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Report Concerning Space Data System Standards

MARS MISSION PROTOCOL PROFILES— PURPOSE AND RATIONALE

INFORMATIONAL REPORT

CCSDS 740.0-G-1

GREEN BOOK

July 2008



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1 INTRODUCTION

1.1 PURPOSE AND SCOPE OF THIS DOCUMENT

This CCSDS Informational Report provides an operations overview for Mars mission interoperability and gives the supporting rationale for the relevant communications protocols to be used in Mars end-to-end operations for packet or file relaying. The purpose of this Report is to promote interoperation between mobile, landed, orbiting, and Earth-based infrastructure whilst reducing to a minimum the amount of intra- and inter-project negotiations.

This document takes a critical view of the present Proximity-1 specification (references [1]-[4]), its implementations, and usage on previous missions, with a view toward deriving recommendations that are to be used as a Recommended Practice for the 2008 through 2015 time frame at Mars.

1.2 APPLICABILITY

This document is a CCSDS Informational Report and contains descriptive materials and supporting rationale for missions that require packet or file relaying for Mars mission interoperability. Its applicability is not limited to Mars, and these approaches may also be suitable for use in other orbital relay operations environments with similar packet or file relaying requirements, e.g., Lunar exploration.

1.3 RATIONALE

A number of space agencies have announced their intentions to participate in programmes involving missions to Mars. In advance of human visits, a number of unmanned, precursor robotics missions will be flown. Such missions involve networked landers, rovers, and orbiters, and are likely to be conducted in a forum of international cooperation requiring and benefiting from common standards and the cross-support possibilities that they bring. CCSDS is chartered to provide such standards and has a significant number of existing or emerging Recommended Standards that are already in widespread international use on and around Mars and between Mars and Earth.

A potential mission user is confronted with how best to use the CCSDS Recommended Standards for both direct-from-Earth and proximity communications with other Mars assets. The choices depend greatly on the operational requirements and the services attainable from assets already in place on Earth and in orbit or landed at Mars. Even after making a selection, the mission must make a further judgment on which options to implement. There is little guidance as to the selection and arrangement of these Recommended Standards to achieve an interoperable implementation. Furthermore, once a protocol has been adopted, interoperability cannot be achieved until agreement exists on the selection of options and Management Information Base (MIB) parameters.

The Mars mission protocol profiling activity will clarify protocol architectures for use in interoperating Mars missions and specify, where possible, options and MIB parameters for the selected protocols. The activity is intended to simplify the selection process by promoting the most applicable CCSDS Recommended Standards and options in the form of a recommended Mars data communications profile.

In order to achieve Mars infrastructure interoperability, a future CCSDS Recommended Practice (Magenta Book) specifying the inter-agency interoperability points and the protocols recommended for use by future missions will be produced. The recommended configurations of these protocols and the profiles of the individual protocols will be given for Mars proximity missions. This will entail, wherever possible, specifying options to be used, populating the MIBs, and adding any ancillary functions required for data-handling operation.

1.4 DOCUMENT STRUCTURE

This document has the following major sections:

- section 0 (this section) contains administrative information, definitions, and references;
- section 2 describes communications scenarios for Mars proximity operations in the scope of this Report and lessons learnt from previous Mars missions with particular regard to interoperability;
- section 3 presents a baseline for near-term cross support at Mars;
- section 4 concludes the document with a summary of the issues emerging and recommendations for their resolution.

1.5 CONVENTIONS AND DEFINITIONS

1.5.1 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) is the first transmitted bit of the field, i.e., ‘Bit 0’ (see figure 1-1).

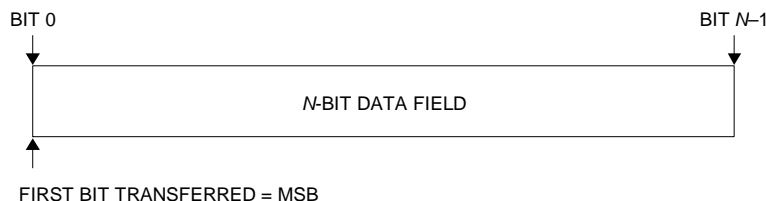


Figure 1-1: Bit Numbering Convention

In accordance with standard data-communications practice, data fields are often grouped into eight-bit ‘words’ that conform to the above convention. Throughout this Report, the terms ‘octet’ and ‘byte’ are used interchangeably to refer to such eight-bit words.

The numbering for octets within a data structure starts with ‘0’.

1.5.2 DEFINITIONS

1.5.2.1 General

Within the context of this document the following definitions apply.

1.5.2.2 Definitions from the Open Systems Interconnection (OSI) Basic Reference Model

This document is defined using the style established by the Open Systems Interconnection (OSI) Basic Reference Model. This model provides a common framework for the development of standards in the field of systems interconnection.

The following terms, used in this Report, are adapted from definitions given in reference [5].

Layer: A subdivision of the architecture, constituted by subsystems of the same rank.

Protocol Data Unit (PDU): A unit of data specified in a protocol and consisting of protocol control information and possibly user data.

Service: A capability of a layer (service provider), together with the layers beneath it, which is provided to the service-users.

Service Data Unit (SDU): An amount of information whose identity is preserved when transferred between peer entities in a given layer and which is not interpreted by the supporting entities in that layer.

1.5.3 TERMS DEFINED IN THIS REPORT

For the purposes of this Report, the following definitions also apply. Many other terms that pertain to specific items are defined in the appropriate sections.

Cross support: An agreement between two or more organisations to exploit the technical capability of interoperability for mutual advantage, such as one organisation’s offering support services to another in order to enhance or enable some aspect of a space mission.

Interoperability: The technical capability of two or more systems or components to exchange information via a common set of business procedures, and to read, write, and understand the same data formats and use the same protocols.

Octet: An eight-bit word commonly referred to as a byte.

Protocol: A set of rules and formats (semantic and syntactic) used to define the interactive communication behaviour of protocol entities in the performance of their functions, the description of the state machines within a Protocol Entity and the PDUs that are exchanged between these entities.

1.6 REFERENCES

The following documents are referenced in 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 documents.

- [1] *Proximity-1 Space Link Protocol—Rationale, Architecture, and Scenarios*. Report Concerning Space Data System Standards, CCSDS 210.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, August 2007.
- [2] *Proximity-1 Space Link Protocol—Data Link Layer*. Recommendation for Space Data System Standards, CCSDS 211.0-B-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, July 2006.
- [3] *Proximity-1 Space Link Protocol—Physical Layer*. Recommendation for Space Data System Standards, CCSDS 211.1-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, March 2006.
- [4] *Proximity-1 Space Link Protocol—Coding and Synchronization Sublayer*. Recommendation for Space Data System Standards, CCSDS 211.2-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, April 2003.
- [5] *Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model*. International Standard, ISO/IEC 7498-1:1994. 2nd ed. Geneva: ISO, 1994.
- [6] *CCSDS File Delivery Protocol (CFDP)*. Recommendation for Space Data System Standards, CCSDS 727.0-B-4. Blue Book. Issue 4. Washington, D.C.: CCSDS, January 2007.
- [7] *CCSDS File Delivery Protocol (CFDP)—Part 1: Introduction and Overview*. Report Concerning Space Data System Standards, CCSDS 720.1-G-3. Green Book. Issue 3. Washington, D.C.: CCSDS, April 2007.

- [8] *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, April 2007.
- [9] *CCSDS File Delivery Protocol (CFDP)—Part 3: Interoperability Testing Final Report*. Report Concerning Space Data System Standards, CCSDS 720.3-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, September 2007.
- [10] *Communications Operation Procedure-1*. Recommendation for Space Data System Standards, CCSDS 232.1-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.
- [11] *AOS Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 732.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, July 2006.
- [12] *TM Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 131.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.
- [13] *TM Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 132.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.
- [14] *TC Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 232.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.
- [15] *TC Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 231.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.
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- [17] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Recommendation for Space Data System Standards, CCSDS 401.0-B-18. Blue Book. Issue 18. Washington, D.C.: CCSDS, December 2007.
- [18] *Cross Support Reference Model—Part 1: Space Link Extension Services*. Recommendation for Space Data System Standards, CCSDS 910.4-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, October 2005.
- [19] *Space Link Extension—Forward CLTU Service Specification*. Recommendation for Space Data System Standards, CCSDS 912.1-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, December 2004.
- [20] *Space Link Extension—Return All Frames Service Specification*. Recommendation for Space Data System Standards, CCSDS 911.1-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, December 2004.

- [21] *Space Link Extension—Return Channel Frames Service Specification*. Recommendation for Space Data System Standards, CCSDS 911.2-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, December 2004.
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2 STATUS OF MARS END-TO-END RELAY COMMUNICATIONS

2.1 APPROACH

In order to derive protocol profiles for Mars proximity operations it is necessary to establish reference architectures based on real missions destined for Mars in or around the 2011 to 2015 time frame. To achieve this, member agencies have provided details of Mars missions expected in this period and descriptions of assets that are currently at Mars and can provide services.

The discontinuous and sporadic nature of communications to Mars, especially when an intermediate orbiter relay is employed, drives operations towards a store-and-forward file-oriented model of communications. As such, current and future scenarios are heavily dependent on the CCSDS Proximity-1 protocol (references [1]-[4]) and the CCSDS File Delivery Protocol (CFDP—references [6]-[9]). A brief overview of these protocols is presented in 2.2 and 2.3, respectively.

Subsection 2.4 relates interoperability experience with past and current missions, and 2.5 summarises current consensus regarding the methods of inter-agency cross support for the future. Details of current implementations of orbiting relays are given in annexes A and B.

2.2 PROXIMITY-1 OVERVIEW

The Proximity-1 protocol was developed by the CCSDS to support missions that require reliable point-to-point communication between two spacecraft. Typical mission scenarios would be communication between a base station and a roving vehicle (e.g., NASA's Mars Pathfinder) or communication between an orbiter and a lander (e.g., NASA's Mars Reconnaissance Orbiter and ESA's ExoMars rover or NASA's Mars Exploration Rover [MER]).

As the name suggests, the Proximity-1 protocol (references [1]-[4]) provides reliable data transfer between spacecraft operating in close proximity. Communications within spacecraft clusters or between orbiting and landed elements of interplanetary missions are examples of proximity operations. The Proximity-1 protocol was developed in part in response to the requirement for mission interoperability between Mars spacecraft.

Proximity-1 is a symmetrical protocol. The same protocol and options may be used for both the forward and return links of two-way communications, and the link data rates may be symmetrical. The advantage of using this type of protocol is that the same equipment can be used in both ends of the communication link. Typically, however, the two-way communications data rates between the assets may be vastly different, with the return rate often being significantly higher than the forward rate. NASA currently operates Proximity-1 (MER-Mars Odyssey Orbiter [ODY]) at highly asymmetrical rates (typically 8k/128k or 8k/256k forward/return) because of asymmetrical data traffic. The rate differential will often be as high as 256 to 1 (but can be as high as 2000 to 1), and that, coupled with variations in the over-flight geometry, signal path and strength during a pass, and the one-way light time when communicating with different assets, makes tuning the various MIB and operational parameters associated with a specific session important.

The key data transport unit used by the Proximity-1 protocol is the Proximity-1 frame. The Proximity-1 frame may carry any format of data within it, and complete implementations of the protocol should support all possible formats. The frame can be of variable length and contains a 32-bit Cyclic Redundancy Check (CRC) that provides a formidable error-detection capability and is used to restrict frame acceptance to error-free frames. The Recommended Standard supports the delivery of CCSDS packet data units as well as user-defined data; the protocol segments the user-supplied data and transports it to the remote asset. In addition, the Recommended Standard provides a capability to acquire data to establish a time reference between two assets' clocks so that the data can be used in clock correlation processes. This capability is achieved by time-tagging the egress and ingress of the same frames between assets.

The Proximity-1 protocol includes two basic operational modes:

- 1) Reliable Mode will transfer data in order, without gaps or duplications;
- 2) Expedited Mode will deliver data in order, without duplicates but with possible gaps.

The heart of the Reliable Mode is a simple, efficient Go-Back-*N* retransmission scheme that uses a small part of the Proximity link bandwidth to acknowledge receipt of data. The receiver can explicitly request a retransmission should it knowingly receive bad data, and the transmitter will automatically perform retransmissions if the receiver does not acknowledge receipt within a (configurable) time-out period. The retransmission protocol is a simplified version of the one contained in the *TC Space Data Link Protocol* Recommended Standard (reference [14]). It operates with no external human supervision and has no intrinsic mechanism for reporting errors; however, performance is typically reported as part of the mission's engineering data.

A key departure from previous CCSDS link protocols is in recognition of the ephemeral nature of Proximity-1 contact periods, resulting from orbiter motion and planetary rotation, and of the remoteness, because of the delay, of the mission control centre. To maximize the contact opportunity, Proximity-1 incorporates a handshake mechanism which allows connection between the orbiting and landed elements to be established locally without recourse to precise mission scheduling. It also allows for mid-contact renegotiation of link data rates to maximize the data throughput opportunities against a background of dynamically changing link budgets.

The Proximity-1 Recommended Standard incorporates a number of features that are unique to the Proximity link for space missions. These are included because of the diverse environments that one can expect at Mars:

- a) The Recommended Standard provides for full-duplex, half-duplex, and simplex operation. Full duplex operation allows for the simultaneous bidirectional flow of data between the assets. Half-duplex operation provides the mechanisms for the transceivers to take turns sending and receiving data. Simplex operations can be set to allow the transceiver either to send or receive data in a broadcast/receive non-gap-free mode.

- b) The frame header in each transmission carries a Data Field Construction Identifier (DFC_ID) that signals whether the frame is carrying a single CCSDS packet or a segment of user-supplied data bits. The later case is provided for a number of reasons, including:
 - the orbiter data handler is transparent to data contents;
 - it provides a means to tailor the frame sizes in order to optimize the throughput with the Go-Back-*N* mechanism matched to link environments;
 - it enables the Proximity link to tunnel the user's data to the direct-from-Earth command process to reduce hardware and testing costs;
 - it allows the decoupling of link-layer data structures from the application and other higher-layer data structures.
- c) The protocol provides a time-correlation capability that allows the time of a frame's egress from one asset and its time of ingress at the other asset to be captured so that the clocks of the two assets can be related to a reference clock.
- d) The protocol has the ability to operate with transceivers that are frequency agile, allowing for a hailing channel to identify and initiate communications and a separate working channel to carry the data interchange. This feature was included to reduce interference between landed elements and orbiters when multiple assets have overlapping view periods.
- e) The Proximity-1 Recommended Standards do not include provision of radiometric aspects even though these are of significant importance at Mars and their setting can be controlled by use of Proximity-1 directives. The Proximity-1 directives containing radiometric parameter settings are intended to be passed from the protocol entity to the transceiver over a private interface. The details associated with the setting of these parameters can be found only in the ICD for a specific mission's transceiver.

The Proximity-1 protocol is now complete and all new relay orbiters should comply with the full capability defined within the specification if that asset will be supporting services after the 2015 time period.

2.3 CFDP OVERVIEW

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. But while these methods are acceptable for managing a limited amount of onboard memory, with the increasing availability of low-cost solid-state mass memory for spacecraft use, previous limitations on the amount of onboard memory no longer apply.

The availability of gigabytes of solid-state memory is leading 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.

The requirement for a space file transfer mechanism arises because:

- 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 multiple paths.
- The increasing onboard use of real-time operating systems (such as VxWorks and RTEMS), which assume the presence of a ‘file system’, make onboard data handling increasingly file-oriented.

In response to these factors, the CCSDS File Delivery Protocol has been developed to complement the existing CCSDS link-layer and packet standards. CFDP provides the capability to transfer ‘files’ to and from a spacecraft mass memory. The content of these 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.

CFDP has many unique characteristics when compared to terrestrial file transfer protocols, such as:

- 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;

- minimisation of link traffic;
- data availability to the user as the file is received;
- minimisation 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.

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 scalable, so that only those elements required to fulfil the selected options need be implemented. The protocol can operate over a wide range of underlying communication services, specifically including CCSDS packet services.

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.

The CFDP specification defines four classes of service:

- Class 1 is best effort and does not include acknowledgement by the receiver nor retransmission of missed data segments. This Class is tuned for transfers over a reliable link-layer service such as the ones provided by Proximity-1 and by TC using reliable COP-1 (see reference [10]) or by some other reliability method such as use of AOS (see reference [11]) with frame retransmission on the Mars Reconnaissance Orbiter (MRO).
- Class 2 is reliable transfer and requires the receiver to acknowledge what it has received and request retransmission of data that was missed. This mode is best utilized over a non-reliable link layer such as TM or TC in bypass mode (see references [13] and [14]).
- Classes 3 and 4 implement reliable transfers for multi-hop relaying and use end-to-end acknowledgments.

In current practice only Class 1 (unacknowledged) and Class 2 (acknowledged) versions are being used across single hop space links. In many cases missions have adopted Class 1 unacknowledged file transfers and added their own, private, underlying frame or packet retransmission for reliability when and where it is required.

2.4 INTEROPERABILITY EXPERIENCE

2.4.1 AGENCY IMPLEMENTATION RATIONALES

The late timing of the Proximity-1 recommendation's development in relation to the development of the Mars Odyssey Orbiter (ODY) spacecraft resulted in only a subset of the Proximity-1 Recommendation being implemented in its transceiver. The ODY spacecraft and then the MRO spacecraft did not implement a local transfer mode that places a user CCSDS packet into a Proximity-1 frame, which limits their implementations to taking only fixed segments of the user supplied data to include in each transfer frame. This method was chosen for four reasons:

- 1) There was a significant Mars Program Office driver to keep the Proximity link transfer protocol transparent to the data contents of the file. This approach also simplified the functionality of the radio and thus the implementation required in the design and operations of the relay. In ODY and MRO, the majority of the Direct-To-Earth (DTE) and Direct-From-Earth (DFE) protocol processing elements are reused for processing the forward and return data that traverses the Proximity-1 link.
- 2) The landed assets supported by those orbiters wanted to minimize their implementation and chose to have all of the data that would be transferred conform to the DFE/DTE CCSDS Protocol (Telecommand and Telemetry Protocols) so that the received contents from the Proximity-1 link could be validated and processed by the same hardware that handled DFE/DTE mechanisms.
- 3) The store and forward nature of the service did not address messaging services between orbiter and lander and thus there was no urgency for the sending element on the orbiter to extract the packets from the data set before the transfer was complete.
- 4) The Mars landed asset data is delivered over a reliable link-layer protocol, so there was no requirement to acknowledge the receipt of the data on the orbiter at a higher level than the link layer, and the relaying of the lander data to Earth from the orbiter uses the best-effort TM protocol. This drove the MER project to tunnel TM frames across the ODY telemetry link, thus simplifying the extraction of packets if orbiter frames were lost (using the standard TM process).

ESA chose to use the packet transfer mode within the Proximity-1 specification for two reasons:

- it added the least amount of overhead;
- all ESA spacecraft depend on the use of the CCSDS space packet.

When receiving data, the APID of the packet header is used to identify the intent of the packet. This may be a direct, low-level command, interpreted in hardware, to resolve an off-nominal situation, a high-level command which is directed toward a command interpreter for subsequent processing, or part of a series of data which together constitute a file.

When sending data, all telemetry data is first assembled into packets. The APID of the packet header is used to identify both the source and type of data being sent.

The only disadvantage of this approach is that it assumes that all cross-supporting implementations are able to support packets. In the case of the Proximity-1 protocol the assumption is that the packet service will be provided. If the packet service is not supported additional features must be incorporated as detailed elsewhere in this book.

Annex I contains a discussion of the use of the Odyssey relay.

2.4.2 BEAGLE 2 VIA ODYSSEY

2.4.2.1 Overview

Mars Odyssey is the orbiter that was to have supported interoperability with the Beagle 2 lander in 2003. Figure 2-1 shows the Mars Odyssey scenario.

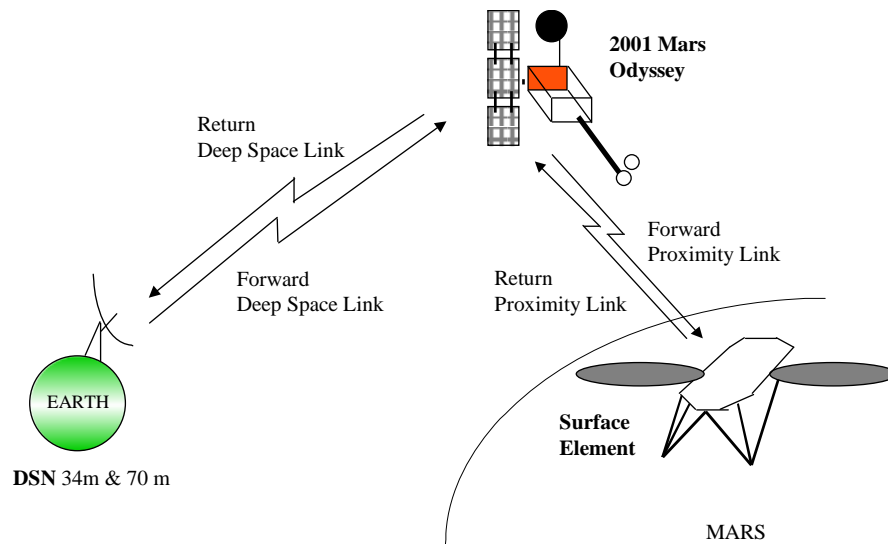


Figure 2-1: Mars Odyssey Relay Scenario

The relay configuration adopted for the Beagle 2/Odyssey interoperability scenario, shown in figure 2-2, used the packet as an end-to-end data construct, but the relay itself operated at a bitstream level. This operation required a dedicated end-to-end packet delimiting mechanism. In the case of the forward link, the mechanism was ad hoc and based on static aspects of the packet header fields; in the return link, an end-to-end conventional TM frame structure was used.

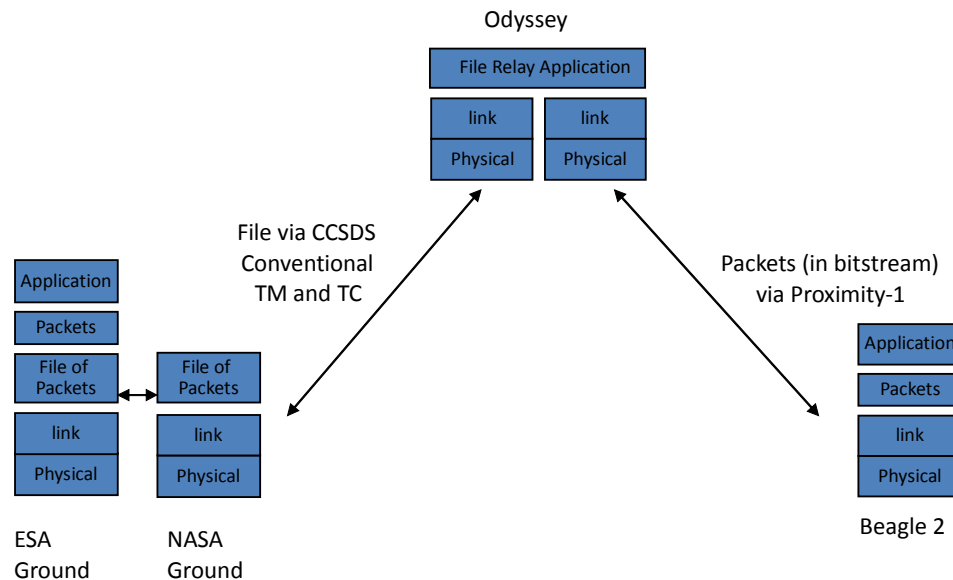


Figure 2-2: Beagle 2 via Odyssey Relay

For both forward and return links, the Proximity-1 links were to carry packets, but in neither case were the packets to be carried using Proximity-1's packet service. The interoperable data service available in these links was the Proximity-1 bitstream service, which was therefore the bearer service by which packets were to be transferred.

2.4.2.2 Forward Link Operation

On the ground, one or more user asset files were to be provided to the relay orbiter Ground Data System (GDS). Once the uplink was successfully validated, these files were to be reconstructed and stored in the orbiter's onboard file system. Files were to be selected for transmission to the asset by the relay orbiter based upon the contents (asset ID, pass number, order number) of the file name.

As part of the operational process for the relay orbiter, a command block was to be loaded into the sequencing system. The command block was to configure the orbiter for the over-flight by providing to the relay orbiter the link characteristics to be employed, identification of the asset to be targeted, and a pass number for selecting the preloaded files for delivery.

Just prior to the pass the relay orbiter was to extract from the file store the files whose filenames contain the asset ID and the pass number contained in the command block. The contents of these files were to be concatenated into a transfer buffer for delivery to the Proximity transceiver.

During the pass, the Proximity transceiver was to access this transfer buffer and transfer the data as a bitstream to the Mars-bound asset. Once the pass was complete, the orbiter was to report the number of octets transferred during the pass in orbiter telemetry to the orbiter GDS.

The data received by the lander therefore would consist of Proximity-1 frames containing a bitstream in which there were CCSDS packets. The Proximity-1 mechanism for packet delimitation would not be used, and the packets would not be octet aligned in the frame. Furthermore, in the forward data there would be numerous artefacts manifested as inter-packet meaningless data.

In order to retrieve the packets and reject invalid data, a method was developed to extract packets based on recognising patterns in the packet header together with further checks on packet length and packet CRC.

Note that, at the time of the original negotiations for Odyssey to relay packets, it was not realised that what would actually be forwarded was an unaligned bitstream. This detail was subsequently discovered during interoperability testing.

2.4.2.3 Return Link Operation

The lander was to generate a bitstream that would be inserted into fixed-length Proximity-1 frames. This bitstream was then to be sent to the convolutional encoder and modulator for transmission to Earth.

The consequence of this scheme was that, in order for Earth-based receivers to receive the data, the bitstream that the lander embedded in the Proximity-1 frames had to be formatted into CCSDS conventional TM frames and, in order to maintain a reasonable orbiter-to-Earth error rate, the TM frames generated by the lander also had to be Reed-Solomon encoded.

The lander-to-orbiter link was therefore rendered less efficient because of the need to transmit a complete TM link including TM frames with Reed Solomon coding inside the Proximity-1 frames. Also, the Reed Solomon encoding overhead was very onerous for the Beagle 2 processor, especially at the 128 kbps return rate.

2.4.3 MARS EXPLORATION ROVER VIA MARS EXPRESS

The MER return link via Mars Express case is shown in figure 2-3. In this case a bitstream service was provided by the ESA relay infrastructure with no recognised structure internal to the NASA data stream. The use of the CCSDS packet was internal to the ESA infrastructure and was not relevant to the end-to-end service provided.

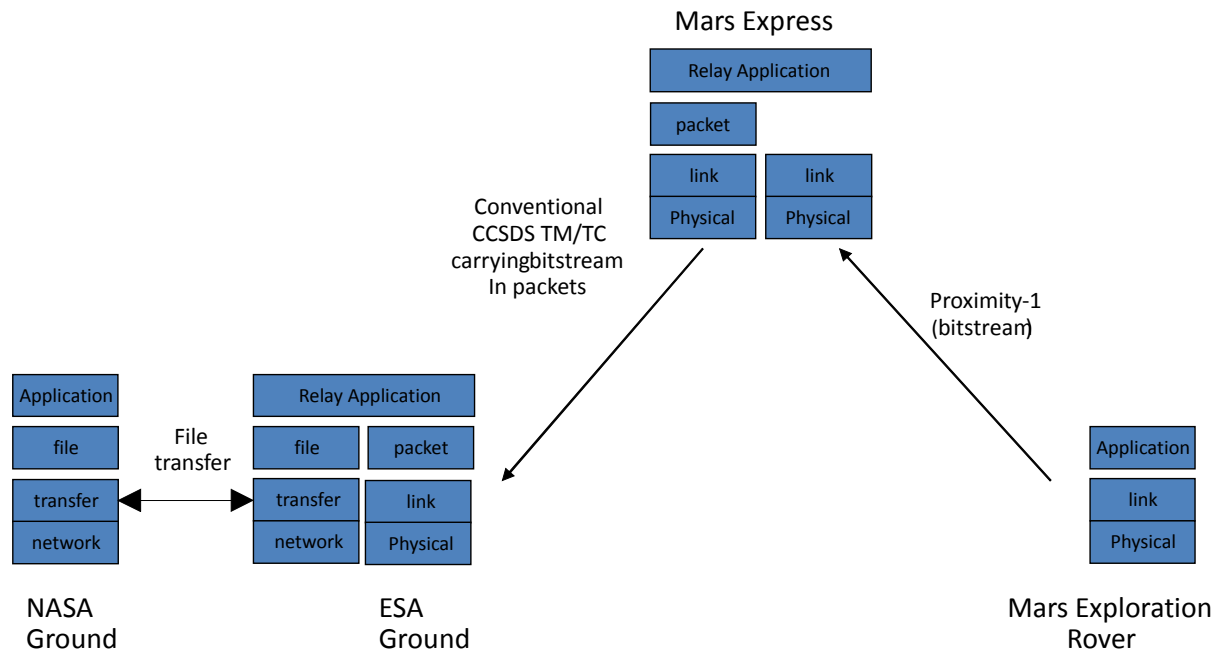


Figure 2-3: MER/Mars Express Relay Scenario

The service was provided during a short integration activity at JPL and subsequently demonstrated in two campaigns during the MER mission.

2.5 INTEROPERABILITY AGREEMENTS

Cooperation between agencies to achieve their mission aims takes many forms, but the significant aspect of interest to CCSDS is that of data interoperability. Of particular interest, for Mars missions, is the use of terrestrial and Mars orbiting communications infrastructure to support data transfer between Earth and Mars landers.

Interoperability is facilitated by inter-agency cross-support agreements, which rely heavily on the standardisation provided by CCSDS Recommended Standards but which also require a considerable further investment in agency resources to fill in additional detail outside the scope of the general-purpose Recommended Standards. It is the intent of the Mars mission protocol profiling activity to provide a further level of standardisation, thus reducing mission cost, timescale, and risk in comparison to this enterprise being embarked upon on a mission-by-mission basis.

Experience with the 2003 Mars missions has demonstrated that providing an interoperable relay service is far more complex than simply agreeing on adoption of the relevant CCSDS Recommended Standards. Reaching agreement on the details of interoperability for these specific missions involved a considerable effort on the part of the cooperating missions. It is evident therefore that, since the future scenarios do not greatly differ from those of 2003, the burden of future missions to provide interoperability could be greatly alleviated by taking the lessons learnt from these extant missions and formalizing solutions within CCSDS.

Thus it is imperative for an agency to publish the support capabilities that its assets provide/require at Mars and document the services it can provide/require. It is also important for an agency to describe fully how another agency can interface to those services.

In addition to reconciling the technical approach to cross support as described in section 2, the CCSDS Mars interoperability effort should seek to minimise the amount of additional project overhead required to achieve interoperability agreements. This minimisation will be achieved by, where appropriate, incorporating the implementation decisions previously documented in project ICDs into a CCSDS Mars Recommended Standard.

2.6 RELAY SERVICE SCHEDULING

In order for an orbiter to provide transport and relay services to a landed asset, the communications plans for the two cooperating missions need to be coordinated. The overall relay coordination process is divided into two sub-processes: a Long-Range Relay Coordination Process and a Short-Range Relay Coordination Process. An overview of the process is provided in figure 2-4.

The Long-Range Relay Coordination Process is designed to overlay longer-term relay opportunity predictions with predictions of the onboard activities of the relevant relay assets in order to estimate forward- and return-link data latencies and to provide a ‘preview’ of the relay opportunities that are available to all source and/or destination assets.

The Short-Range Relay Coordination Process is the mechanism to determine the details of specific relay opportunities. It also allows for a revision of the estimates for forward- and return-link data latencies based upon improved navigation predictions and an updated understanding of the relay assets’ onboard activities nearer to the time when the service will be rendered.

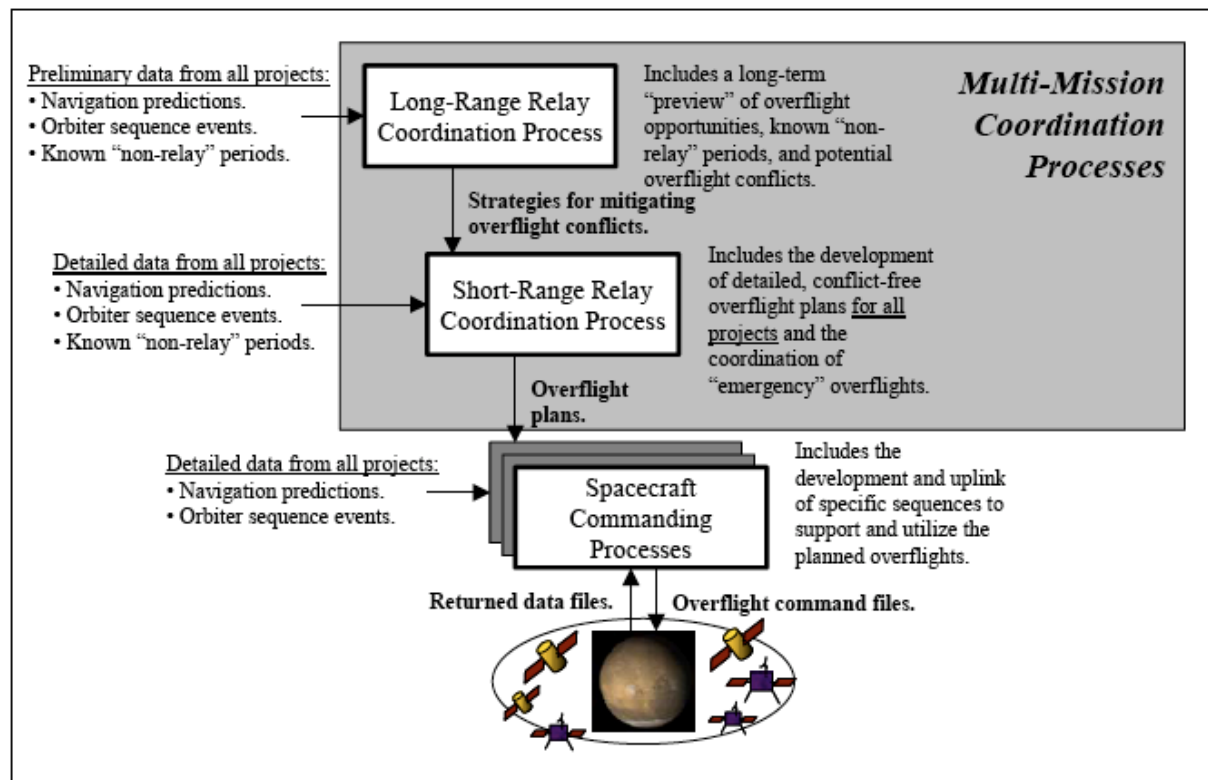


Figure 2-4: Relay Services Scheduling Process

3 MARS INTEROPERABILITY TECHNICAL BASELINE

3.1 APPROACH

The previous Mars-based implementations having been analysed, this section concludes on a recommended cross-support approach for cross support for missions in the 2008 to 2015 timeframe.

Although CCSDS has developed a set of Recommended Standards applicable to the Mars scenario, infrastructure, equipment, and missions were being specified during the development of the Recommended Standards. There is, as a consequence, some variation in the approach taken to the provision of CCSDS services, and this variation needs to be taken into account in the cross-support baseline.

The approach taken in this section is to describe how the CCSDS Recommended Standards are to be implemented in existing infrastructure and missions that are in development. Cross support in future infrastructure and missions that are not yet in development will be the subject of a future CCSDS activity.

Note that the relay operations scenario requires, among the user, cross-support provider, and ground communications infrastructure, an interactive scheduling process that takes place long before the actual relay activity instance occurs. The details of the scheduling process are not included in this document and are left for the ICD between the relay, the asset, and the ground communications-infrastructure service provider. But, to summarize, in the scheduling process, the relay orbiter and asset operations teams agree on the over-flights that will be utilized and the parameters that are required to configure the communications equipment for that session.

The ExoMars and Mars Science Laboratory (MSL) missions typify the driving scenario for the CCSDS Recommended Practice. At the time of writing, the ExoMars flight elements consist of a lander and rover. While both elements will have DTE links, they will rely on the support of the NASA MRO and associated ground segment, and possibly a Russian orbiter that will directly communicate with the ESA ground segment. A reference architecture based on this configuration is illustrated in figure 3-1.

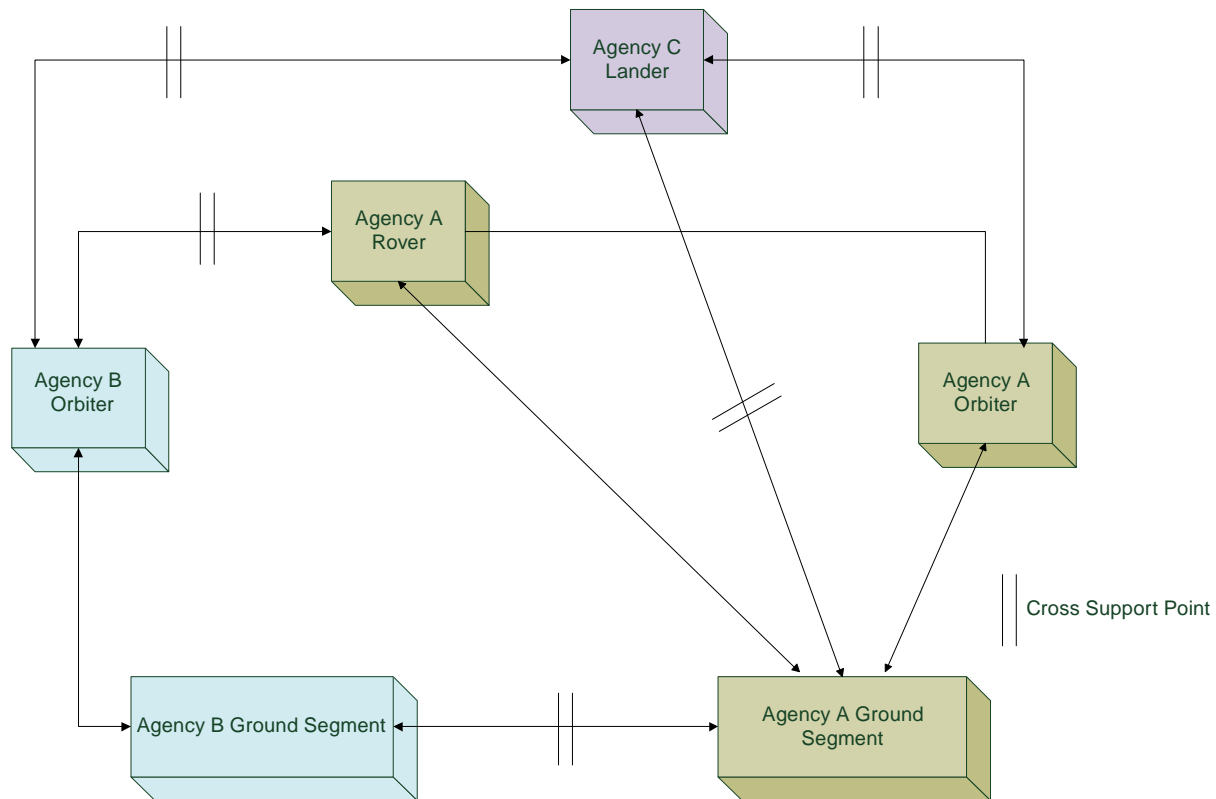


Figure 3-1: Mars Interoperability Reference Architecture

3.2 NEW MISSION PROFILES

Any new mission (including that of ExoMars) should fully comply with the CCSDS Recommended Standards at the cross-support points. These may include:

- RF and modulation (reference [17]);
- TM/TC and AOS data links (references [13], [14], and [11]);
- CCSDS Space Packet Protocol (reference [16]);
- Proximity-1 Space Link Protocol (reference [2]);
- CFDP (reference [6]);
- SLE services for ground communication (references [19]-[21]).

The following subsections describe the technical baselines for interoperability at the cross-support points located at the interfaces between:

- user orbiter and cross-support lander; and
- user ground segment and cross-support ground segment.

These baselines are described for both near-term and longer-term future missions.

NOTE – This discussion intentionally conflates the cross-support GDS and the ground communications service provider. In most real deployments these are different systems owned and operated by different organisations, and some of these services, such as CFDP file delivery, may be provided by the ground communications service provider and not by the orbiter cross-support GDS.

3.3 RECOMMENDATIONS FOR NEAR TERM MISSIONS

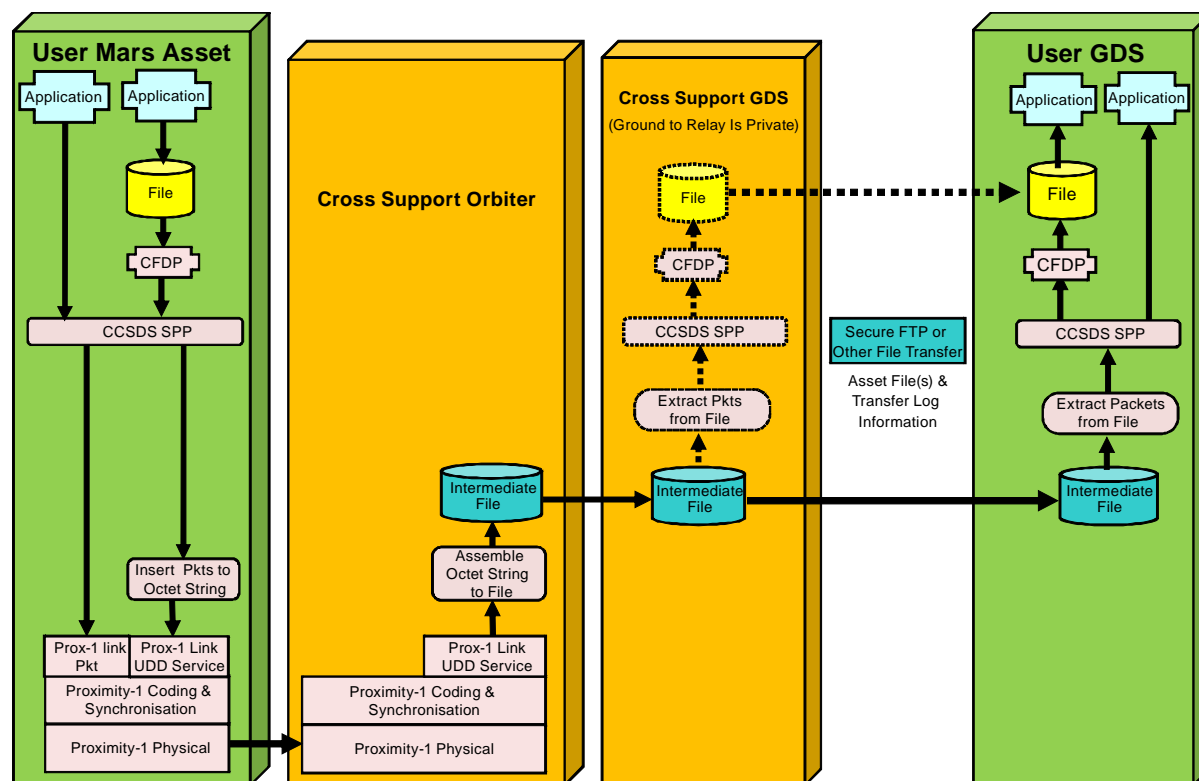
3.3.1 GENERAL

In this subsection are defined the recommended configurations to be used for near-term missions focusing on the known capabilities of MRO and the requirements of ExoMars. Note that the existing orbiter infrastructure implements only the User Defined Data (UDD) service defined in Proximity-1 and will treat all data as ‘user defined’ even if a packet service is signalled by the protocol. Proximity-1 is used between orbiter and the landed Mars asset as part of the provision of an end-to-end data transfer between the originating GDS on Earth and the landed asset on Mars. Two cross-support points may be identified:

- between the user Mars asset and the cross-support orbiter;
- between the user GDS and the cross-support GDS.

At the ground cross-support point, a file transfer takes place between the two agencies whilst at the orbiter/lander cross-support point data are transferred via a user-defined data stream carried in the Proximity-1 frames.

3.3.2 NEAR TERM RETURN LINK



Notes:

Details of the file delivery are orbiter implementation-specific and are not shown but need to be shown. For example, for MRO the intermediate file consists of three subfiles multiplexed together in CFDP format: user data file, Doppler file, time tag file.

Any transport artifacts put on by the orbiter are removed in the cross-support GDS before delivery to user.

Figure 3-2: Near Term Return Link Possibilities

Figure 3-2 shows the end-to-end delivery of data from a user Mars asset (e.g., rover) to the user GDS on Earth. The Mars asset has the capability to return data as a series of packets either from mass storage or real-time generation. For data originating from mass storage a file transfer protocol is required, and CFDP has been selected for this purpose. CFDP relies on an underlying packet service for PDU transmission. There are two alternative methods available for transmission of the packets to the orbiter over the Proximity-1 link:

- using the Proximity-1 packet service;
- using the Proximity-1 UDD service.

Note that the orbiter treats both of these services as a UDD octet stream.

If the Mars asset selects to use the Proximity-1 packet service, the generated data packets may be submitted directly to the Proximity-1 packet service without further treatment. If the UDD service is selected, then the Mars asset needs to follow procedures to ensure that the packets are inserted contiguously into the Proximity-1 UDD service. The relevant procedures

are those for inserting packets into an octet string described in annex G. In order to preserve packet integrity it is necessary for the orbiter to follow the procedures for assembling an octet string into a file as described in annex H.

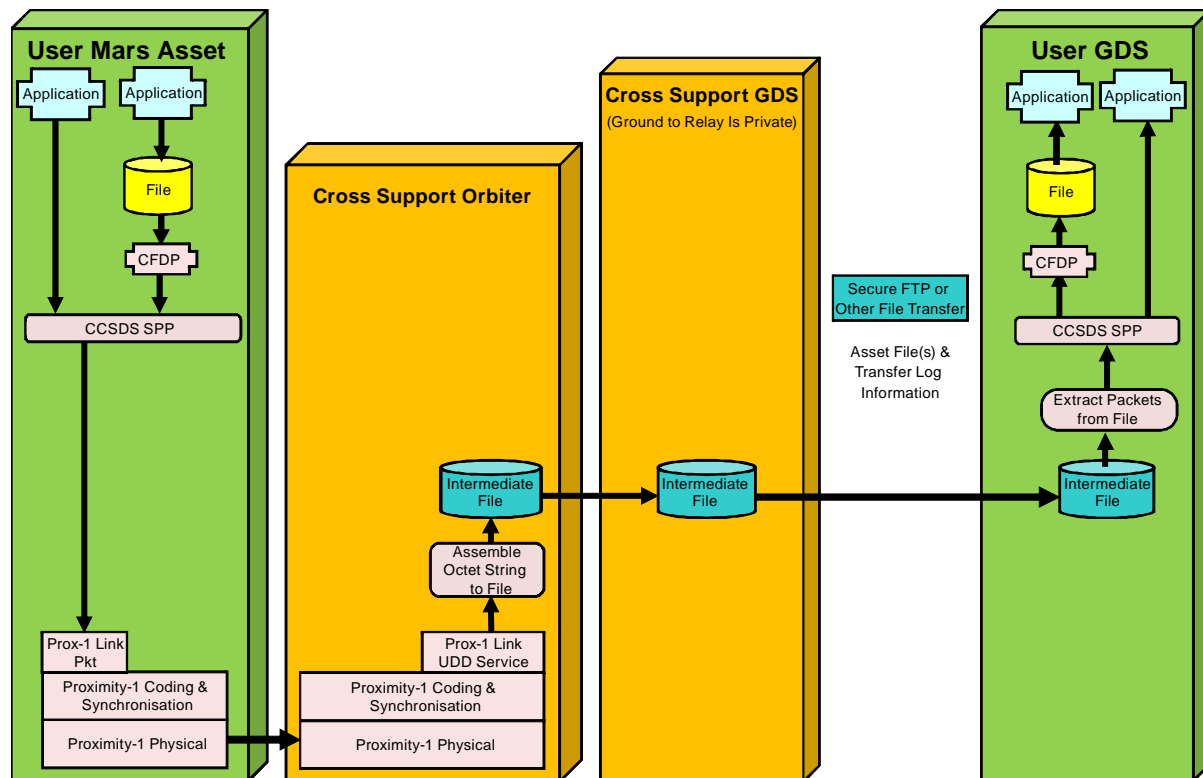
Provided the procedures shown in the figure are followed and the Proximity-1 link is operated in sequence-controlled mode, it is then possible to reconstitute the packets in the user or cross-support ground segment using the procedures for extracting packets from a file (annex E).

The figure shows two possibilities for termination of CFDP in the ground segment. The primary (non-dotted) option shows CFDP operating end-to-end by virtue of an end-to-end packet capability that is transparent to the cross-supporting agency. An alternative is to terminate the CFDP protocol in the cross-support GDS, which must then be capable of extracting packets from the return link intermediate file using the procedures for extracting packets from a file as described in annex E.

The resulting end-to-end file, regenerated by CFDP, is transferred to the user GDS using any appropriate terrestrial file transfer method. The advantage of terminating CFDP at the cross-support GDS is that the data may be partitioned at the lander with a view to prioritising file delivery from the cross-support GDS to the user GDS. However, extra complexity is introduced into the cross-support GDS, and different interfaces are required at the user GDS for packet and file services.

Regarding CFDP, note that it is very inefficient to perform reliable (requiring acknowledgements) Class 2 CFDP end-to-end given the discontinuity of the orbiter-to-lander and orbiter-to-Earth contact times and the resulting large end-to-end delay. It is therefore advisable to operate Class 1 CFDP at the lander and ground segment with reliability attained independently in the lander/orbiter hop and the orbiter/Earth hop. This will be achieved using sequence-controlled Proximity-1 in the cross-supporting agency's lander/orbiter link and some other form of reliability, such as packet, frame, or CFDP segment retransmission in the orbiter/Earth link.

In order to present projects with an unambiguous baseline, it is felt that the configuration of figure 3-3 can be simplified to eliminate unnecessary options. Figures 3-3 and 3-4 therefore show down-selected recommended near-term return link configurations for specific application to an ESA lander using NASA orbiting relay infrastructure and to a NASA lander using ESA orbiting relay infrastructure.



Notes:
The contents and format of the intermediate file (i.e., pass file) is implementation-specific and for NASA MRO contains multiplexed user data, Doppler, and time tags of the data that arrived at the orbiter from the lander.
What is delivered by default to the user GDS is just the data contents that arrived at the orbiter.
An ICD will specify how an end user can access ancillary data (Doppler, time) from the supporting mission.

Figure 3-3: Near Term Return Link for ESA Lander via NASA Relay

The configuration in figure 3-3 takes advantage of the transparency of the cross-support infrastructure to the use of packet or UDD services in the lander, thus simplifying the lander implementation. In addition, the cross-support GDS and the interface between cross-support GDS and user GDS are simplified by terminating CFDP at the user GDS.

Note that the orbiter-to-Earth link may, temporarily, not be able to deliver the complete set of return link frames. The real-time packet retrieval process may, therefore, be disturbed in the case of these TM frames not being delivered. Consideration should be given to the packet resynchronisation process and whether this process can be informed by knowledge of frame loss in the return link.

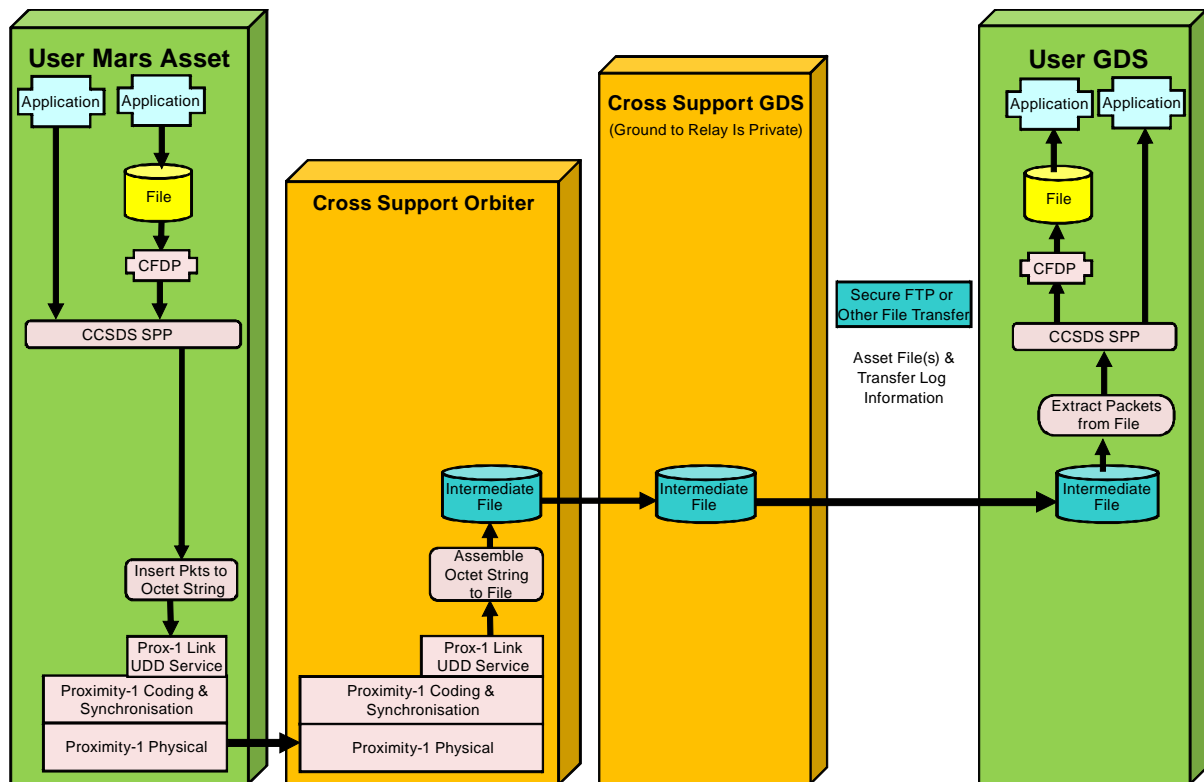


Figure 3-4: Near Term Return Link for NASA Lander via ESA Relay

3.3.3 NEAR TERM FORWARD LINK

Figure 3-5 depicts the end-to-end delivery of data from the user GDS on Earth to a user Mars asset (e.g., rover).

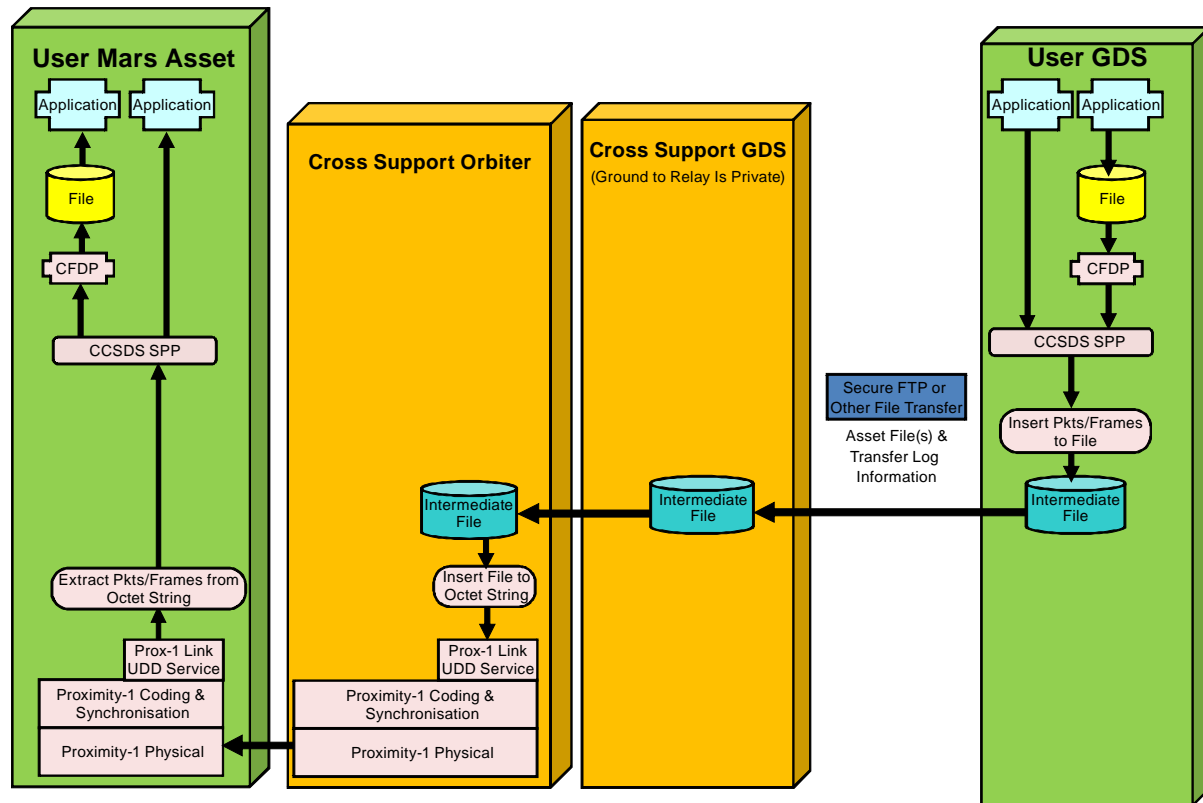


Figure 3-5: Near Term Forward Link

The existing Mars orbiter cross-support service is store-and-forward in nature, with hop-by-hop transfer. The cross-support GDS accepts only files that are constructed by the user GDS according to its own rules; such files may contain packets, TC frames, or other user-defined data structures. The whole file is transferred into the cross-support GDS using some standard file transfer mechanisms like FTP.

The existing Mars orbiter *transfer service* implements only the reliable UDD transfer defined in Proximity-1. This is used for the reliable transfer of the file contents between the cross-support orbiter and the lander. Thus, at the ground cross-support point, a file transfer takes place between the two agencies, whilst at the orbiter/lander cross-support point data are transferred via a user-defined data stream carried in the Proximity-1 frames.

It is up to the user Mars asset to be able to parse this octet stream and recover the data structures that were originally sent from the ground. The only responsibility that the cross-support systems, GDS and orbiter, assume is to deliver the data in the file in order, without

gaps or additions, and to provide a means for the user GDS to verify that the file was successfully transferred.

To initiate the end-to-end delivery of data from the user GDS to the user Mars asset, the user GDS prepares an intermediate file or set of files. These files contain a series of packets/frames for delivery to Mars asset applications. The packets/frames may contain either direct execution data, a set of PDUs generated by CFDP from an original file, or a hardware command that is directed to the user Mars asset's hardware configuration controller. Files must be prepared as a continuous series of packets/frames using the procedures for inserting packets/frames into a file (see annex D). The file is passed (for example, using secure FTP) to the cross-support GDS along with a set of ancillary information relating to the delivery requirements. The cross-support GDS forwards the files, in accordance with the delivery requirements, to the orbiter.

At the orbiter the intermediate file is communicated to the Mars asset using the Proximity-1 UDD service. To ensure the Mars asset can reconstruct the original files or series of packets/frames, two complementary functions are used to transmit and receive data using the Proximity-1 UDD service. The procedures for inserting a file into an octet string (see annex C) are used by the orbiter to generate a continuous stream of octets for transmission over the Proximity-1 link. At the Mars asset, the procedures for extracting packets/frames from an octet string (annex F) are used to retrieve individual packets/frames. The packets may then be routed directly to destination applications or to a CFDP receiving entity for reconstruction and storage of the original files. As with the return link configuration, CFDP is used in an unacknowledged mode as defined by the CFDP Class 1 procedures.

3.3.4 NEAR TERM FILE TRANSFER

The following paragraphs describe the proposed procedures for transferring files across the ground and orbiter cross-support points using the current infrastructure. The forward path starts with the asset users determining what they want forwarded from the relay orbiter to their asset. Then a binary file is created to carry the data in the form that the asset requires. The form of the data is not limited by the relay orbiter other than by requiring that it be a binary file and that the first bit in the file be the first bit to be transferred within the first bit of the frame data field of the initial Proximity-1 data frame containing actual file data. The file will be transferred from the asset GDS to the cross-support GDS by secure FTP. The file will be accompanied by the required metadata that is needed by the relay operations to format, name, and schedule its delivery to the relay orbiter.

The contents of the files are mission unique and are not examined by the relay orbiter GDS. The only user requirement are that these files not exceed the maximum onboard storage size and that they have filenames that conform to the file naming convention of the NASA orbiters. The file naming convention requires that the filename contain the asset ID, the date, the pass ID, and a unique file order number for the pass.

The present infrastructure has the capability to handle several individual files in a contact period. On the forward link the user GDS may request the delivery of several files by

providing these to the cross-support GDS along with delivery requirements, including priority. These files will be sent to the cross-supporting orbiter and stored as intermediate files. During the contact period with the user Mars asset, the files will be transmitted to the Mars asset according to the delivery requirements of the user GDS request. The Mars-asset receiving CFDP entity will reconstruct the original files in the order transmitted by the cross-supporting orbiter.

In the return path, the cross-support relay orbiter will, unless directed otherwise by an ICD, capture the received data and, after the over-flight session, transfer that data via DTE telemetry to its GDS. Upon receipt of the asset's data, the relay GDS will organize the received data into a file for delivery to the asset's GDS. This file will be accompanied by a metadata file (a CFDP transaction log) documenting the completeness of the file and providing other transport-related information such as time of receipt of first and last data segment.

As with the forward process, the cross-support GDS is responsible for removing any transport artefacts introduced by the orbiter or its GDS and for returning the original data sent by the Mars asset, in order, without gaps, omissions, or additions. These files will be delivered from the relay's GDS to the asset's GDS using secure FTP.

The cross-supporting orbiter is unable to distinguish individual files sent by the Mars asset. Therefore, although the Mars asset may transmit multiple files during a single contact period, these files will not be recognized as such by the orbiter. Rather, the orbiter will treat the data sent by the Mars asset as an octet stream that will be stored as one or more intermediate files. These files will be delivered to the cross-supporting GDS and subsequently to the user GDS. It is only at the user GDS that the original files may be reconstituted by the receiving CFDP entity.

3.4 DIRECT-TO-EARTH CROSS SUPPORT

The cross-support architecture for use of an agency's deep space network communications services needs to be considered. The standards used will be CCSDS SLE Forward CLTU Service and Return All Frames (RAF) or Return Channel Frames (RCF) service (references [19]-[21]).

In this service level, responsibility for formatting, processing, and reconstructing files or other data structures remains entirely with the user GDS and its Mars asset. The cross-support communications services are used only to transport CLTUs or other mission-defined data on the forward path, and AOS or TM frames on the return path. Additional services that use CFDP for the recreation of individual files by a receiving network and their delivery via a secure FTP file transfer may be available and can be arranged for in the mission's service agreement.

3.5 POSSIBLE UPGRADES FOR NEAR TERM MISSIONS

The current scenarios for the 2008 through 2015 timeframe do not require that the relay prioritize the files received from the Mars landed assets for transfer to Earth. This capability is not currently provided by the NASA MRO relay orbiter but could be added if requirements exist. One approach to achieve this capability would require the user Mars asset to use CFDP and to send its data in Proximity-1 frames that contain a CFDP PDU within a packet. In order to provide a two-level priority capability, two or more APIDs would be used for CFDP to differentiate their desired priority. The NASA MRO flight software would have to be modified to extract the packets from the intermediate file that is created by the Electra radio, and to use their contained APIDs to signal on which telemetry Virtual Channel (VC) to transmit that data on the DFE link from the orbiter. The NASA MRO flight software would then use its standard VC priority frame selection process for delivery control. Once on the ground these data could then be sent via an SLE RCF service or, after running them through CFDP, as reconstituted files using secure FTP.

3.6 POSSIBLE UPGRADES FOR FUTURE MISSIONS

The current infrastructure at Mars, and the Missions presently scheduled for the 2008 to 2015 time frame, are designed to relay the returned data collected by a user Mars asset to Earth as a single file, and cross-support orbiter operations just relay any forward data, sequencing, software, and configuration information assembled on the ground to the user Mars asset. There are no requirements for messages or files to be sent from a landed user Mars asset to an application located on the cross-support orbiter, nor are there requirements to send messages or files originating on the cross-support orbiter to a user Mars asset. In addition there are not at present networking requirements at Mars where data sent by a landed asset is to be delivered to another asset.

However, the day when those capabilities will be required is foreseen. Each of these services will require the cross-support orbiter to be capable of understanding the contents of the data stream and of processing it for these purposes. In order to provide for these enhancements it is recommended that all of these data be packaged in CCSDS recognized packets (i.e., Space Packets or Encapsulation Packets), and use the Packet frame-data-field construction mode in Proximity-1. It is recommended that future cross-support orbiter relay infrastructure (Relays) implement the total capability provided by the Proximity-1 recommendation and include the ability to merge data created on the relay with the data to be relayed from Earth.

This approach, combined with use of CFDP as described previously, will provide an end-to-end service for the relaying of file data and also will provide for the delivery of messages between orbiter and lander. The use of messages between the lander and the orbiter could be used as a means to signal future requests for return service or to announce available orbiter data storage for future passes. In addition, the use on the forward link of Class 2 CFDP, which will provide reliable uplink delivery of files, is also a possibility. This has been used successfully on some deep space missions, though not yet at Mars, and has been proven to be very effective.

Future provision of networking services, when it is required, can be constructed upon this same set of basic services. For example, the Delay Tolerant Networking (DTN) protocols are eminently suitable for exactly the sort of sporadically connected environment at Mars. These protocols are defined in draft standards and are now maturing. Demo flights are planned within the FY08-09 timeframe. When the population of assets at Mars reaches a size such that there is a need for automated transfers to simplify planning, or when there are multi-spacecraft mission requirements for networking, these protocols will provide a solution to the requirement. The basic changes suggested in the future infrastructure, as reflected in figure 3-6, provide exactly the necessary infrastructure on which to build such a networking capability.

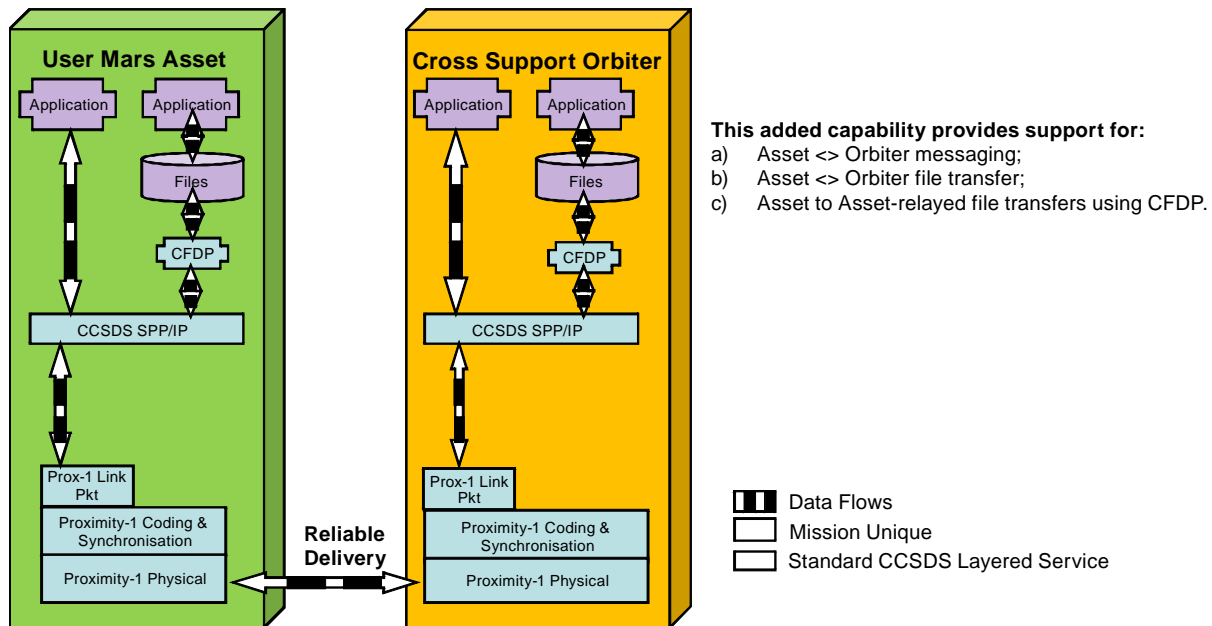


Figure 3-6: Upgraded Capabilities Desired for Future Mission Services

4 ISSUES AND RECOMMENDATIONS

4.1 ISSUES

This section identifies the major issues associated with interoperable data exchange in the Mars environment based on the experience outlined in previous sections. Subsection 4.2 puts forward recommendations with direct traceability to these issues.

- 1) Conformance to the CCSDS Recommended Standards is not, in itself, sufficient to guarantee interoperability between items of mission infrastructure belonging to or operated by different agencies. The ICDs and associated documentation needed to achieve interoperability between agencies and to achieve communication between elements belonging to single agencies require extensive analysis and negotiation over and above adoption of the CCSDS Recommended Standards. These negotiations have to encompass CCSDS protocol selection, options within the protocols, MIB specification, and system performance issues. Given the specifics of the Mars environment and the experience gained, it should be possible to provide a more complete basis for interoperability than the more general-purpose Recommended Standards currently tabled.
- 2) The available CCSDS Recommended Standards do not include concise guidance about which options and option dependencies to select. Neither do they provide the values of the MIB parameters for the protocols.
- 3) The cross-support solutions adopted for the 2003 missions were the result of expediency in retro-fitting interoperability into already-specified missions. This resulted in some ad hoc solutions, lack of link and relay robustness and accountability, complexity of implementation in certain elements, and protracted negotiations.
- 4) Because of the limitations of orbital dynamics, the method of relaying data via an orbiter will almost always be via a store-and-forward mechanism. The cross-support service provided by one agency to another has an interface on Earth between the user GDS and cross-support orbiter GDS, and another at the cross-support orbiter to Mars-asset communications link. It is generally agreed that the essential cross-support services to be provided in space are those of transferring files, or CCSDS packets or frames that will typically be transported in files, intact across a cross-supporting agency's infrastructure. Methods for achieving these services have been identified at three cross-support points. These are the user ground segment-to-orbiter ground segment interface, the ground communications service provider-to-orbiter interface, and the orbiter-to-landed asset interface.
- 5) On Earth, as a rule, a file containing CCSDS packets or other mission data structures such as TC frames or uplinked flight software is exchanged using existing standard methods of file exchange such as secure FTP. The packet cross-support interface between orbiter and lander differs according to the options selected from Proximity-1, and some differing options are not interoperable. The present implementation of the NASA orbiters (with the exception of an ODY implementation anomaly for which there are known work-arounds) conforms to the Proximity-1 specification, but

implements only the user-defined data transfer mode. Conformance to the Proximity-1 specification ensures that it can support the required data transfers.

- 6) The effect of the internal behaviour of a cross-supporting agency's infrastructure as it transports data between the Earth cross-support interface and the Mars cross-support interface does not emerge as an issue when considering solely the profiling of the CCSDS Recommended Standards. However, this behaviour does have an effect on the quality of service provision by the orbiter. This effect is manifested in attributes such as the maximum data volume that can be exchanged in an orbiter pass (limited by pass duration and by orbiter buffer availability), packet sequence preservation, data completeness, and data correctness. It is not within the purview of CCSDS protocol Recommended Standards to control these characteristics. However, they can and should be controlled within any generic Mars cross-support regime.
- 7) Many of the issues related to interoperability became apparent only during system interoperability testing and were not exposed at the analysis stage. A purely analytical approach is therefore not sufficient to identify all cross-support issues, and the need for a parallel programme of empirical interoperability testing is strongly indicated to reduce cost and risk in later stages of programme development.
- 8) The limiting resource for science return from landed elements is the data volume (i.e., the contact time, data rate product) which can be relayed by an orbiter during a pass of the lander. Missions have yet to take advantage of the opportunity to increase this volume by way of variable data rates during the pass.
- 9) While there are existing approaches that could be standardized, there is no formalisation of naming and addressing regime within CCSDS for data that traverses cross-support infrastructure. This lack could easily lead to data misrouting, duplication, or loss.
- 10) Cross-support scenarios may be envisaged using direct-to-Earth links where the cross-support infrastructure consists of a cooperating agency's deep space network facilities. These scenarios fall within the oversight of the CCSDS SLE activities.
- 11) Many of the current file delivery mechanisms use private file protocols and a variety of different file aggregation schemes. The use of CFDP in either reliable or unacknowledged mode for standard end-to-end transfer of files provides the means for advanced services in the future and added services for the return path.
- 12) With the exception of reliable Proximity-1 orbiter-to-landed asset links, most of the reliable data delivery and ARQ mechanisms that are in use are mission-specific. These may involve mission-specific approaches, such as sending a forward file twice for reliability or using frame, packet, or segment retransmission requests sent as a command to the relay asset. The retransmission required for completeness of data returned from the relay will add significant latency to the delivery of a complete file of transferred data. Pre-emptive methods of ensuring timely data delivery need to be matched to the bandwidth available in the links, the quality of these links, and the round trip propagation delays.

4.2 RECOMMENDATIONS

The following recommendations are therefore made and should form the principles for formulation of the Mars Mission Protocol Profiles CCSDS Recommended Practice. The recommendations are cross referenced to the issues of 4.1 to which they are traceable.

Table 4-1: Recommendations with Traceability to Issues

Recommendation	Issues Addressed
A Mars mission protocol-profiling CCSDS Recommended Practice should be produced identifying the cross-support points and the protocols in use at these cross-support points. This should form the basis for inter-agency cross-support agreements.	1
All relevant protocol specifications should include a Protocol Implementation Conformance Statement (PICS) proforma. As an interim measure, this information could be contained in the Recommended Practice document.	1
The Recommended Practice document should include completed PICSes for the protocols in use at cross-support points.	1
The PICS proforma and PICS for the whole protocol stack in use should include all aspects of the protocol MIB relevant to cross support.	2
The Recommended Practice document should be agreed to at the earliest opportunity and be promoted to the mission project offices to influence subsystem procurement.	3
An early inter-agency prototyping activity should take place to demonstrate the effectiveness of the chosen interoperability options in the same way as is mandatory for CCSDS protocol Recommended Standards.	3, 7
The services to be supported by cross-support infrastructure should be transfer of files or of CCSDS packets or frames carried in files for relaying. At terrestrial cross-support points these should be exchanged in accordance with CCSDS SLE or agreed file transfer methods. Ideally, at orbiter-to-lander cross-support points they should be exchanged as the packet service of Proximity-1 (for packets) and CFDP (for files). In current practice the UDD service of Proximity-1 is used on this link. The ground-to-orbiter cross-support point shall use CCSDS AOS or packet TM or TC, which can support the CCSDS packet protocol and CFDP. This should be documented in the Recommended Practice.	4

Recommendation	Issues Addressed
Legacy equipment will exchange files using the UDD service of Proximity-1. Procedures can be established to ensure support of CCSDS packet or CFDP end-to-end services. These procedures are documented in annexes to this document.	5
The Recommended Practice should identify end-to-end characteristics to be agreed upon by any cross-support agreement and, where possible, quantify these characteristics.	6
The capability of varying Proximity-1 protocol data rates during a pass should be incorporated, where possible, into future missions. An Adaptive Data Rate (ADR) capability will be added into the MRO orbiter before 2010. This should be reflected in the Recommended Practice.	8
The Recommended Practice should identify the naming and addressing scheme and the scheme for attached metadata for data traversing cross-support infrastructure to avoid ambiguity and conflicts in, e.g., lander and orbiter addressing domains.	9
The Recommended Practice should specify cross-support services for direct-to-Earth communications and for end-to-end file transfer.	4, 10, 11
The Recommended Practice should specify the means for achieving end-to-end reliable and timely file delivery using either CFDP Class 2 and SFO, or CFDP Class 1 combined with pre-emptive retransmission from the relay, or with underling link reliability as provided by Proximity-1 between the relay and the lander. Long erasure codes that are currently under study could provide a variant form of forward error correction for the information contents of file.	12

ANNEX A

NASA RELAY APPROACH

A1 OVERVIEW

A key feature of Mars relay operations is the store-and-forward data relay process. Data sent to the relay spacecraft in the forward direction as well as data received by the relay from the assets in the return direction are typically stored onboard until a scheduled relay to/from Earth tracking pass occurs. In the forward direction, the user creates data files that it wants transferred from a relay spacecraft to the Mars asset during a scheduled over-flight. These data files are sent to the GDS of the relay spacecraft where they are loaded into the data store of the relay spacecraft via direct-from-Earth communications with the relay's GDS. The data files are relayed to the designated Mars asset during the over-flight.

Simultaneously, in the return direction, data generated by the Mars asset is transmitted to the relay spacecraft. Scheduling (view periods) determines when the relay spacecraft transfers the data received from the Mars asset to Earth. The relayed data from the asset is extracted from the relay spacecraft's telemetry and delivered to the user. This summarizes the current operational scenario. What follows is a description of how this scenario is executed, currently along with possible extensions, including the user's data interfaces with the relay spacecraft's GDS and the operational interface between the relay spacecraft and the Mars asset. See figure A-1.

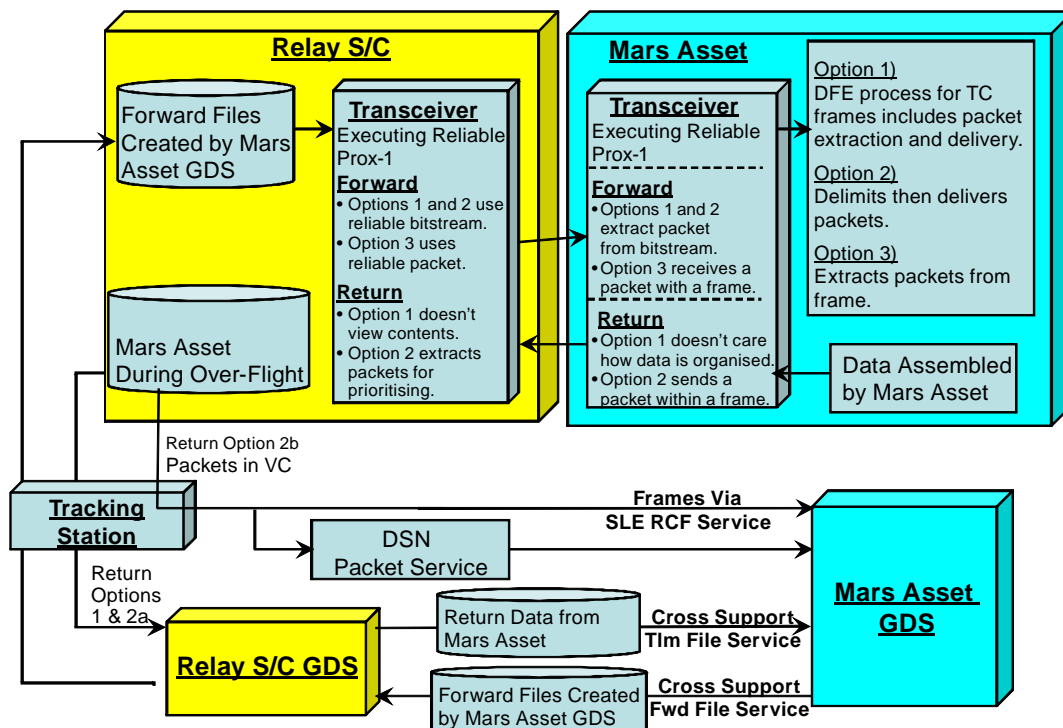


Figure A-1: Overview of NASA Relay Operations

A2 FORWARD LINK DATA TRANSFER SERVICE

A2.1 OVERVIEW

The Mars Lander GDS creates files containing the data that are intended to be transferred from a NASA relay (MRO or ODY) to a Mars asset. These files will be delivered to the relay orbiter GDS using a file transfer protocol (e.g., FTP). Each data file will be named in accordance with the NASA file relay naming convention. This convention identifies the orbiter that is to provide the relay function, the Session ID that identifies the relay pass within which the transfer is to occur, the target Mars asset that will receive the data, and a priority number for sequencing the delivery of the files during the relay session.

NOTE – Multiple files can be loaded onboard the relay in any order, and the files will be selected for transfer based on their priority number (0=first, 20=last).

A2.2 FORWARD LINK OPTIONS

A2.2.1 Forward Option 1—File of TC Encoded Frames over Proximity-1 Reliable Bitstream

The file's content is a series of TC encoded frames encapsulating the packets for delivery. The Proximity-1 reliable bitstream (user-defined DFC ID) will be used for transferring the data from the NASA orbiter to the Mars lander. Upon receipt of the Proximity-1 frames from the relay spacecraft, the series of received bits extracted from the received Proximity-1 transfer frames by the asset will be routed to the asset's DFE processing element to delimit and deliver the packets. See figure A-2 (NOCC = Network Operations Control Center).

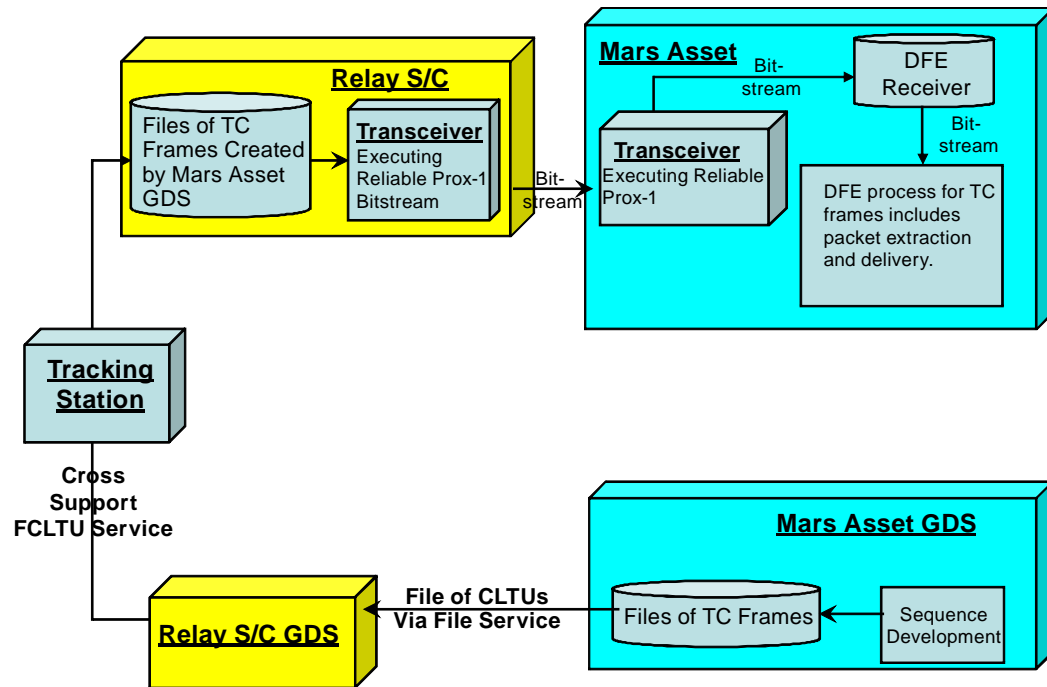


Figure A-2: Forward Relay Operations: Option 1

A2.2.2 Forward Option 2—File of Packets over Proximity-1 Reliable Bitstream

The file's content is a series of packets. The Proximity-1 reliable bitstream (user-defined DFC ID) will be used to transfer the data from the NASA relay orbiter to the Mars Lander. During (or after) the transfer to the Mars Lander, the receiving lander delimits and extracts the received packets from the received stream of data bits contained within the transferred Proximity-1 frames. The packets are distributed as they are extracted. See figure A-3.

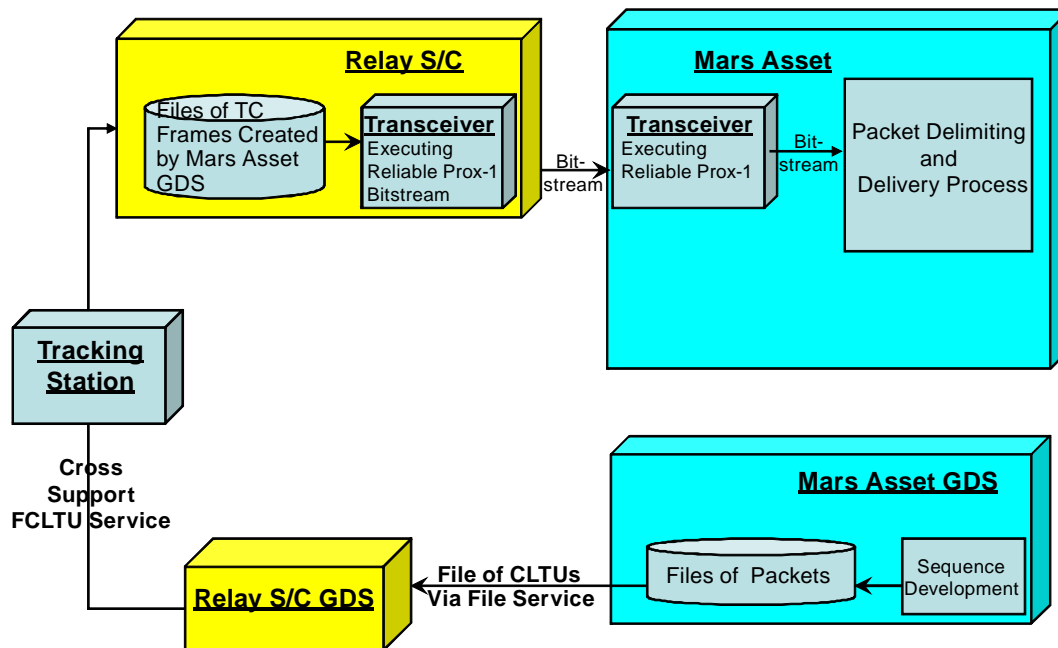


Figure A-3: Forward Relay Operations: Option 2

A2.2.3 Forward Option 3—Packet-by-Packet over Proximity-1 Reliable Packet Service

The file's content is a series of packets. The relay orbiter (or its transceiver) will delimit the packets contained within the series of files that are to be transferred, and it will place a single unsegmented packet or a segment of a packet within each Proximity-1 transfer frame for transfer to the lander. The Proximity-1 reliable packet transfer mode (DFC ID equal to either unsegmented packets or segments) will be used for the transfer. The receiving asset will immediately distribute the complete packets contained within the received frames. See figure A-4.

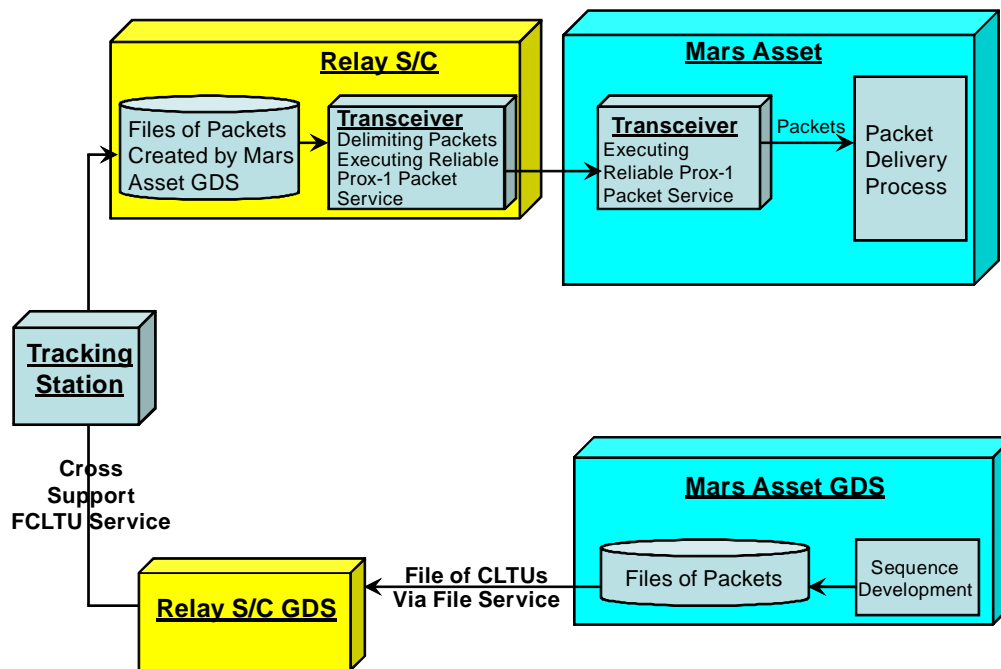


Figure A-4: Forward Relay Operations: Option 3

A2.3 FORWARD RELAY ISSUES, COMMENTS AND RECOMMENDATIONS

Note that ODY has a few hardware problems that require special processing:

- a) A few extraneous bits, from time to time, can inadvertently be inserted in the transfer preceding the first valid bits.
- b) ODY's forward reliable protocol handler has a problem in which it can inject a copy of a transfer frame into the bitstream.
- c) ODY cannot be modified to provide Option 3 under any circumstances.
- d) The use of Class 1 CFDP, between the Mars asset GDS and Mars asset, provides added assurances and increases the probability of complete transfers especially when ODY is the relay. This is because CFDP can perform with redundant PDUs and includes features that test completeness of the transferred data. Without CFDP, incomplete transfers could occur without detection.

Forward Option 1: File of TC Encoded Frames over Proximity-1 Reliable Bitstream

This option is how NASA employs the service today and would require no added costs on NASA's part. For rovers that also support DFE links, this option establishes a common user-asset data interface for both DFE and Proximity links. The DFE interface provides the required synchronisation to ignore the extraneous bits and recover from ODY's data corruption, which requires resynchronisation after an injected data incident. If one assumes that the forward relay packets contain approximately 250 data bits, then an overhead penalty of about 30 percent will be incurred.

Forward Option 2: File of Packets over Proximity-1 Reliable Bitstream

This option is consistent with the way NASA employs the service today and would require no added costs on NASA's part. The receiving unit is required to delimit the packets that arrive within the bitstream. If the data transfer is reliable with no data corruption, loss, or repetitions, then the process is simple. However, the ODY hardware issues add to this functionality complexities that are not simple to overcome. If ODY is not going to be used, then the packet delimitation would not be costly, and this option would require a minimum amount of transfer overhead.

Forward Option 3: Packet-by-Packet over Proximity-1 Reliable Packet Service

This option is consistent with the NASA ground and relay file handling functions employed today. A modification would be required to the Electra transceiver on MRO to provide the service in the described manner. This change would most likely be expensive. The Electra transceiver would need to be modified to delimit the packets and then transfer them within a Proximity-1 frame. This approach again requires no added overhead and is simplest for the Mars lander that receives a single packet per transfer frame.

A2.4 FORWARD TRADE OFFS

Table A-1 shows the trade offs for the three forward options.

Table A-1: Forward Trade Offs

	Option	Pros	Cons
1	<ol style="list-style-type: none"> 1) User delivers file of TC frames to relay GDS. 2) Relay uses reliable Proximity-1 bitstream. 3) Asset uses DFE process for handling uplink data. 	<ol style="list-style-type: none"> 1. Current (2008) practice for relay 2. Consistent with current (2008) NASA and ESA relay S/C Implementations. 3. Can deliver hardware commands. 	<ol style="list-style-type: none"> 1. Added overhead from TC framing and BCH coding. 2. No packet accounting.
2	<ol style="list-style-type: none"> 1) User delivers file of packets to relay GDS. 2) Relay uses reliable Proximity-1 bitstream. 3) Asset must extract packets from received bitstream (not aligned with Proximity-1 frames). 	<ol style="list-style-type: none"> 1. Current (2008) practice for relay 2. Consistent with current (2008) NASA and ESA relay S/C Implementations. 3. Minimum overhead. 	<ol style="list-style-type: none"> 1. Requires asset to delimit packets from received bitstream. 2. Incompatible with ODY because of ODY protocol implementation anomaly 3. No packet accounting.
3	<ol style="list-style-type: none"> 1) User delivers file of packets to relay GDS. 2) Relay uses reliable Proximity-1 packet service. 3) Asset distributes packets extracted from frames. 	<ol style="list-style-type: none"> 1. Current (2008) practice for relay GDS. 2. Consistent with current (2008) ESA asset implementation. 3. Minimum overhead. 4. Packet accountability. 	<ol style="list-style-type: none"> 1. Requires reprogramming of Electra FPGAs. 2. Incompatible with NASA present (and proposed) asset implementations.

A2.5 FORWARD PREFERENCES

NASA prefers Forward Option 1) if both ODY and MRO support Mars-bound assets.

NASA prefers Forward Option 2) if only MRO supports Mars-bound assets.

Option 3) would impose major implementation, integration, and testing efforts on operational spacecraft and is therefore the least favoured approach.

A3 RETURN LINK DATA TRANSFER SERVICE

A3.1 OVERVIEW

Under current nominal mission models, the Mars asset will collect data for an extended period. The collected data will be transferred to the relay during an over-flight. The transfer mechanism will typically use a Proximity-1 reliable protocol to assure that the Mars asset's collected data is transferred to the relay spacecraft for later return to Earth. The options that can be accommodated to perform this functionality, and their pros and cons, are described in A3.2-A3.4.

A3.2 RETURN LINK OPTIONS

A3.2.1 Option 1: Bulk Data File with CFDP Transaction Log

The present relay transfer capability included within both NASA relay spacecraft is to accept data transferred via UHF transceivers utilizing the Proximity-1 reliable bitstream protocol. The relay spacecraft do not examine the content of the data that they receive; instead, they place all of the received data from a single over-flight into a buffer whose contents are then transmitted to Earth as a single file, nominally during the next communications session with Earth. See figure A-5.

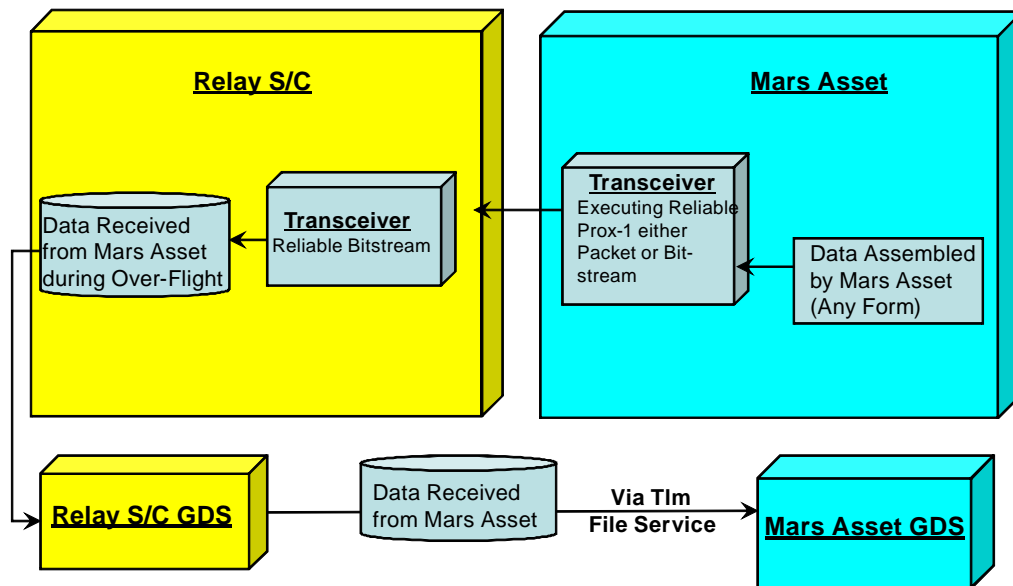


Figure A-5: Return Relay Operations: Option 1

The return process is executed as it has been done for the NASA missions. The exact mechanics of what is done on each of the relays is different, but the operations described below are not seen by the user; i.e., they are transparent. The user will receive a single file containing all of the data that was transferred during the over-flight. For example:

The Mars asset sends packets to MRO using reliable bitstream (DFC ID equals UDD). That is, the Mars asset transmits one packet per Proximity-1 frame and aligns the start of the packet to the beginning of the frame. The Electra transceiver encapsulates the received packet into a CFDP PDU within a CCSDS Space Packet, assigning it an 'Electra Received Data APID'. The packet is placed within the MRO 'SSR Electra session data buffer'. The MRO C&DH then extracts a segment of that SSR buffer and creates its own CFDP PDU within a Space Packet with 'Electra TLM APID'. The tracking station executes CFDP on the Electra TLM file PDUs and recreates the contents of the 'SSR Electra session data buffer'. A second CFDP run is performed on the contents of the recreated buffer, resulting in a series of files, one of which is a file containing the received contents (series of packets) of the relay session with the Mars asset. This Mars asset data file along with a CFDP transaction log (used for accountability) is forwarded to the Mars asset GDS for further processing (packet extraction).

A3.2.2 Option 2: End-to-End Packet Delivery

Option 2 is designed to accommodate the prioritisation of transfer among multiple data sets and to reduce the latency of a subset of the data transferred during the over-flight. It is available only for operations using the MRO spacecraft and requires a significant software redesign. For example:

The Mars asset sends packets to MRO using reliable bitstream (DFC ID equals UDD). That is, the Mars asset transmits one packet per Proximity-1 frame and aligns the start of the packet to the beginning of the frame. In this example scenario, the Mars asset creates a high-priority CFDP APID and a low-priority CFDP APID. The Electra transceiver encapsulates either type of packet into a CFDP PDU within a Space Packet with 'Electra Received Data APID'. The packet is placed within the MRO 'SSR Electra session data buffer'. The MRO C&DH extracts the packet contents from the 'SSR Electra session data buffer' (this could happen during or after the session). When an extracted packet contains the 'Electra Received Data APID' the contained Mars asset packet is extracted by the MRO C&DH and sent to the VC-forming processor for that APID. In this manner the high-priority packets are placed into a high-priority VC and telemetered in advance of the other data to Earth. The lower-priority CFDP APID are sent on a lower-priority VC. On Earth the tracking station extracts the packets and routes them to the CFDP Processor. See figure A-6.

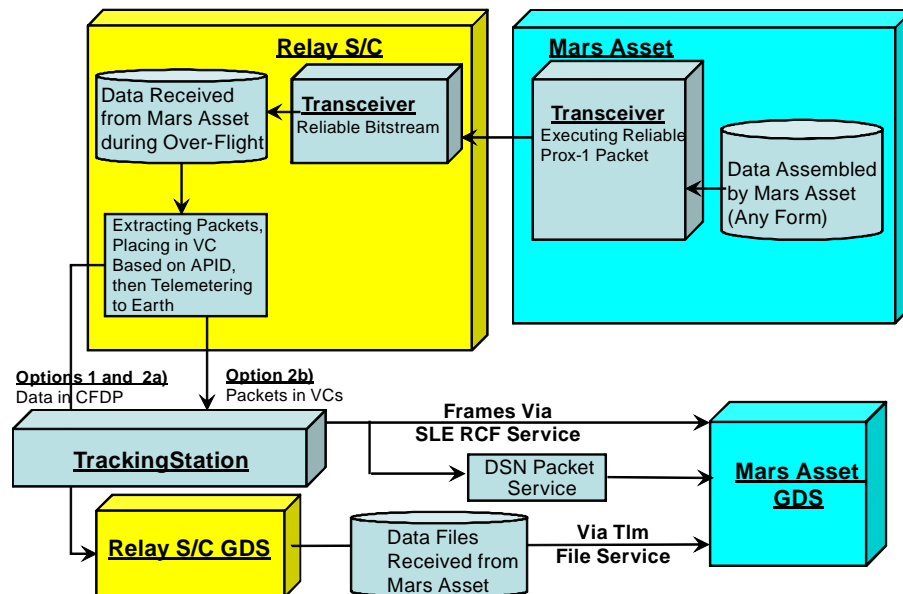


Figure A-6: Return Relay Operations: Options 2a) and 2b)

Alternatively, as shown in option 2b), the packets could be acquired by the user from the tracking station's SLE RCF Service. The SLE RCF Service could be utilized as the delivery service if these packets are placed into a defined VC by MRO for this data exclusively.

Note that a high-priority VC can be defined to carry only the Mars asset CFDP engineering packets for which the SLE RCF process could be used for real-time delivery.

A3.3 RETURN TRADE OFFS

Table A-2 shows the trade offs for the three return options.

Table A-2: Return Trade Offs

	Option	Pros	Cons
1	1) Asset transfers data using a reliable Proximity-1 service. 2) Relay GDS delivers a file of the received data without concern about its format or content.	1. Current (2008) practice for relay. 2. Consistent with current (2008) NASA relay S/C implementations.	1. All relayed data delivered to user at the same time in a single file. 2. Lack of prioritisation for relay to Earth. 3. Limited station accounting.
2a	1) Asset transfers packets within Proximity-1 frames using reliable Proximity-1 service. 2) Packets are extracted from received data. 3) CFDP packets are prioritized for delivery.	1. Delivery latency from relay can be reduced for prioritized files. 2. Packet accountability within service provider.	1. Can be supported only by MRO. 2. Requires MRO software reprogramming.
2b	1) Asset transfers packets within Proximity-1 frames using reliable Proximity-1 service. 2) Packets are extracted from received data. 3) Packet APIDs are used to route to assigned VC frames.	1. Delivery latency is minimized. 2. Delivery is direct from tracking station using SLE RCF service. 3. Packet accountability within service provider.	1. Can be supported only by MRO. 2. Requires MRO software reprogramming. 3. Requires APID management across projects and special VCs.

A3.4 RETURN PREFERENCES

NASA prefers Return Option 1.

Either variant of Option 2 would impose major implementation, integration, and testing efforts on operational spacecraft and therefore Option 2 is the least-favoured approach.

ANNEX B

ESA RELAY APPROACH

B1 OVERVIEW

The ESA approach is exemplified by the implementation chosen for the Beagle 2/Mars Express mission. The ESA relay unit uses the Melacom payload of the Mars Express spacecraft. Melacom extracts CCSDS packets from the return Beagle 2-to-MEX Proximity-1 frames and the forward Earth-to-MEX telecommand frames and transfers these, respectively, into return CCSDS telemetry frames and forward Proximity-1 frames. Variable-length Proximity-1 frames are therefore supported to accommodate these packets directly.

The Mars Express relay implementation adopts the CCSDS packet as the unit to be relayed. This allows independence of the orbiter-to-Earth and orbiter-to-lander links. The native capabilities of the CCSDS TM, TC, and Proximity-1 protocols for support of packets are used, and maximum link efficiency is achieved.

The chief concern with the MEX implementation was that it is not possible to use the Mars Express memory as a buffer for the forward link data. All of the data to be transferred up to the lander is sent to Melacom prior to the link session. This was not indicated or appreciated at the Melacom specification stage and it was fortunate that sufficient memory (20 kBytes) was available in Melacom to provide an intermediate buffer for telecommands.

B2 FORWARD LINK OPERATION

One packet at a time is extracted from the 'File of Packets', on the ground, and sent to Mars Express in a CCSDS TC frame (one packet per frame). Once the frame has been accepted by MEX the packet is extracted and sent to a local packet store. The packets are then sent via an OBDH bus into the Melacom relay local memory, which has a capacity of 16 kBytes.

Once contact with the lander is established, the packets are extracted from the local memory and inserted into Proximity-1 frames for transmission to the orbiter with one packet per frame. Go-back- N retransmission, with variable values for N depending on link rate and delay, is implemented for link reliability.

The Proximity-1 frames are received by Beagle 2's transceiver, where the COP-P process is handled. On a successful acceptance of the frame, the packet is extracted and sent over a direct serial link to the Central Electronics Processor (CEP). It is this subsystem that checks the validity of the packet, as no packet processing is done by the transceiver.

The forward link data flow is shown in figure B-1.

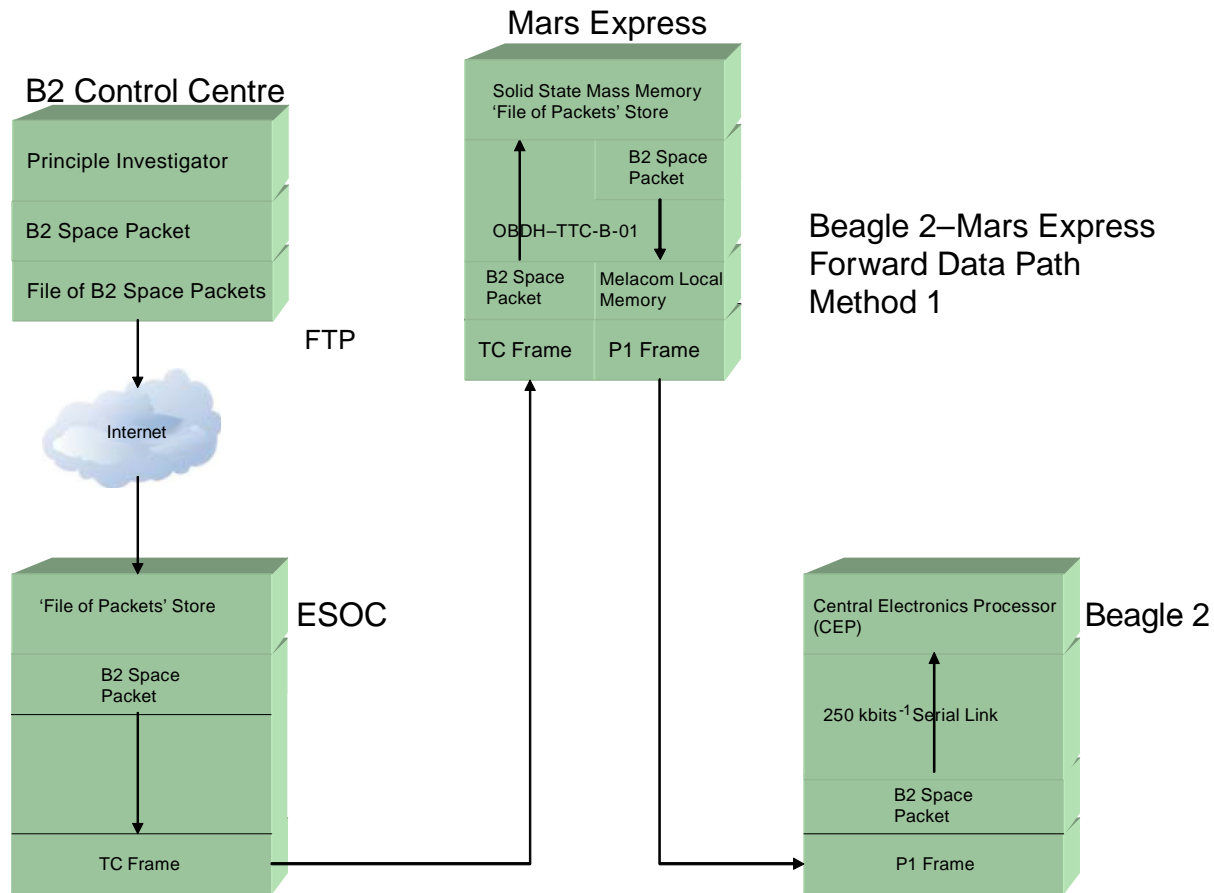


Figure B-1: Beagle 2/Mars Express Forward Link, Single Encapsulation

An alternative mode which could have been utilised was to encapsulate the Beagle 2 packet inside a Melacom Space Packet for transmission to Mars Express. The Melacom packet header would be discarded by the Melacom unit, and the contained B2 packet would then be inserted into the Proximity-1 frame. This had the advantage that the B2 and Mars Express packet IDs would not need to be jointly managed, and the B2 link would consume only one Mars Express packet ID. This mode is illustrated in figure B-2.

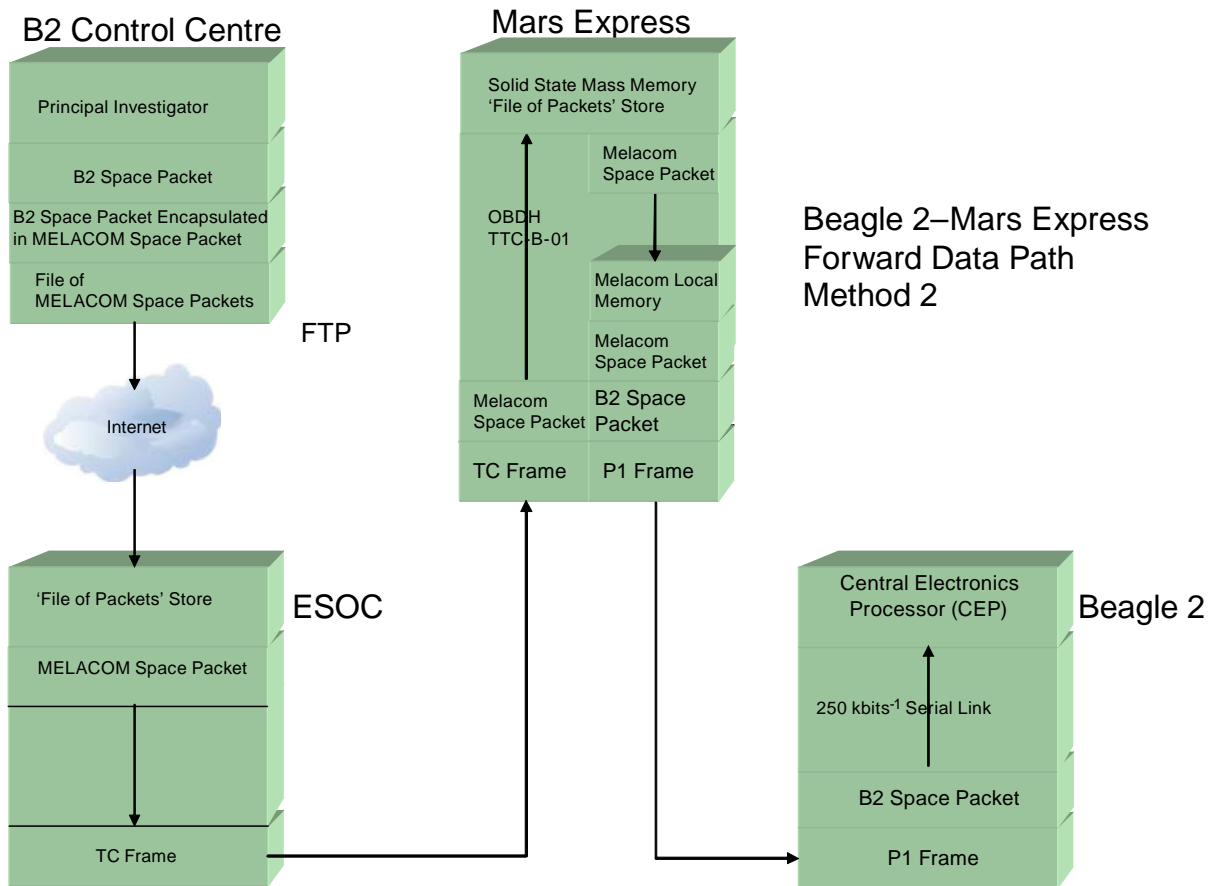


Figure B-2: Beagle 2/Mars Express Forward Link, Double Encapsulation

The relay also has the capability to transfer an unstructured bitstream. The bitstream is placed into the Melacom local memory, and Melacom inserts the data into arbitrary-length Proximity-1 frames, which are sent to the lander.

B3 RETURN LINK OPERATION

As a result of power constraints on Beagle 2, the transceiver was not powered continuously, and so the link scheduling was handled by the CEP. The transceiver would be powered a suitable time before a link was scheduled to start. The CEP would stream packet data, on the serial link, until notified that the transceiver's buffer was full. It had the same buffer capacity as Melacom (20 kBytes). Beagle 2 would listen for a hail, as it was agreed that all hails would be initiated by the orbiter. Once the link had been established, the data would be emptied from the buffers and CEP would be notified to resume the streaming of packets. The disadvantage of this method was that the CEP had no visibility of which packets had been sent, as the link could have been lost before the complete transfer of the transceiver's buffer. This made the job of packet accountability slightly more complex.

Lander packets were received from the lander, with each packet occupying a Proximity-1 frame. These packets were extracted from the frame and immediately transferred over the Mars Express high-speed bus with an additional packet header encapsulating the received packet. The nature of the IEEE-1355 link requires the data transfer to be in multiples of 32 bits. If the received data did not conform to this rule Melacom would pad the end of encapsulating packet to ensure it was in multiples of 32 bits.

The resulting packets were stored in mass memory until an opportunity for download to Earth occurred. In this case the packets were transferred to Earth multiplexed into CCSDS telemetry frames. This is shown in figure B-3.

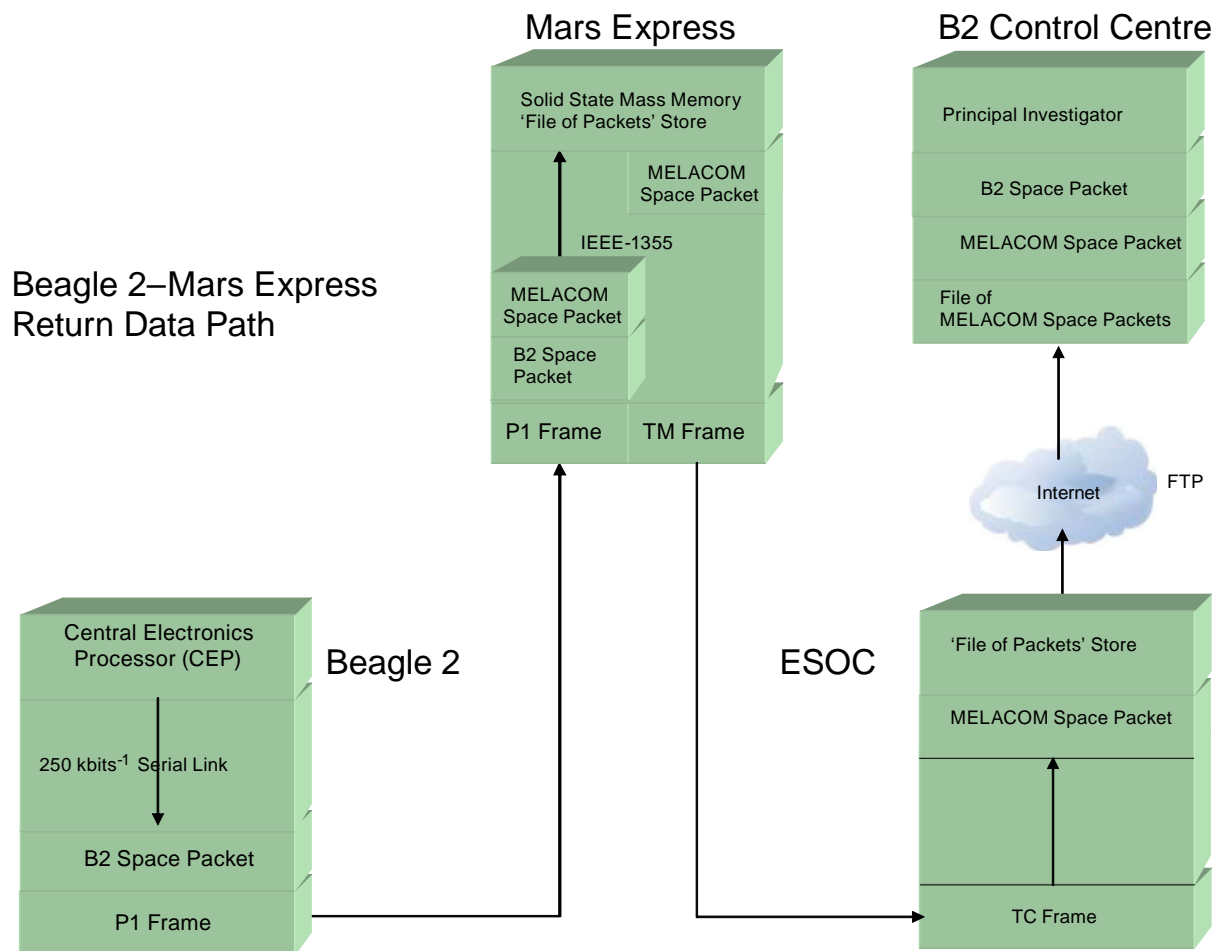


Figure B-3: Beagle 2/Mars Express Return Link

A bitstream capability was also provided. In this case, the bitstream content of an incoming frame was encapsulated into a packet by Melacom and then sent to the mass memory for subsequent Earth return via CCSDS telemetry frames.

Go-Back-*N* reliability was also incorporated into the return Proximity-1 link if required.

B4 PREFERENCES

ESA mandates that all missions be CCSDS compatible, ensuring that all new ESA spacecraft will interoperate with the existing ground infrastructure. This includes the receiving stations, mission operations, and the ground-support equipment used in assembly, integration, and test. As a result the CCSDS Space Packet is used as a method of routing to the specific subsystems on the ground and onboard the spacecraft and is independent of the underlying bus architecture.

This arrangement has led the development of the Packet Utilisation Standard (PUS) by ESA. This application-layer protocol depends on the end-to-end transmission of CCSDS packets in both forward and return directions. The standard defines an application-level interface between the ground and space, which interface includes services such as telecommand verification, housekeeping, and diagnostic data reporting. The PUS is now mandatory for all current and future ESA missions (Telecommunications, Science, Earth Resources, Microgravity, etc.).

ESA's fundamental requirement is therefore for end-to-end packet relaying between ESA ground infrastructure and Mars asset. Commonality between DTE links and relay links is at the packet level with completely separate frame-level processing.

ESA is in the process of assimilating CFDP into their ground infrastructure and will therefore, in the future, require and support file forwarding via interoperating relay.

ESA's DTE links are supported by ESA infrastructure, and there is no nominal requirement for cross support by other agencies' deep space network assets. However, cross support for non-nominal events may be provided using established methods of frame forwarding.

ANNEX C

PROCEDURE FOR INSERTING A FILE INTO AN OCTET STRING

Landers and orbiters which provide the Proximity-1 User Defined Data service may use this procedure to transfer a delimited file. Should this method be used, then:

- The first octet of the first data frame of the pass contains the first octet of the first file to be transferred.
- The file octets are aligned with the frame octets.
- A variable-length frame carries the last octets of the last file of a pass with no padding.
- Should multiple files be transferred in a pass, they will be transferred contiguously with no requirement to disestablish and re-establish the proximity-1 link.
- The last octet of the preceding data file will be contiguous with the first octet of a succeeding file with no requirement to start a new frame.
- Should a file not be transferred or be incompletely transferred because of termination of a pass, then it will be deleted from the orbiter transfer queue, and no attempt will be made to transfer remaining parts on a subsequent pass.

ANNEX D

PROCEDURE FOR INSERTING PACKETS OR FRAMES INTO A FILE

The Proximity-1 File Transfer Procedure for User Defined Data (annex C) may be used to transfer a file of CCSDS packets or frames. In this case:

- The first octet of the file will be the first octet of the first packet or frame to be transferred.
- Packets or frames will be placed contiguously in the file with no intervening protocol control information.
- The last octet of the file will be the last octet of the last packet or frame to be transferred.

ANNEX E

PROCEDURE FOR EXTRACTING PACKETS FROM A FILE

In order to extract packets from a file:

- It is assumed that the first octet of a file is the first octet of the first packet.
- Packets are extracted using the packet length field; it is assumed that packets are continuous with no data loss.
- The last octet of the file will be the last octet of the last packet.

ANNEX F

PROCEDURE FOR EXTRACTING PACKETS OR FRAMES FROM AN OCTET STRING

In order to extract packets or frames from an octet string or frame:

- It is assumed that the first octet of a Proximity-1 connection is the first octet of the first packet or frame.
- Packets are extracted using the packet length field; it is assumed that packets or frames are continuous with no data loss.
- The last octet of the connection will be the last octet of the last packet or frame.

ANNEX G

PROCEDURE FOR INSERTING PACKETS INTO AN OCTET STRING

In order to insert packets into an octet string:

- The first octet of the first data frame of the pass contains the first octet of the first packet to be transferred.
- The packet octets are aligned with the frame octets.
- The concatenated user-defined data fields of the frames form a contiguous octet string.
- Packets are inserted contiguously into the octet string with no extraneous data.
- A variable-length frame carries the last packets of a pass with no padding.

ANNEX H

PROCEDURE FOR ASSEMBLING AN OCTET STRING TO A FILE

In order to extract files from an octet string:

- The first octet of a Proximity-1 connection is the first octet of the file.
- The file is assembled using the octets extracted from the octet string.
- Should the file contain packets, then any file segmentation must observe packet boundary alignment with segmented file boundaries.
- The last octet of the connection will be the last octet of the file.

ANNEX I

UTILISATION OF THE ODYSSEY MARS RELAY

I1 INTRODUCTION

When operating with Odyssey there are a number of idiosyncrasies that need to be taken into account. These mainly affect the forward link from the orbiter to the lander. Aside from the restrictions discussed in this section, the return link should operate in a similar manner to MRO with the exceptions that ODY assigns a special APID (up to 4 [TBC] possible) for downlink of Mars asset data (does not use CFDP files) and downlinks packets to Earth using TM, on a best-effort (non-reliable) basis.

NOTE – The NASA Mars Odyssey Project can be contacted for more detailed information.

I2 ISSUES

I2.1 ONLY FOUR DATA RATES

Only four data rates are possible and there is only one data rate allowed per Proximity-1 session.

I2.2 PROXIMITY-1 SESSION HALTS FOR ANY LOSS OF SIGNAL LOCK

The Odyssey CE-505 radio has no ‘grace period’ or ‘flywheel timer’ for signal outage. If carrier lock or symbol lock is lost for any instant, Odyssey terminates data exchange and re-hails to start a new Proximity-1 session.

The exception to this is during the hail process where a CE-505 response time of two seconds or eight seconds is allowed.

I2.3 G2 INVERSION IS NOT SUPPORTED IN VITERBI DECODING

The ATMEL/TEMIC codec chip in the CE-505 radio does NOT support encoding or decoding of the NASA standard and Proximity-1 compliant code with G2 symbol inversion. Only non-inverted G2 is supported.

I2.4 EXTRA PAD BYTE

The Odyssey orbiter transceiver inserts one byte of pad after each frame is transmitted. Its reported purpose was to facilitate better capture and identification of the ASM on the following frame.

This byte is not called for in the Proximity-1 standard but is allowed and should be ignored by any Proximity-1 radio.

I2.5 IDLE BIT PATTERN

The Proximity-1 protocol specifies that ‘Idle’ bits should be transmitted when there is no data to send on the link.

I2.6 CHANNEL ZERO OPERATION ONLY

The CE-505 radio on Odyssey operates only on Proximity-1 Channel zero. This is true for both hail and active channel operations

I2.7 FRAME DUPLICATION

In some sudden low-signal conditions the Odyssey orbiter CE-505 radio can lose track of the frame counter in the Go-Back-2 mechanism resulting in duplication of frame data but with a different frame sequence number.

I2.8 STALE DATA IN THE FORWARD LINK BUFFER

The Odyssey link has sometimes been seen to have garbage data in its transmitting buffer causing erratic start-up of the Proximity-1 session. This data has to be handled by the packet search algorithm in the same way as idle data is processed.

I3 ODYSSEY PROXIMITY-1 FORWARD LINK CONSIDERATIONS

I3.1 OVERVIEW

The following subsection provides guidelines for the use of Odyssey when transferring packets between the orbiter and rover as in the case of ExoMars. It is stressed that while the information given provides a basic approach to link synchronisation and packet recovery, there may be alternative mechanisms and solutions to achieve the same result. Any implementation must undergo intensive ground testing to ensure correct operation under all operational conditions.

I3.2 FRAME SYNCHRONISATION

Three situations must be handled by the receiving Mars asset:

- a) The introduction of erroneous bits in the frame when a Proximity-1 session is initiated. Solution depends on precise problem. This occurs when the link is lost and an erroneous byte is transmitted from the Odyssey buffer. This is reportedly only a problem at 256 kbits/s and affects only data in the Proximity-1 data field (not the header). The erroneous data must be detected using the processing of higher-level data structures.
- b) The introduction of an extra padding byte between consecutive Proximity-1 frames. This may be simply filtered by the frame synchronisation process skipping the extra byte and searching for a new start of frame. This does not violate the Proximity-1 standard as idle/pseudo-random data between asynchronous active frames is expected.
- c) The possible duplication of frames when go-back-*N* retransmission is activated. It is understood that occasionally frames with duplicate frame sequence numbers may be transmitted. These will be rejected by the Proximity-1 FARM. More seriously, frame data may be repeated with a valid in-sequence frame number. This will be accepted by Proximity-1 and passed, undetected, to the Proximity-1 user protocol. Embedded structures (packets or frames) may therefore be interrupted or duplicated and measures must be taken to ameliorate these effects in the processing of these data structures.

I3.3 PACKET SYNCHRONISATION

Once frame synchronisation has been obtained the Mars asset must retrieve packets from the incoming bitstream. To achieve this the receiver must search for a unique data pattern within the stream of bits. It is suggested that the APID within the packet header be used for this purpose. The APID consists of an 11-bit field; as the probability of the APID's value appearing as part of the data field is reasonably high, it is suggested that the APID field be searched for in combination with other fixed values of the packet header, e.g., packet version number, packet type, secondary header flag. Once a correct value has been found in the stream of bits, an additional check should be made by retrieving the length field of the packet and confirming that the packet length is below 256 octets (maximum allowed packet size for an ESA TC packet). If the APID together with other selected header fields and packet length is acceptable, then the packet can be assumed to be correct and be released for processing. The same process is repeated until the end of the Proximity-1 session.

The above technique assumes the use of a single APID for all data transfers. If the use of additional APIDs is required there are two options:

- a) the process searching the bitstream must check for all valid APIDs;
- b) packets are encapsulated within an encapsulation packet.

Option a) above increases the complexity of the search routine, whereas b) operates on a single APID at the expense of additional packet overhead.

Additional consideration must be given in the case where a Mars landed asset operating with both Odyssey and MRO orbiters. To limit the complexity of the Mars landed asset, the preferred solution should allow operation with either orbiter in a transparent manner, that is, the landed asset should be unaware of which orbiter is in use at any given time. While complete orbiter agnostic operation may not be feasible, the packet encapsulation option provides a common mechanism for initial packet recovery using a single APID.

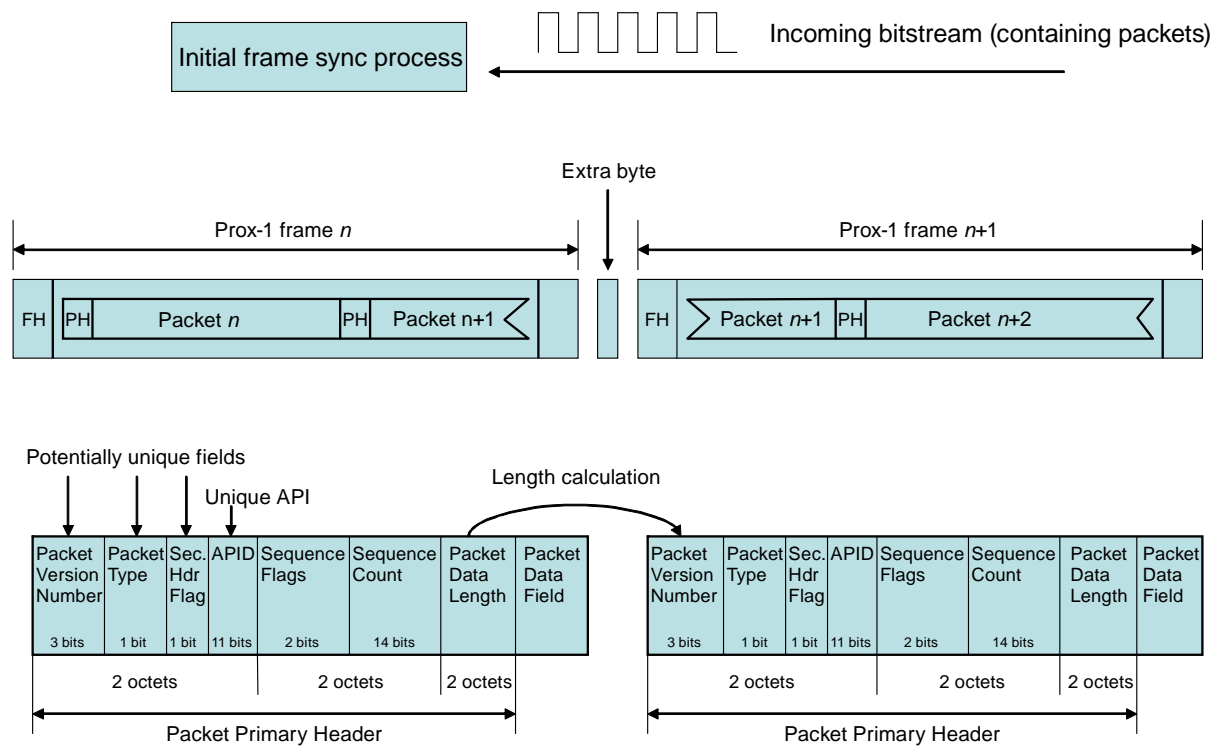


Figure I-1: Packet Synchronisation

ANNEX J

ACRONYMS AND ABBREVIATIONS

<u>Term</u>	<u>Meaning</u>
ADR	Adaptive Data Rate
AOS	Advanced Orbiting Systems
APID	Application Process Identifier
ARQ	Automatic Repeat Queuing
B2	Beagle 2
C&DH	Command and Data Handling
CCSDS	Consultative Committee for Space Data Standards
CEP	Central Electronics Processor
CFDP	CCSDS File Delivery Protocol
CLTU	Communications Link Transmission Unit
CRC	Cyclic Redundancy Check
DFC ID	Data Field Construction Identifier
DFE	Direct-From-Earth
DTE	Direct-To-Earth
FARM	Frame Acceptance and Reporting Mechanism
FPGA	Field-Programmable Gate Array
Fwd	Forward
GDS	Ground Data System
ICD	Interface Control Document
MER	Mars Exploration Rover
MEX	Mars Express
MIB	Management Information Base
MRO	Mars Reconnaissance Orbiter

MSB	Most Significant Bit
MSL	Mars Science Laboratory
NOCC	Network Operations Control Center
Pkt	Packet
Prox-1	Proximity-1
OBDH	OnBoard Data Handling
ODY	Mars Odyssey
OSI	Open Systems Interconnection
PDU	Protocol Data Unit
PICS	Protocol Implementation Conformance Statement
PUS	Packet Utilisation Standard
RAF	Return All Frames
RCF	Return Channel Frames
RF	Radio Frequency
S/C	Spacecraft
SDU	Service Data Unit
SFO	Store-and-Forward Overlay
SLE	Space Link Extension
SSR	Solid State Recorder
TBC	To Be Confirmed
TC	Telecommand
TLM	Telemetry
TM	Telemetry
UDD	User Defined Data
VC	Virtual Channel