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Introduction: Over the next decade, international plans and commitments are underway to develop an infrastructure at Mars to support future exploration of the red planet. The purpose of this infrastructure is to provide reliable global communication and navigation coverage for on-approach, landed, roving, and in-flight assets at Mars. The claim is that this infrastructure will: 1) eliminate the need of these assets to carry Direct to Earth (DTE) communications equipment, 2) significantly increase data return and connectivity, 3) enable small mission exploration of Mars without DTE equipment, 4) provide precision navigation i.e., 10 to 100m position resolution, 5) supply timing reference accurate to 10ms. [1]. This paper in particular focuses on two CCSDS recommendations for that infrastructure: CCSDS Proximity-1 Space Link Protocol [2] and CCSDS File Delivery Protocol (CFDP)[3]. A key aspect of Mars exploration will be the ability of future missions to interoperate. These protocols establish a framework for interoperability by providing standard communication, navigation, and timing services. In addition, these services include strategies to recover gracefully from communication interruptions and interference while ensuring backward compatibility with previous missions from previous phases of exploration. [4].

Need for Standardization: The diversity of communication links within the future potential Mars environment creates challenging engineering problems. Problems such as frequency coordination, link operations, standard data transfer, product accountability, link performance, scheduling vs demand access of services, and network-wide data prioritization need to be addressed. The CCSDS Proximity-1 Space Link Protocol provides recommendations for dealing with the components of these issues in the physical and data link layers. These include frequency allocation, coding, data rates, link establishment, maintenance, and termination procedures, reliable or expedited data transfer, ranging and time transfer. On top of Proximity-1, the CCSDS File Delivery Protocol at the transport layer provides applications the capability of transporting their data products end to end across the entire space link either expedited or reliably.

Proximity-1 Key Characteristics: Proximity-1 provides standard services for transferring command, telemetry, and radiometric data products across the In-Situ link. It provides a timing service which includes techniques for round trip light time (RTLT) calculation and setting remote spacecraft time. It also provides a messaging service between In-Situ assets. Proximity-1 is a bi-directional protocol using the same format and procedures in the forward (command) as well as the return (telemetry) link. It provides for expedited as well as reliable data transfer. It is truly a modeless protocol meaning all of the services provided do not require that the caller or responder be configured into a particular mode for operations. It supports all types of directionality: full, half duplex, and simplex. It uses a data driven technique as opposed to a managed approach for on-board data processing. It supports both coded and uncoded links as well as asynchronous (variable frame) vs synchronous (fixed frames) links. Communication is point-to-point but includes one to many on the forward link.

CFDP Key Characteristics: CFDP is an international standard for automatic, reliable or expedited bi-directional file transfer between spacecraft or spacecraft and ground, built on top of the CCSDS data link layer. Unlike TCP/IP, it requires no handshaking and is datagram and transaction based to deal with space link characteristics e.g., long RTLT and non-persistent links but is adaptable to fit the proximity link as well. Metadata associated with each transaction describes the data transfer including data processing once the file arrives.

Operational Scenarios: The following scenarios examine operations across two separate links: proximity (landed assets to orbiters) and deep space (orbiters to Earth). The proximity link is characterized by short distance (within 400,000 km), moderate signal strength, and single sessions. The deep space link is characterized by long delays, and weak signals. The following 5 scenarios generically demonstrate operations between Mars landed assets, orbiter relays, and Earth ground stations.

Scenario 1: Simple Relay. The objective is to transfer a file by means of an orbital relay. A file may be transferred from a landed asset to Earth or visa versa. The orbital relay functions as a store and forward node. The on-board command and data handling system manages the data it receives from Earth or the landed asset, as a file in it's on-board file management system. In those cases where the lander does not manage data as a file, the relay orbiter can accept data not organized in files e.g., byte streams, CCSDS packet sets, and create one or multiple files from this data on-board. Once the file is successfully transferred to the orbiter, it takes custody of the data (custody transfer), and relays status back to the lander acknowledging its receipt. Given adequate resource margins on-board the orbiter, the lander can now delete this data providing storage space for future data acquisition.

Scenario 2:Multi-Hop Relay (Rover to lander to orbiter to Earth) Now a rover enters the environment and transfers its data to the lander. The rover having limited computing power and storage does not have the resources to run CFDP. Depending upon the required completeness of the data transfer, the rover utilizes either the expedited or the sequence controlled service of Proximity-1. Both the lander and orbiter function as store and forward nodes. Custody transfer occurs first between the lander and the rover and later between the orbiter and the lander.

Scenario 3:Point-to-Multi-point (forward link) Within the proximity link environment, an orbiter encounters multiple landed assets. Assuming the orbiter has only one transceiver, it can simultaneously communicate to all or a subset of the Mars assets within its field of view. By cycling through a set of spacecraft IDs during the hailing period, the orbiter can a) broadcast commands for all Mars assets, or b) multicast commands to a subset of landed assets e.g., all landers, or c) poll each landed asset to determine the priority of its return link data transfer and once determined choose the asset with the highest priority. The Proximity-1 frame verification rules specify that only data marked with the called asset's spacecraft ID or multicast address will be accepted by the asset.

Scenario 4:Time-Sequenced Point-to-Point (return link) Again assuming the orbiter has only one transceiver, it can time share the return link with multiple Mars assets based upon a priority scheme. It does this by establishing communications with a specific asset by hailing it, limiting the period of the data contact to a subset of the total pass time, terminating the link with that asset before hailing the next asset and repeating the process.

Scenario 5:Point-to-Point Network This scenario will require some form of multiple access scheme. Candidates under study at this time are frequency division multiple access (FDMA), code division multiple access (CDMA), and time division multiple access (TDMA). End-to-End file transfers through a point-to-point network will require the use of CFDP to route the data to the correct end destination.

Transition Plan for Protocol Infusion: The NASA/JPL Mars 2001 orbiter and ESA Mars Express/Beagle II project will be the first Mars missions to implement a subset of Proximity-1 for the In-Situ Martian UHF link. In order for these and future Mars missions to benefit from all the advantages of file transfer, a step wise transition from the current state of on-board protocol development to a complete implementation of Proximity-1 and CFDP is envisioned. A three phased approach below describes how the bi-directional file transfer concept can be infused into future Mars missions. The description below uses a simple communications model of a landed asset, an orbiter relay, and Earth stations as illustrative only.

Phase 1:Expedited CFDP (Deep Space Link)/reliable Proximity-1 Link The objective of this phase is to relay data collected by the landed asset via a reliable Proximity-1 link to an orbiter, store the data on-board, and later transmit that data as a file to Earth using the expedited features of CFDP. This phase does not require the landed asset to transmit nor store its data as a file. This version of CFDP does not include the automated selective repeat (report) feature.

Phase 2: Expedited CFDP (In-Situ and Deep Space)/reliable Proximity-1 Link The objective here is to move the functionality of building the file into the landed asset. The orbiter is provided with the functionality of receiving the file and storing it in the on-board data management. As in phase 1, the orbiter transmits the data as a file to Earth using expedited CFDP.

Phase 3: Reliable CFDP (In-Situ and Deep Space)/ unreliable Proximity-1 Link. Here the landed asset uses the more efficient and reliable QoS (selective repeat methodology) of CFDP to transfer a file to the orbiter using the expedited QoS of the Proximity-1 link. Similarly, for the Deep Space link, CFDP can be run reliably on top of either CCSDS Packet Telemetry [5] or CCSDS Telecommand [6] Standard to/from Earth.

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