The Consultative Committee for Space Data Systems

Report Concerning Space Data System Standards

OVERVIEW OF THE UNIFIED SPACE DATA LINK PROTOCOL

INFORMATIONAL REPORT

CCSDS 700.1-G-1

GREEN BOOK

June 2020

The Consultative Committee for Space Data Systems

Report Concerning Space Data System Standards

OVERVIEW OF THE UNIFIED SPACE DATA LINK PROTOCOL

INFORMATIONAL REPORT

CCSDS 700.1-G-1

GREEN BOOK
June 2020

AUTHORITY

Issue:	Informational Report, Issue 1
Date:	June 2020
Location:	Washington, DC, USA

This document has been approved for publication by the Management Council of the Consultative Committee for Space Data Systems (CCSDS) and reflects the consensus of technical panel experts from CCSDS Member Agencies. The procedure for review and authorization of CCSDS Reports is detailed in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4).

This document is published and maintained by:

CCSDS Secretariat
National Aeronautics and Space Administration
Washington, DC, USA
Email: secretariat@mailman.ccsds.org

FOREWORD

This document is a technical Recommendation for use in developing flight and ground systems for space missions and has been prepared by the Consultative Committee for Space Data Systems (CCSDS). The Unified Space Data Link Protocol described herein is intended for missions that are cross-supported between Agencies of the CCSDS.

This Recommendation specifies a communications protocol to be used by space missions to transfer space application data over space-to-ground or space-to-space communications links. Note that:

a) this protocol can be used to transfer any data over any space link in either direction;

b) all CCSDS space link protocols are specified in a unified manner;

c) the specification matches the OSI Basic Reference Model (references [1] and [2]).

Through the process of normal evolution, it is expected that expansion, deletion, or modification of this document may occur. This Report is therefore subject to CCSDS document management and change control procedures, which are defined in *Organization and Processes for the Consultative Committee for Space Data Systems* (CCSDS A02.1-Y-4). Current versions of CCSDS documents are maintained at the CCSDS Web site:

http://www.ccsds.org/

Questions relating to the contents or status of this document should be sent to the CCSDS Secretariat at the email address indicated on page i.

At time of publication, the active Member and Observer Agencies of the CCSDS were:

Member Agencies

– Agenzia Spaziale Italiana (ASI)/Italy.
– Canadian Space Agency (CSA)/Canada.
– Centre National d'Etudes Spatiales (CNES)/France.
– China National Space Administration (CNSA)/People's Republic of China.
– Deutsches Zentrum für Luft- und Raumfahrt (DLR)/Germany.
– European Space Agency (ESA)/Europe.
– Federal Space Agency (FSA)/Russian Federation.
– Instituto Nacional de Pesquisas Espaciais (INPE)/Brazil.
– Japan Aerospace Exploration Agency (JAXA)/Japan.
– National Aeronautics and Space Administration (NASA)/USA.
– UK Space Agency/United Kingdom.

Observer Agencies

– Austrian Space Agency (ASA)/Austria.
– Belgian Federal Science Policy Office (BFSPO)/Belgium.
– Central Research Institute of Machine Building (TsNIIMash)/Russian Federation.
– China Satellite Launch and Tracking Control General, Beijing Institute of Tracking and Telecommunications Technology (CLTC/BITTT)/China.
– Chinese Academy of Sciences (CAS)/China.
– China Academy of Space Technology (CAST)/China.
– Commonwealth Scientific and Industrial Research Organization (CSIRO)/Australia.
– Danish National Space Center (DNSC)/Denmark.
– Departamento de Ciência e Tecnologia Aeroespacial (DCTA)/Brazil.
– Electronics and Telecommunications Research Institute (ETRI)/Korea.
– European Organization for the Exploitation of Meteorological Satellites (EUMETSAT)/Europe.
– European Telecommunications Satellite Organization (EUTELSAT)/Europe.
– Geo-Informatics and Space Technology Development Agency (GISTDA)/Thailand.
– Hellenic National Space Committee (HNSC)/Greece.
– Hellenic Space Agency (HSA)/Greece.
– Indian Space Research Organization (ISRO)/India.
– Institute of Space Research (IKI)/Russian Federation.
– Korea Aerospace Research Institute (KARI)/Korea.
– Ministry of Communications (MOC)/Israel.
– Mohammed Bin Rashid Space Centre (MBRSC)/United Arab Emirates.
– National Institute of Information and Communications Technology (NICT)/Japan.
– National Oceanic and Atmospheric Administration (NOAA)/USA.
– National Space Agency of the Republic of Kazakhstan (NSARK)/Kazakhstan.
– National Space Organization (NSPO)/Chinese Taipei.
– Naval Center for Space Technology (NCST)/USA.
– Research Institute for Particle & Nuclear Physics (KFKI)/Hungary.
– Scientific and Technological Research Council of Turkey (TUBITAK)/Turkey.
– South African National Space Agency (SANSA)/Republic of South Africa.
– Space and Upper Atmosphere Research Commission (SUPARCO)/Pakistan.
– Swedish Space Corporation (SSC)/Sweden.
– Swiss Space Office (SSO)/Switzerland.
– United States Geological Survey (USGS)/USA.

DOCUMENT CONTROL

Document	Title	Date	Status
CCSDS 700.1-G-1	Overview of the Unified Space Data Link Protocol, Informational Report, Issue 1	June 2020	Original issue

CONTENTS

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

This document is an adjunct document to the Unified Space Data Link Protocol (USLP) (reference [3]). The USLP specification introduces a new transfer frame format that has been designated as Version 4. USLP utilizes the proven features of existing CCSDS link-layer protocols (references [7]–[10]), providing many familiar functions along with additional options that allow missions to tailor all space link-layer implementations. This document contains material helpful in understanding the USLP, which will assist decision makers and implementers in evaluating the applicability of the protocol to mission needs and in making implementation, option selection, and configuration decisions related to the protocol.

This report provides supporting descriptive and tutorial material. **This document is not part of the Recommended Standard.** In the event of conflicts between this report and the Recommended Standard, the Recommended Standard is the controlling specification.

1.2 DOCUMENT STRUCTURE

This document is divided into six numbered sections and three annexes:

– Section 1 defines the purpose and scope and lists the definitions and references used throughout this document.

– Section 2 provides an overview of the Unified Space Data Link Protocol including the rationale behind the design requirements.

– Section 3 describes the operational use of the Direct From Earth (DFE), Direct To Earth (DTE), and space-to-space (Proximity) links, and the provided mission services.

– Section 4 provides the rationale for the protocol data unit structures and procedures.

– Section 5 Data Link Layer Operational Modes for Use with USLP.

– Section 6 Utilization of USLP Operational Modes for Space Link Types.

– Annex A lists all acronyms used within this document.

– Annex B provides a short discussion on USLP use cases.

– Annex C provides an overview of mission services.

1.3 DEFINITIONS

1.3.1 DEFINITIONS FROM THE OPEN SYSTEMS INTERCONNECTION BASIC REFERENCE MODEL

This Report makes use of a number of terms defined in the Open Systems Interconnection (OSI) Basic Reference Model (reference [1]). The use of those terms in this Report is to be understood in a generic sense; that is, in the sense that those terms are generally applicable to any of a variety of technologies that provide for the exchange of information between real systems. Those terms are:

a) blocking;

b) entity;

c) Network Layer;

d) Physical Layer;

e) protocol control information;

f) real system;

g) Service Access Point (SAP);

h) SAP address;

i) service data unit (SDU).

1.3.2 DEFINITIONS FROM OPEN SYSTEMS INTERCONNECTION BASIC REFERENCE MODEL SERVICE DEFINITION CONVENTIONS

This Report makes use of a number of terms defined in reference [2]. The use of those terms in this Report is to be understood in a generic sense; that is, in the sense that those terms are generally applicable to any of a variety of technologies that provide for the exchange of information between real systems. Those terms are:

a) layer;

b) Network Layer;

c) Data Link Layer;

d) Physical Layer;

e) Protocol data unit;

f) service provider;

g) service user.

1.3.3 DEFINITIONS FROM CCSDS 131.0-B-3, *TM SYNCHRONIZATION AND CHANNEL CODING*

block encoding: A one-to-one transformation of sequences of length k of elements of a source alphabet to sequences of length n of elements of a code alphabet, $n>k$.

codeblock: The aggregation of one or more codewords. In this document, the term codeblock is used for R-S coding and for Low Density Parity Check (LDPC) coding. An R-S codeblock is the aggregation of I codewords, where I is the interleaving depth. An LDPC codeblock is the aggregation of m codewords. If I=1 or m=1, the terms codeblock and codeword are used interchangeably.

codeword: In a block code, one of the sequences in the range of the one-to-one transformation (see **block encoding**). A codeword of an (n,k) block code is a sequence of n channel symbols that are produced by encoding a sequence of k information symbols.

Frame validation: The function that, after decoding is performed, informs the upper layers at the receiving end whether or not each decoded Transfer Frame can be used as a valid data unit; that is, an indication of the quality of the received frame is needed.

1.3.4 DEFINITIONS FROM CCSDS 232.0-B-3, *TC SPACE DATA LINK PROTOCOL*

delimited: Having a known (and finite) length; applies to data in the context of data handling.

1.3.5 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.

aligned: Arranged so that both items start and end in unison. This term is used to describe the relationship of the transfer frame and the Forward Error Correcting (FEC) code block when they start and end in unison.

asynchronous: Not **synchronous** (see below).

control command: Discrete message conveying protocol control information as the contents of a transfer frame data field.

NOTE – In this document, control commands are related to an associated procedure or protocol, that is, COP-1, COP-P, or Space Data Link Security (SDLS).

isochronous: Characterized by occurring at equal intervals of time.

Mission Phase: A period of a mission during which specified communications characteristics are fixed. The transition between two consecutive Mission Phases may cause an interruption of the communications services.

periodic: Of or pertaining to a sequence of events in which each event occurs at a fixed time interval (within specified tolerance) after the previous event in the sequence.

Physical Channel: A stream of bits transferred over a space link in a single direction.

space link: A communications link between two entities, at least one of which is not on Earth. Typically, a space link is between a spacecraft and its associated ground system, or between two spacecraft. A space link consists of one or more Physical Channels in one or both directions by which a transmitter on one entity sends data to the receiver on the other entity.

synchronous: Of or pertaining to a sequence of events occurring in a fixed-time relationship (within specified tolerance) to another sequence of events.

NOTE – In this document, 'synchronous' implies occurring repetitively at a 'constant rate'.

1.4 REFERENCES

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

[1] *Information Technology—Open Systems Interconnection—Basic Reference Model: The Basic Model*. 2nd ed. International Standard, ISO/IEC 7498-1:1994. Geneva: ISO, 1994.

[2] *Information Technology—Open Systems Interconnection—Basic Reference Model—Conventions for the Definition of OSI Services*. International Standard, ISO/IEC 10731:1994. Geneva: ISO, 1994.

[3] *Unified Space Data Link Protocol*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.1-B-1. Washington, D.C.: CCSDS, October 2018.

[4] *Communications Operation Procedure-1*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 232.1-B-2. Washington, D.C.: CCSDS, September 2010.

[5] *Encapsulation Packet Protocol*. Issue 3. Recommendation for (Blue Book), CCSDS 133.1-B-3. Washington, D.C.: CCSDS, May 2020.

[6] *Space Data Link Security Protocol*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 355.0-B-1. Washington, D.C.: CCSDS, September 2015.

[7] *TM Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 132.0-B-2. Washington, D.C.: CCSDS, September 2015.

[8] *Proximity-1 Space Link Protocol—Data Link Layer*. Issue 5. Recommendation for Space Data System Standards (Blue Book), CCSDS 211.0-B-5. Washington, D.C.: CCSDS, December 2013.

[9] *TC Space Data Link Protocol*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 232.0-B-3. Washington, D.C.: CCSDS, September 2015.

[10] *AOS Space Data Link Protocol*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-3. Washington, D.C.: CCSDS, September 2015.

[11] *TC Synchronization and Channel Coding*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 231.0-B-3. Washington, D.C.: CCSDS, September 2017.

[12] *Proximity-1 Space Link Protocol—Coding and Synchronization Sublayer*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 211.2-B-3. Washington, D.C.: CCSDS, October 2019.

[13] "Registries." Space Assigned Numbers Authority. https://sanaregistry.org/r.

[14] *TM Synchronization and Channel Coding*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.0-B-3. Washington, D.C.: CCSDS, September 2017.

[15] *Flexible Advanced Coding and Modulation Scheme for High Rate Telemetry Applications*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.2-B-1. Washington, D.C.: CCSDS, March 2012.

[16] *CCSDS Space Link Protocols over ETSI DVB-S2 Standard*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.3-B-1. Washington, D.C.: CCSDS, March 2013.

[17] *Variable Coded Modulation Protocol*. Issue 1. Draft Recommendation for Space Data System Standards (Red Book), CCSDS 431.1-R-1. Washington, D.C.: CCSDS, December 2018.

[18] *Extensible Space Communication Cross Support—Service Management—Concept*. Issue 1. Report Concerning Space Data System Standards (Green Book), CCSDS 902.0-G-1. Washington, D.C.: CCSDS, September 2014.

[19] *Proximity-1 Space Link Protocol—Rationale, Architecture, and Scenarios*. Issue 2. Report Concerning Space Data System Standards (Green Book), CCSDS 210.0-G-2. Washington, D.C.: CCSDS, December 2013.

[20] *TM Synchronization and Channel Coding—Summary of Concept and Rationale*. Issue 3. Report Concerning Space Data System Standards (Green Book), CCSDS 130.1-G-3. Washington, D.C.: CCSDS, June 2020.

2 OVERVIEW

2.1 CONCEPT OF UNIFIED SPACE DATA LINK PROTOCOL

2.1.1 ARCHITECTURE

The CCSDS Space Link Protocols (SLP) Working Group (WG) along with the user community has identified the following major deficiencies in the existing link-layer protocols: 1) Transfer Frame Size and Accountability is too limited for CCSDS agencies' envisioned future mission set. This is largely due to advances in forward error correction coding algorithms and advances in microelectronic technology allowing improved uplink and crosslink performance to be achieved for space-borne systems. 2) There are inadequate spacecraft ID assignments available in the current CCSDS link-layer protocols. 3) the development of a single data link sublayer protocol for all space link applications will reduce development and implementation costs for future missions that must communicate over multiple types of space data links.

USLP is a Data Link Layer protocol (see reference [1]) to be used by space missions to transfer data across the space link. This protocol has been designed to meet the requirements of space missions for efficient transfer of space application data of various types and characteristics over ground-to-space, space-to-ground, and space-to-space communications links (hereafter called space links). USLP is an evolutionary development built on the experiences and deployments of TeleCommand (TC) (reference [9]), TeleMetry (TM) (reference [7]), Proximity-1 (reference [8]), and Advanced Orbital Systems (AOS) (reference [10]). The intent of USLP is to extend previous CCSDS space data link protocols and add new features to support technological innovation. As such, USLP is a convergence of CCSDS protocols anticipating needs in upcoming missions. Its primary goals are to reduce costs and simplify systems engineering by utilizing advances in onboard computational ability and modern security models (including those supported by CCSDS), allowing for increased data rates, and using high performance coding options, for example, LDPC.

Figure 2-1 illustrates the five lower layers of the OSI model and its relation to the CCSDS Layered Model and lists the CCSDS Protocols within those layers. This specification is focused on the Data Link Layer that the CCSDS has divided into two sublayers. The Data Link Protocol Sublayer provides the interfaces to the Network Layer and accepts user data via SAPs and creates the data structures to transport the data across the link. The Data Link Protocol SubLayer (DLP-SL) provides for the inclusion of the CCSDS SDLS protocol and Communications Operation Procedures (COPs) COP-1 (reference [4]) or COP-P (reference [8]) to add reliable delivery and data link layer security services to USLP. The Service Data Unit between the DLP-SL and the Coding and Synchronization (C&S) SubLayer (CS-SL) is the transfer frame. The CS-SL interfaces to the physical layer. The CS-SL is used to provide synchronization mechanisms as well as Forward Error Correction Coding to obtain the desired very low error rate data channel for the data transfer. The CS-SL, on the sending end of the link, creates the symbol stream that is provided to the Physical Layer. On the receiving side, the CS-SL accepts the received symbol stream, performs the required de-randomization and decoding, extracts the frame, and then provides it to the DLP-SL for processing. (See references [11], [12], and [14]–[16] for the CCSDS Coding and Synchronization Blue Books.)

CCSDS Service Management incorporates the managed parameters (see section 4) as part of its configuration profile information for managing space links. Reference [18] provides more information, and, in particular, the 'SCCS Mission Support Lifecycle' in subsection 2.2 of that document should be consulted for an overview of the service management processes.

In order for the link to be established, the sending and receiving sides must know about the characteristics of the link: the frequency and modulation, the forward error correction coding (if used), the transfer frame format, and the alignment of the transfer frame with the coding. The operational modes are described in 2.1.2.4. Different codes are utilized on different links primarily to obtain the best performance within the available power and implementation constraints.

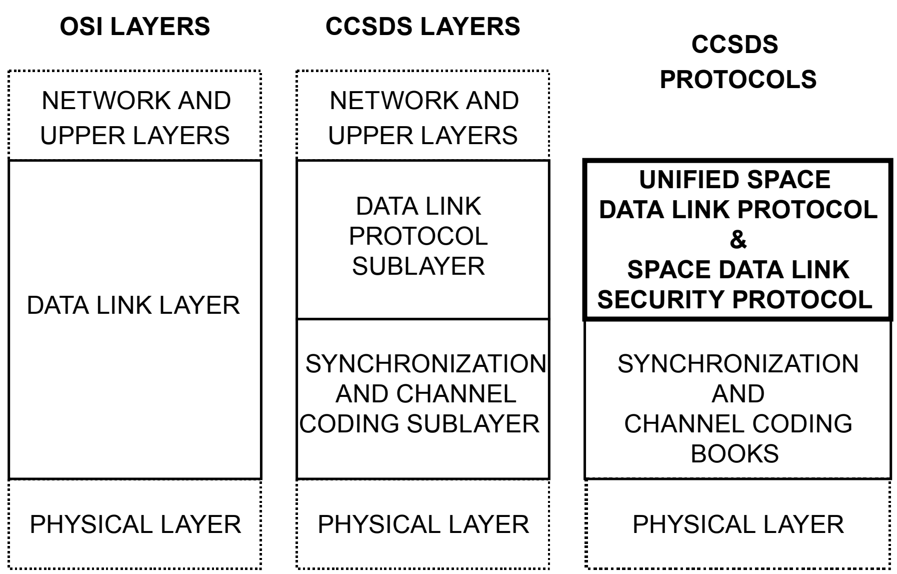

Figure 2-1: OSI and CCSDS Protocol Stack

2.1.2 PROTOCOL FEATURES

2.1.2.1 Overview of the USLP Frame

The Data Link Layer is composed of two sublayers. DLP-SL incorporates a flexible transfer frame structure that can be optimized for the specific needs of each space link type and its constraints, all using the flexible USLP frame format and the channel coding options provided by the CS-SL.

The USLP frame contains a primary transfer frame header that includes a frame length field, and a flag for signaling the inclusion of Operational Control Service Data Units. This header contains a Spacecraft ID that is used either to identify the creator of the frame or its destination. Sixty-four Virtual Channel (VC) IDentifiers (VCIDs) are provided, each with a configurable length sequence counter and 16 Multiplexer Access Point (MAP) IDentifiers (MAP IDs) to identify each SAP for the VC. The Bypass Flag, when set to '0', is used to identify when the frame is using the COP's sequence-controlled data delivery procedure. The Transfer Frame (TF) Data Field (TFDF) has a header that identifies the construction rules for the data and the USLP Protocol ID associated with it. In addition, the End of Frame Primary Header Flag provides the capability of generating a very short emergency command for use when link characteristics dictate.

The USLP format provides sufficient data visibility within the frame header to enable the receive-side link-layer frame processing to provide data-driven services with limited managed parameters. The following services can be provided by the receiving systems without knowledge of the security encoding key: 1) transfer of the Master and/or VC frames, and 2) the extraction and delivery of OCF_SDUs using the signaling provided in the primary transfer frame header for supporting the COP and SDLS procedures and verifying that the frame has not been modified in transit. The extraction of user data from the TFDF requires knowledge of the optional inclusion of security and/or Isochronous Insert data and the fields' lengths. The assembly of the data delivered in the TFDF is performed using the information in the Transfer Frame Data Field Header and the managed parameters, and is delivered to the user utilizing the MAP and VCIDs. The exception is when the truncated frame is invoked that shortens the primary transfer frame header and declares that the contained data in the frame is mission specific. The tailoring of the frame's functionality is accommodated within the transfer frame header and the transfer frame data field header with security and Insert details acquired from managed parameters. How one tailors the capabilities of the transfer frame is explained in section 3. The frame is the Protocol Data Unit (PDU) passed between the Data Link Protocol sublayer and the CS-SL. The sending side for frame assembly is detailed in 3.3.2. The receiving side is detailed in 3.3.3.

2.1.2.2 Optional Inclusion of the COP Procedures

The COP procedures provide a reliable delivery attribute to the services that utilize these procedures. The COP procedures for Direct from Earth links (COP-1) reference [4] and Proximity links (COP-P) (reference [8]) are slightly different, but those differences are transparent to USLP. A 'False' or '0' value contained in the Bypass/Sequence Control Flag in the Transfer Frame Primary Header signals the sequence-controlled Quality of Service (QoS) of the COP procedures for the data carried with a frame. The COP on the receiving side monitors the VC frame count in order to control frame deliver to be in order without duplication or loss and provides a report that is transferred to the sending entity. The sending entity will resend frames in response to those reports when required.

2.1.2.3 Optional Inclusion of Space Data Link Security Protocol

The inclusion of the SDLS procedures, specified in reference [6], is controlled by mission management through the use of the USLP managed parameters with SDLS in reference [3], subsection 6.6. The SDLS protocol can provide security, such as authentication and/or encryption, for USLP Transfer Frames. Support for the SDLS protocol is an optional feature of USLP. The presence of security on a VC is managed; that is, there are no fields in the transfer frame header that signal this capability. The managed parameters must provide the lengths of the required Security Header that will precede the TFDF and Security Trailer that will follow the TFDF.

The security provided by the SDLS protocol can vary between VCs. So, for example, there can be some VCs with security and some without. A security association is limited to a single VC; however, multiple VCs can have their own Security Associations.

NOTE – SDLS is applicable for use over the Proximity-1 Space Data Link Protocol when the Version-4 transfer frame is used. (See annex E in reference [3].)

2.1.2.4 Alignment of the Transfer Frame and the Codeblock

2.1.2.4.1 General

The Coding and Synchronization Sublayer provides options to the user with respect to the alignment of the USLP transfer frame to the codeblock. The options are: 1) transfer frames align on codeblock boundaries; 2) the frame is unaligned to the codeblock; or 3) the link is uncoded. The managed parameters for selected coding options (table 12-1 in reference [14]) specify the alignment between transfer frames and codeblocks. In all modes, the CS-SL must output an uninterrupted stream of channel symbols to the physical layer.

There are four types of coding that require the transfer frame and the codeblock to be aligned: Reed-Solomon (R-S), Concatenated R-S and Convolutional, Turbo, and LDPC coding of a transfer frame. In each of these cases, the content of the codeblock is the transfer frame, thus delimiting the start of the frame is a natural consequence of delimiting the codeblock. There is one mode in which the transfer frame and the codeblock are unaligned: LDPC coding of a stream of Sync-Marked Transfer Frames. (It should also be noted that Serial Concatenated Convolutional Codes (SCCCs) and Digital Video Broadcasting—Satellite—Second Generation (DVB-S2) codeblocks are also unaligned to the transfer frame.) In these modes, the delimiting of the frame is independent from the delimiting of the codeblock. There are two modes in which no block code is used: 1) uncoded mode and 2) convolutional only coded mode.

Table 2-1 provides a summary of the frame-to-codeblock alignment options available with the current CCSDS coding schemes.

Table 2-1: Codeblock to Frame Alignment Options with CCSDS Channel Codes

USLP Frame and Codeblock Alignment	CCSDS Coding Schemes	Comments
Fixed Aligned Mode	– Reed-Solomon – Concatenated Code – Turbo – LDPC coding (of a Transfer Frame)	Option 1 in 2.1.3.5. Normally used space-to-ground. Subset allowed ground-to-space. All (or subset) allowed space-to-space.
Variable Aligned Mode	– BCH – TC LDPC Slicing	Option 4 in 2.1.3.5.
(Fixed) Unaligned Mode	– TM LDPC Slicing – SCCC – DVB-S2	Option 2 in 2.1.3.5. Normally used space-to-ground. Subset allowed ground-to-space. All (or subset) allowed space-to-space.
(Variable) Unaligned Mode	– Proximity-1 LDPC slicing	Option 3 in 2.1.3.5 Limited to proximity links. It may be extended in the future to other links.
No Codeblock Mode	– TM uncoded – TM convolutional alone – Proximity-1 uncoded – Proximity-1 convolutional only	No Option in 2.1.3.5. Normally used space-to-ground OR space-to-space (proximity links only). Not allowed ground-to-space.

2.1.2.4.2 Fixed Aligned Mode

In the Fixed Aligned Mode, with the start of the codeblock. This pattern repeats continuously. The DLP-SL must supply a constant frame rate to the CS-SL to match the constant rate of production of codeblocks in the CS-SL. Therefore the DLP-SL must supply one or more Only Idle Data (OID) frame(s) when informational data frames are not available to maintain the continuous stream of frames to CS-SL. Two of the benefits attributed to the fixed aligned mode are: 1) when the code being used has a very low undetected error rate then the Frame Error Control Field (FECF) need not be included in the frame; and 2) the alignment of the frame and the codeblock aids in time correlation because the frames are received at a continuous rate, and the time tagging of a frame on the Earth and reporting when the codeblock (and therefore the frame) was delivered to the transmitter can be directly correlated.

2.1.2.4.3 Variable Aligned Mode

In the Variable Aligned Mode, the frames delivered by the DLP-SL to the CS-SL can vary both in length and timing. Examples of this mode are Telecommand and Proximity-1. In this case, the codeblock will expand as necessary (containing a variable number of codewords) to encapsulate the frame. Moreover, since the size of the frame is not constrained to fit exactly within the information fields of the codewords, fill data bits may be needed to be appended to the frame to complete the last codeword of the codeblock. Because there may be periods when there are no data frames to transport, the CS-SL (and not the DLP-SL, as in the above section) will have to provide Idle data in order to maintain a constant symbol output stream.

2.1.2.4.4 Unaligned Modes

In the Unaligned Modes, the frame and the codeblock are unaligned. The use of the variable-length frames unaligned to fixed-length codeblocks provides a level of independence between frame production and coding and also allows for different sized frames to share the same link. An example is the use of variable-length Proximity-1 frames over Proximity-1 LDPC slicing. Since fixed-length is a special case of variable length, the frame's production process could create a series of VCs with different sizing constraints. In these cases, the only limitations on the size of the frame are the managed parameters that limit the maximum size and variability of the frame's length. The delivery of frames by the DLP-SL need not be continuous. The CS-SL must provide idle data when no frame data has been provided by the DLP-SL. Selection of the channel code may add constraints that require the DLP-SL to deliver a continuous stream of fixed-length frames; therefore if the frame construction cannot maintain a continuous sequence of frames, then one or more OID frames must be provided.

2.1.2.4.5 No Codeblock Modes

In the No Codeblock Modes, no codeblock is involved. In this mode, the managed parameters can require the CS-SL to transmit uncoded or Convolutional Coded output data. For Telecommand and Proximity-1, when frame delivery from the protocol sublayer is not continuous, Idle Data are added to the data stream by the CS-SL in order to provide a continuous output symbol stream from the transmitter. For fixed-length transfer frames, when no production mode telemetry is available for transmission, TM Sync and Channel Coding requires OID frames to be generated by the DLP-SL in order to provide a constant frame rate to the channel.

2.1.2.5 Compatibility with Variable Coding and Modulation

Variable Coding and Modulation (VCM) is codified in the CCSDS specifications for DVB-S2 (reference [5]) and SCCC (reference [6]), and *Variable Coded Modulation Protocol* (reference [17]). In essence, the technique has the capability of changing the error control coding algorithm and the modulation of each codeblock. This technique utilizes the fixed Unaligned Mode, but since the codeword size in each codeblock can change each codeblock, the data stream slicer must be interactive with the VCM process. In addition, the Code Synchronization Marker (CSM) is designed to not only identify the start of the codeblock but also to identify the modulation and error control algorithm for that codeblock. Because the codeblock and the frames are unaligned, it is possible that the starting portion of a frame can be coded differently than the portion that will reside in the next codeblock. The function of reassembling the segments of the frame that are transferred in separate codeblocks is the responsibility of the CS-SL. It should be noted that this action is hidden from the DLP-SL and should not result in frame loss unless the VCM process does not perform its task to the precision required by the mission.

2.1.3 DESIGN DRIVERS

2.1.3.1 Meeting the Increasing Frame Processing Needs of High Rate Missions

High rate (such as optical communications at Gb/s rates) missions require more efficient frame processing (both on board and on the ground) than CCSDS standards currently permit. This requirement implies that the current maximum CCSDS frame size of 2048 octets is too small and therefore must be enlarged. The higher rates will also increase the need for larger VC sequence numbers to provide adequate frame accountability and for ordering when transfers occur over multiple tracking stations.

There are numerous missions in the planning phase that require significantly higher rates, including Earth Science missions planning to use Ka, Ku band, more advanced coding schemes, and optical downlinks. It is anticipated that Observatory Class missions in this decade will downlink up to 2 gigabits/second (an example being the ESA Euclid dark matter/energy mission planned to launch in 2022 and have a 75 Mb/s telemetry rate). Part of the problem with today's ground systems is that they are incapable of processing the data received at rates that are above 1 Gb/s. Thus operational equipment needs to be developed to handle those very high rates, and these developments need to start soon enough to ensure future mission support.

Higher data rates create data handling problems for agencies when implemented with short-length frames. As the data rate increases substantially, greater is the need to increase the corresponding frame length. Optical links are projected to have data rate capabilities up to 30 Gb/s. This means that with a frame size of 16000 octets and a downlink rate of 30 Gb/s, 2343750 frames per second will be transferred, placing a significant burden on the operational link-layer services.

USLP has a maximum frame size of 65536 bytes (i.e., 64 x 1024) as a result of the 16-bit field assigned to the frame length. This enhanced frame length capability provides for frame sizes 32 times larger than the current set of standards. A larger maximum CCSDS frame size would reduce the frame rate for very high data rate missions, and the increased size of the VC frame count would provide the required accountability. The variability in frame size would reduce packet segmentation and reconstruction because frame boundaries could stretch to encompass complete packets or user data units (i.e., supporting in particular Internet Protocol [IP] datagrams or Delay Tolerant Networking [DTN] Bundles). The exceeding low error floor of high performance error correcting codes along with their exceeding low undetected error rates facilitate the use of very large transfer frames that are transferred over multiple code words. The TM Synchronization and Channel Coding specifications (references [14], [15], and [16]) limit the maximum input size of the transfer frame because of the size of the TM (reference [7]) and AOS (reference [10]) First Header Pointer field. Furthermore, although there is a maximum transfer frame length limitation due to the Frame Length field for TC in reference [9], the Telecommand Synchronization and Channel Coding specification (reference [11]) allows multiple transfer frames within a Communications Link Transmission Unit (CLTU), so in principle, there is no frame number limitation; however, USLP (reference [3]) allows only one frame. For Proximity-1 Synchronization and Channel Coding (reference [12]), the maximum Proximity Link Transmission Unit (PLTU) size is 2055 octets, so there is at most one frame included.

2.1.3.2 Increase the Number of Spacecraft IDs

The current number of version 1 and version 2 Spacecraft IDs (SCIDs) is insufficient to meet agencies needs for future Spacecraft ID growth. This implies the need for a larger SCID field.

In 2016, the number of Spacecraft IDs available to future missions is limited, and current missions consume 75% of the available Version 1 SCIDs and 63% of the Version 2 SCIDs, according to the CCSDS Secretariat. Currently, there are two sets of SCIDs, one for the TC and TM Recommended Standards (Version 1) up to 1024 SCIDs, and one for AOS that supports 256 SCIDs. As a result, if a spacecraft uses the TC-Space Data Link Protocol (SDLP) on the forward link and the AOS-SDLP on the return link, it must be assigned two SCIDs, one for the TC-SDLP (Version 1) and the other for the AOS-SDLP (Version 2). Another factor that leads to the rapid consumption of SCIDs is multiple assignments per spacecraft. Currently, most missions have required multiple SCID assignments in order to differentiate the data based upon mission phase (i.e., System Test vs. Mission Operations). Another driver for an increased number of SCIDs is the anticipated increase in agency activities in developing cube/microsatellites and the future expectation of internetworking in space.

NOTE – Only a handful of Version 3, Proximity-1 SCIDs are in use today with a maximum of 1024 possible IDs. The USLP provides for 65536 Version 4 SCIDs.

2.1.3.3 Enable Receiving System to Provide Services for a Received Frame before Security Processing

The inclusion of the SDLS header and trailer is not signaled within the frame header and is a managed parameter. But the information necessary to provide Operational Control Field (OCF) services is available from the contents of the non-secure portion of the frame, and the insert zone is controlled by a managed parameter and is always transferred as clear text. The process of verifying that the frame has not been modified in transit is possible without decrypting the frame. The frame primary header is in the clear, and thus the length of the frame and OCF included flag is in clear text and is thus readable. The OCF can be extracted when signaled by the OCF Flag. The Insert Zone presence and its size are obtained from the managed parameters.

2.1.3.4 Enable Multiple Data Streams to be Supported by a Single Security Association and/or Sequence Control

The inclusion of MAPs allows a single VC to be divided into multiple sub-channels, each included in the sequence controls and security applied to the VC. This allows, for example, a VC channel to use a single Security Association and/or a single sequence control procedure. This provides added addressing for directing the delivery of the transferred data unit to the desired application within the receiving entity.

2.1.3.5 Support Variable-Length Frames on Telemetry, Telecommand, and Proximity Links

USLP offers the option of using a variable-length transfer frame that is unaligned to the code block on space links in addition to the aligned frame and code block methods defined in the TM Synchronization and Channel Coding specifications (references [14], [15], and [16]). Therefore USLP requires a service from the Coding and Synchronization Sublayer that by the use of modes will support four variations (see table 2-1 for actual coding schemes applied for each option):

- Option 1: fixed-length frames aligned with fixed-length code blocks per reference [14];
- Option 2: fixed-length frames unaligned with fixed-length code blocks;
- Option 3: variable-length frames unaligned to the fixed-length code blocks.

The fourth variation that is currently included in the TC Synchronization and Channel Coding specification (reference [11]) provides for the use of variable-length frames that are aligned to variable-length codeblocks. The codeblock is created from an integer number of code words that will encompass the variable-length frame.

2.1.3.6 Support Selective-Repeat Commanding

There is an emerging requirement to support selective-repeat-based commanding. In the past, a spacecraft only accepted an uplink if the entire uplink was valid. This leads to an in-order, without duplicates, in-sequence approach of COP delivery for reliable command delivery. A COP-2 protocol was proposed in the 1980s for selective retransmission, but the need at that time was limited, and the protocol was never codified. However, both uplink and downlink rates and volumes have increased, and the need for a selective repeat option is growing.

A selective retransmit protocol may become a more likely approach for command reliability in the future. That requirement has driven the development and codification of the CCSDS File Delivery Protocol (CFDP), the Bundle Protocol (BP), and the Licklider Transmission Protocol (LTP) in order to facilitate the use of selective repeat commanding. CCSDS has a requirement to provide a mechanism to enable it and provide a path to support COP and selective retransmission protocols for data transfer. USLP can use the COP, but it is also future looking towards providing the interface for upper-layer protocols to execute selective repeat procedures.

2.1.3.7 Transfer Frame Services

The transfer frame master channel (subsection 3.8 of reference [3]) or VC (subsection 3.7 of reference [3]) frame services deliver the entire transfer frame to the user. The TFDF header identifies both the content-specific rules for the inclusion of the data and the USLP protocol ID of the contained data unit.

2.1.3.8 Data Unit Segmentation vs. Spanning Overview

The current Telecommand Protocol relies on a segmentation process to allow service data units larger than a TC frame to be carried within smaller frames, while the TM and AOS protocols provide that capability by allowing the data unit to span across one or multiple transfer frames. Both segmentation and spanning are selectable options within USLP, being signaled in the TFDF header.

Packets are allowed to span transfer frame boundaries with the next available packet starting where the preceding one ended. This process requires that the First Header Pointer/Last Valid Octet Field be included in the TFDF header. This is a dual-use field. It provides a First Header Pointer for packet resynchronization and alternatively as a ‘Last Octet Pointer’, as required by the MAP Access (MAPA) service. The First Header Pointer is required to restart the packet delimiting process when one or more frames are lost. The ‘Last Octet Pointer’ is required to delimit a MAPA_SDU when the TFDF is larger than the contained user data (the remaining data in the TFDF will be Idle Data that will be discarded).

USLP also provides a segmentation process similar to that defined in TC and Proximity-1 when short frame lengths are employed. In this process, portions of a data unit are contained within sequential frames of the same VC within the same MAP ID. The TF Data Zone

(TFDZ) Construction Rules Field in the TFDF header identifies if the contained segment is the first, the last, or a continuing segment of the data unit.

When variable-length frames are employed, then the need for segmentation is minimized and typically the entire data unit is placed within a single frame. In this mode, the TFDF is required to be filled only with user data, and no Idle Data are allowed. It is believed the need to utilize segmentation of packets in the future will be reduced because USLP provides a transfer frame size that is up to 32 times larger than the current Data Link Layer Recommended Standards. The protocol also provides for blocking multiple short packets of the same protocol into a single TFDF.

The allowable values and use of the TFDZ Construction Rules field are provided in 3.2.4.2.4.

2.1.3.9 Truncated Transfer Frame for Emergency Commanding

Missions have relied on very short commands that can be received in a minimum time window that can be used to change the spacecraft's state. The End of Frame Primary Header Flag provides the capability of generating a shortened primary transfer frame header for efficiency purposes. One such use case could be for emergency commanding. The truncated transfer frame size and the inclusion of the FECF are set by the managed parameters.

2.1.3.10 Isochronous Insert for Transporting Blocks of Data at a Constant Rate

This service is only available when set by the managed parameters. The managed parameters will specify that an insert is to be included in every frame with a defined octet length. It should be noted that this service is only synchronous if all frames are a constant size and there is no Idle between frames.

2.1.3.11 Delivery of the Master Channel OCF Data Field

The capability exists to formulate either a fixed-length or a variable-length frame that includes an OCF data field. This capability provides the means for the COP or SDLS to send a report when no other data is available for transfer on that link. This capability maintains the same mechanism for delivering the Communications Link Control Word (CLCW) (COP-1), Proximity Link Control Word (PLCW) (COP-P), or Frame Security Report (FSR) (SDLS) reports in all operational conditions.

2.1.3.12 Inclusion of OID Frames/Fill Data /Idle Data

OID Transfer frames are fixed-length transfer frames (i.e., managed parameter, 'Transfer Frame Type' equals Fixed Length) that contain mission-specific data (e.g., a fixed pattern or random generated data) in the TFDZ, sent to maintain synchronization at the receiver. It should be noted that if the link is specified to provide Insert Service, an OID frame must carry the insert zone.

When variable-length frames are used, OID frames are not generated. However, it is necessary for the Coding and Synchronization Sublayer to generate Idle Data to maintain an output symbol stream for synchronization with the receiver.

Fill Data is supplied under the following scenarios: 1) the TC Synchronization and Channel Coding Sublayer may add fill octets to complete the information portion of the last code word when codes defined in reference [11] are utilized (see reference [3], subsection 4.3.9.3); 2) the mission adds fill octets to complete a MAPA_SDU transferred in fixed-length TFDZs (see reference [3], subsection 4.1.4.2.1.5.6); and 3) the mission completely fills a TFDZ with fill data (see reference [3], subsection 4.1.4.2.1.4.3).

Idle data can be introduced into the data stream in order to allow the Coding and Synchronization Sublayer to output a continuous symbol stream.

2.2 SERVICES ASSUMED FROM THE SYNCHRONIZATION AND CHANNEL CODING SUBLAYER

USLP requires a service from the Coding and Synchronization Sublayer to accept either variable- or fixed-length frames at the sending end and delivers (validated) variable- or fixed-length frames at the receiving end. The functions of Coding and Synchronization Sublayer are:

a) on the sending side:

   1) accept frames from the Data Link Protocol Sublayer;

   2) add Frame Synchronization Marker (and possible Code Synchronization Marker) or Message Start Sequence to frame (when required);

   3) perform error control encoding (optional);

   4) perform bit transition generation (randomization) (optional);

   5) creates a continuous symbol stream to deliver to the Physical Layer;

b) on the receive side:

   1) receive the symbol stream from Physical Layer;

   2) decode the symbol stream;

   3) delimit the frame;

   4) eliminate idle data (if present for TC, reference [11], or Proximity-1, reference [12]);

NOTE – As OID Transfer Frames are not recognized by the Coding and Synchronization Sublayer, it is a mission specific USLP decision to keep or discard the OID transfer frames.

5) validate the frame depending upon the underlying Coding and Synchronization Sublayer (available for Proximity-1, reference [12], TM, reference [14], SCCC, reference [15], DVB-S2, reference [16], but not for TC (reference [11]); see table 2-2 below);

6) deliver frames to the Data Link Protocol Sublayer.

Table 2-2: Frame Type and Validity Checks Performed by Underlying Coding and Synchronization Sublayer

Channel Coding and Synchronization	Frame Type	C&S Sublayer Delivers
TM Synchronization & Channel Coding (reference [14])	Fixed-length	Validated frame with or without FECF.
SCCC (reference [15])	Fixed-length	Validated frame with FECF.
DVB-S2 (reference [16])	Fixed-length	Validated frame with FECF.
TC Synchronization & Channel Coding (reference [11])	Variable-length	Data stream corresponding to a decoded Transfer Frame, possibly incomplete or containing fill data: USLP can deliver a fully validated Frame utilizing the USLP Frame Delimiting and Fill Data Removal Procedure (reference [3], subsection 4.3.10.2) and the USLP Frame Validation Check Procedure (reference [3], subsection 4.3.10.3).
Proximity-1 Synchronization & Channel Coding (reference [12])	Variable-length	Validated frame via mandatory FECF.

3 PROTOCOL DATA UNIT RATIONALE

3.1 OVERVIEW

USLP incorporates a flexible transfer frame structure that can be optimized for the specific needs of each space link type and its constraints, all using the flexible USLP frame format. This format provides sufficient data visibility within the frame primary header to enable the receive side link-layer frame processing to delimit the frame and separate and deliver Master and/or VC frames with neither management details (aside from those required for physical-layer operation and forward error correction decoding) nor the security encoding incorporated within them. The tailoring of the frame functionality is accommodated within the transfer frame header. The contents and structure of the Transfer Frame Data Field is identified within the Transfer Frame Data Field Header. The details of the tailoring capabilities of the transfer frame will be explained in this section below.

In order to provide missions with enhanced operability by augmenting the services provided within the Telecommand and Proximity-1 Protocols, the USLP has provided a way to integrate sub channels into a VC. This is accomplished by providing a 4-bit field in the frame primary header that identifies each of the 16 possible sub channels carried within the VC. These sub channels are called MAPs. USLP requires each of these MAPs share the same VC sequence counter and optional security process. This capability enables a single VC to provide reliable delivery and security to all the MAPs carried within the VC.

The current TC Protocol relies on a segmentation process to allow large packets to be carried within small frames, while the TM and AOS protocols provide this capability by allowing a packet to span across several transfer frames by use of the First Header Pointer in the Transfer Frame Primary Header. The USLP protocol supports both segmentation and the First Header Pointer.

3.2 USLP TRANSFER FRAME

3.2.1 OVERVIEW

The Transfer Frame contains up to 7 fields: Transfer Frame Primary Header, Insert Zone (IZ), SDLS Security Header/Trailer, TFDF, OCF, and the FECF. The Transfer Frame Primary Header is the only mandatory field in the transfer frame. The Transfer Frame Primary Header contains the frame length field providing the link the capability of transporting variable-length frames whenever there is no management restriction requiring only fixed-length frames. The inclusion of the Transfer Frame Insert Zone, the Security Header and/or Trailer, and the FECF are controlled by managed parameters. The presence of the Operational Control Field is optional and signaled in the TF Primary Header.

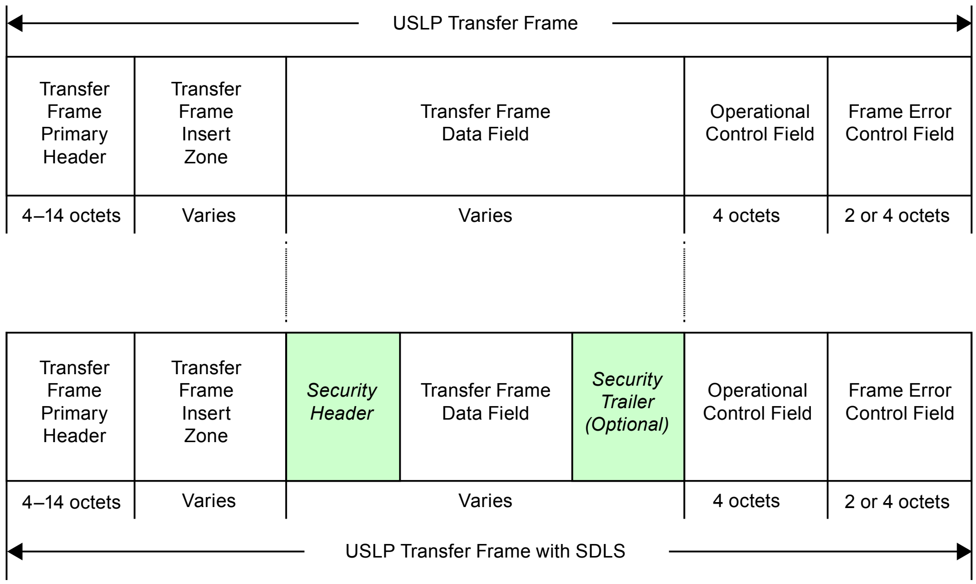

Figure 3-1: USLP Transfer Frame with and without Security Fields

3.2.2 TRANSFER FRAME PRIMARY HEADER

3.2.2.1 General

The Transfer Frame Primary Header contains 13 fields and the order in which they appear is shown in figure 3-2 below.

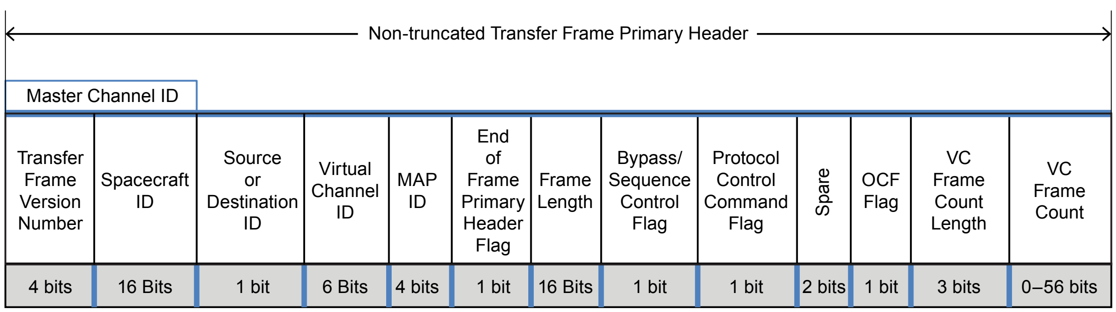

Figure 3-2: USLP Transfer Frame Primary Header

3.2.2.2 Transfer Frame Version Number

The TF Version Number (TFVN) identifies the format of the USLP transfer frame as the Version 4 frame. By examining the TFVN Space Assigned Numbers Authority (SANA) registry, one can determine the space data link protocol associated with a given TFVN. This field is 4 bits long. The original field specified in references [7]–[10] has been extended by 2 bits to allow for added future versions. The USLP Transfer Frame uses the last remaining value available in the 2-bit Transfer Frame Version Number field, that is, '11', and appends '00' to it to complete the 4-bit version number ('*1100*').

3.2.2.3 Spacecraft Identifier

The value contained in the SCID identifies the Master Channel for that transfer frame. The Spacecraft ID field has been extended from the current 8 bits (Version 2) or 10 bits (Version 1 and 3) to 16 bits (Version 4) to accommodate a larger population of spacecraft expected (up to 65536), especially due to the advent of cube/microsatellites and landed data gathering sensor platforms.

3.2.2.4 Source-or-Destination Identifier

The Source-or-Destination Identifier is used to interpret the value of the SCID field. A Source or Destination ID of ‘0’ (source) identifies the spacecraft that created this frame. A value of ‘1’ (destination) identifies the intended recipient of this frame.

The behavior of the recipient of this frame with respect to the values of the SCID field and Source-or-Destination Identifier is described below:

When the value contained within the Source-or-Destination Identifier field is ‘0’ (source), then the recipient may accept this frame if allowed by mission management. This methodology allows the sender to broadcast the data to one or more recipient entities while identifying itself.

When the value contained within the Source-or-Destination Identifier field is ‘1’ (destination) then the recipient only accepts this frame if its assigned SCID equals the value of the SCID contained within the frame or if its function is to relay that frame toward the identified recipient. The methodology is used to transfer data exclusively to the designated entity.

3.2.2.5 Virtual Channel Identifier

The VCID field is 6 bits in length and provides the capability to create up to 64 VCs. VCs are used to multiplex different types of data across the master channel.

A VC used for transmission of OID Transfer Frames is indicated by VCID having the reserved value of ‘all ones’ (i.e., 63).

3.2.2.6 Multiplexer Access Point Identifier

A 4-bit field is included to allow a VC to carry sub channels that share the same reliability and security services. There currently is no defined MAP service that multiplexes and de-multiplexes MAPs from a VC. The MAP ID associated with a given VCID identifies the source of the data contained in the TFDZ.

3.2.2.7 End of Transfer Frame Primary Header Flag

The End of Transfer Frame Primary Header Flag signals the use of a truncated Transfer Frame Primary Header instead of the complete header. When its value is ‘1’, the Transfer Frame Primary Header is limited to 4 octets. Transfer frames that contain the truncated Transfer Frame Primary Header are of fixed length, defined by the managed parameter ‘Truncated Transfer Frame Length’. This shortened header is a more efficient use of bandwidth and can be used to facilitate the transfer of mission-specific data, for example, a very short emergency hardware command.

3.2.2.8 Transfer Frame Length

The Transfer Frame Length Field is 16 bits in length providing the capability to create a maximum frame of 65536 octets long and thus enabling larger transfer frames than the previous constraint of 2048 octets that can reduce the operational frame handling complexities at very high rates.

3.2.2.9 Bypass/Sequence Control Flag

This field signals the COP-1/COP-P process that this frame is a sequence control frame when its value equals ‘0’ or an expedited frame when its value is ‘1’.

3.2.2.10 Protocol Command Control Flag

The Protocol Command Control Flag signals that the data contained within the TFDZ is either used by the COP Procedures (COP-1 or COP-P) or by the user.

3.2.2.11 Spare

A spare field that is 2 bits in length is included for possible future definition.

3.2.2.12 Operational Control Field Flag

This field is 1 bit and signals the presence or absence of the optional OCF field (see 3.2.6).

3.2.2.13 Virtual Channel Frame Count Length

The value contained within this field identifies the size of the VC Frame Count. This 3-bit field allows the user to configure the size of the VC Frame Count Field. The user can choose between 0 to 7 octets in length. However, once chosen, this field is fixed for a given VCID. Emergency and COP control commanding that traditionally use the bypass options in their respective protocols do not require any sequence count, and this feature allows for a minimum frame size of 0 octets. The very high rate links that utilize the sequence counts for both accounting and ordering of received frames, especially when received from multiple ground stations, can set the sequence size to the size that they require. For VCs that are not sequence controlled and carry data that utilize selective retransmission, the sequence counter value may be inconsequential, and thus the counter size field could be set to zero. The size of the VC Count can be any size from 1 to 7 octets for sequence control, but only the least significant octet is used by the COP in its operation. USLP allows a VC to support both sequence control and expedited services and requires an individual VC Frame Count for each service; the length of the VC count must be the same and invariant.

3.2.2.14 Virtual Channel Frame Count Field

The size of this field is determined by the value contained within the VC Frame Count Length Field. The VC Frame Count field size may vary from 0 to 7 octets in length. The maximum count would be approximately 7.2×10^{16}. This field may be larger than currently obtainable using the AOS Space Data Link Protocol (reference [10]) or as small as desired (not required to be present) for COP control commanding, messaging, or emergency telemetry modes. The Frame Count field provides the means to determine sequence continuity for a VC.

3.2.3 SECURITY HEADER

The Security Header is an optional field within the USLP. It is mandatory if the SDLS protocol reference [6] is used. It is provided for delimiting the protected data and conveying the necessary cryptographic parameters within the transfer frame. The size of the Security Header reduces the maximum size of the Transfer Frame Data Field allowed by the USLP.

The presence of the Security Header is a managed parameter of the VC. (See section 5 of reference [3].)

3.2.4 TRANSFER FRAME DATA FIELD

3.2.4.1 General

The Transfer Frame Data Field contains the user-supplied data contents of a VC. The contents of this field are managed by the VCID in the Transfer Frame Primary Header. The TFDF consists of a TFDF header and a TFDZ. The size and content of the TFDF Header are dependent on how it is used. It may consist of up to three fields: TFDZ Construction Rules, USLP Protocol ID, and First Header/Last Valid Octet Pointer field.

USLP supports the AOS concept of the Multiplexing Protocol Data Unit (M_PDU) defined in reference [10] by allowing packets to span multiple transfer frames. (See TFDZ Construction Rule ‘000’.) Similar to the AOS M_PDU, USLP uses a fixed-length TFDZ whose contents are CCSDS Packets concatenated together that span Transfer Frame boundaries. The First Header Pointer is required for packet extraction.

However, USLP does not support the AOS concept of the Bitstream Protocol Data Unit (B_PDU) because in USLP, all data is required to be octet aligned.

A frame need not have a TFDF in the following cases:

a) when the End of Frame Primary Header Flag is set to '1', then the only contents for the frame is a mission command/directive and a possible FECF (as per managed parameters);

b) when there is no data to send, but it is required to send an OCF report. Thus the frame will contain the OCF and possible a FECF.

3.2.4.2 Transfer Frame Data Field Header

3.2.4.2.1 General

The TFDF header is provided to enable the receiver of the frame to process the frame contents without knowledge of the management rules for the VC. The TFDF header contains up to three fields and is always present if there is a TFDZ in the frame. The TFDZ construction rules (as specified in table 3-1) identify how the data is organized within the TFDZ. The USLP protocol ID (UPID) field contains the Protocol ID that identifies the protocol of the data (two mission specific UPIDs are also provided). This 5-bit field can directly accommodate 32 UPIDs. The UPID identifies the protocol to which the PDU belongs. These may be Packets, mission unique data units, or control commands (for an associated procedure or protocol, i.e., COP-1, COP-P, or SDLS).

The MAP packet service can support the extraction and delivery of CCSDS packets, including CCSDS Encapsulation protocol packets carrying IP datagram, DTN bundles, and LTP data units. The functions for extraction and reassembly of data Packets and MAP access data (see figure 3-3 below) are provided, but delivery of those entities requires mission-specified MAP management data.

The Octet Stream service delivers the content of the TFDZ to the designated recipient without any processing.

The MAP Access service delivers user-provided data units for which neither the length of the SDU is included within the unit nor is the protocol of the unit registered with SANA.

TFDZ Construction Rules	USLP Protocol Identifier	First Header/ Last Valid Octet Pointer (Optional)
3 bits	5 bits	16 bits

Figure 3-3: Transfer Frame Data Field Header

3.2.4.2.2 USLP Protocol ID

This field identifies the Protocol of the User data. This field is 5 bits in length. The Protocol IDs currently recognized by CCSDS for transmission over the CCSDS space link are registered in SANA (reference [13]).

3.2.4.2.3 First Header or Last Valid Octet Pointer Field

The first header or last valid octet pointer field is required only for fixed-length TFDZs. It provides the mechanism that allows packet delimiting to be reinitialized when frame loss occurs or for determining where the last valid octet (MAPA service) is located in the TFDZ.

3.2.4.2.4 TFDZ Construction Rules

This TFDZ Construction Rules field identifies data packing rules for inclusion in the TFDZ. The options are as specified in table 3-1, below.

Table 3-1: Transfer Frame Data Zone Construction Rules and Interpretation

TFDZ Construction Rules	Interpretation of Rule
000	Packets Spanning Multiple Frames
001	Complete or Portion of a MAPA_SDU
010	Continuing Portion of a MAPA_SDU
011	Octet Stream (User defined octet aligned)
100	Starting Segment
101	Continuing Segment
110	Last Segment
111	No Segmentation

3.2.4.3 Transfer Frame Data Zone

The Transfer Frame Data Zone field contains the user data units that are transported by the transfer frame. The managed parameters can specify that this field is a fixed- or variable-length Field.

- The Constraints for the content of each TFDZ Data Field are:
  - Data unit must be from the same MAP ID;
  - Data Unit must be of the same UPID.
- For fixed-length TFDFs, the TFDF header constraints are:
  - A Pointer Field must be included;

  - Only Construction Rules ‘000’ or ‘001’ or ‘010’ are allowed.
- For variable-length TFDFs, the TFDF header constraints are:
  - TFDF header does not contain a Pointer Field;
  - Only Construction Rules ‘011’,’100’,’101’,’110’ or ‘111’ are allowed.

TFDZ Construction Rule usage is illustrated in figure 3-4.

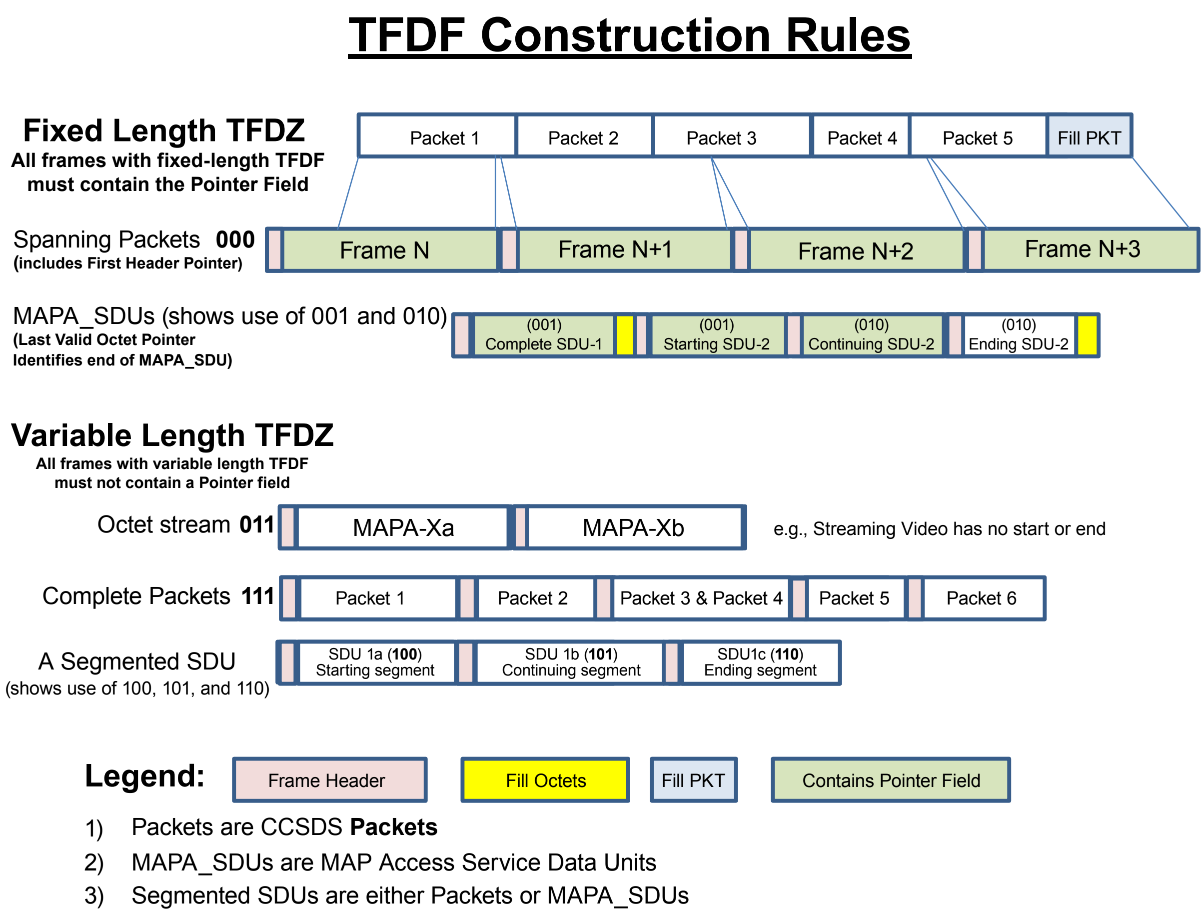

Figure 3-4: Example of User Data Illustrating the TFDZ Construction Rules

3.2.5 SECURITY TRAILER

The Security Trailer is an optional field within the USLP if the SDLS protocol (reference [6]) is used with the Security Trailer option. It is provided for delimiting the protected data and conveying the necessary cryptographic parameters within the transfer frame. The size of the Security Trailer reduces the maximum size of the Transfer Frame Data Field allowed by the USLP.

The presence of the Security Trailer is a managed parameter of the VC. (See section 5 of reference [3].)

3.2.6 OPERATIONAL CONTROL FIELD

The Master Channel OCF Service is used to deliver both COP reports (CLCW/PLCW) and SDLS service report FSR. The OCF SDUs are each 4 octets long, and the first 3 bits distinguish the SDU type.

For provisioning the Master Channel (MC) OCF service on the sending side, the user provides the OCF data to the OCF service. The OCF service transfers the data within the OCF over any one of the available VCs selected by the mission. For fixed-length transfer frames, once selected, the OCF is required to occur in every frame on that VC. The managed parameter 'Inclusion of OCF' set to 'true' informs the sending side to include the OCF in every frame on that VC when the frame type is fixed length. For variable-length frames, however, the OCF is not required to appear in every frame on the designated VC, and the rules for inclusion of the OCF in the variable-length frame case is driven by the periodic need for the reports as determined by the OCF Service. These rules are generated and provided by the mission. On the receive side, the OCF Flag in the Transfer Frame Primary Header signals the presence or absence of the OCF on a frame-by-frame basis within an MC.

3.2.7 FRAME ERROR CONTROL FIELD

The purpose of the optional FECF field is to provide a capability for detecting errors that may have been introduced into the Transfer Frame during the transmission and/or data handling processes. This field may be mandatory on a particular Physical Channel, and its presence should be determined based on the mission requirements for data quality and the selected options for the underlying Channel Coding Sublayer.

CCSDS provides two Cyclic Redundancy Check (CRC) coding procedure options, producing either a 16-bit or a 32-bit result. Both of these codes are formally defined in annex B of reference [3]. A comprehensive description of the CRC-16 code is provided in subsection 9.4 of reference [20], and the CRC-32 is described in annex B of reference [19].

The CRC-16 procedure provides an undetected bit error rate of approximately 10^{-5}, compared to approximately 10^{-11} for the CRC-32 procedure. The presence of the FECF is controlled by the USLP managed parameters, section 5 of reference [3].

With the exception of Proximity-1 (reference [12]), when the protocol sublayer optionally adds a FECF (containing a CRC), it is part of the transfer frame. In the case of Proximity-1, the Coding and Synchronization Sublayer adds a CRC that is not part of the transfer frame. The placement of the FECF in the frame allows for end-to-end frame verification, not just for the transmission portion. The placement of the FECF in CS-SL (as currently done only in Proximity-1, reference [12]) limits its verification to the transport function but does not check for errors occurring before or after transport. If the FECF is required to be added by CS-SL, then the length of the FECF will not be included in the value of the transfer frame length field.

In telemetry, it is the decoding process that declares whether the frame is error free or not. When the decoding, frame extraction, and possibly VC demultiplexing are done in the ground station, then the Space Link Extension (SLE) Return All Frames (SLE-RAF) service is able to report to the user whether the frame is error free or not, since SLE Return Channel Frames (SLE-RCF) returns only valid frames. When the applied coding scheme does not provide sufficient validation, the CRC contained in the FECF is used.

3.3 FRAME PROCESSING PROCEDURES

3.3.1 OVERVIEW

The procedures described in this subsection are defined in an abstract sense and are not intended to imply any particular implementation approach of a protocol entity.

3.3.2 PROTOCOL PROCEDURES AT THE SENDING END

The procedures for accepting user-supplied data to the delivery of a frame to the Coding and Synchronization Sublayer is discussed in this subsection. The SAPs provide the interface between the user and the frame-generation function. The SAP is assigned a Global MAP ID (Master Channel ID + VCID + MAP ID) and can be assigned for either sequence-controlled or expedited delivery service (or that information can be supplied by the data source with the delivered data). The SAP will accept the data for transfer and insert it into one or more TFDZs. The SAP computes the TFDF Header that identifies the protocol or process with which the data is associated and identifies the construction rules followed to include the data in the TFDZ. Since management parameters can impose constraints on the TFDZ, the SAP uses different construction techniques, as outlined in 3.2.4.2.4. The SAP initiates the process of building the frame header and inserting the GMAP ID, the Bypass Flag, and the length of the TFDF that will be included in the frame length. The incomplete frame header and the TFDF that will be included in the frame then begin the processes to complete the frame for delivery to the Coding and Synchronization Sublayer.

The Frame will eventually contain a frame header and TFDF, plus it may include an Insert Zone, a security header and trailer, an OCF_SDU, and a FECF. The inclusion of these fields is controlled by management parameters that are established for the link. The order of construction is controlled by the implementation; therefore the order of processing presented here is only an example. This subsection will provide an example of how the frame pieces are built and then assembled. The process described will not include the details of the COP retransmission processing nor the SDLS processing, only a statement on how they affect the created frame.

The managed parameters for the physical channel will determine if a FECF is required and which FECF algorithm is to be used. The Physical Channel Managed Parameters will determine if an Isochronous Insert is to be included and provide its length. The MC Managed Parameters will determine the set of VCIDs defined for a given MC. The VC Managed Parameters will determine if the security fields and an OCF_SDU shall be allowed to be included in the frame. In this example, the possible order of processing is as follows in figure 3-5 below:

a) The SAP utilizing its inherent processing capability accepts user provided data units. The data unit is processed complying with the construction rules dictated by the USLP protocol to create one or more TFDFs that will become the data fields for frame(s). In addition, the SAP using the managed parameters creates a frame header for the TFDF(s) created. At this point the frame header that will carry the TFDF contains the GMAP ID (Transfer Frame Version Number + SCID + VCID + MAP ID), the Bypass Flag value, a length field containing the size of the Isochronous Insert and the size of the FECF.

b) The VC MAP multiplexing process will order the delivery of its received embryonic frame to the VC Count Assignment process. The VC MAP multiplexing process must ensure that all the segments of a data unit are included in sequential VC frames.

c) The VC Count Assignment process uses the COP attribute expressed in the Bypass Flag to select the VC count that is incremented and appended to the frame header. The length of the frame header is then added to the length field value in the embryonic frame header.

d) If the VC Managed Parameters specify that the security process is to be performed on this VC, then the required security process is invoked. If authentication is indicated, then the GMAP ID, VC Count, and TFDF are delivered to the security process. If authentication is not to be included, then only the TFDF is provided. The output products of the security process are wrapped around the TFDF as required by the frame protocol. The length of the security products is added to the length field in the frame header.

e) At this point, the COP retransmission buffer process should be included to store new emergent frames that can be reintroduced later if retransmission is required by the FOP.

NOTE – This step is required in order to include the latest OCF value in the resent frame.

f) The VC multiplexing process can now order the VCs to form a Master Channel.

g) If an OCF_SDU is to be included and it is available, then it is placed into the frame. The value ‘4 octets’ is added to the value in the frame length field and the OCF Flag in the Transfer Frame Primary Header is set true.

h) At this point, fill is included into the frame that will eventually be replaced by the Isochronous Insert-SDU and FECF fields.

i) The frame can now be multiplexed with other MC frames.

NOTE – The protocol sublayer will make available to C&S an OID frame when the managed parameters require the inclusion of an OID frame when the production process cannot provide one as required for Coding and Synchronization Sublayer.

j) The Isochronous Insert can now be placed into its position in the frame.

k) If it is specified that an FECF is required, it is computed and inserted into its portion of the frame.

l) The frame can then be delivered to the Coding and Synchronization Sublayer.

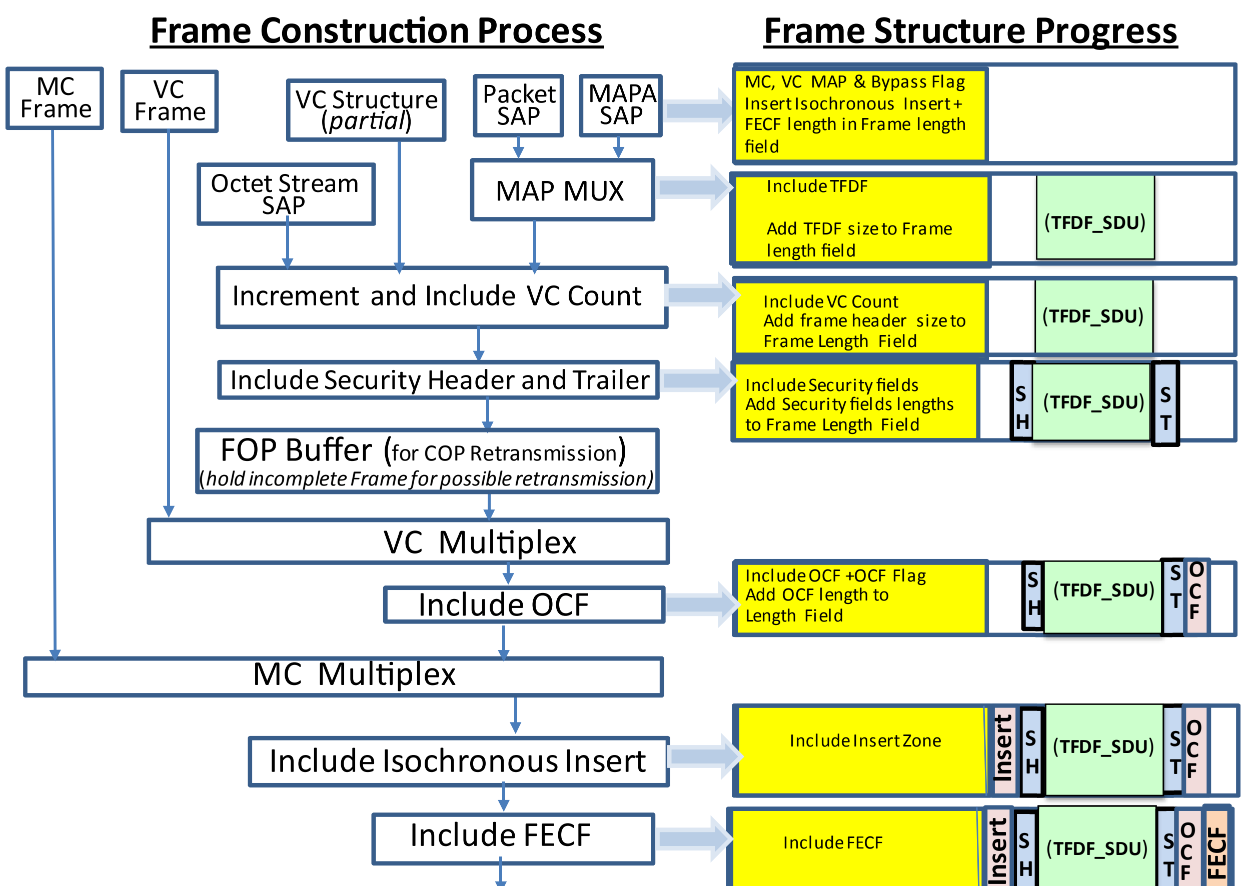

Figure 3-5: Sending Side Transfer Frame Assembly Process

3.3.3 PROTOCOL PROCEDURES AT THE RECEIVING END

This subsection describes the series of procedures at the receiving end (see figure 3-6). The order of the data-handling functions performed by the protocol entity at the receiving end logically will follow the order described in the example provided in this subsection. This example is not intended to imply any hardware or software configuration in a real system. Depending on the services actually used for a real system, not all of the functions may be present in the protocol entity. The procedures described in this subsection are defined in an abstract sense and are not intended to imply any particular implementation approach of a protocol entity.

a) The delimited frame is delivered to the Data Link Protocol Sublayer by the Coding and Synchronization Sublayer. The managed parameters will identify:

   1) if an FECF is included and which CCSDS codified CRC algorithm is used;

   2) if an Isochronous Insert is included and its size;

   3) which VC includes security: The Security Association will identify the security algorithm and the sizes of the Security Header and Trailer fields.

b) If a FECF is included in the frame, the first task will be to perform the required CRC decoding procedure to compute the syndrome polynomial and determine if the frame has not been modified in transit.

c) If an Isochronous Insert is employed, then the Insert SDU will be extracted and delivered to the designated user. The start of Insert SDU will be located by using the frame header length and the Insert Zone length (specified in the managed parameters).

d) Master channel de-multiplexing is performed delivering each spacecraft's frames to the designated mission's handling facility.

e) An INSERT.indication service primitive will trigger the Insert extraction process. The Insert SDU will be located by using the frame header length, and its length will be equal to the value in the managed parameters.

f) If the OCF flag is set to '1', then the OCF service will extract the OCF SDU that will be located by subtracting the FECF length and the value of the OCF length (4 octets) from the value in the frame's primary header length field.

g) The size of frame's primary header plus the size of the Insert SDU is offset from the beginning of the frame to the next included field.

h) If the managed parameters indicate the next process would be the security process. The length of the security header and trailer are contained in the managed parameters and the length of the TFDF can be calculated by subtracting the FECF's length plus the OCF's length plus the security header and trailer sizes plus the Insert Zone and TFDF Primary Header length from the value in the frame length field.

i) Since a single Security Association may be employed for multiple VCs, the security process is invoked at this point in the processing. If the security process is successful, the frame will be provided to the VC De-multiplexer.

j) The VC De-multiplexer will deliver the VC Frame to the designated user.

k) The frame process will extract the TFDF and deliver it to its specified data processing entity (MAP-SAP).

l) The MAP-SAP will process the TFDF header to identify its protocol and the construction rules used to originally place the data in the TFDZ.

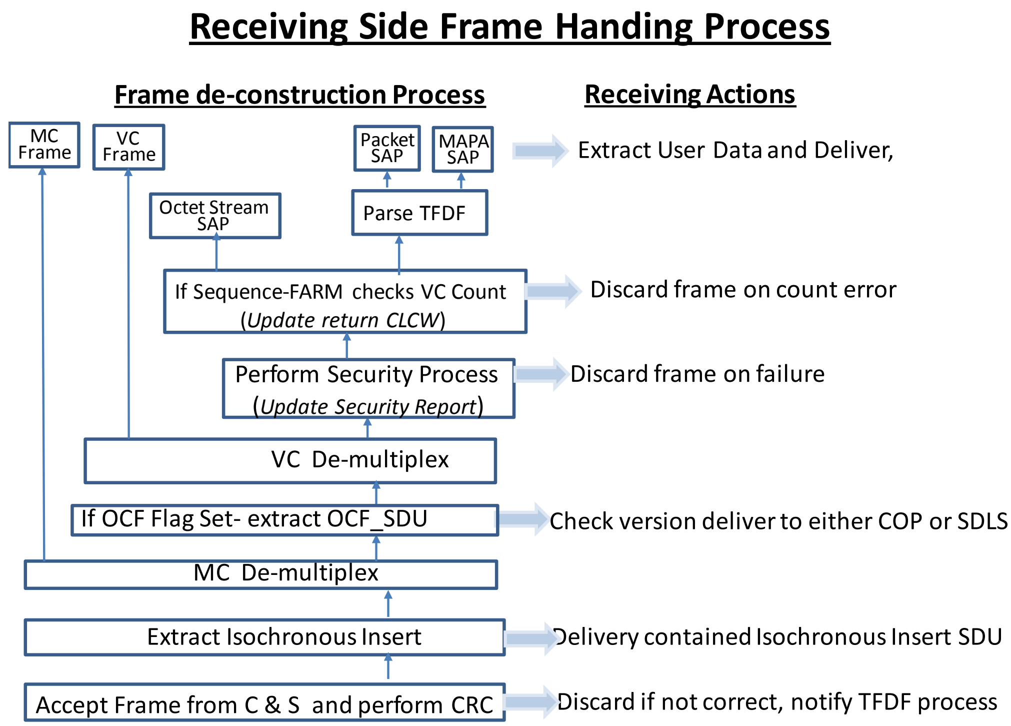

Figure 3-6: Receiving Side Transfer Frame Assembly Process

4 MANAGED PARAMETERS

4.1.1 OVERVIEW

The managed parameters are those parameters that tend to be static for long periods of time, and whose change generally signifies a major reconfiguration of the protocol entities associated with a particular mission. Through the use of a management system, management conveys the required information to the protocol entities.

In this section, the managed parameters used by USLP are listed, and the rationale for their existence is explained. These parameters are defined in an abstract sense and are not intended to imply any particular implementation of a management system. The allowable values are defined in [3], section 5, Managed Parameters without SDLS Option, as well as in subsection 6.6, Managed Parameters with SDLS.

4.1.2 MANAGED PARAMETERS FOR A PHYSICAL CHANNEL

TFVN identifies the frame version number (version 4 is USLP) that is to be inserted into the version of the transfer frame header when it is created. The earlier CCSDS versions have a 2-bit TFVN, and USLP would have used the last available value. Thus the TFVN was extended to 4 bits, allowing an additional three versions to be codified if necessary.

Physical Channel Name is only used to reference the created space link.

MC Multiplexing Scheme is a mission-specified function that controls how the various Master Channels (MCs) are to utilize the space link. The specification of this function is not part of the protocol but must be employed by the space link creator to satisfy the mission needs. An example of this could be a table providing the percentage of the channel bandwidth that is allocated to each master channel and their priority for access. This managed parameter will most certainly vary at different mission periods. The value associated with this parameter is a mission-unique function.

The following Managed Parameters establish or constrain the operating mode for the entire link.

Transfer Frame Type determines if the frame length is fixed or variable. This must be coordinated with the C&S managed parameters in order to establish an operating mode.

- When the parameter's value is *variable*, then the possible operating modes are UC, CC, VA, and UA (i.e., all coding schemes defined in references [11]–[12]);
- When the parameter's value is *fixed*, then the possible operating modes are UC, CC, FA, and UA (i.e., all coding schemes defined in references [14]–[16]).

When the Transfer Frame Type is '*Fixed Length'* and the Mode is either 'Fixed Aligned', 'Fixed Unaligned', or 'No codeblock', then those MCs in the physical channel with these characteristics must provide an OID frame when production cannot provide a frame and one is required by the CS-SL.

Transfer Frame Length defines the maximum allowed frame length. When the value in the Transfer Frame Type managed parameter is *Fixed*, then the value in this managed parameter is the fixed length for all the frames on the space link.

Presence of Frame Error Control specifies whether an FECF is to be included in every frame created for the space link. The inclusion of the FEC is to provide a known probability that the frame has not been altered since its creation. Also, in some cases, it is required to perform frame validation within the coding sublayer (e.g., turbo codes, convolutional codes).

Frame Error Control Length specifies which of the two CCSDS approved FECF coding procedures will be utilized. The Frame Error Control length field not only identifies the length of the FEC field but also the specific CCSDS approved CRC algorithm because different FEC algorithms have different lengths. The identification is made by the length of the FECF contained in the value of this managed parameter, that is, either 2 or 4 octets.

Generate OID Frame specifies whether or not an Only Idle Data Transfer Frame will be generated on this Physical Channel.

Presence of Insert Zone determines if an Insert Zone is included in every frame on the physical channel. The value *zero* in the Presence of Insert Zone means that no insert zone is to be included in the frames on the space link.

Insert Zone Length determines the size of the Insert Zone. An Insert Zone Length other than *zero* is only allowed when the operating mode is the Fixed-Aligned Mode, and every frame on the Physical Channel must contain the same sized Insert Zone.

Maximum Number of Transfer Frames Given to the Coding Sublayer as a Single Data Unit is only applicable for the Variable-Aligned Mode. It puts a limit on the framing process to limit the number of complete frames that are to be sent to the CS-SL for inclusion in a single variable-length code block. Currently this value is set to ‘1’.

Maximum Value of the Repetitions Parameter to the Coding and Synchronization Sublayer constrains the number of repeated frame transmissions for a single frame that can be requested of the C&S. A managed parameter is provided within the VC managed parameter group that sets a fixed number of frame repetitions for a frame in that VC.

4.1.3 MANAGED PARAMETERS FOR A MASTER CHANNEL

The managed parameters associated with a Master Channel (reference [3], table 5-2) are for a specified Master Channel that can be merged with other MCs to form the space link. Any constraints that are enumerated for the Physical Channel also apply to a Master Channel. An example of this is when the frame type specified for the physical channel is fixed, then any included MC must have fixed-length frames of the same length specified by the physical channel managed parameters.

Transfer Frame Type identifies whether the frames for this specific MC are fixed or variable in length. This managed parameter is subservient to the Physical Channel Transfer Frame Type and is only the controlling parameter when the value in the Physical Channel Transfer Frame Type is '*variable'*.

Spacecraft ID provides the identification of the spacecraft that is associated with the data contained in the Transfer Frame for this MC. This value can be either the identity of the source or the intended recipient of the frame. Within the SANA registry for Spacecraft ID, there is a further decomposition of the assignment of this value (i.e., Q-SCID) based upon the frequency band of the operating spacecraft (see reference [13]).

VCIDs identify the VCs that are supported by this Master Channel.

VC Multiplexing Scheme is a mission-specified function that controls how the various VCs are assigned to this Master Channel's output data stream. The specification of this function is not part of the protocol but must be employed by the transfer frame generator to satisfy the mission needs. Some examples of multiplexing schemes are: FIFO, absolute priority, polling vector. This managed parameter will most certainly vary for different mission phases.

4.1.4 MANAGED PARAMETERS FOR A VIRTUAL CHANNEL

The managed parameters associated with a VC (reference [3], table 5-3) are described below:

Transfer Frame Type identifies whether the frames for this specific VC are fixed or variable in length. This managed parameter is subservient to both the Physical Channel and Master Channel Transfer Frame Type managed parameters and is only the controlling parameter when the value in both of those Managed Parameters is '*variable'*.

Virtual Channel ID identifies the VC that is transporting the contained data across the space link. Valid values range from 0 to 62. VCID 63 is reserved for the OID transfer frame, which only applies in the Fixed-Aligned Mode.

VC Count Length for Sequence Control QoS identifies the size of the VC counter for Sequence Control QoS. A VC may have two VC Counters, one for sequence control service and a separate one for expedited service. The VC Counter Size for Sequence Control parameter can be set from 0 to 7 octets in length. The size of this field limits the count obtainable before the count returns to zero and resumes counting from there. The report generated by the COP only includes the least significant octet.

VC Count Length for Expedited QoS identifies the size of the VC counter for Expedited QoS. A Virtual Channel may have two VC Counters, one for sequence control service and a separate one for expedited service. The VC Counter size for Expedited parameter can be set from 0 to 7 octets in length. The size of this field limits the count obtainable before the count returns to 0 and resumes counting from there. This field is used to order frames and test for missing frames.

COP in Effect specifies if the sequence control process is to be or will not be provided by this VC. The values are either COP-1, or COP-P, or None.

CLCW Version Number identifies the version of the CCSDS CLCW that is used on this VC.

CLCW Reporting Rate is the maximum allowed interval between CLCW reports transported via this VC. A '*null'* value indicates there is no required constraint.

MAP IDs are the allowed set of MAP IDs associated with this VC.

MAP Multiplexing Scheme is a mission-specified function that controls how the various MAPs are to be ordered in the formation of VC frame. The specification of this function is not part of the protocol but must be employed by the frame generator to satisfy the mission needs, for example, a table providing the percentage of the VC channel bandwidth allocated to each MAP ID and their associated priority for access. This managed parameter will most certainly vary at different mission phases.

Truncated Transfer Frame Length specifies the length of the transfer frame when the End of Frame Primary Header Flag is set to '*True'*. An example use case for truncating the frame header is to enable the creation of a short hardware command. The size of the frame is most probably constrained by the underlying encoding algorithm.

Inclusion of OCF Allowed applies to the variable-length frame case. The value '*False'* means that no OCF is to be included. The value '*True'* allows the inclusion of an OCF Field in the frame when required/signaled by the OCF service.

Inclusion of OCF Required applies to the fixed-length frame case. The value '*False'* means that no OCF is to be included. The value 'True' means that every frame of this VC shall contain an OCF Field.

Value for the Repetitions parameter to the Coding Sublayer when transferring USLP Frames carrying service data on the Sequence-Controlled Service. Management sets an upper limit for the value of the Repetitions parameter specified in reference [11].

Value for the Repetitions parameter to the Coding Sublayer when transferring USLP Frames carrying COP Control Commands. When requesting the transfer of USLP Frames carrying SDUs on the Expedited Service (used by COP control commands), USLP does not limit the value of the Repetitions parameter.

Maximum delay in milliseconds for a TFDF to be completed, once started, before it must be released is required to support a VC that is providing a delivery service that requires a frame to be delivered within a designated time interval.

Maximum delay in milliseconds between releases of frames of the same VC is required to support a VC that is providing a delivery service that requires frames to be delivered within a designated time interval.

NOTE – The maximum amount of time that an incomplete frame can wait to be filled before released for transmission. A fill packet would be required if the TFDZ were carrying packets, and the Last Valid Octet Pointer would be set for a MAPA_SDU of fixed length.

4.1.5 ADDITIONAL MANAGED PARAMETERS FOR A VIRTUAL CHANNEL

In subsection 6.6.2 of reference [3], the managed parameters associated with a VC for USLP that supports the SDLS protocol are provided. These parameters are controlled by the SDLS protocol, reference [6]. For information only, they are:

– **Presence of Space Data Link Security Header**;

– **Presence of Space Data Link Security Trailer**;

– **Length of Space Data Link Security Header (octets)**;

– **Length of Space Data Link Security Trailer (octets)**.

4.1.6 MANAGED PARAMETERS FOR A MAP CHANNEL

The managed parameters associated with a MAP Channel are:

– **MAP ID** is the Multiplexer Access Point ID, which is a selectable integer from 0 to 15.

– **SDU Type** is the type of SDU that is transferred across the MAP channel, that is, CCSDS packet, MAPA_SDU, or Octet Stream Data.

– **UPID supported** identifies the type of data that is supported at the SAP that will create this MAP. This managed parameter identifies the data type by a protocol ID defined in USLP that is registered in SANA.

4.1.7 MANAGED PARAMETERS FOR PACKET TRANSFER

The managed parameters associated with a MAP Channel used for the MAP Packet Service are:

– **Valid Packet Version Numbers** identifies the Packet Version Numbers that are supported by the SAP that creates the Transfer Frame Data Field.

– **Maximum Packet Length** identifies the maximum length of the packets that are supported by the SAP in octets.

– **Whether incomplete Packets are required to be delivered to the user at the receiving end** specifies whether or not received incomplete Packets are to be delivered to the user. It should be noted that incomplete packets are not required to be delivered in cross-support situations. Values are: *'Required'*, '*Not required'*.

ANNEX A

ABBREVIATIONS AND ACRONYMS

AOS	Advanced Orbiting Systems
AOS-SDLP	AOS Space Data Link Protocol (see reference [10])
B_PDU	bitstream protocol data unit
BP	Bundle Protocol
C&S	coding and synchronization
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
CLCW	communications link control word
CLTU	communications link transmission unit
COP	communications operation procedure
CRC	cyclic redundancy check
CSM	code synchronization marker
CS-SL	Coding and Synchronization Sublayer
DFE	direct from Earth
DLP-SL	Data Link Protocol Sublayer
DTE	direct to Earth
DTN	Delay Tolerant Networking
DVB-S2	Digital Video Broadcasting—Satellite—Second Generation
FEC	forward error correcting
FECF	frame error control field
FSR	frame security report
Gb/s	gigabits per second
GMAP ID	global multiplexer access point identifier

IP	Internet Protocol
IZ	Insert Zone
LDPC	Low Density Parity Check
LTP	Licklider Transport Protocol
M_PDU	multiplexing protocol data unit
MAP ID	multiplexer access point identifier
MAP	multiplexer access point
MAPA	MAP access
Mb/s	megabits per second
MC	master channel
OCF	operational control field
OCF_SDU	operational control field service data unit
OID	only idle data
OSI	Open Systems Interconnection
PDU	protocol data unit
PLCW	Proximity link control word
PLTU	Proximity link transmission unit
QoS	quality of service
SANA	Space Assigned Numbers Authority
SAP	service access point
SCCC	serial concatenated convolutional codes
SCID	spacecraft identifier
SDLS	Space Data Link Security
SDU	service data unit
SLE	Space Link Extension

SLE-RAF	Space Link Extension Return All Frames
SLE-RCF	Space Link Extension Return Channel Frames
TC	telecommand
TC-SDLP	TC Space Data Link Protocol (see reference [9])
TF	transfer frame
TFDF	transfer frame data field
TFDZ	transfer frame data zone
TFVN	transfer frame version number
TM	telemetry
TM-SDLP	TM Space Data Link Protocol (see reference [7])
UPID	USLP protocol ID
USLP	Unified Space Link Protocol
VC	virtual channel
VCID	virtual channel identifier
VCM	variable coding and modulation

ANNEX B

USLP USE CASES

B1 DIRECT FROM EARTH LINKS (ROBOTIC AND CREWED MISSIONS)

The USLP frame can be structured to resemble the Telecommand frame (reference [9]). It is recommended not to use the BCH Forward Error Correction code but rather the short length LDPC code defined in the TC Synchronization and Coding Book, reference [11]. The mission would assign at least one VC for sequence-controlled reliable delivery. That VC could be used for sending COP control commands, but it is recommended that another VC that is not sequence controlled be used for that functionality. One or more other VCs could be assigned to deliver data that could be serviced by a selective repeat process by a protocol higher in the protocol stack. Variable-length transfer frames have traditionally been used for this purpose, but any form could be employed. The transfer frames may carry all types of data packets including the Encapsulation packets containing, for example, IP datagrams directly to an IP router for network delivery and operations. Very large data packets, CFDP files, or DTN bundles can be delivered within a single transfer frame or may be segmented for transfer. The frame sequence counter can be of any size but only the least significant byte need be included in the transfer frames for sequence-controlled support. No sequence counter octets need be included in COP control commands or by-pass frames. The FECF may be included if extra assurance of correct delivery is required, especially if an uncoded link is utilized, or to verify frame integrity at any time (e.g., after storage). The number of codewords that are concatenated to form the codeblock could be fixed for a mission, or the coding scheme applied could change during mission phases, and in some cases, VCM techniques may be used. This would have the effect of reducing the overhead on the link, and it would allow a single codeword decoder to be used.

B2 DIRECT TO EARTH LINKS

The USLP transfer frame can be structured to provide for telemetry for all sorts of missions, even those that have unique instrument characteristics and delivery requirements. For most coding techniques (with the exception of LDPC slicing and the Convolutional only code), the AOS or TM frame format can be logically replicated using fixed-length USLP frames that are aligned to the codeblock and use streaming-data processes. The sequence counter behavior would be set to provide an independent counter size for each VC. The requirement for a FECF is limited and probably need not be included except when desired to minimize the undetected error rate.

The ability to have the frames non-aligned to the codeblock allows the Earth-based receivers to be fully tested independently of the transfer frame length. This process can support either fixed- or variable-length frames. When variable-length frames are allowed, then the Insert Zone can be used to deliver low latency reports by being included in high-rate long data frames and allows OCF_SDUs to be included only as needed. When variable-length frames are used, then a number of options can be used to simplify mission accounting and delivery. The frame can be tailored to the individual need of an instrument on a VC. The length could accommodate an instrument's fixed time division mechanism for data acquisition or the variability of an instrument's unique data compression process while at all times providing the spacecraft control process to inject messages in the Insert Zone.

The current standard method has fixed-length frame partials, which are loaded to a solid state memory and then extracted from the memory during a downlink session, during which the frame would be completed. This process could still be used, but if the frame is not tied to the codeblock and is allowed to be of variable length, the frame partial would be a fixed-length TFDF, and when removed from the memory, then the frame assembly process could add whatever is needed to complete the frame.

B3 SPACE TO SPACE LINKS

The USLP transfer frame may be structured to resemble the Proximity-1 frame (reference [8]). It is recommended that the Convolutional Forward Error Correction code may be replaced by a short-length LDPC code with the frame unaligned to the code block (see reference [11]). One or more VCs would be assigned to provide reliable delivery while other VCs could be used for COP control directives or the transfer of data that is not required to be reliable, or for which the reliability is provided by an upper-layer process. The transfer frames may carry all types of data packets delivering, for example, IP datagrams directly to an IP router for network delivery and operations. Very large data packets, CFDP files, or DTN bundles may be delivered within a single transfer frame or may be segmented for transfer. The frame sequence counter can be of any size, but only the least significant byte need be included in the frames and OCF fields. No sequence counter octets need be included in COP control commands. The FECF can be included if extra assurance of correct delivery is required, especially if an uncoded link is utilized. All Proximity-1 COP-P control commands and processes can be supported. The OCF need not be sent in its own frame but can be delivered within a data frame if desired to improve link efficiency. The relationship between the Proximity-1 (Version-3) transfer frame fields to USLP (Version-4) transfer frame is discussed in annex E of reference [3].

ANNEX C

USLP OVERVIEW OF MISSION SERVICES

C1 OVERVIEW

The USLP Recommended Standard supports single space vehicles or constellations of space vehicles, which simultaneously execute a wide spectrum of applications in near-Earth orbit, geostationary orbit, or deep space. The USLP can be tailored to support observational science, experimental science, crewed and robotic platforms/vehicles, launch services, and the transfer of engineering data for the operational control of the space vehicle ('core') systems.

C2 OBSERVATIONAL SCIENCE

Observational science is primarily performed from unpressurized platforms in orbits around the Earth or other planetary bodies. Examples include astronomy, space physics, and Earth observation.

Typically, the lifetime of observational payload investigations is in the order of years. The user equipment is relatively stable in terms of location and functionality and usually requires minimal on-orbit human interaction during the life of a mission. There is therefore a relatively static association between a space instrument and its ground processing facility.

Since transmitted data rates are often high, the observational user requires streamlined techniques for acquiring, buffering, and delivering large volumes of data from space to ground, with protocols optimized so as to reduce requirements for onboard processing resources and communications bandwidth. The data taking process usually is performed during much of the trajectory path but communication is often limited to preplanned periods. The process therefore typically requires the acquired data to be buffered until it can be downlinked during a communications session. Because of the need to share limited onboard resources between multiple users (i.e., instruments), observational operations may require extensive preplanning and scheduling. Uplink data delivery requirements are significantly lower than the downlink rate requirements. A large degree of protocol flexibility, such as the capability to change addresses dynamically, is therefore unnecessary.

C3 EXPERIMENTAL SCIENCE

Experimental science, such as materials processing and the effects of space on human physiology, is conducted primarily in pressurized space vehicles since a high degree of flight crew interaction may be required.

In contrast to observational science, experimental science investigations are often scheduled for only a limited time duration. General purpose 'laboratory' equipment that has been used in one experiment may be almost immediately reconfigured for use in another. A crew member may control an experiment from workstations at different locations, possibly assisted by an investigator on Earth. Hence, source-destination data communications pairs may be only temporarily associated with any particular experiment, and these associations will typically exist only for relatively short sessions. The level of human interaction is high in terms of monitor and control of the experiment, and much of the information that is generated will be evaluated on board. Thus the volume of data that is transmitted to and from the ground may be relatively low.

Experimental users have needs that are quite similar to those of users of a local area network facility located on the ground. In particular, they need data communications protocols that provide routing flexibility by supporting global source and destination addressing and that support a rich repertoire of upper-layer data handling services.

C4 ROBOTIC PLATFORMS/VEHICLES

The links that support robotic platforms/vehicles typically operate in short windows of time based on the available geometry between the robotic platforms/vehicles and the other terminus of the link. These links can be end-to-end or rely on a relay system to forward the data between the robotic platform/vehicle and its Earth based control entity. The link characteristics can be significant different, but the end-to-end services would likely be the same. The USLP is designed to accommodate the differences in link characteristics primarily by allowing the frame and the link-layer coding to be independent. This frees the framing from the constraints of link's coding implementations.

Disassociating the frame from the codeblock also provides the opportunity to provide a frame relay service. In this mode, the communications hub can receive frames and relay them toward their destination based on a managed path for frames using their SCID and the value in the destination/source flag.

C5 CREWED PLATFORMS/VEHICLES

Communications links to support crewed missions are typically 24/7. The required links include emergency control and voice delivery, science data telemetry, instrument and vehicle remote control, human text type services, health and safety data, and video. The data for these services, as currently being designed for the NASA crewed program, utilizes Internet network packets and services. The USLP is designed to efficiently transfer these network packets, contained within CCSDS Encapsulation Service Packets, between Internet routers on the ground and in space. It is anticipated that during normal operations, link data rates can be in the multi-megabit range for selected data. It is also anticipated that Operations Control Centers would provide some form of link-layer security for the user data that is under its purview, and it is desired to limit the number of Security Keys required. Security for other users may use the security algorithm but may control their own keys. In total, the desire might be to limit the number of different security associations to limit the key management complexity.

The use of the USLP allows the crewed missions to use the same data link protocol for all of their links. It will also provide a more efficient platform for transferring IP Datagrams and DTN Bundles. The USLP also provides mechanisms to reduce latencies.

C6 LAUNCH VEHICLES

The data rates supporting launch vehicles are typically limited in both directions. Timeliness of data delivery is the critical factor in both the return and forward links. The USLP has a few features that are designed to support these requirements, for example, the capability to use fixed-length transfer frames with Isochronous Insert Zone for time-critical data delivery.

C7 CORE OPERATIONS

The core infrastructure operates and maintains the space vehicle systems that support the payload users. Core user requirements share attributes that are common to all space vehicle applications. Since the safety of the space mission (as well as often the safety of human lives) is involved, reliability concerns may strongly influence the selection of services that are used for transmission of core data.

A high degree of interaction is required in order to perform adaptive command and control (similar to experimental users), yet fairly large quantities of systems monitoring data must be repetitively and continuously returned to static locations on Earth in order to support long-term analysis of engineering performance (similar to observational users). Core users are therefore likely to use both the Internet service and the Path service for message exchange. For piloted missions, synchronized digitized audio and video must also be integrated with message traffic between ground controllers and onboard crew; the Path service can often satisfy these needs, but for some applications, special CCSDS point-to-point space link data-transfer mechanisms have been provided.

C8 SPACE NETWORKING ENVIRONMENT

Space/ground data transmission requires use of high capital-investment tracking facilities that must be shared not only by multiple users, but also by multiple space missions. Onboard resources are almost invariably subject to constraints of power, weight, volume, and the high costs of flight-qualifying hardware and software.

All of these considerations point to the need for robust space data handling services that are optimized for efficiency and low utilization of onboard resources. Because of the intermittent nature of the space/ground link transmission contacts, onboard data storage and replay must be accommodated. Removing the artifacts of transmission across the space link often requires considerable value-added processing prior to delivery of data to end users.