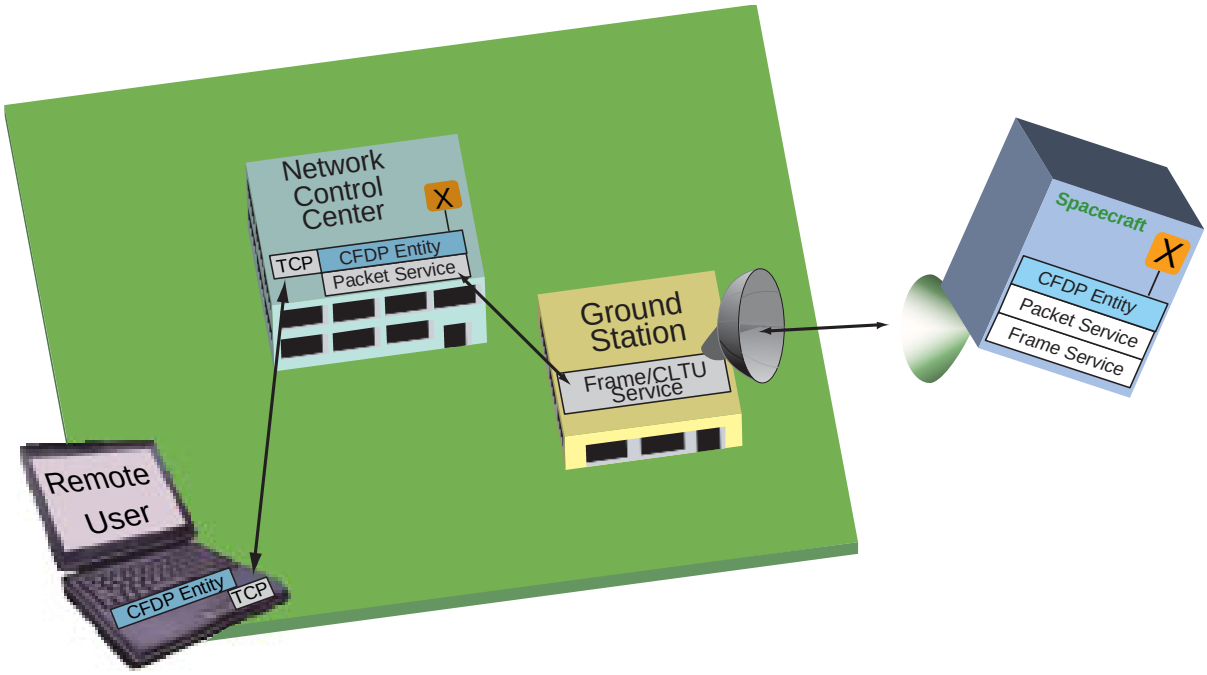



**Figure 3-7: Example Mission Configuration 2 (Three Party Proxy)**

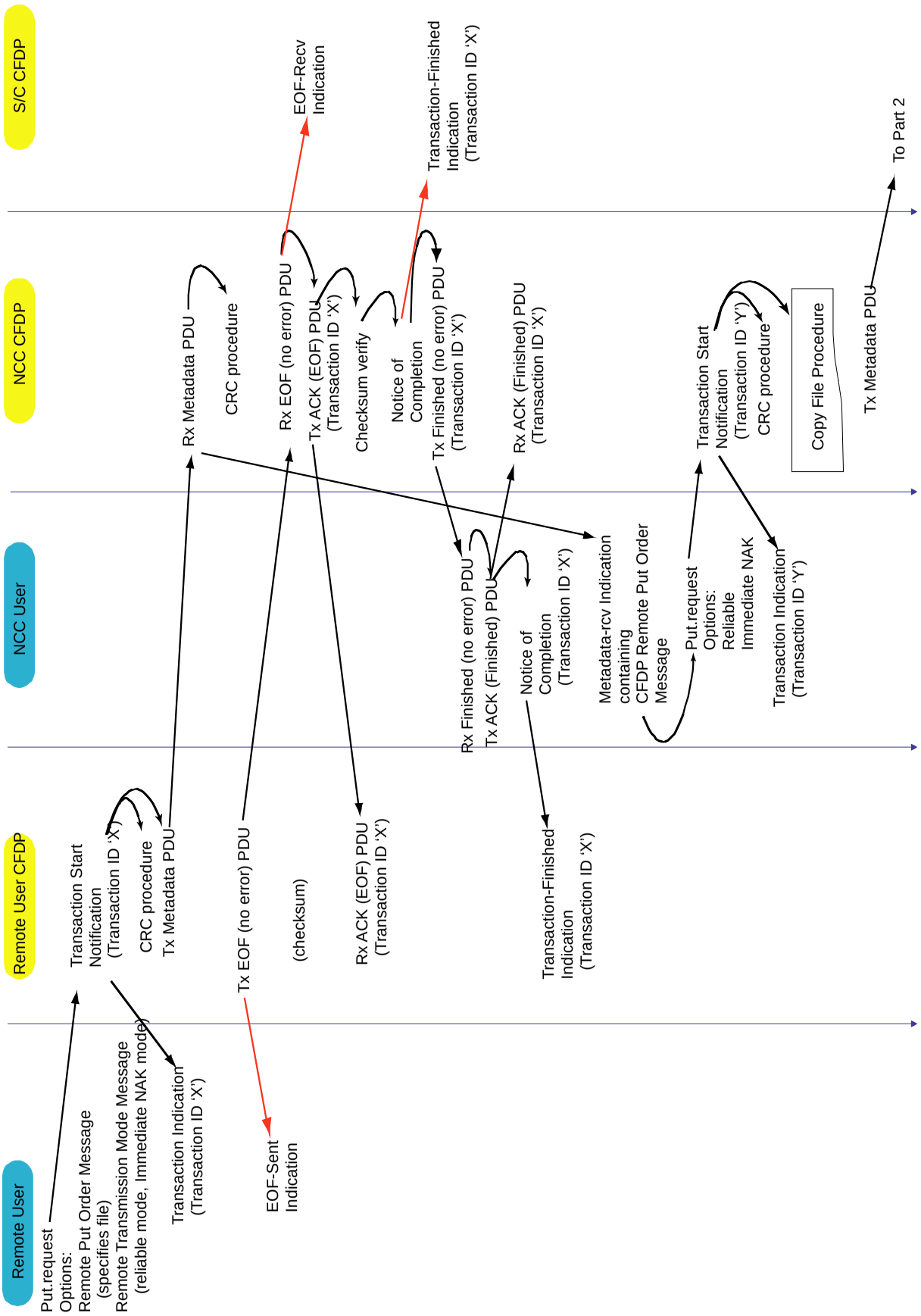



**Figure 3-8: Three Party Proxy (Part 1)**

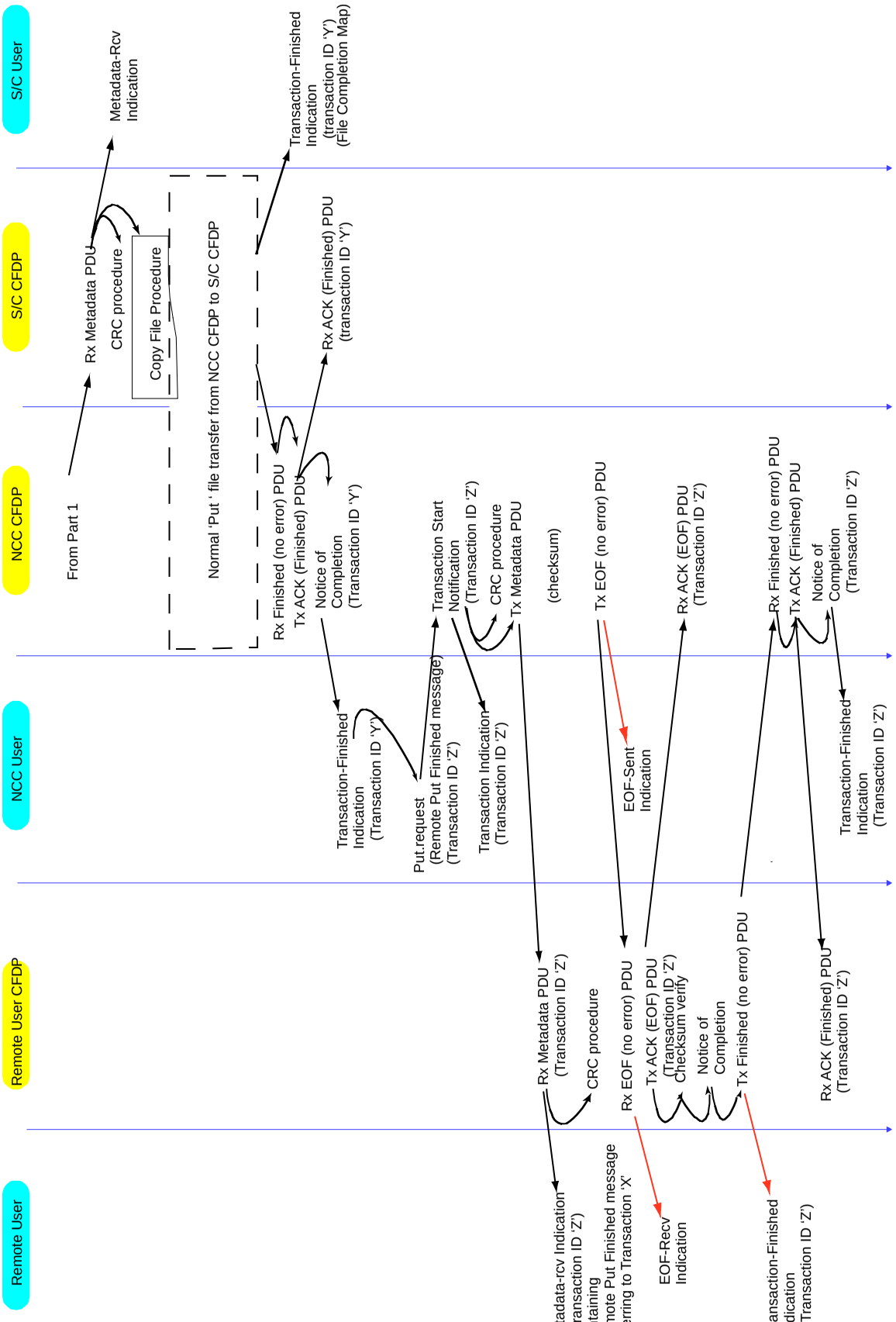



**Figure 3-8: Three Party Proxy (Part 2)**

### 3.2.3 EXAMPLE CONFIGURATION 3: FILE DELIVERIES VIA ONE WAYPOINT

#### 3.2.3.1 General

In Example Mission Configuration 3, a file transfer takes place involving three CFDP entities, one of which acts as a waypoint. In figure 3-9 the CFDP entities are shown contained in a spacecraft, an NCC, and a remote science laboratory, but they could as easily be a spacecraft, a communications spacecraft, and a ground station, or any other mix of facilities. In the figure, a ground station handles frames and routes data between the spacecraft and an NCC. The ground station does not contain a CFDP entity and, therefore, is a relay. Within this configuration examples are given for unreliable space-to-ground, reliable space-to-ground, and reliable ground-to-space file deliveries.

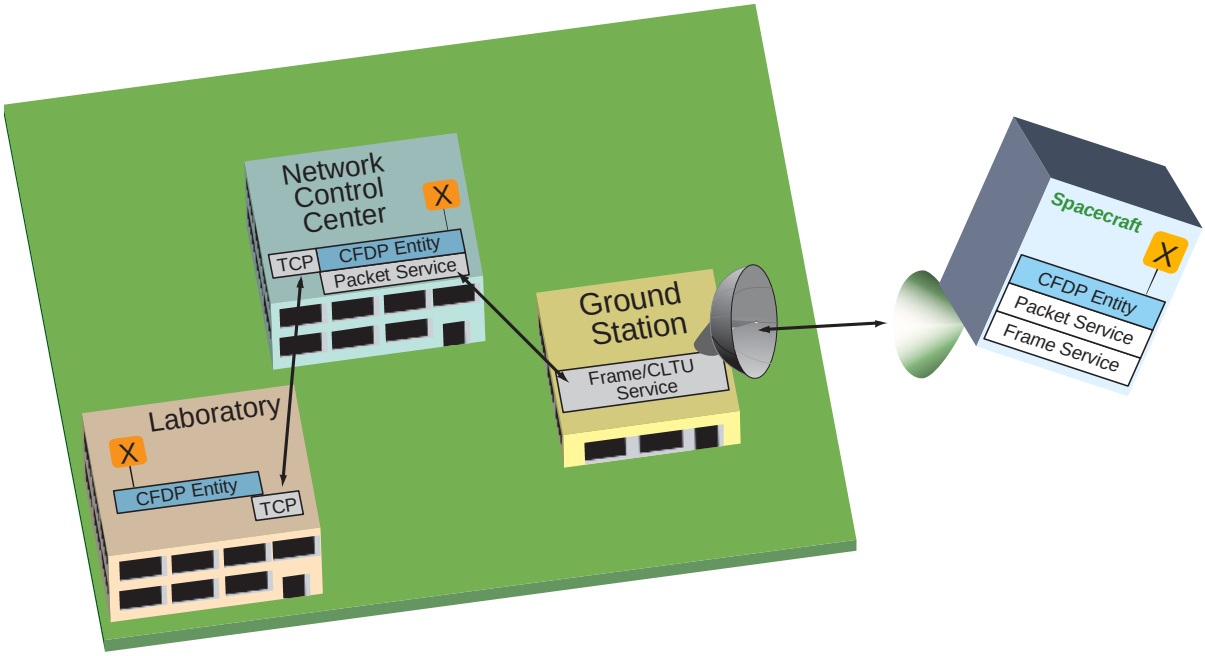



**Figure 3-9: Example Mission Configuration 3**

#### 3.2.3.2 Unreliable Download via One Waypoint

This example begins with an intelligent spacecraft that, having detected an anomaly in a science instrument, wishes to deliver telemetry data to a user located in a science facility (laboratory) remote from an NCC. As this is real-time telemetry data, the file size is unbounded. Since the telemetry data inherently contains a great deal of information redundancy, it is not necessary that every bit of it be received by the science facility. The spacecraft therefore selects unreliable mode. The remote user has a local CFDP entity, but does not have direct communication with the spacecraft, and thus requires the use of the NCC as an intermediary. Also, the laboratory does not operate 24 hours per day, so store-

and-forward service is needed from the NCC. The NCC contains a CFDP entity. The ground station does not contain a CFDP entity and provides only lower layer services. This configuration is shown in figure 3-9.

The following options could be selected to meet the requirements:

- implementation—extended procedures;
- transaction type—Put;
- quality of service—unreliable.

The anomaly detection system on the spacecraft initiates the transaction by causing a Put request to be sent to the local spacecraft CFDP entity.

Upon receipt of the Put request, the spacecraft CFDP entity initiates the transaction. It configures the protocol options (e.g., quality of service) according to the information contained in the MIB, unless overridden by information in the Put request. The CFDP entity places the required information in the file metadata and begins the file delivery operation. Each item that the CFDP entity wishes transmitted is placed in a PDU and passed to the lower layer network. In this case, the interface is to CCSDS Path Service. The operation through the Path Service has been described previously (3.2.1.2).

A TCP/IP network service is used between the NCC and the user. Upon receipt of the complete file, and when the laboratory is online, the NCC forwards it to the user over the TCP/IP network.

The sequence of events is shown in figure 3-10. Note that since the file size is unbounded (the data is real-time telemetry), file closing is triggered by an external event, in this example a trigger from the onboard spacecraft sequencer.

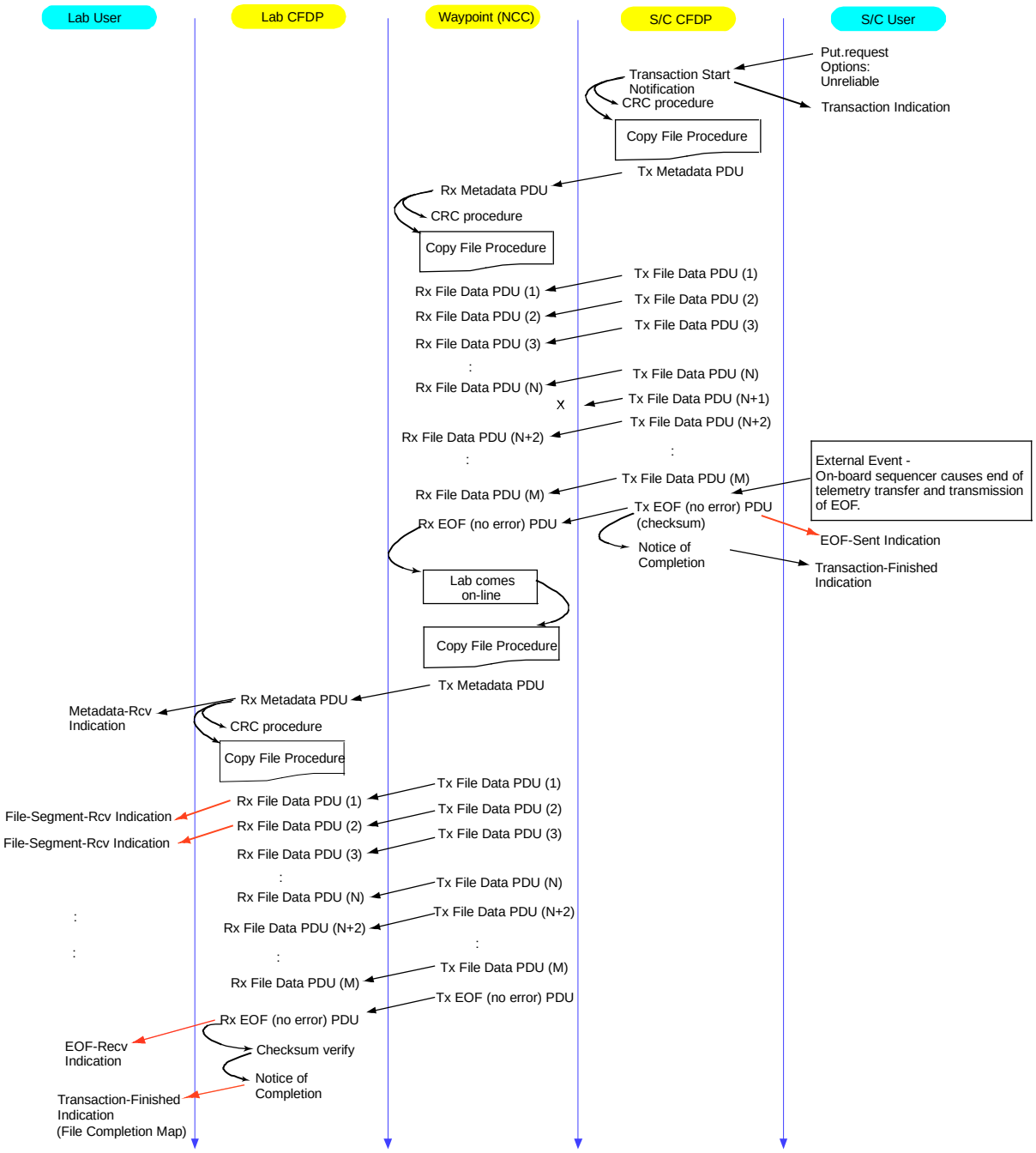



**Figure 3-10: Unreliable Download via One Waypoint**

### 3.2.3.3 Reliable Download via One Waypoint

This example begins with an intelligent spacecraft that, having detected a special event (e.g., volcanic activity on a planetary surface), wishes to deliver telemetry data to a user located in a science facility (laboratory) remote from an NCC. Since this is real-time telemetry data, the file size is unbounded. The spacecraft is at a very long interplanetary distance. Since completeness of data is important (i.e., it is irreplaceable science data, with very little information redundancy), the spacecraft selects reliable mode. For operational reasons it is desirable to minimize uplink traffic until the end of the science operation, indicating the deferred NAK mode. The laboratory has a local CFDP entity, but does not have direct communication with the spacecraft and, therefore, requires the use of the NCC as an intermediary. The laboratory is online 24 hours per day. Since this event-triggered data may in turn indicate other targets of opportunity, it is important that the data be delivered from the NCC to the science facility as soon as it is received, without waiting for the retransmissions that will make the data complete. The NCC contains a CFDP entity, and its 'immediate delivery' option is therefore enabled. The ground stations do not contain CFDP entities and provide only lower layer services. This configuration is shown in figure 3-11.

The following options could be selected to meet the requirements:

- implementation—extended procedures;
- transaction type—Put;
- quality of service—reliable;
- NAK mode—deferred.

The sequence of events is shown in figure 3-11.

The events detection system on the spacecraft initiates the transaction by causing a Put request to be sent to the local spacecraft CFDP entity.

Upon receipt of the Put request, the spacecraft CFDP entity initiates the transaction. The CFDP entity places the required information in the file metadata and begins the file delivery operation. Each item that the CFDP entity wishes transmitted is placed in a PDU and passed to the lower layer network. In this case, the interface is to CCSDS Path Service. The operation through the Path Service has been described previously (3.2.1.2).

A TCP/IP network service is used between the NCC and the user. Because the 'immediate delivery' option was enabled, as soon as the file transfer transaction from the spacecraft to the NCC begins, the NCC initiates the forwarding of the file to the laboratory over the TCP/IP network. Thus the CFDP entity at the NCC begins forwarding the file to the user before it is completely received from the spacecraft, thereby greatly decreasing the time before data (though perhaps incomplete) is available to the user.

Note that as soon as the file is completely received by the NCC it sends a Finished (completed) PDU to the spacecraft, allowing it to release any buffers it has assigned to the file transmission process. The Finished (completed) PDU contains a flag that signifies that the PDU is from the waypoint and not the final destination. When the file is completely received by the laboratory, the laboratory sends a Finished (completed) PDU to the NCC, allowing it to release any buffers it has assigned to the file transmission process. The laboratory Finished (completed) PDU contains a flag that signifies that the PDU is from the final destination. This causes the NCC to forward the PDU to the spacecraft, notifying it that the file has been successfully delivered to its final destination.

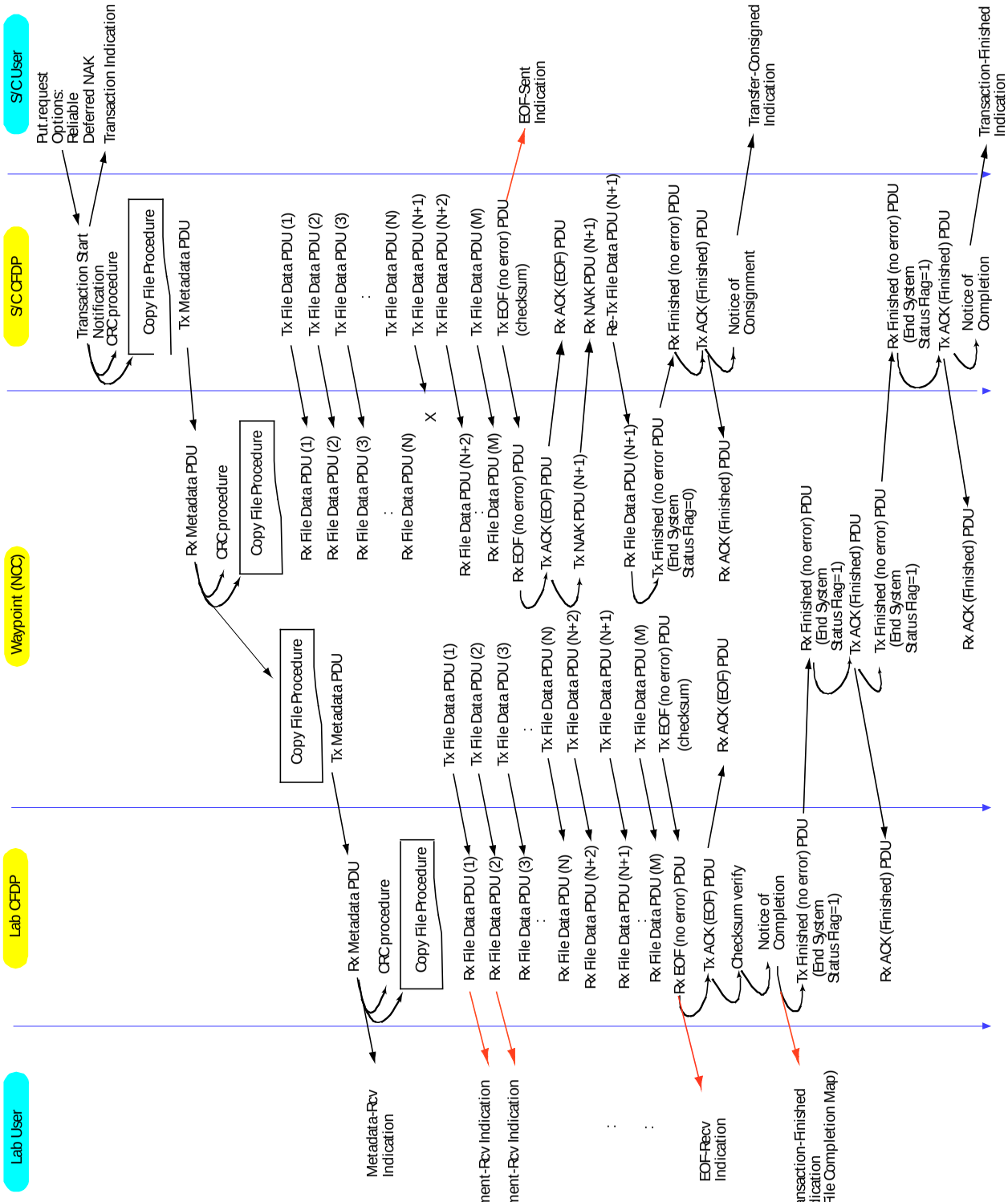



**Figure 3-11: Reliable Download via One Waypoint**

### 3.2.3.4 Reliable Upload via One Waypoint

This example is of a file transfer from a science laboratory to a spacecraft, via an NCC. For operational convenience, the file delivery from the laboratory to the NCC takes place before the beginning of the space-to-ground contact with the spacecraft. The NCC is a reliable entity and, therefore, the file in the laboratory is deleted after the transfer to the NCC is completed. When contact with the spacecraft is established, the forwarding of the file from the NCC to the spacecraft begins.

The following options could be selected to meet the requirements:

- implementation—extended procedures;
- transaction type—Put;
- quality of service—reliable;
- NAK mode—deferred.

The sequence of events is shown in figure 3-12. As previously described in 3.2.3.3, as each transfer between one entity and the next is completed, that fact is signaled to the sending entity and any buffers it has reserved for the transfer can be released. When the final destination has completely received the file, its notification of completion is carried all the way back to the original sending entity, notifying it that the file has successfully reached its final destination.

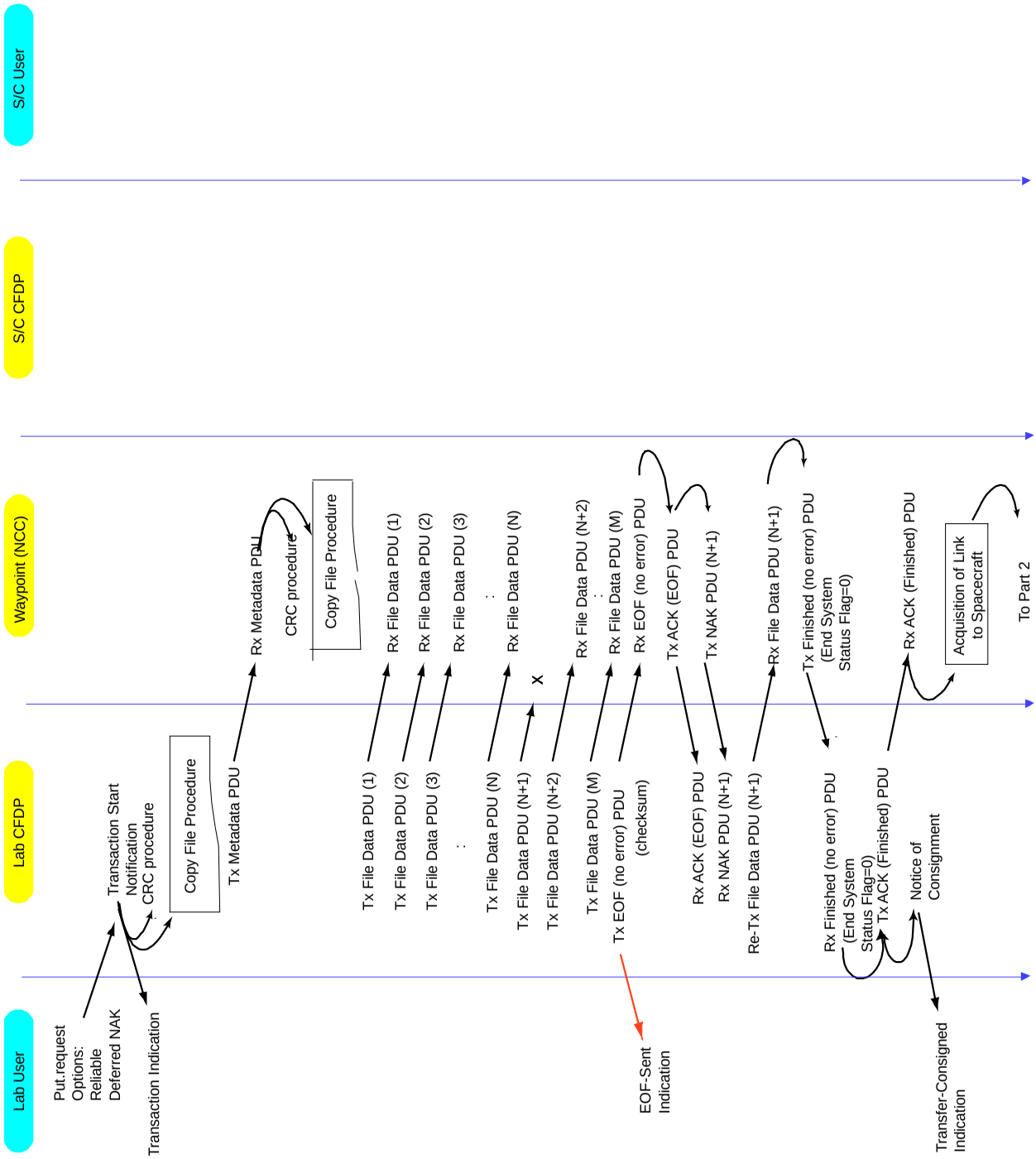



**Figure 3-12: Reliable Upload via One Waypoint (Part 1)**

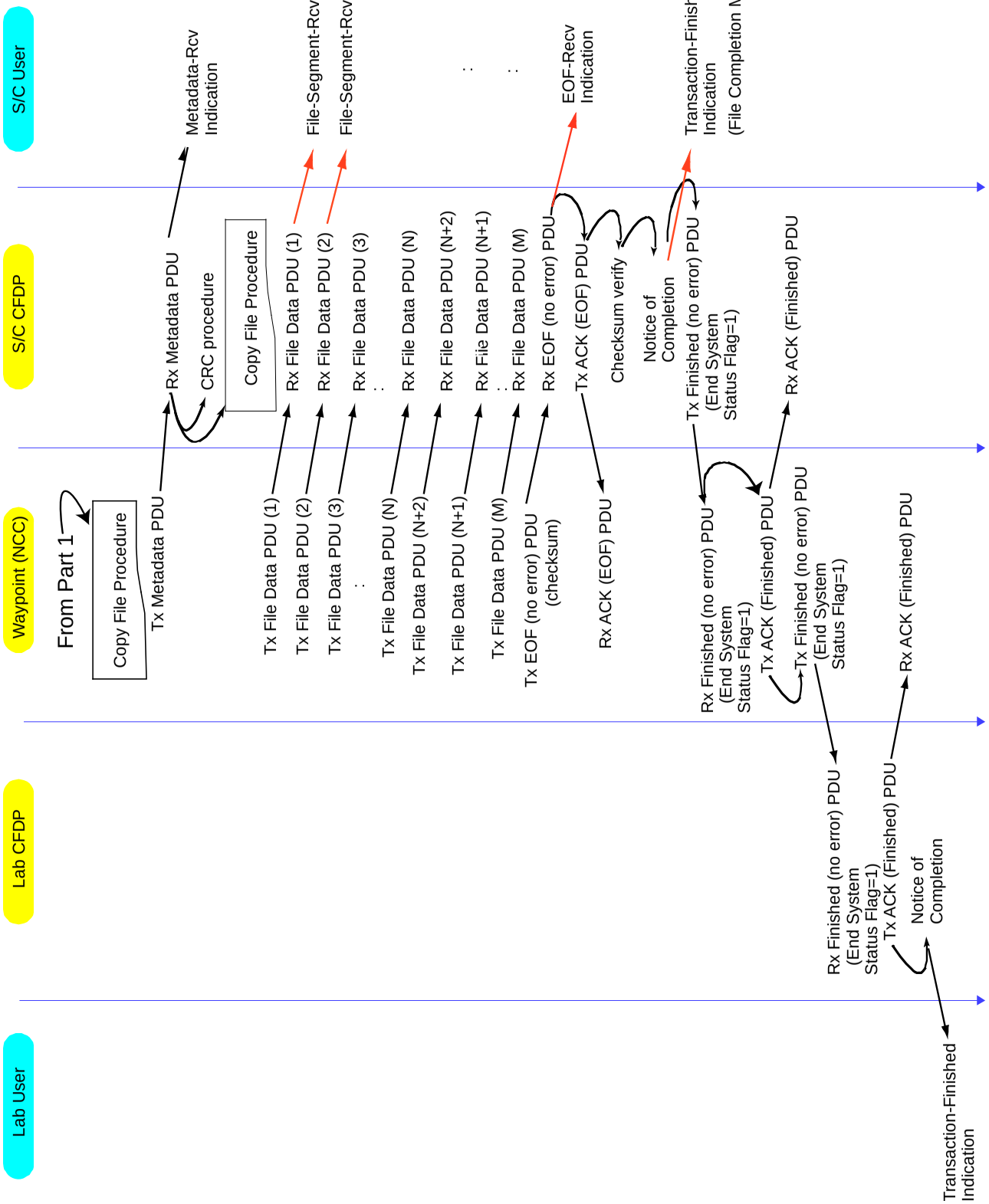



**Figure 3-12: Reliable Upload via One Waypoint (Part 2)**

# ANNEX A

# THE CFDP INTER-AGENCY TEST PROGRAM

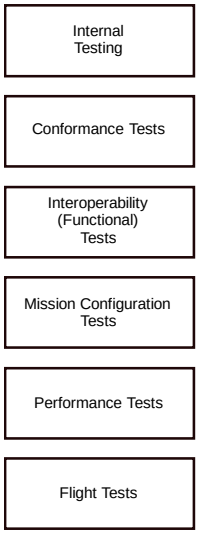
## A1 HISTORY

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 world-wide distributed configuration utilizing the Internet, and finally utilized a specialized Protocol Testing Laboratory at NASA/JPL. 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 may well serve as a model for similar testing in other areas of the CCSDS domain.

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

## A2 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 that 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.



## A3 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 in the protocol definition statements that are subject to different interpretations, that are unclear, that are or appear to be in conflict with another part of the specification, or that are simply incorrect. It also finds areas that need to be but are not in the specification. Of all these, perhaps the most important, and most difficult to achieve by any other kind of testing, is identifying in the protocol definition statements that are subject to different interpretations. It is of particular importance for international standards, where the nuances of language can be and often are a serious problem.

The tests in the interoperability testing are not totally comprehensive and are not Conformance Tests. However they do thoroughly exercise the procedures and options of the CFDP and provide a high level of confidence in interoperability for follow-on testing specifically oriented toward the planned application.

Testing aids available to implementers include the document CCSDS File Delivery Protocol (CFDP) - Notebook Of Common Inter-Agency Tests, the document CCSDS File Delivery Protocol (CFDP) - Notebook Of Common Inter-Agency Tests For Extended Procedures, and the document CCSDS File Delivery Protocol (CFDP) - Notebook Of Common Inter-Agency Tests For Store And Forward Overlay (SFO), In addition, a Conformance Tester and associated test scripts has been contributed by NASDA/NEC, and testing software, called a 'Relay Module', was contributed by ESA/ESTEC. The latter is a general purpose CFDP testing item that is especially useful in executing the tests through its ability to create many different types of specific error conditions on the intermediate links. These items are all available on the Internet to interested parties, as are reference implementations of the CFDP by ESA and NASA/JPL.

The CFDP Inter-Agency interoperability testing program had four distinct purposes. These were:

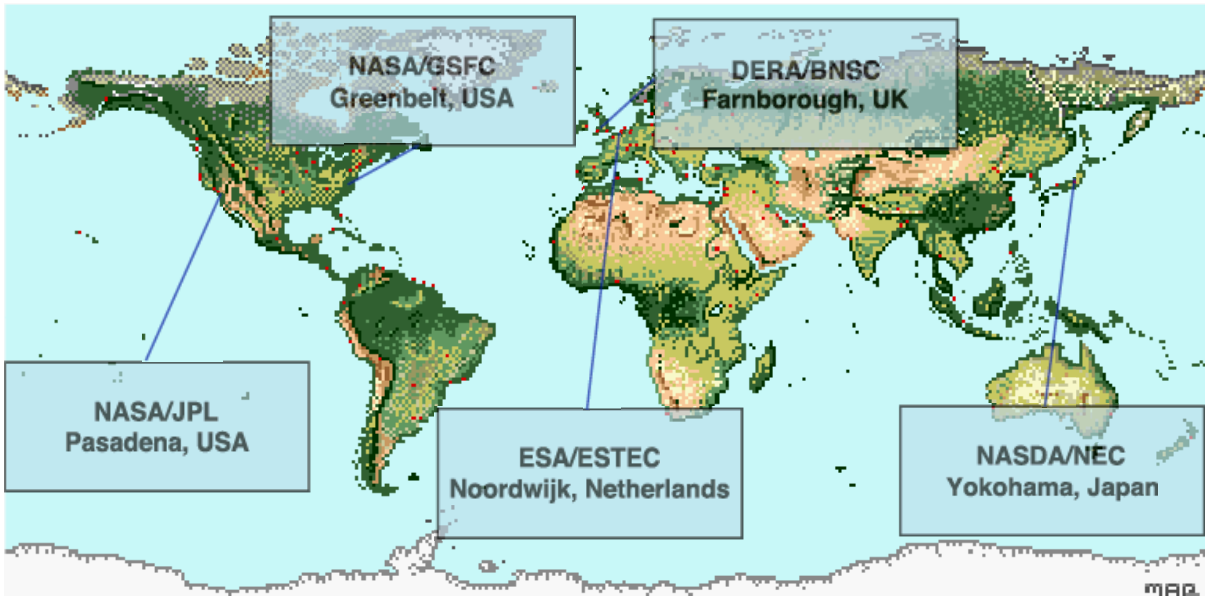
- to verify the correctness of the protocol specification by creating multiple implementations according to that specification and thoroughly testing those implementations;
- to provide measurements of the resources required by the protocol from its hosting system, including the size of the software implementations;
- to demonstrate the interoperability of independent implementations by inter-implementation testing; and
- to make available the tested implementations as reference implementations for the use of projects and programs that wish to use the CFDP.

## A4 CORE PROCEDURES TESTING

The first Workshop for interoperability testing of the CFDP Core Procedures 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, California, 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 a 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 became a worldwide Distributed Inter-Agency Testbed, operating over the Internet. The resulting configuration is shown below. It is especially interesting that the implementers were 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.




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 that 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).

The interoperability testing approach was so successful with the CFDP Core Procedures that it was determined such testing should extend to the Extended Procedures and to the Store and Forward Overlay Procedures.

## A5 EXTENDED PROCEDURES AND STORE AND FORWARD OVERLAY TESTING

SFO testing was begun in May of 2004, at a workshop held during the Spring CCSDS meeting in Montreal, Canada. At this meeting, it was decided to complete both the SFO and Extended Procedures testing within the Protocol Testing Laboratory (PTL) at NASA/JPL. Therefore, after the Montreal meeting, testing of the SFO and EP took place in the PTL. The testing between then and the Fall of 2005 was accomplished almost entirely by PTL personnel with minimal assistance from the ESA and JPL software implementers. This proved to be a very slow, difficult process, and therefore a face-to-face workshop was arranged to take place in September 2005 between the PTL personnel and the ESA and JPL implementers. This workshop had the desired result of enabling the testing laboratory personnel to proceed with and complete testing of both the SFO and the Extended Procedures in the fall of 2005.

## A6 PRODUCTS OF TESTING

The results of the CFDP Interoperability Testing effort have been:

- clarified, verified, specifications of the protocols;
- verified ‘reference model’ implementations from ESA and NASA JPL, available to interested users;
- A verified set of Interoperability Testing Notebooks, one each for the Core Procedures, Extended Procedures, and Store and Forward Overlay, available to implementers and projects wishing to perform interoperability testing of their implementations;
- the ESA Relay Module tester, a software device developed and contributed by ESA/ESTEC, which provides for the insertion of known errors into 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 National Space Development Agency of Japan (NASDA) Conformance Tester, developed and contributed by NASDA/NEC, which provides both the software system and the attendant (software) scripts that allow an implementer to perform true CFDP Conformance tests on his/her implementation.

# ANNEX B

# ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| ACK | Positive Acknowledgment |
| CCSDS | Consultative Committee for Space Data Systems |
| CFDP | CCSDS File Delivery Protocol |
| EOF | End of File |
| FD(n) | File Data Segment |
| FIN | Finished (receiver to sender) |
| FDU | File Delivery Unit |
| M | Metadata |
| MIB | Management Information Base |
| MSB | Most Significant Bit |
| NAK | Negative Acknowledgment |
| NCC | Network Control Center |
| OSI | Open Systems Interconnection |
| PDU | Protocol Data Unit |
| PRMPT | Prompt |
| TCP | Transmission Control Protocol |
| TM | Telemetry |