Consultative Committee for Space Data Systems

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SPACE DATA LINK PROTOCOLS

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FOREWORD

(WHEN THIS RECOMMENDATION IS FINALIZED, IT WILL CONTAIN THE FOLLOWING FOREWORD:)

This document is a CCSDS Report, which contains background and explanatory material to support the CCSDS Recommendations on the TC, TM and AOS Space Data Link Protocols (references [1], [2], and [3], respectively), and the Communications Operation Procedure-1 (reference [4]) that accompanies the TC Space Data Link Protocol.

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DOCUMENT CONTROL

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1 INTRODUCTION

1.1 PURPOSE

This Report has been developed to present the concept and rationale of the CCSDS Recommendation on the TC, TM and AOS Space Data Link Protocols (references [1], [2], and [3], respectively), and the Communications Operation Procedure-1 (reference [4]) that accompanies the TC Space Data Link Protocol.

It has specifically been prepared to serve the following purposes:

a) To provide an architectural overview of the Space Data Link Protocols;

b) To provide information on how the Space Data Link Protocols should be used by users to transfer various kinds of data over space links;

c) To provide information on how the Space Data Link Protocols should be deployed in space data systems to process and transfer data supplied by users.

1.2 SCOPE

The information contained in this Report is not part of the CCSDS Recommendations on the Space Data Link Protocols (references [1]-[3]) or the Communications Operation Procedure-1 (reference [4]). In the event of any conflict between the Recommendations and the material presented herein, the Recommendations shall prevail.

1.3 ORGANIZATION OF THIS REPORT

This document is divided into five numbered sections and two annexes:

a) Section 1 presents the purpose, scope, and organization of this Report, and lists the definitions and references used throughout the Report;

b) Section 2 explains what the Space Data Link Protocols are and how they are used in the protocol stack used over space links;

c) Section 3 explains the services provided by the Space Data Link Protocols and their features;

d) Section 4 shows how the Space Data Link Protocols should be implemented in onboard and ground data systems;

e) Section 5 presents frequently asked questions and their answers;

f) Annex A lists all acronyms used within this document;

g) Annex B contains a quick summary of the services provided by the Space Data Link Protocols.

1.4 DEFINITIONS

The following definitions are used throughout this Report. Many other terms that pertain to specific items are defined in the appropriate sections.

aperiodic: not periodic (see below).

asynchronous: not synchronous (see below).

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: 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 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.

synchronous: of or pertaining to a sequence of events occurring in a fixed time relationship (within specified tolerance) to another sequence of events. Note that ‘synchronous’ does not necessarily imply ‘periodic’ or ‘constant rate’.

Space Data Link Protocols: Data Link Layer protocols specified in references [1]-[3], which have been developed to transfer space application data over space-to-ground, ground-to-space, or space-to-space communications links.

1.5 REFERENCES

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

[1] *TC Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 232.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[2] *TM Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 132.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[3] *AOS Space Data Link Protocol*. Recommendation for Space Data System Standards, CCSDS 732.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[4] *Communications Operation Procedure-1*. Recommendation for Space Data System Standards, CCSDS 232.1-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[5] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-8. Yellow Book. Issue 8. Washington, D.C.: CCSDS, July 2002.

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

[7] *Proximity-1 Space Link Protocol- Data Link Layer*. Recommendation for Space Data System Standards, CCSDS 211.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, April 2003.

[8] *TC Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 231.0-B-1. Red Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[9] *TM Synchronization and Channel Coding*. Recommendation for Space Data System Standards, CCSDS 131.0-B-1. Red Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[10] *Radio Frequency and Modulation Systems—Part 1: Earth Stations and Spacecraft*. Recommendations for Space Data System Standards, CCSDS 401.0-B. Blue Book. Washington, D.C.: CCSDS, June 2001.

[11] *Overview of Space Link Protocols*. Report Concerning Space Data System Standards, CCSDS 130.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, June 2001.

[12] *Space Packet Protocol*. Recommendation for Space Data System Standards, CCSDS 133.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, September 2003.

[13] *Space Communications Protocol Specification (SCPS)—Network Protocol (SCPS-NP)*. Recommendation for Space Data System Standards, CCSDS 713.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 1999.

[14] J. Postel. *Internet Protocol*. STD 5, September 1981. [RFC 791, RFC 950, RFC 919, RFC 922, RFC 792, RFC 1112]

[15] *Space Link Identifiers*. Recommendation for Space Data System Standards, CCSDS 135.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, January 2002.

[16] *Encapsulation Service*. Recommendation for Space Data System Standards, CCSDS 133.1-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, ??? 200?.

[17] *CCSDS Global Spacecraft Identification Field Code Assignment Control Procedures*. Recommendation for Space Data Systems Standards, CCSDS 320.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, April 2003.

[18] *The Application of CCSDS Protocols to Secure Systems*, CCSDS 350.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, March 1999.

2 WHAT ARE THE SPACE DATA LINK PROTOCOLS? - *ARCHITECTURAL INTRODUCTION*

2.1 DESIGN GOALS

The Space Data Link Protocols are protocols of the Data Link Layer of the OSI Basic Reference Model (reference [6]). They were designed by CCSDS to meet the requirements of space missions for efficient transfer of space application data of various types and characteristics on space links.

Most of the present-day spacecraft use micro-processors for processing data (e.g., for compressing data, checking the status of susbsystems, executing timelines, etc.). As a result, they need to send and receive various types of data (e.g., compressed images, housekeeping telemetry, event reports, commands, timelines, etc.) that have different quality of service (QoS) requirements in terms of data volume, data rate, latency, reliability, and so on. However, since the processing capability available onboard spacecraft is limited due to the physical constraints imposed by the fact that the spacecraft are flying, the protocols must be simple enough to be implemented by small hardware and/or processors. The Space Data Link Protocols have the capability of transferring various kinds of data with different QoS requirements using relatively simple algorithms. Further, care was taken to ensure that these protocols are upper-compatible with the basic data formats used by earlier spacecraft.

CCSDS has developed four Space Data Link Protocols: the TC Space Data Link Protocol (TC-SDLP, reference [1]), the TM Space Data Link Protocol (TM-SDLP, reference [2]), the AOS Space Data Link Protocol (AOS-SDLP, reference [3]), and the Data Link Layer of the Proximity-1 Space Link Protocol (reference [7]). Since there is a separate CCSDS Report that explains the concept and rationale of the Proximity-1 Space Link Protocol (reference TBD), this Report only deals with TC-SDLP, TM-SDLP and AOS-SDLP.

2.2 BASIC CONCEPTS

A space link is defined to be a communications link between a spacecraft (which may be a lander or a rover on a distant planet) and its associated ground system or between two spacecraft. Therefore, at least one end of a space link is a spacecraft of some kind.

A space link consists of one or more Physical Channels in one or both directions. A Physical Channel is defined to be a stream of bits transferred over a space link in a single direction. A space link usually consists of one forward Physical Link for sending commands from the ground system to the spacecraft (or from the controlling spacecraft to the target spacecraft), and one or multiple return Physical Links (possibly using multiple frequency bands) for

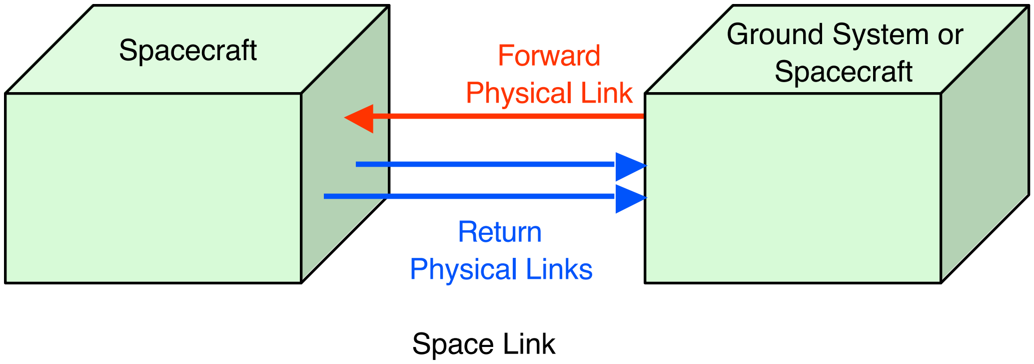


Figure 2-1: Space Link

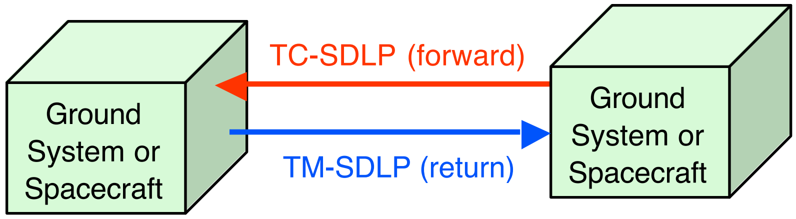
sending telemetry from the spacecraft to the ground system (or from the target spacecraft to the controlling spacecraft) (see figure 2-1).

Each Space Data Link Protocol provides one-way transfer from the sending end to the receiving end of a Physical Channel, but the TC-SDLP usually uses a service provided by the TM-SDLP or AOS-SDLP on a different Physical Channel in the other direction of the same space link (see 4.4) to provide feedback from the receiving end to the sending end. However, it is possible to use the same Space Data Link Protocol for both directions on a single space link. In such cases, one instance of the Space Data Link Protocol is used on a Physical Channel in one direction and another instance on another Physical Channel of the other direction.

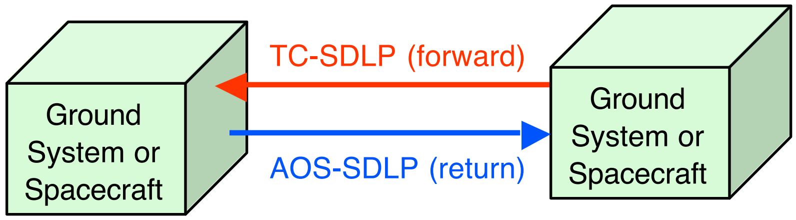
On a given Physical Channel, only one Space Data Link Protocol must be used (i.e., multiple Space Data Link Protocols must not be mixed on a single Physical Channel).

The TC-SDLP is usually used for (but not limited to) sending commands from a ground system to a spacecraft (or from a spacecraft to another spacecraft) on a forward Physical Link. The TM-SDTP is usually used for (but not limited to) sending telemetry from a spacecraft to a ground system (or from a spacecraft to another spacecraft) on a return Physical Link. The AOS-SDLP is also used for sending telemetry from a spacecraft to a ground system (or from a spacecraft to another spacecraft) on a return Physical Link, but it may be used on a forward Physical Link as well if there is a need for two-way on-line communications (e.g., audio and video) between a spacecraft and a ground system (or between two spacecraft).

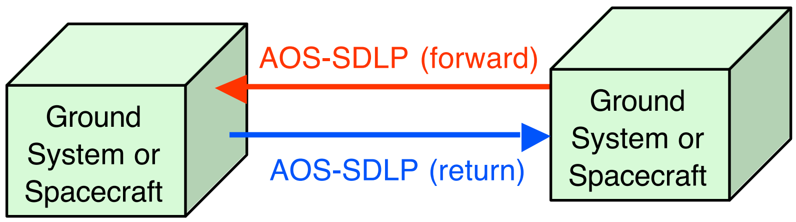
If we suppose that a space link consists of one forward Physical Link and one return Physical Link, there are three combinations of Space Data Link Protocols that are frequently used by space missions (see figure 2-2). Combination (a) of figure 2-2 has been used by most missions, while combination (b) is used by missions that require extended features provided by AOS-SDTP for the return Physical Link. Combination (c) is used by missions such as



(a) TC-SDLP and TM-SDLP



(b) TC-SDLP and AOS-SDLP



(c) AOS-SDLP for both directions

piloted missions that need two-way on-line communications between the spacecraft and the ground system.

2.3 LAYER ARCHITECTURE

Figure 2-3 shows how the Space Data Link Protocols are used with other protocols of other layers and how they are related with the OSI Basic Reference Model (reference [6]).

CCSDS defines two Sublayers in the Data Link Layer of the OSI Model: the Data Link Protocol Sublayer and the Synchronization and Channel Coding Sublayer. The Space Data Link Protocols belong to the Data Link Protocol Sublayer, which specifies methods of transferring data supplied by the higher layer over a space link using data units known as Transfer Frames. The Synchronization and Channel Coding Sublayer specifies methods for reliably transferring Transfer Frames over noisy space links, which include methods of delimiting and synchronization of Transfer Frames and methods of error correction and/or detection.

CCSDS has developed two standards for the Synchronization and Channel Coding Sublayer: the TC Synchronization and Channel Coding Recommendation (reference [8]) and the TM Synchronization and Channel Coding Recommendation (reference [9]). When the TC Space

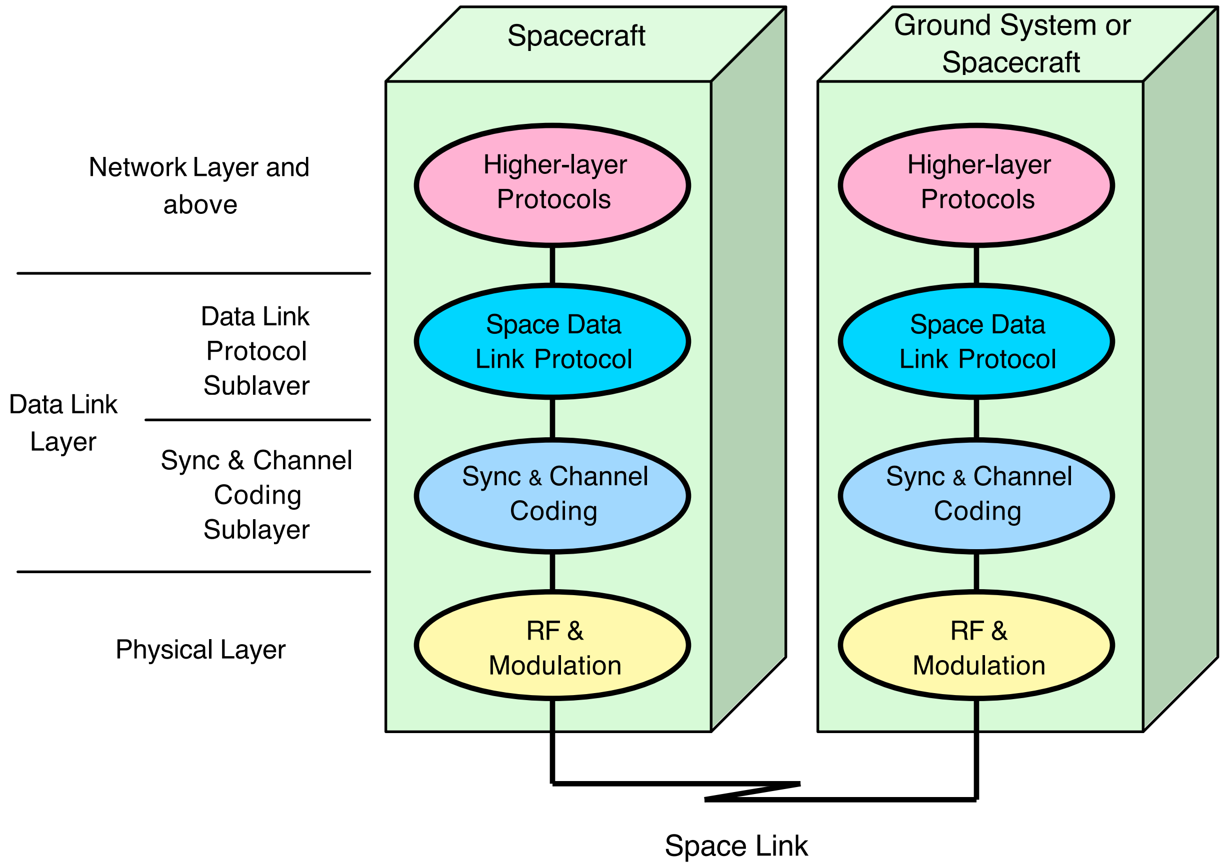


Figure 2-3: Layer Architecture

Data Link Protocol is used, the TC Synchronization and Channel Coding Recommendation must be used for the Synchronization and Channel Coding Sublayer. Likewise, when the TM or AOS Space Data Link Protocol is used, the TM Synchronization and Channel Coding Recommendation must be used for the Synchronization and Channel Coding Sublayer.

Below the Synchronization and Channel Coding Recommendations, Physical Layer protocols (for example, the CCSDS RF and Modulation Systems defined in reference [10]) are used to transmit delimited and coded Transfer Frames over space links.

Above the Space Data Link Protocols, higher-layer protocols belonging to the Network Layer and above use the services provided by the Space Data Link Protocols. Most of these higher-layer protocols are end-to-end protocols and are responsible for transferring data from end to end across the entire network, which contains the space link.

How the Space Data Link Protocols should be used in the entire space data system is explained in reference [11].

3 WHAT DO THE SPACE DATA LINK PROTOCOLS PROVIDE? - *FROM USERS' PERSPECTIVE*

3.1 SERVICES

The Space Data Link Protocols provide protocols of the Network and higher Layers with services to transfer data over a space link. The entities (i.e., the elements that implement communications protocols) of the Space Data Link Protocols are called service providers and the entities that use services are called service users.

A service provided by a service provider (an entity of a Space Data Link Protocol) transfers data supplied by a service user (sending user) to another service user (receiving user) over a space link (see figure 3-1). In doing this, the Space Data Link Protocol uses the capabilities of the Synchronization and Channel Coding Sublayer and the Physical Layer as explained in 2.3. However, the and the physical characteristics of the space link are invisible to the service users.

The point at which a service is provided by a service provider for a service user is called a Service Access Point (SAP). Each SAP has a SAP address, and the service user that uses the service through the SAP is also identified by the SAP address. In figure 3-1, there are two SAPs: one for the sending user and the other for the receiving user. In this case, these two SAPs share the same SAP address because these SAPs provide the same service to the sending and receiving users.

The sending user of a service passes Service Data Units (SDUs) and some control information (CI) to the service provider. The SDUs are the data that are delivered to the receiving user.

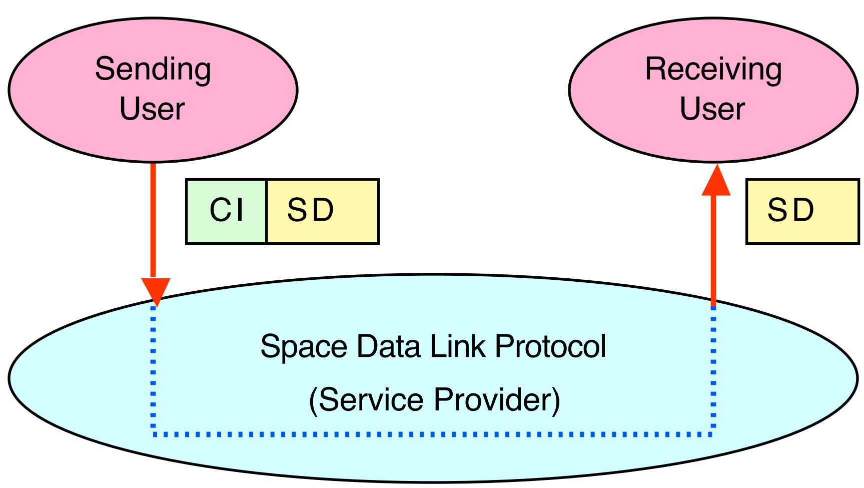


Figure 3-1: A Service Provided by a Space Data Link Protocol

The control information is used to specify how the SDUs should be handled by the service provider.

In the case of TC-SDLP, the sending user may receive from the service provider information on the status of the delivery of SDUs to the receiving user.

The interactions between a service user and a service provider are defined in the form of "primitives". Primitives present an abstract model of the logical exchange of SDUs and control information between the service provider and the service user, but they do not specify how the interactions should be implemented.

3.2 SERVICE FEATURES

3.2.1 DIRECTIONALITY

All the services provided by the Space Data Link Protocols are unidirectional. The sending user of a service can send data to the receiving user using a service provider (i.e., an entity of a Space Data Link Protocol), but it cannot receive data from the receiving user using the same service provider (see figure 3-1). If the sending user requires to receive data as well from some user, it must use a service of a different service provider (of the same or a different Space Data Link Protocol) that provides services in the other direction.

3.2.2 RELIABILITY

The reliability guaranteed by the services depends on the protocol used and, in some cases, the service type selected by the user.

3.2.2.1 Reliability Provided by TC-SDLP

Most of the services provided by the TC Space Data Link Protocol (TC-SDLP) have two service types: the Sequence-Controlled Service (or the Type-A Service) and the Expedited Service (or the Type-B Service). The service types determine how reliably the Service Data Units supplied by the sending user are delivered to the receiving user.

Sending users of a service which has two service types specify for each Service Data Unit whether Type-A or Type-B should be applied.

3.2.2.1.1 Sequence-Controlled (Type-A) Service

The Type-A Service utilizes an Automatic Repeat Request (ARQ) procedure of the ‘go-back-*n*’ type, which is called the Communications Operation Procedure-1 (COP-1) and specified in reference [4]. COP-1 is implemented by sequence-control mechanisms, which include retransmissions of lost data, at both sending and receiving ends of the space link. It also uses a standard report returned from the receiving end to the sending end using a service of the protocol used in the other direction on the space link.

The service provider guarantees, with a high probability, complete, in-sequence delivery of Type-A Service Data Units supplied by a sending user at a single SAP (i.e., no Service Data Unit is lost, duplicated or delivered out of sequence). However, there is no guarantee that Type-A Service Data Units supplied at multiple SAPs by multiple sending users will be delivered to the receiving users in the order initially supplied.

3.2.2.1.2 Expedited (Type-B) Service

The Type-B Service is normally used either in exceptional operational circumstances, typically during spacecraft recovery operations, or when a higher layer protocol provides a retransmission capability.

For the Type-B Service, Service Data Units supplied by the sending user are transmitted only once (i.e., no retransmission is performed). The service provider does not guarantee that all Type-B Service Data Units are delivered to the receiving user. However, the sequence of Service Data Units supplied by the sending user at a SAP is preserved through the transfer over the space link, although there may be gaps in the sequence of Service Data Units delivered to the receiving user.

3.2.2.2 Reliability Provided by TM-SDLP and AOS-SDLP

Neither the TM Space Data Link Protocol (TM-SDLP) nor the AOS Space Data Link Protocol (AOS-SDLP) does not guarantee completeness of the Service Data Units delivered to the receiving users, but some services may signal gaps in the sequence of delivered Service Data Units. These protocols do not provide the sending users with a confirmation that data has been received by the receiving users.

The sequence of Service Data Units supplied by the sending user at a SAP is preserved through the transfer over the space link, although there may be gaps in the sequence of Service Data Units delivered to the receiving user. The order of Service Data Units submitted to different SAPs is not maintained.

3.2.3 PRIORITY AND LATENCY

The mechanism used by the Space Data Link Protocols for transferring data with different priority and latency requirements is the use of 'Virtual Channels'. The Virtual Channel facility allows one Physical Channel to be divided into multiple separate logical data channels, each known as a Virtual Channel (VC). Each Virtual Channel carries a separate sequence of Service Data Units, which may have different priority and latency requirements from those carried on the other Virtual Channels.

By using an appropriate algorithm for multiplexing Virtual Channels onto the Physical Channel, the priority and latency requirements of Service Data Units can be met to some extent (see 4.2). CCSDS does not recommend any standard algorithm for multiplexing Virtual Channels. It is the responsibility of the project to ensure that the multiplexing algorithm used for that project actually satisfies the requirements.

The TC-SDLP optionally uses MAP (Multiplexer Access Point) Channels to multiplex different sequences of Service Data Units, each of which may have different priority and latency requirements, onto one Virtual Channel. CCSDS does not recommends any standard algorithm for multiplexing MAP Channels, and it is the responsibility of the project to ensure that the multiplexing algorithm used for that project actually satisfies the requirements.

3.2.4 TRANSFER TIMING

The timing at which Service Data Units supplied by the sending users are transferred over the space link and delivered to the receiving users differs depending on the protocol and the service.

3.2.4.1 Transfer Timing of TC-SDLP

The TC Space Data Link Protocol does not specify any rules for the timing of the transfer of Service Data Units supplied by the sending user. The user may submit Service Data Units at any time, but the timing of actual data transfer is determined by the service provider in accordance with mission-specific rules (such as multiplexing algorithms) and may depend on the data traffic at the time of transfer.

3.2.4.2 Transfer Timing of TM-SDLP and AOS-SDLP

The TM and AOS Space Data Link Protocols have three service types (asynchronous, synchronous, and periodic) that determine the timing at which Service Data Units supplied by the sending user are transferred over the space link.

3.2.4.2.1 Asynchronous Service

In asynchronous service, there are no timing relationships between the submission of Service Data Units by the service user and their transfer by the service provider over the space link. The sending user may request data transfer at any time, but the timing of actual data transfer is determined by the service provider in accordance with mission-specific rules (such as multiplexing algorithms) and may depend on the data traffic at the time of transfer.

In this service type (figure 3-2), each Service Data Unit from a sending user is placed in a queue, the contents of which are sent to a receiving user in the order in which they were presented. Although transmission errors may prevent delivery of some Service Data Units,

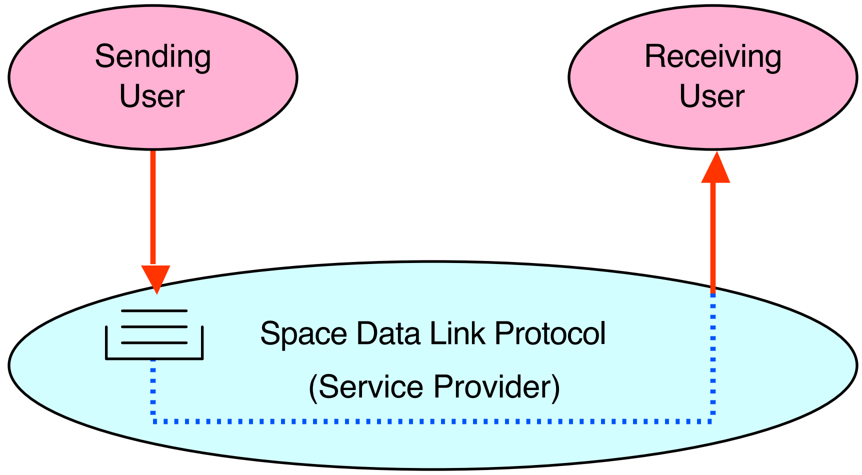


Figure 3-2: Asynchronous Service Model

the service provider attempts to transfer all Service Data Units provided by the sending user exactly once. The key feature of this service type is that all of the Service Data Units from the sending user are transferred, and transferred only once.

3.2.4.2.2 Synchronous Service

In synchronous service, the transfer of Service Data Units is synchronized with the release of Transfer Frames associated with the service by the service provider. (Transfer Frames are Protocol Data Units of the Space Data Link Protocols and will be explained in 4.1). The transfer timing may be periodic or aperiodic (not periodic).

In this service (figure 3-3), each Service Data Unit from a sending user is placed in a buffer that can hold only one Service Data Unit; the content of the buffer is sent to a receiving user

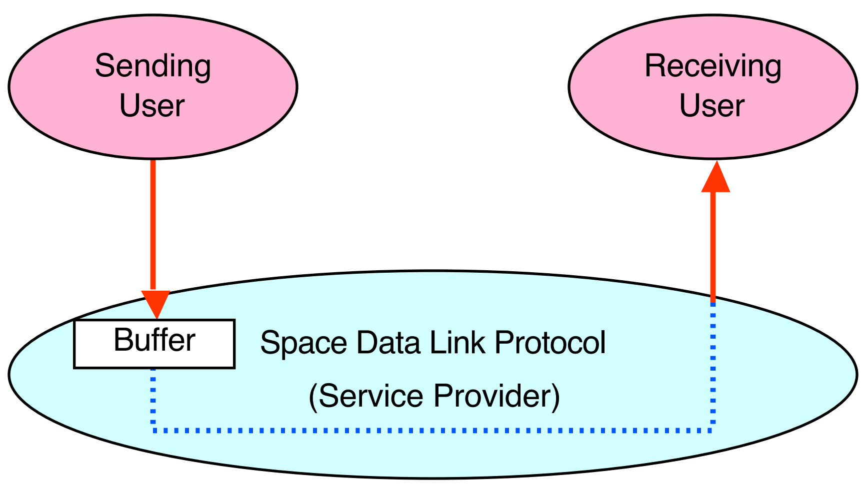


Figure 3-3: Synchronous Service Model

at the time when a Transfer Frame associated with the service is transmitted. The transmission timing of Transfer Frames is determined by the service provider according to mission-specific rules (which are usually known to the user). The key feature of this service type, which is essentially time-division multiplexing, is that the timing of data transfer is driven by the transfer mechanism, not by individual service requests from the user. Thus a particular Service Data Unit from a sending user might be sent once, several times (if the 'new' value is not placed in the buffer soon enough), or not at all (if one value is replaced by a second before the service provider can send it).

3.2.4.2.3 Periodic Service

Periodic service is a special case of synchronous service in which Service Data Units are transferred at a constant rate. Periodic transfer from service interface to service interface is provided with a specified maximum delay and a specified maximum jitter at the service interface. A synchronous service is periodic if the Channel associated with the service (which is either a Virtual Channel or a Master Channel) transfers Service Data Units at a constant rate. (Virtual Channels and Master Channels are logical data channels established over a space link and will be explained in 4.2 and 4.3, respectively).

For periodic services, all Service Data Units are sent only once if the sending user supplies Service Data Units at the same rate as the rate at which the service provider transfers them.

3.2.5 CHANNELS

For each instance of a service, Service Data Units are transferred over a Channel (either a Physical Channel, a Master Channel, a Virtual Channel, or a MAP Channel (TC-SDLP only)). In addition to the Virtual Channels and MAP Channels explained in 3.2.3, the Space Data Link Protocols use Physical Channels and Master Channels. Physical Channels are explained in 2.2. A Master Channel is a set of Virtual Channels associated with one spacecraft. In most cases, a Physical Channel has only one Master Channel, but it may consist of multiple Master Channels. For explanation on how these Channels are identified and multiplexed, see 4.3.

3.3 SERVICES PROVIDED BY THE SPACE DATA LINK PROTOCOLS

Table 3-1 shows the services provided by the Space Data Link Protocols categorized by the types of Service Data Units (SDUs) transferred by the services.

Table 3-1: Services Provided by the Space Data Link Protocols

Type of Service Data Units	TC Space Data Link Protocol	TM Space Data Link Protocol	AOS Space Data Link Protocol
Packets	MAP Packet Service, VC Packet Service, Encapsulation Service	Packet Service, Encapsulation Service	Packet Service, Encapsulation Service
Fixed-length private data	(None)	VC Access Service	VC Access Service
Variable-length private data	MAP Access Service, VC Access Service	(None)	(None)
Short fixed-length data	(None)	VC FSH Service, MC FSH Service, VC OCF Service, MC OCF Service	Insert Service, VC OCF Service
Bit stream	(None)	(None)	Bitstream Service
Transfer Frames	VC Frame Service, MC Frame Service	VC Frame Service, MC Frame Service	VC Frame Service, MC Frame Service

3.3.1 SERVICES TO TRANSFER PACKETS

The Space Data Link Protocols provide services for transferring various types of Service Data Units on space links, but the most important services are those for transferring variable-length data units commonly known as Packets, that is, Protocol Data Units of protocols of the Network Layer, such as the Space Packet Protocol (reference [12]), SCPS-NP (reference [13]) and IP (reference [14]).

Each packet format transferred by the Space Data Link Protocols must have a Packet Version Number (PVN) authorized by CCSDS. A list of the Packet Version Numbers presently authorized by CCSDS is contained in reference [15]. A user of this service is a protocol entity that sends or receives Packets with a single PVN.

3.3.1.1 Services to Transfer Packets Provided by TC-SDLP

The TC-SDLP has two services for transferring packets: the MAP (Multiplexer Access Point) Packet Service (or the MAPP Service) and the Virtual Channel Packet Service (or the VCP Service). These services transfer a sequence of Packets over a space link on a MAP Channel (in the case of the MAPP Service) or a Virtual Channel (in the case of VCP Service).

Both Sequence-Controlled (Type-A) and Expedited (Type-B) service types (see 3.2.2.1) are provided for these services. The sending user specifies for each Packet whether Type-A or Type-B should be applied.

Different users (i.e., Packets with different PVNs) can share a single MAP Channel (in the case of the MAPP Service) or a single Virtual Channel (in the case of the VCP Service), and if there are multiple users on a MAP or VC Channel, the service provider multiplexes Packets with different PVNs to form a single stream of Packets to be transferred on that Channel.

3.3.1.2 Service to Transfer Packets Provided by TM-SDLP and AOS-SDLP

The TM-SDTP and AOS-SDTP each have a service called the Packet Service for transferring Packets. A sequence of Packets supplied by a sending user is transferred on a single Virtual Channel.

These services do not guarantee complete delivery of the Packets supplied by the sending user to the receiving user, nor do they signal gaps in the sequence Packets delivered to the receiving user.

Different users (i.e., Packets with different PVNs) can share a single Virtual Channel, and if there are multiple users on a Virtual Channel, the service provider multiplexes Packets with different PVNs to form a single stream of Packets to be transferred on that Virtual Channel.

3.3.2 ENCAPSULATION SERVICE

Packets with authorized Packet Version Numbers can be directly transferred by the Space Data Link Protocols using the services explained in 3.3.1. Packets that do not have an Packet Version Number can be transferred with a service called the Encapsulation Service, defined in reference [16]. With this service, Packets are transferred encapsulated in either Space Packets defined in reference [12] or Encapsulation Packets defined in reference [16].

This service can be used with any Space Data Link Protocol and it uses a service to transfer Packets provided by the underlying Space Data Link Protocol.

3.3.3 SERVICES TO TRANSFER PRIVATE DATA

The Space Data Link Protocols provide services to transfer sequences of privately formatted Service Data Units (i.e., Service Data Units not formatted as Packets).

3.3.3.1 Services to Transfer Private Data Provided by TC-SDLP

The TC-SDLP provides two services to transfer sequences of privately formatted Service Data Units: the MAP Access (MAPA) Service and the Virtual Channel Access (VCA) Service.

The MAPA and VCA Services transfer sequences of privately formatted Service Data Units of variable length across a space link over a MAP Channel and a Virtual Channel, respectively.

The length of the Service Data Units transferred by these services is constrained by the length of the Transfer Frames (see 4.1) used by the service provider.

Both Sequence-Controlled (Type-A) and Expedited (Type-B) service types (see 3.2.2.1) are provided for these services. The sending user specifies for each Service Data Unit whether Type-A or Type-B should be applied.

In a Virtual Channel that provides the VCA Service, only one user can use this service, and Service Data Units from different users are not multiplexed together within the Virtual Channel. In a MAP Channel that provides the MAPA Service, only one user can use this service, and Service Data Units from different users are not multiplexed together within the MAP Channel.

3.3.3.2 Services to Transfer Private Data Provided by TM-SDLP and AOS-SDLP

The TM-SDLP and AOS-SDLP each provide a service called the Virtual Channel Access (VCA) Service that transfers a sequence of privately formatted Service Data Units of fixed length over a Virtual Channel across a space link. The length of the Service Data Units transferred by this service is determined by the length of the Transfer Frames (see 4.1) used by the service provider.

The VCA Service is either asynchronous (see 3.2.4.2.1) or periodic (see 3.2.4.2.3). The service does not guarantee completeness, but it may signal gaps in the sequence of Service Data Units delivered to the receiving user.

In a Virtual Channel that provides the VCA Service, only one user can use this service, and Service Data Units from different users are not multiplexed together within the Virtual Channel.

3.3.4 SERVICES TO TRANSFER SHORT, FIXED-LENGTH DATA

The TM-SDLP and AOS-SDLP provide services to transfer sequences of short, fixed-length Service Data Units. These services are used to transfer, at relatively short intervals, data used for spacecraft operations (for example, reports on command reception or data used for clock calibration). These services are synchronous (see 3.2.4.2.2)

3.3.4.1 Services to Transfer Short, Fixed-Length Data Provided by TM-SDLP

The TM-SDLP provides four services to transfer sequences of short, fixed-length Service Data Units: the Virtual Channel Frame Secondary Header (VC_FSH) Service, the Virtual Channel Operational Control Field (VC_OCF) Service, the Master Channel Frame Secondary Header (VC_FSH) Service and the Master Channel Operational Control Field (VC_OCF) Service.

The VC_FSH and VC_OCF Services provide transfer of fixed-length Service Data Units synchronized with the release of Transfer Frames of a Virtual Channel. The MC_FSH and MC_OCF Services provide transfer of fixed-length Service Data Units synchronized with the release of Transfer Frames of a Master Channel.

These services do not guarantee completeness but may signal gaps in the sequence of Service Data Units delivered to the receiving user.

In a Virtual or Master Channel that provides one of the above services, only one user can use this service, and Service Data Units from different users are not multiplexed together within the Virtual or Master Channel. However, one or more users of the Packet or Virtual Channel Access Service may coexist in the Virtual or Master Channel used to support this service.

3.3.4.2 Services to Transfer Short, Fixed-Length Data Provided by AOS-SDLP

The AOS-SDLP provides two services to transfer sequences of short, fixed-length Service Data Units: the Virtual Channel Operational Control Field (VC_OCF) Service and the Insert Service.

The VC_OCF Service provides transfer of fixed-length Service Data Units synchronized with the release of Transfer Frames of a Virtual Channel. The Insert Service provides transfer of fixed-length Service Data Units synchronized with the release of Transfer Frames of a Physical Channel.

These services do not guarantee completeness but may signal gaps in the sequence of Service Data Units delivered to the receiving user.

In a Virtual Channel that provides the VC_OCF Service or in a Physical Channel that provides the Insert Service, only one user can use this service, and Service Data Units from different users are not multiplexed together within the Virtual or Physical Channel. However, one or more users of the Packet or Virtual Channel Access Service may coexist in the Virtual or Physical Channel used to support this service.

3.3.5 SERVICES TO TRANSFER FRAMES

The Space Data Link Protocols each have two services to transfer Transfer Frames over a space link: the Virtual Channel Frame (VCF) Service and the Master Channel Frame (MCF) Service. As will be explained in 4.1, Transfer Frames are Protocol Data Units of the Space Data Link Protocols and therefore should be generated within the Space Data Link Protocols. Therefore, these services are used to provide functions for different entities of the same protocol, not for entities of protocols of higher layers. In this sense, these services are not services as defined by the OSI Basic Reference Model (reference [6]), but CCSDS has been using the word 'service' to mean functions provided for entities of the same protocol as well.

The VCF (or MCF) Service provides transfer of a sequence of Transfer Frames, created by an independent protocol entity of the same protocol, on a Virtual (or Master) Channel across a space link.

In a Virtual or Master Channel that provides the VCF or MCF Service, only one user can use the service, and Service Data Units from different users are not multiplexed together within the Virtual or Master Channel.

The VCF and MCF Services provided by the TC-SDLP do not guarantee completeness. The service provider do not make any distinction between Type-A and Type-B Services (see 3.2.2.1) for Service Data Units supplied by the user. The user should perform necessary procedures to provide Type-A and Type-B Services.

The VCF and MCF Services provided by the TM-SDLP and AOS-SDLP do not guarantee completeness, but it may signal gaps in the sequence of Service Data Units delivered to the receiving user. Transfer Frames supplied as Service Data Units to these services must have the same length as those generated by the service provider.

3.4 TYPICAL EXAMPLE

Figure 3-4 shows an example of how the TM Space Data Link Protocol provides users with services for transferring various type of data over a space link.

In this example, there are three sending users onboard a spacecraft and three receiving users on the ground, each receiving user corresponding to one of the sending users. (1) An onboard entity of the Space Packet Protocol sends urgent and non-urgent Packets to a ground entity of the same protocol over the space link. Onboard the spacecraft and on the ground, there may be other entities of the Space Packet Protocol that are not shown in the figure, but they are

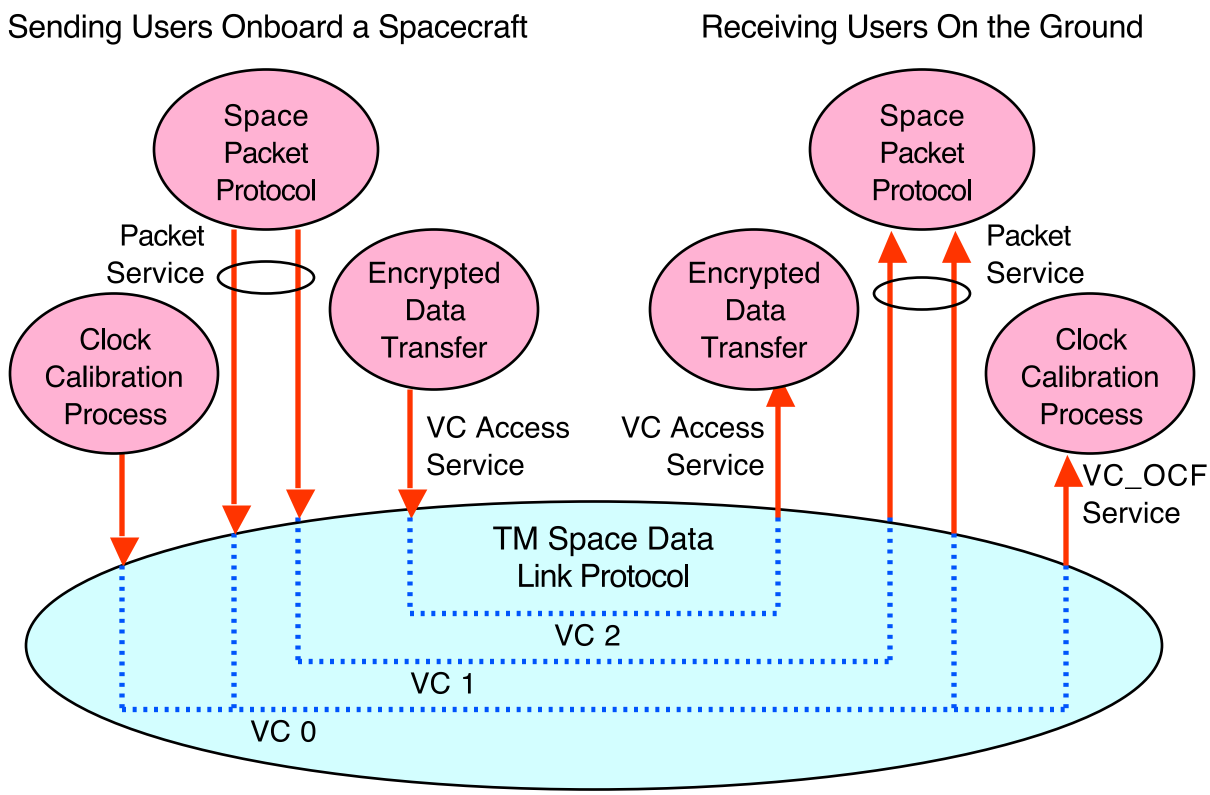


Figure 3-4: Example of How TM-SDLP Provides Services

connected via onboard and ground links (or sub-networks), respectively, and how they communicate within these links (or sub-networks) is outside the scope of this document. (2) An onboard process for calibrating the onboard clock needs to send the current value of the onboard clock to the corresponding process on the ground so that the ground process can calibrate the onboard clock against the ground clock. (3) A stream of encrypted data whose structure is unknown to the TM-SDLP needs to be sent over the space link.

The sequence of urgent and non-urgent Packets are transferred with two instances of the Packet Service, each on a different Virtual Channel (urgent Packets on VC 0 and non-urgent Packets on VC1 in this case). It will be explained in 4.2 how the traffic on these two Virtual Channels is handled and how their quality of service is controlled.

Since the clock calibration data is short and of a fixed-length, it is transferred with the VC_OCF Service, one of the services for transferring a sequence of short, fixed-length Service Data Units. In this example, VC 0 is chosen for transferring clock calibration data.

The mechanism used in this example for transferring a stream of encrypted data, multiplexed with the other data, is to use the VC Access Service on Virtual Channel 2, which is dedicated to the transfer of encrypted data. The sending user generates a sequence of chunks of fixed-length from the stream of encrypted data and supplies them to the service provider as Service Data Units, which are delivered to the receiving user for decryption.

4 WHAT DO THE SPACE DATA LINK PROTOCOLS PERFORM? - *FROM DEVELOPERS' PERSPECTIVE*

4.1 TRANSFER FRAMES

The Protocol Data Units exchanged between entities of the Space Data Link Protocols are called Transfer Frames. Transfer Frames used by the TC-SDLP, TM-SDLP and AOS-SDLP are called TC Transfer Frames, TM Transfer Frames, and AOS Transfer Frames, respectively. Each Transfer Frame consists of a header which provides protocol control information and a data field within which Service Data Units are carried.

4.1.1 TC TRANSFER FRAMES

The TC-SDLP uses variable-length Transfer Frames to facilitate reception of short messages with a short delay. The length of each TC Transfer Frame is contained in its header. The TC-SDLP uses another data unit called the Communications Link Control Word (CLCW). CLCWs are sent from the receiver to the sender of TC Transfer Frames and contain a report that describes the status of acceptance of TC Transfer Frames at the receiver. CLCWs are usually transferred with a service provided by the TM-SDLP or the AOS-SDLP.

4.1.2 TM AND AOS TRANSFER FRAMES

The TM-SDLP and AOS-SDLP use fixed-length Transfer Frames to facilitate simple, reliable, and robust synchronization procedures over weak-signal, noisy links. Their length must be fixed on a particular Physical Channel during a Mission Phase and must be known to the receiver through a management activity before the actual reception occurs. The length of Transfer Frames must be determined according to the rules specified in reference [9].

4.2 VIRTUAL CHANNELS

The mechanism used by the Space Data Link Protocols for transferring data with different QoS (Quality of Service, mostly priority and latency in this case) requirements is the use of Virtual Channels. The Virtual Channel facility allows one Physical Channel to be divided into multiple separate logical data channels, each known as a Virtual Channel (VC) and identified by a Virtual Channel Identifier (VCID) (see figure 4-1). Each Virtual Channel carries a separate sequence of Service Data Units, which may have different QoS requirements from those carried on the other Virtual Channels. Each Transfer Frame transferred over a Physical Channel belongs to one of the Virtual Channels of the Physical Channel.

Figure 4-2 shows an example that illustrates how Virtual Channels are used to transfer Packets with different QoS requirements. The Physical Channel has two Virtual Channels:

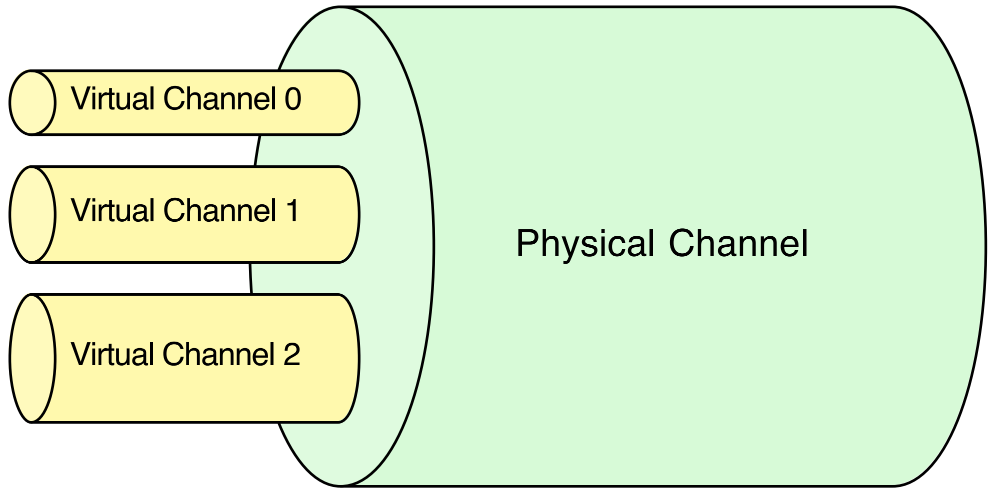


Figure 4-1: Virtual Channels

VC 0 for priority traffic and VC 1 for normal traffic. In figure 4-2, a long, non-urgent Packet (for memory upload or download, for example) is being transmitted on Virtual Channel 1. Since this Packet is longer than what can be carried by the maximum-size Transfer Frame (if the TC-SDTP is used) or the fixed-length Transfer Frame (if the TM-SDTP or AOS-SDTP is used), it is carried by two consecutive Transfer Frames of Virtual Channel 1. Then, when the first Transfer Frame carrying this non-urgent Packet is being transmitted, a short, urgent Packet (carrying an on-off command or an event report, for example) is generated. Since this urgent Packet needs to be transmitted as soon as possible, a Transfer Frame of Virtual Channel 0 is generated to carry this urgent Packet and inserted between the first and second Transfer Frames of Virtual Channel 1 that carry the non-urgent Packet. To use this kind of algorithm, a buffer memory with a sufficient capacity to temporarily store Service Data Units

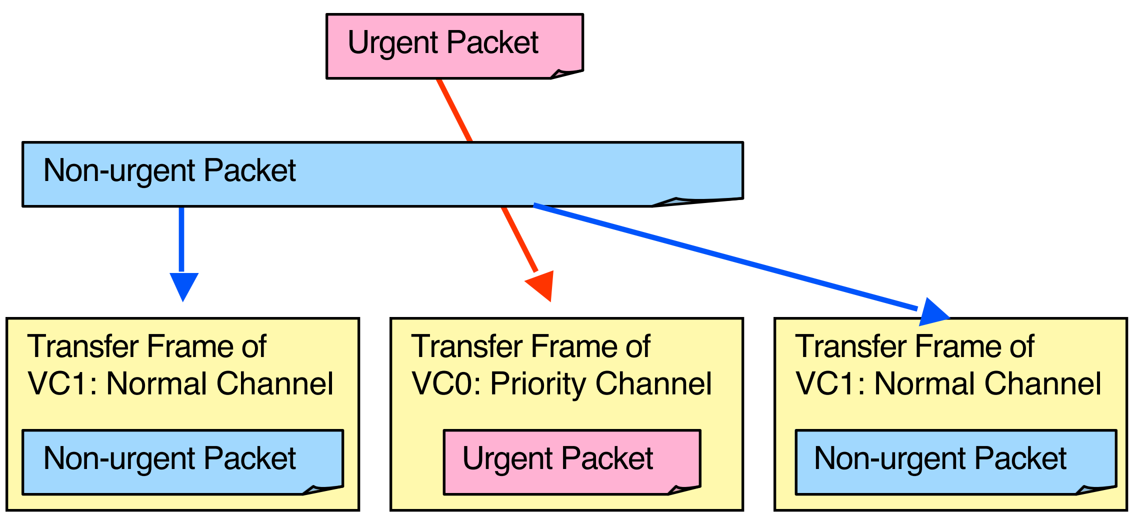


Figure 4-2: An Example of How to Use Virtual Channels

and/or Transfer Frames must be implemented in the service provider.

By using a proper algorithm for multiplexing Transfer Frames of different Virtual Channels, the QoS requirements of Service Data Units can be met to some extent. However, CCSDS does not recommends any standard algorithm for multiplexing Virtual Channels. It is the responsibility of the project to devise a multiplexing algorithm that satisfies their QoS requirements.

4.3 ADDRESSING AND MULTIPLEXING

The Space Data Link Protocols use some addresses or identifiers to identify data streams. All the Space Data Link Protocols use the following identifiers: the Transfer Frame Version Number (TFVN), the Spacecraft Identifier (SCID), the Virtual Channel Identifier (VCID) (explained in 4.2), the Master Channel Identifier (MCID), and the Physical Channel Name. In addition to these identifiers, the TC-SDLP optionally uses an identifier called the Multiplexer Access Point Identifier (MAP ID).

Figure 4-3 shows the hierarchy of these identifiers and the channels identified by them.

4.3.1 TRANSFER FRAME VERSION NUMBER

The Transfer Frame Version Number (TFVN) is used to distinguish among different Transfer Frames. The values for the TC, TM and AOS Transfer Frames are 1 (00), 1 (00), and 2 (01), respectively. The numbers in the parentheses are binary encoded values that actually appear in the header of Transfer Frames. The TC and TM Transfer Frames, which share the same

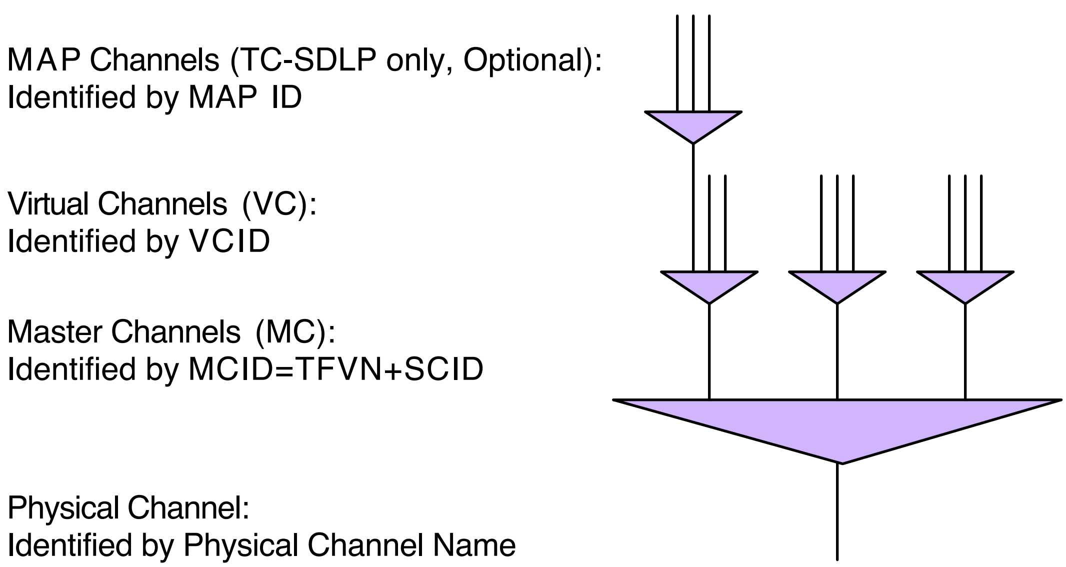


Figure 4-3: Hierarchy of the Identifiers and Channels used by the Space Data Link Protocols

TFVN value, are distinguished by the Start Sequence defined in reference [8] or the Attached Sync Marker defined in reference [9].

4.3.2 SPACECRAFT IDENTIFIER

The Spacecraft Identifier (SCID) is used to identify the spacecraft associated with the space link, but it must always be modified by the TFVN. In other words, there are a set of SCIDs for spacecraft that use the TC-SDLP and TM-SDLP and another set for spacecraft that use the AOS-SDLP. How the SCIDs should be assigned to spacecraft is specified in reference [17].

4.3.3 MASTER CHANNEL IDENTIFIER

The concatenation of a TFVN and a SCID is known as a Master Channel Identifier (MCID), and it is the identifier that uniquely identifies the spacecraft. All Transfer Frames with the same MCID on a Physical Channel constitute a Master Channel (MC). A Master Channel consists of one or more Virtual Channels, each of which is identified with a VCID. The concatenation of an MCID and a VCID is called a Global Virtual Channel Identifier (GVCID).

In most cases, a Physical Channel only carries Transfer Frames of a single MCID, and in these cases the Physical Channel is identical with the Master Channel identified with the MCID. But a Physical Channel may carry Transfer Frames with multiple MCIDs (with the same TFVN) and in these cases the Physical Channel consists of multiple Master Channels. That is, Transfer Frames associated with multiple spacecraft may be multiplexed into a single Physical Channel, but the length of all Transfer Frames must be the same if TM-SDLP or AOS-SDLP is used.

Transfer Frames of different Space Data Link Protocols must not be multiplexed on a Physical Channel.

4.3.4 PHYSICAL CHANNEL NAME

A Physical Channel is identified with a Physical Channel Name, which is set by management and not included in the header of Transfer Frames.

4.3.5 MULTIPLEXER ACCESS POINT IDENTIFIER

The TC-SDLP uses an optional identifier called the Multiplexer Access Point Identifier (MAP ID) that is used to create multiple streams of data within a Virtual Channel. All the Transfer Frames on a Virtual Channel with the same MAP ID constitute a MAP Channel. If the MAP ID is used, a Virtual Channel consists of one or multiple MAP Channels.

MAPs also provide the capability of segmenting Packets and must be used if Packets whose lengths exceed the maximum length that can be carried by Transfer Frames are to be transferred (see 4.5.1).

Both Virtual Channels and MAP Channels can be used for multiplexing streams of Service Data Units. The difference between Virtual Channels and MAP Channels is as follows. The retransmission control mechanism COP-1, which is explained in 4.4.1, is operated on each Virtual Channel, and if multiple Virtual Channels exist, multiple instances of COP-1 must be implemented, thus increasing the complexity of the retransmission mechanism. However, the MAP Channels in a Virtual Channel shares a single instance of COP-1 and the complexity of the retransmission mechanism can be kept to a minimum at the cost of using an extra identifier.

4.4 RETRANSMISSION

The TC-SDTP has the capability to retransmit lost or corrupted data to ensure delivery of Service Data Units in sequence, without gaps or duplication, over a space link. This capability is provided by a retransmission control mechanism called the Communications Operation Procedure-1 (COP-1), which is defined in reference [4] and explained in 4.4.1. This procedure only guarantees complete delivery of Service Data Units over the space link and if the Service Data Units traverse a larger network of which the space link is an element, COP-1 does not guarantee complete end-to-end delivery through the entire network.

Neither TM-SDLP nor AOS-SDLP has a retransmission capability, so retransmission must be done by a higher-layer protocol if complete delivery of data is required.

4.4.1 COMMUNICATIONS OPERATION PROCEDURE-1 (COP-1)

(There will be more explanation on COP-1 in the next issue of this document.)

4.5 TRANSFER OF PACKETS

How Packets are transferred with Transfer Frames differs depending on the Space Data Link Protocol. The following subsections provide an informal overview of the procedures for transferring Packets with Transfer Frames. The exact procedures are specified in the Recommendations (references [1], [2] and [3]).

4.5.1 TRANSFER OF PACKETS BY THE TC SPACE DATA LINK PROTOCOL

If MAPs (see 4.3.5) are used, Packets whose lengths exceed the maximum length that can be carried by Transfer Frames are transferred by dividing them (i.e., segmentation) into portions that are compatible with insertion into Transfer Frames. In this case, each Transfer Frame contains either a portion of a large Packet, a single complete Packet, or multiple complete

Packets. The portions of a divided Packet must be transferred in consecutive Transfer Frames of the MAP Channel without being interlaced with other Packets or portions of other Packets in the same MAP Channel.

If MAPs are not used, segmentation is not performed and each Transfer Frame contains either a single complete Packet or multiple complete Packets.

When extracting multiple Packets from a single Transfer Frame, the length field of the Packets is used. Therefore, the location and meaning of the length field of the Packets transferred over the space link must be known to the service provider.

4.5.2 TRANSFER OF PACKETS BY THE TM AND AOS SPACE DATA LINK PROTOCOLS

Packets are inserted into a Transfer Frame concatenated together until it is full. If a Packet exceeds the Transfer Frame length, it will be split, filling the Transfer Frame completely, and starting a new Transfer Frame on the same Virtual Channel with the remainder. Construction of the next Transfer Frame will continue with the concatenation of Packets until it overflows. The First Header Pointer field of the Transfer Frame will be set to indicate the location of the first octet of the first Packet occurring within the Transfer Frame.

The service provider may generate an Idle Packet in the absence of sufficient Packets supplied from the sending users to fill a Transfer Frame at release time. The format of the Idle Packet is defined by reference [12]. If it is necessary, the service provider may generate a Transfer Frame without any Packets using the methods specified in the Recommendations (references [2] and [3]).

At the receiving end, the service provider extracts Packets from Transfer Frames. The First Header Pointer of Transfer Frames will be used in conjunction with the length field of each Packet contained within the Transfer Frames to provide the delimiting information needed to extract Packets. Therefore, the location and meaning of the length field of the Packets transferred over the space link must be known to the service provider.

If the last Packet removed from the Transfer Frame is incomplete, the service provider retrieves its remainder from the beginning of the next Transfer Frame received on the same Virtual Channel. The First Header Pointer for the next Transfer Frame is used to determine the length of the remainder and, hence, the beginning of the next Packet to be extracted.

5 FREQUENTLY ASKED QUESTIONS ON THE SPACE DATA LINK PROTOCOLS

5.1 HOW DO THE SPACE DATA LINK PROTOCOLS DIFFER FROM HDLC?

One difference between the Space Data Link Protocols and HDLC is that the former assume that a powerful error coding method is used to protect data from errors induced while the physical signals are being transmitted across the space link and the frame structure is designed in such a way that synchronization and decoding of received data can be performed in an efficient way, while the latter does not take such things in account. Therefore, care must be taken if HDLC is to be used over a noisy space link so that its performance is not degraded too much by the errors that occur on the space link.

Another difference is that the frame structures used by the Space Data Link Protocols are upper-compatible with those of traditional (time division multiplexing) frame formats so that the base-band portion of the conventional receiving systems can be used to support the Space Data Link Protocols without any major modification.

5.2 ARE THE SPACE DATA LINK PROTOCOLS SECURE PROTOCOLS?

No. But how security can be implemented with these protocols is explained in reference [18].

5.3 IS THERE A STANDARD METHOD FOR MANAGING PARAMETERS SUCH AS (TM AND AOS) TRANSFER FRAME LENGTHS?

CCSDS is developing a standard method for managing such parameters as part of the Space Link Extension Service Management Recommendation. Please check the CCSDS web site for information on its development.

5.4 CAN COP-1 BE APPLIED TO DEEP SPACE COMMANDING AND BLIND COMMANDING?

(Answer to be provided in the next issue of this document.)

(Do you have more Frequently Asked Questions on the Space Data Link Protocols?)

ANNEX A

ACRONYMS

This annex lists the acronyms used in this Report.

AOS	Advanced Orbiting Systems
CCSDS	Consultative Committee for Space Data Systems
ID	Identifier
IP	Internet Protocol
MAP	Multiplexer Access Point
MC	Master Channel
PVN	Packet Version Number
SCID	Spacecraft Identifier
SLE	Space Link Extension
TC	Telecommand
TFVN	Transfer Frame Version Number
TM	Telemetry
VC	Virtual Channel

ANNEX B

SUMMARY OF SERVICES

(To be provided in the next issue of this document.)