APPLICATION OF AN EXTENDED CCSDS TELECOMMAND STANDARD FOR ALL MARS IN-SITU TELECOMMUNICATION LINKS

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ABSTRACT

The purpose of this paper is to propose a link layer standard for bi-directional telecommunication for in-situ links for data transfer between landers, rovers, and orbiters based upon the CCSDS Telecommand Recommendation. This proposal, capitalizing on this Recommendation, and the availability of ground software, minimizes cost and is compatible with the emerging CCSDS file transfer protocol.

A discussion of the technical details of this extension is provided, along with the operational scenarios for its use, a suggestion of how to implement the functionality, and how to justify its use from a cost savings perspective. In summary, this approach: 1) exploits the characteristics of the in-situ environment, 2) builds upon a well-established and internationally supported protocol, 3) allows for the migration of software between ground and flight systems, 4) provides an efficient and flexible routing mechanism for a wide variety of application data and operational control directives.

SUMMARY

The key aspects of this proposal are:

• It assumes the physical link layer includes a r = 1/2, K = 7 convolutional code

• It is based upon the CCSDS Telcommand Recommendation with two exceptions: the Bose-Chaudhuri-Hocquenghem (BCH) code at the link layer is not used and a Command Link Transmission Unit (CLTU) is limited to one frame.

The key drivers of this proposal are:

• The small simple space-based receivers envisioned to operate in the in-situ link environment are incompatible with coding schemes that supply a high coding gain and operate at a very low receiver signal to noise ratio (SNR).

• The protocol is bi-directional and supports both short transmission units for link acquisition, configuration, and control as well as longer more efficient frames for command and telemetry transfer.

This paper provides the technical details of the protocol and illustrates its application in several operational scenarios.

1. INTRODUCTION

NASA is providing an ambitious Mars Exploration program, the Mars Surveyor project with launches planned every two years, consisting of a series of landers, orbiters, and rovers. The program starts with the '98 climate orbiter and polar lander and culminates in a Mars sample return mission launched in '05. Although not yet an approved mission, The European Space Agency (ESA) also plans to send an orbiter and several landers to Mars through the '03 Mars Express project. ISAS, the Institute of Space and Astronautical Science of Japan is launching its Planet-B spacecraft to Mars in June 1998. Even though the Planet-B mission has no landed vehicles it demonstrates that a number of national space agencies are committed to participate in the exploration of Mars. All of these participants are potential beneficiaries of a well planned and standardized telecommunications link strategy for in-situ links at Mars.

This paper proposes the establishment of a link layer standard for the in-situ communication required to support all the Mars programs and those missions that require short connecting links which are non-interfering with earth based operations (e.g. ESA's Rosetta). The establishment of a link layer standard will: 1) lower costs, 2) insure interoperability and non-interference for in-situ communications at Mars, 3) provide a path toward the development of higher level standards for use with in-situ communications (e.g. CCSDS Protocol-X file and message transfer protocol), see reference [1], 4) insure that future landed elements (rovers, landers, microprobes) will be compliant with the communications protocol provided by an earlier orbiter which is still in service.

The protocol provides the following services: 1) selectively addresses one or more recipient vehicles, 2) provides dynamically scaleable data unit delivery (i.e. short acquisition and link configuration directives or long telemetry and command data units), 3) selectable quality of service provides reliable delivery (error-free, in order without omission) or lower quality such as delivering only error-free frame data units (irrespective to order or omissions as desired by Protocol-X), 4) provides multiple service access points (SAPs) to directly interface to individual on-vehicle applications or via specified I/O ports (i.e. the file transfer protocol, the vehicle command processor, a point-to-point serial interface, the vehicle's data bus, etc).

2. KEY CHARACTERISTICS OF THE IN-SITU LINK ENVIRONMENT

The in-situ communications environment for the "Mars Network" of orbiters, landers and rovers exhibits significant differences from the traditional deep space environment. Unlike the deep space links which have significantly different uplink and downlink SNR environments, the in-situ environment has link characteristics and needs more similar to telecommand than to telemetry. These links are characterized by a high signal-to-noise ratio, very short round-trip light times, and the need for reliability for data transfers independent of direction.

- High SNR environment/simple coding scheme

Given the short path length (approximately 400 Km) between orbiters and landed elements and equipment miniaturization requirements, relatively small and low-cost receivers are utilized for these links.

- Use of ARQ protocols to provide reliability

The in-situ communication links are short but the lack of continuous connections and the inclusion of the long delays associated with transfer to earth make ARQ (Automatic Repeat Queuing) necessary on a hop-by-hop basis. The link layer will need to provide in-order guaranteed delivery, for selective links. The majority of the data transfers will utilize the developing CCSDS file transfer protocol, see reference [2]. For file transfers, the ARQ will be provided by Protocol-X (PX). The link layer would not be required to provide complete in order data delivery because the file transfer protocol will more efficiently utilize a selective repeat methodology. This strategy eliminates the need for the link layer to resend data that was received correctly but out of sequence.

- Asymmetrical data rates

Currently, the return link can be a maximum of 30x greater than the forward link. This is especially required to return the 40 MB of data expected from the Mars Surveyor rovers. It is expected that all landed elements will require much smaller command volumes which can be satisfied by a single forward data rate of about 8 kbps. Since a landed element need only look for one forward data rate, this simplifies the design of their telemetry system.

- Efficient protocol

The protocol must be efficient given the operational scenario of having the lander or rover communicate with the orbiter only twice per sol with a maximum pass duration of 15 minutes. Both the go-back-n protocol supported by the CCSDS Telecommand Recommendation and the selective repeat protocols of PX are significantly more efficient than the stop and wait protocol presently under consideration for one of the Mars missions.

- Variety of spacecraft

The variety of spacecraft affects levels of service. The protocol must accommodate a wide variety of landed elements, from severely power and thermally limitied micro probes to multi-meter sized landers. These elements will create a demand for multiple levels of service: from the simplistic approach of using a simplex link with a fixed number of repeat cycles to full-duplex using a selective repeat protocol.

3. DATA LINK LAYER

The functionality of the proposed link layer for in-situ communication provides for:

- Bi-directional data exchange (Example - Regardless of the directionality of the link, rovers, landers and orbiters utilize the telecommand frame for both forward and return in-situ links.)

- Spacecraft (node) addressing (Example - All landed elements and the orbiter are unambiguously addressed via the spacecraft ID field in the telecommand header.)

- Data content interpretation, multiplexing, and routing via Multiplexer Access Points (MAP) (Example - The data link layer is extended by adding a sublayer to provide the additional functionality of routing application data by MAP ID. Link layer commands are specified by conceptually dividing the MAP ID field into both physical and logical components. Multiplexing of various MAPs onto virtual channels is another supported feature of the protocol.)

- Error detection (Example - The CCSDS Telecommand Recommendation provides for an error detection mechanism at the frame level using a CRC (cyclic redundancy check) which can be used to prevent frames with errors from reaching higher protocol layers.)

The key characteristics of the link layer are:

- Bandwidth efficient (Example - Link layer commands such as a flight software reset command or set data rate can be accomplished with minimal overhead and by MAP assignment i.e., 10 bytes.)

• Scaleable and self-delimiting transmission units (Example - The CCSDS Telecommand Recommendation provides for a dynamically scaleable transmission unit length, from 5 to 1019 bytes. The data unit is self-delimited by the frame's length field.)

• Data Link Layer error control (Example - The scaleability of the telecommand frame provides mission operations with some additional control of the link BER. The detected frame error rate can be reduced by dynamically shortening the frame size. This approach is particularly useful at lower elevations where low signal conditions exist during link acquisition and termination.)

• Supports both coded and uncoded links (Example - A landed element can transmit fixed length R-S encoded frames in order to benefit from the coding gain while the less power limited orbiter relay can transmit uncoded variable length frames.

• Based upon the proven CCSDS Telecommand standard (Example - The data structures, retransmission schemes, accountability features have all been proven on numerous NASA and ESA missions.)

• Provides a conduit for express execution of link layer commands (Example - Commands can be addressed directly to the specific subsystem for execution. This facilitates the efficient routing and timely execution of hardware commands.)

• Supports both bypass (file transfer) and go-back-n forms of COP-1 (Example - The sequence number is checked for sequentiality in an upcounting fashion for COP-1 go-back-n mode or used only for frame start validation in the bypass mode)

• Facilitates rapid data rate control based upon link error rate monitoring (Example - If the landed element can monitor the RF link layer bit error rate, then the return link data rate can be dynamically controlled by the sending element addressing commands directly to the telecom subsystem of the orbiter relay at the data link layer.)

4. BASIC IN-SITU LINK SCENARIO

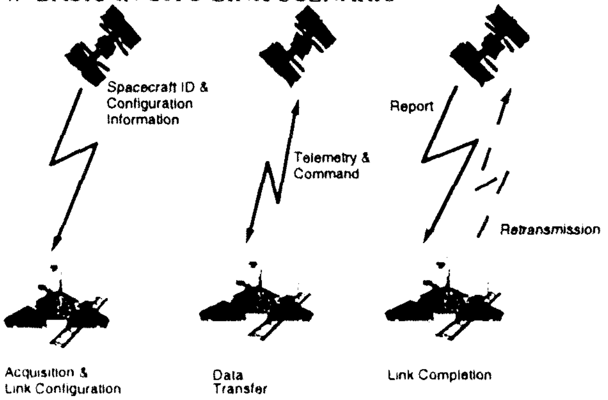

Figure 1. Basic Link Scenario

Acquiring the Link

The link is always initiated by the orbiter relay which transmits a short command containing the spacecraft identifier of the landed element repeatedly while sweeping the carrier. The frame data of each transmission unit contains the link initialization parameters for the landed element. Once the landed element acquires the carrier and decodes the commands, it signals the orbiter to terminate the frequency sweep. The orbiter will either transmit commands to and/or receive telemetry from the landed element based upon the link configuration parameters as contained in the transmitted command to the landed element.

Configuring the Link

The parameters that can be set by the orbiter include: 1) the duration of the communication session, 2) the return data rate based upon the landed unit's predicted thermal and power state, 3) the communication directionality: full duplex, half duplex, or simplex, 4) the communication session termination mechanism e.g., how to gracefully terminate a command or telemetry session, 5) the choice of link layer quality of service i.e., reliable error-free delivery vs error-free irrespective of data order and gaps, 6) initialization of the frame sequence counter, if COP-1 is used.

Transmitting Data

Once the link has been configured, the bulk of the data transfer between the landed element and the orbiter occurs using long frames (1019 bytes maximum). For example, if the mode is half duplex and Protocol-X is used, then the landed element will send its data to the orbiter. Once the data has been completely transferred or after a time out, the directionality of the link will switch and the orbiter will report the results of the transmission. If data was missed the orbiter will report the results followed by the retransmission of those data units by the landed vehicle. For commanding a microprobe, COP-1 using a simplex mode might be the correct approach. In this case the orbiting element can transmit the data several times depending upon the link SNR to ensure a reliable data transfer.

Reporting Results

Based upon the link configuration, the orbiter may provide a report to the landed element specifying the completeness of the data transfer: a report-PDU if Protocol-X is used or by the Command Link Control Word (CLCW), if the sequenced controlled service of COP-1 is desired. The landed element utilizing this report can decide: 1) which data to resend to the orbiter and 2) which on-board memory to free up.

5. USE OF MAP IDENTIFIERS

Unlike the traditional use for MAP identifiers i.e., to allow user command data from different sources to be multiplexed within a given virtual channel, a MAP is used to specify the format and content of the data portion of a forward or return link transmission unit. In order to provide a framework for assigning MAPs to both physical and logical applications, the 6 bit MAP ID field can be conceptually divided into two 3 bit fields: 1) a logical MAP ID and 2) a physical MAP ID. Therefore, a maximum of 64 MAP identifiers can be assigned. The following MAP assignments for in-situ links are envisioned:

Figure 2. MAP ID Assignments

MAP ID	Application
0	Flight Computer Reset
1-4	Link layer hardware commands
5	Serial data to Serial port #1
6	Serial data to Serial port #2
7	Command Link Control Word
8	Single packet to spacecraft bus
9	Integer number of packets to spacecraft bus
10	Packet telemetry type frame data unit
11	Protocol X Protocol Data Unit

MAP Identifiers provide an efficient mechanism for routing commands both internally through the on-board local network, and through to external networks within the enterprise connected by port numbers. Routing by MAP identifiers are at least 50% more efficient than command packets.

6. TRANSMISSION UNIT CHARACTERISTICS

	Telecommand (TC) Frame		
Start Sequence	TC Frame Header	TCFrame Data	CRC

+

(optional)10101010101010101010101...

+

	Telecommand (TC) Frame		
Start Sequence	TC Frame Header	TCFrame Data	CRC

Figure 3. Bi-directional Transmission Units

The dynamically scaleable bi-directional transmission unit is shown above. Each frame must be preceeded by a start sequence to ensure frame synchronization. An idle pattern may be supplied between frames to ensure that the command decoder remains in bit synchronization when no data is transmitted. The message start sequence along with the TC frame header flags and frame sequence count can be used as an extended synchronization marker to lessen the probabilityof false synchronization.

The following exceptions to the CCSDS Telecommand Standard are recommended: 1) The BCH(63,56) code is not used. This obviates the need for a tail sequence. The single error correcting, double error detection mode of this code is poorly matched to the burst error statistics of the physical layer convolutional code. Furthermore, the marginal performance provided by this code does not outweigh the coding overhead of 12.5%. 2) The number of frames per CLTU are limited to one. This restriction simplifies the design of the link layer software.

7. BASIC DATA FLOW

In Figure 4, the return link (from the landed element to the orbiter) was chosen to illustrate the basic data flow and functionality carried out by the application, link, and RF layers of the landed element and orbiter for in-situ communication links.

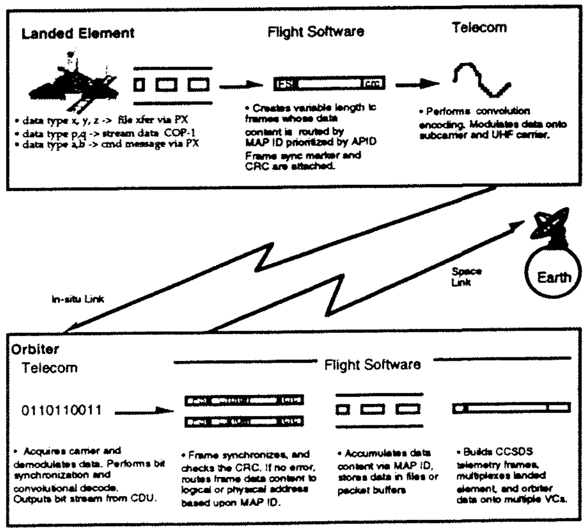

Figure 4. Return Link Data Flow for Mars In-Situ Communication Links

8. CONCLUSION

In conclusion, this paper covered the basic link scenario of how communications (link acquisition, configuration, data transfer, and data accountability and closure) between landed elements and orbiters is carried out. The definition and use of MAP identifiers as an efficient means of formatting and routing commands at the link layer was provided. The format of the bi-directional transmission unit along with an operational scenario illustrating a typical return link data flow was given.

The further exploration of Mars provides an outstanding target of opportunity for the international space agencies to establish an interoperable standard for Mars in-situ communication links. This paper demonstrates how existing standards can be extended to provide a link layer protocol which provides an efficient mechanism to address in-situ data transfers in a bi-directional sense and be compatible with higher layer protocols e.g.. Protocol-X.

9. REFERENCES

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3. "Telecommand, Part 2: Data Routing Service", Recommendation CCSDS 202.0-B-2, Blue Book, Consultative Committee for Space Data Systems. November 1992.

10. ACKNOWLEDGMENT

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