Mars Interoperability 2008-2015: Options for Relay Orbiter Support to Mars Bound Assets

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The current relay orbiter infrastructure at Mars, in support of the user assets presently at Mars and those scheduled for the 2008 to 2015 time frame, only have a need to store-and-forward the returned data collected by an asset to Earth as a single non-prioritized data file. In the forward direction, the relay orbiters are only required to relay the forward link data, i.e., command sequences, software and configuration information assembled on the ground, to the Asset. There are currently no requirements for status/control messages or files to be sent in the return direction from an Asset to an application located on the Relay, nor are there requirements in the forward direction to send status/control messages or files originating on a Relay to an Asset. In addition there are currently no networking requirements at Mars where data originally sent by an Asset is to be delivered to another user asset. However, we foresee the day when standard services for 1) on-board file prioritization of user asset data by a Relay, 2) control/status message transfer between assets and a Relay, and 3) networking between assets i.e., Asset to Asset message/file transfer via a Relay will be required. Each of these services will require the Relay to be capable of understanding the data type and routing needs of the user asset data and be capable of processing it for these purposes. This paper will focus on the innovative enhancements required to the existing communications infrastructure at Mars to enable these future services.

Nomenclature

AOS	=	Advanced Orbiting Systems
CCSDS	=	Consultative Committee for Space Data Systems
CFDP	=	CCSDS File Delivery Protocol
DTE	=	Direct to Earth (Link)
ExoMars	=	(ESA) Aurora Exploration Programme ExoMars Rover
ICD	=	Interface Control Document
MRO	=	(NASA) Mars Recognizance Orbiter
MSL	=	(NASA) Mars Science Laboratory (Project)
PDU	=	Protocol Data Unit
Prox-1	=	(CCSDS) Proximity-1 Space Link Protocol
SLE	=	(CCSDS) Space Link Extension
SPP	=	(CCSDS) Space Packet Protocol
TC	=	(CCSDS)Telecommand (Recommendation)
TM	=	(CCSDS) Telemetry (Recommendation)

I. Introduction

Having analyzed the current Mars Infrastructure implementations this section provides a recommended cross support approach for missions in the 2008 to 2015 timeframe. This is formally documented in an accompanying CCSDS recommended practice Magenta book. Although CCSDS has developed a set of

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recommendations applicable to the Mars scenario, infrastructure, equipment and missions were being specified during the development of the recommendations. There is, as a consequence, some variation in the approach taken to the provision of CCSDS services and this needs to be understood and taken account of in the cross support baseline. The approach therefore is firstly to describe how the CCSDS recommendations have been implemented in existing infrastructure and current ongoing missions and, secondly, to identify what should be included in future infrastructure elements, and possible upgrades to current ground and space infrastructure, for conducting cross support for the future.

Note that the relay operations scenario requires an interactive scheduling process among the user, cross support provider, and ground communications infrastructure that takes place long before the actual relay activity instance occurs. The complete 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 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 do not communicate with each other, but will rely on the support of the NASA MRO and associated ground segment and possibly a Russian orbiter which will directly communicate with the ESA ground segment. A reference architecture based on this
configuration is illustrated in Fig. 1.

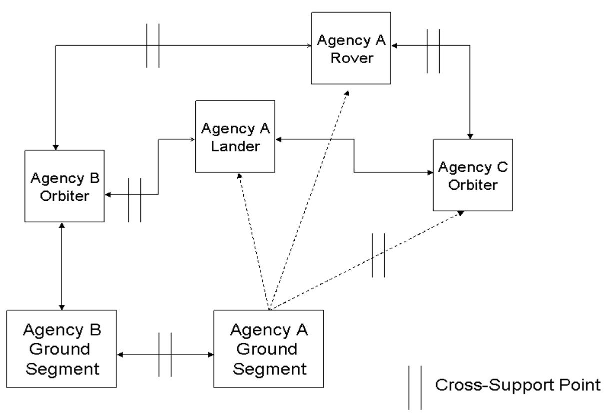

Figure 1. Mars Interoperability Reference Architecture

II. New Mission Profiles

Any new missions (including ESA ExoMars) should fully comply with the CCSDS recommendations at the cross support points, these may include:

1) RF and modulation
2) TM[1]/TC[2] and AOS[3] space data link protocols
3) The CCSDS Space Packet Protocol[4]
4) The Proximity-1 protocol[5]
5) CFDP protocol[6]
6) The CCSDS SLE services for ground communication

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

1) user orbiter and cross support lander and;
2) user ground segment and cross support ground segment for both the Forward Service Segment and Return Service Segment

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

Note that in this discussion we are intentionally conflating the Cross Support GDS and the ground communications service provider. In most real deployments these are different systems owned and operated by different organizations, 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.

III. Recommendations for Near Term Missions

Here we define the recommended configurations to be used for near term missions focusing on the known capabilities MRO and the requirements of ExoMars and MSL. Note that the existing obiter 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 signaled by the protocol. Proxmity-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 Ground Data System (GDS) on earth and the Landed asset on Mars. Two cross-support points are identified but each has slightly different characteristics for Forward and Return operations:

1) Between the user Mars asset and the cross-supporting orbiter
2) Between the user GDS and the cross-supporting 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.

A. Near Term Return Link

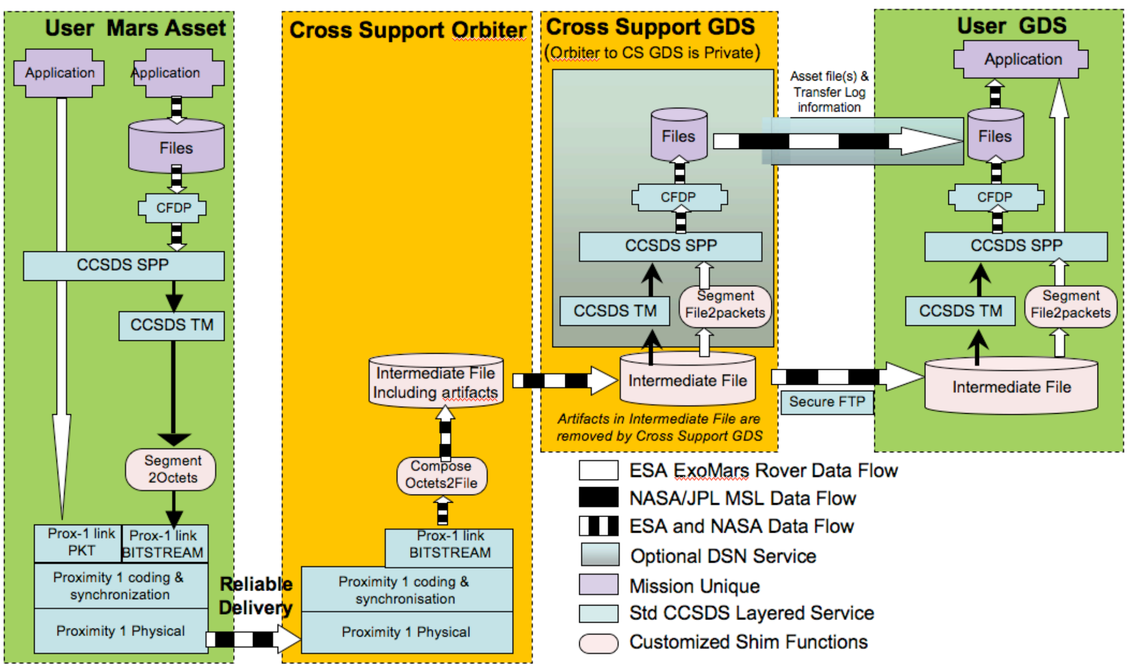

Figure 2. Near Term Return Link Possibilities

Figure 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 either return data from mass storage or generate it in real-time. Packets are the carriers of real time data. 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:

1. ESA prefers to transfer raw packets using the Proximity-1 Packet mode , while
2. NASA prefers to encapsulate the packets in TM or AOS Frames and segment the frames for transfer using the user data delivery mode (UDD).

These are both depicted in Fig. 2. Note that the orbiter treats both of these services as a UDD octet stream even when the frames are identified as carrying packets.

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, which is currently used by NASA, then the Telemetry frames must be segmented into fixed data segments and provided to the transceiver framing function for transfer. The relevant procedure is the CCSDS TM/AOS Frame Protocol which is streamed to the Transceiver and segmented into fixed length Proximity-1 frames. These functions are described in Fig. 2. Provided the procedures shown above are followed and the proximity-1 link is operated in sequence controlled mode then it is possible to reconstitute the packets in the user or cross support ground segment. This is true for UDD service in all of the following scenarios since the received relay data is handled transparently by the cross supporting agency waypoints. The underlying Sequence Controlled Proximity -1 process will provide the reliability required and allows the cross support relay service to be transparent to the actual protocol entities carried within the Asset's return data stream.

Since each Agency uses different data protocols within the transferred data (intermediate file) the user GDS must operate with slightly different processes to extract the packets for delivery or for CFDP processing. Figure 2 shows two possibilities for termination of CFDP in the ground segment The Primary option has the user GDS performing whichever service is tuned to its selected methodology and shows CFDP operating over the virtual end-to-end packet capability.

An alternative is to terminate the CFDP protocol in the cross support GDS which must now be capable of extracting packets from the return link intermediate file using either the Segment File2Packets function as described in Fig. 2 for the ESA approach or the TM/AOS process for the NASA approach. Note that each method has its advantages and disadvantages which will be discussed in a later section . The resulting end-to-end file, regenerated by CFDP, is transferred to the user GDS using any appropriate terrestrial file transfer method (FTP). The advantage of terminating CFDP at the cross support GDS is that the data may be partitioned with a view to prioritizing file delivery from the cross support GDS to the user GDS. However another complexity is introduced into the cross support GDS since different interfaces are required to the user GDS for delivery of packets and files.

Note that even though the data may be formatted in CFDP PDUs the orbiter does not know that it is handling CFDP PDUs since it handles all of the data received during a pass as a single file. Additionally the reliability associated with the direct to earth return link from MRO is provided by either a private MRO frame retransmission or by duplicated transmission of the relay frames. As a consequence, Class 1 CFDP is the preferred CFDP mode to use with the current MRO infrastructure.

Regarding CFDP, note that it is inefficient to perform reliable Class 2 CFDP end-to-end (requiring acknowledgements) 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 shall 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.

B. Near Term Forward Link

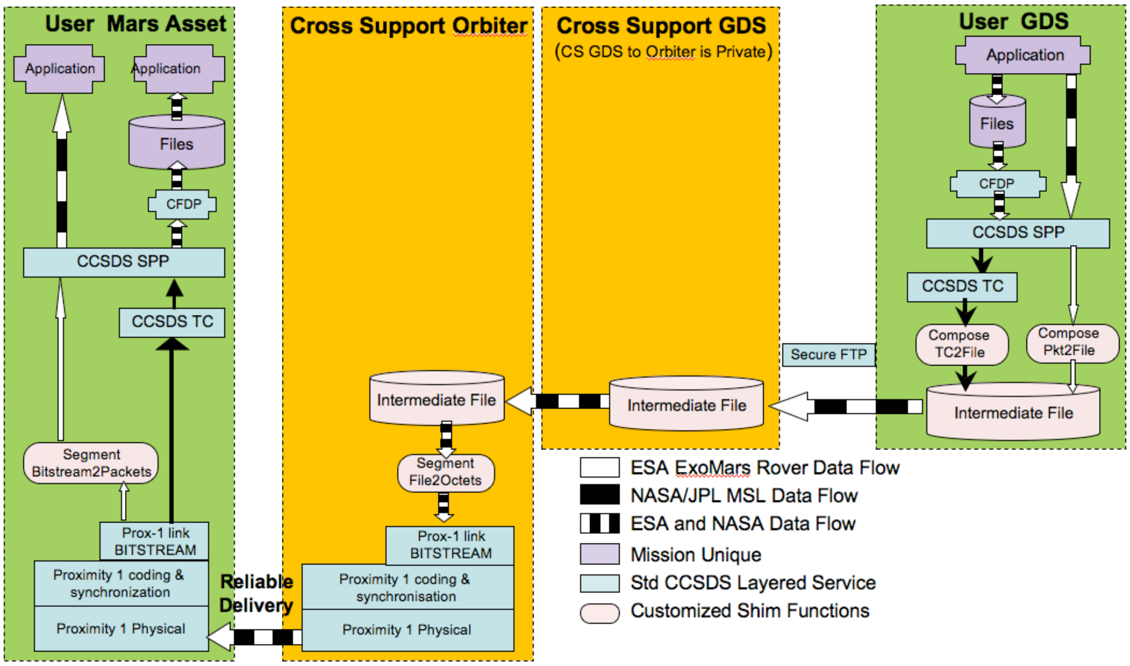

Figure 3. Near Term Forward Link Possibilities

Figure 3 depicts the end-to-end delivery of data from the user GDS on earth to a user Mars asset (e.g. Rover). The existing Mars orbiter Cross Support service is store and forward in nature, with hop by hop transfer. The Cross Support GDS only accepts files that are constructed by the User GDS (according to the User Mars Asset's own rules), which may contain packets, or TC frames, or other user defined data structures. This whole file is transferred into the Cross Support GDS using some standard file transfer mechanisms like secure FTP. The existing Mars orbiter to lander *transfer service* implements only the reliable transfer user defined data (UDD) defined in Proximity-1. This is used for the reliable transfer of the files 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 we 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 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 or TC frames for delivery to Mars asset. The packets / frames may either contain direct execution data, a set of PDUs generated by CFDP from an original file, or a hardware command that is directed to the Asset's hardware configuration controller. Files must be prepared as a continuous series of octets using either the Compose Packets2File for packets or the TC Framing function.

The file will be transferred from the Asset Ground Data System (GDS) to the Cross Support GDS by secure FTP. The file will be accompanied by the required metadata (ancillary information) 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 constraint is that these file not exceed the maximum on-board storage size, and have a filename that conforms to the file naming convention of the NASA orbiters. The file naming convention requires the filename contains the asset ID, the date, the pass ID and a unique file order number for the pass. On the forward link the user GDS may request the delivery of several files by providing these to the cross supporting GDS along with delivery requirements, including priority. The present orbiter relay infrastructure has the capability to handle and forward several individual files in a contact period.

The cross support GDS forwards the files, in accordance with the delivery requirements, to the orbiter. At the Obiter the intermediate file is communicated to the Mars asset using the Prox-1 UDD service. To ensure the Mars asset can reconstruct the original files or series of packets two complementary functions are used to transmit and receive data using the Proximity-1 UDD service. The Segment File2Octets function is used by the orbiter to insert a continuous stream of octets into the Proximity-1 link. The first octet of the first file transferred within an over flight will be placed in the first octet of the first Proximity-1 data frame. At the Mars asset the Segment Bitstream2Packets function or the TC function is used to retrieve individual packets. 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 may be used in an unacknowledged mode as defined by the CFDP class 1 procedures. The Segment Bitstream2Packets, the Compose Packets2File and the Segment File2Octets functions are shown in Fig. 3.

IV. User GDS to Cross Support GDS

The cross support architecture for use of an agency‘s deep space network communications services needs to be considered. This shall be the CCSDS SLE forward CCSDS CLTU service and Return All Frames (RAF) or Return Channel Frames (RCF) service. The cross support communications services are just used to transport CLTUs or other mission defined data on the forward path and AOS or TM frames on the return path. As described previously, 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.

V. 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. To achieve this capability the User Mars Asset would need to send its data in Proximity-1 frames that contained a CFDP PDU within a packet. Two 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, which is created by the Electra radio, and use their contained APIDs to signal which telemetry virtual channel to transmit that data on the DFE link. The NASA MRO flight software would then use its standard VC priority frame selection process for delivery control. These data could then be sent via a SLE RCF service or, CFDP, as reconstituted files using secure FTP.

VI. Possible Upgrades for Future Missions

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

However, we foresee the day that those capabilities will be required. Each of these services will require the Relay 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), be addressed on the orbiter to a different output port ID than the data destined for transfer to Earth, and to use the Packet per frame construction mode in Proximity-1. Also, when files are to be sent we recommend that the Class-1 CFDP be used and that the destination address be carried within the Message to User field within the Metadata PDU for the file. Figure 4 illustrates what would be required in order to provide these added services. We recommend that future 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. Use of class 2 CFDP on the forward link, 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. 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.

Future provision of networking services, when it is required, can be constructed upon this same set of basic services. For Mars use the Delay Tolerant Networking (DTN) protocols will be most suitable since they are designed for exactly this sort of sporadically connected environment. These protocols are now defined in draft standards and are maturing nicely. Demo flights are planned within the FY08-09 timeframe. When there are sufficient assets at Mars to need automated transfers to simplify planning, or when there are multi-spacecraft mission requirements for networking, these protocols will be available. The basic changes suggested in the future infrastructure, as reflected in Fig. 4, provide exactly the necessary infrastructure on which to build such a networking capability.

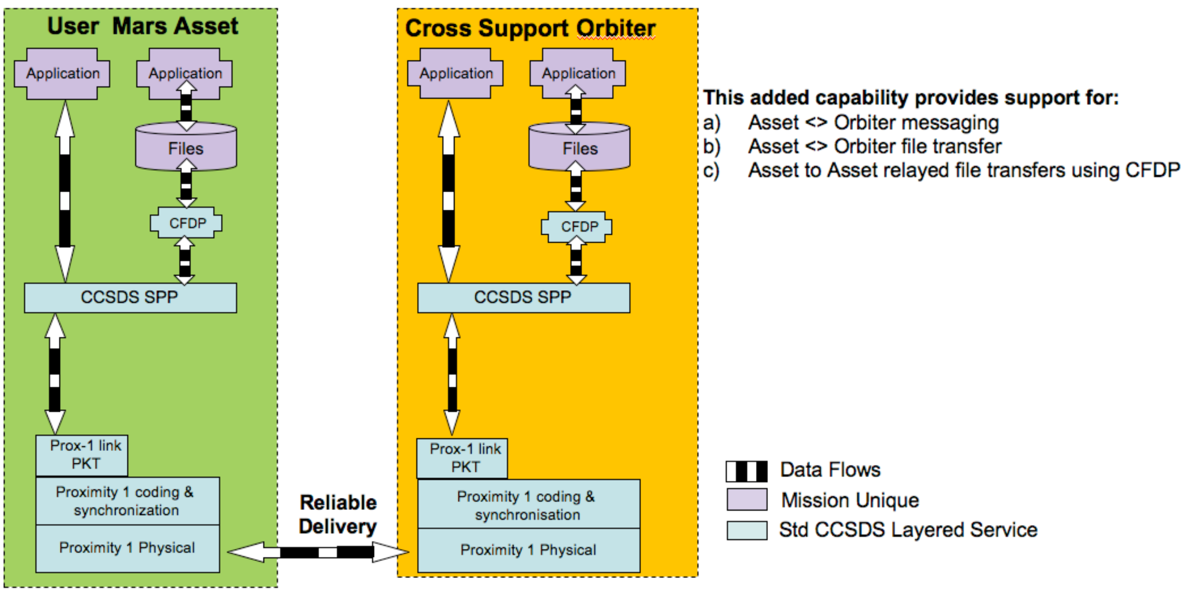

Figure 4. Upgraded capabilities desired for future mission services

VII. Conclusion

In this paper we have documented the current (2008-2015) paradigm of data exchange into and out of the Mars Enterprise by means of file transfer to/from Earth and bit-stream transfer over the Proximity link. Looking further towards the future, we have discussed how networking capabilities such as status and control messaging between assets and relays, asset to asset relayed data transfer, and data transfer between assets and relays for consumption on-board the relay . However the key to these enhanced capabilities lies within the relay's ability to interrogate and understand the data type and routing needs of the user asset. 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), be addressed on the orbiter to a different output Proximity-1 port ID than the data destined for transfer to Earth, and to use the Packet per frame construction mode in Proximity-1.

Acknowledgments

The work described in this paper was performed at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration. The authors also acknowledge the contribution of Peter Shames NASA/JPL, Dai Stanton and Chris Taylor ESA/ESTEC.

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