The Consultative Committee for Space Data Systems

Report Concerning Space Data System Standards

SPACE PACKET PROTOCOLS

INFORMATIONAL REPORT

CCSDS 130.3-G-1

GREEN BOOK
April 2023

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Email: secretariat@mailman.ccsds.org

FOREWORD

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:

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1 INTRODUCTION

1.1 PURPOSE

This Report has been developed to present the concept and rationale of the CCSDS Packet Protocols:

a) the CCSDS Recommended Standard for Space Packet Protocol (SPP) (reference [1]); and

b) the CCSDS Recommended Standard for Encapsulation Packet Protocol (EPP) (reference [2]).

It has specifically been prepared to serve the following purposes:

a) to provide an introductory overview on the concept of both the SPP and EPP;

b) to provide information on how these protocols should be applied by end users to efficiently develop their mission systems (including onboard instruments and ground support systems);

c) to provide information on how these protocols should be deployed in space data systems to efficiently develop multi-mission infrastructures (including both onboard and ground infrastructures);

d) to describe the key distinctions between these protocols, so that both end users and developers are provided sufficient guidance in order to make the correct choice between implementing one or both protocols.

1.2 SCOPE

The information contained in this Report is not part of the CCSDS Recommended Standard for either the SPP (reference [1]) or the EPP (reference [2]). In the event of any conflict between these Recommended Standards and the material presented herein, the Recommended Standards shall prevail.

1.3 ORGANIZATION OF THIS REPORT

This document is divided into four numbered sections and an annex:

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 SPP is and how it may be applied by end users to transfer either Application Layer data directly to the Data Link Layer or used as a 'shim' protocol to enable the transfer of upper-layer Protocol Data Units (PDUs) to the Data Link Layer;

c) section 3 explains what the EPP is and how it may be applied by end users as a 'shim' protocol to encapsulate and transfer higher-layer PDUs recognized by CCSDS to the Data Link Layer;

d) section 4 presents several frequently asked questions concerning the SPP and the EPP, along with the rationale for choosing one over the other or for using both;

e) annex A lists abbreviations and acronyms used within this document.

1.4 DEFINITIONS

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

CCSDS packet protocols: CCSDS Space Packet Protocol and/or Encapsulation Packet Protocol.

destination user application: A *user application* (see below) that receives application data using the Space Packet Protocol.

Encapsulation Packet Protocol, EPP: A protocol, specified in reference [2], used to encapsulate higher-layer PDUs recognized by CCSDS over applicable ground-to-space, space-to-ground, or space-to-space communications links using Space Data Link Protocol (SDLPs). It is not a Network Layer protocol.

node: A physical entity used as a unit in a system.

source user application: A *user application* (see below) that sends application data using the Space Packet Protocol.

space link: A communications link between a spacecraft and its associated ground system or between two spacecraft.

Space Packet Protocol, SPP: A protocol specified in reference [1], which has been developed to transfer space application data from one user application to one or more user applications or to be used as a 'shim' protocol between the upper layer CCSDS protocol stack and the Space Data Link Layer protocols. It is not a Network Layer protocol.

Entity: A functional entity that performs all or a portion of the functions of the SPP or EPP.

Subnetwork: A local network that connects two or more SPP or EPP entities.

user application: A functional entity that sends or receives application data using the Space Packet Protocol.

1.5 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] *Space Packet Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 133.0-B-2. Washington, D.C.: CCSDS, June 2020.

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

[3] *TM Space Data Link Protocol*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 132.0-B-3. Washington, D.C.: CCSDS, October 2021.

[4] *TC Space Data Link Protocol*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 232.0-B-4. Washington, D.C.: CCSDS, October 2021.

[5] *AOS Space Data Link Protocol*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-4. Washington, D.C.: CCSDS, October 2021.

[6] *Proximity-1 Space Link Protocol—Data Link Layer*. Issue 6. Recommendation for Space Data System Standards (Blue Book), CCSDS 211.0-B-6. Washington, D.C.: CCSDS, July 2020.

[7] *Unified Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.1-B-2. Washington, D.C.: CCSDS, October 2021.

[8] *CCSDS File Delivery Protocol (CFDP)*. Issue 5. Recommendation for Space Data System Standards (Blue Book), CCSDS 727.0-B-5. Washington, D.C.: CCSDS, July 2020.

[9] *Licklider Transmission Protocol (LTP) for CCSDS*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 734.1-B-1. Washington, D.C.: CCSDS, May 2015.

[10] "Space Packet Protocol Secondary Header Format Document." Space Assigned Numbers Authority. https://sanaregistry.org/r/space_packet_protocol_secondary_header_format_document.

[11] *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.

[12] *CCSDS Bundle Protocol Specification*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 734.2-B-1. Washington, D.C.: CCSDS, September 2015.

[13] *IP over CCSDS Space Links*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 702.1-B-1. Washington, D.C.: CCSDS, September 2012.

[14] “Packet Version Number.” Space Assigned Numbers Authority. https://sanaregistry.org/r/packet_version_number.

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

[16] “Protocol Identifier for Encapsulation Service.” Space Assigned Numbers Authority. https://sanaregistry.org/r/protocol_id.

[17] “Extended Protocol Identifier for Encapsulation Packet Protocol.” Space Assigned Numbers Authority. https://sanaregistry.org/r/extended_protocol_id.

[18] “Internet Protocol Extension Header.” Space Assigned Numbers Authority. https://sanaregistry.org/r/ipe_header.

2 THE SPACE PACKET PROTOCOL FROM USERS' PERSPECTIVE

2.1 BASIC CONCEPTS OF SPACE PACKET PROTOCOL

2.1.1 SPP ARCHITECTURE

The SPP is designed as a self-delimited carrier of a data unit (i.e., a Space Packet) that contains an Application Process Identifier (APID) used to identify the data contents, data source, and/or data user within a given enterprise. A typical use would be to carry data from a specific mission source to a mission user. Different data types often require additional information (such as time) to fully utilize the contained data, and those parameters and the format of the data contents must be identified, in the mission context, by using the APID.

The SPP is designed to meet the requirements of space missions to efficiently transfer space application data of various types and characteristics between nodes over one or more onboard subnetworks, possibly involving one or more ground-to-space, space-to-ground, space-to-space, or onboard communication links.

Figure 2-1 illustrates where the SPP can be located in the protocol stack. The SPP is able to provide the functionality of an Application Layer protocol or a 'shim' protocol. For this reason, the SPP appears twice in the figure. At the Application Layer, the SPP defines the Space Packet, which can be used directly by the user to contain application data. Additionally, the SPP, similar to the EPP (reference [2]) can provide the functionality of a 'shim' protocol.

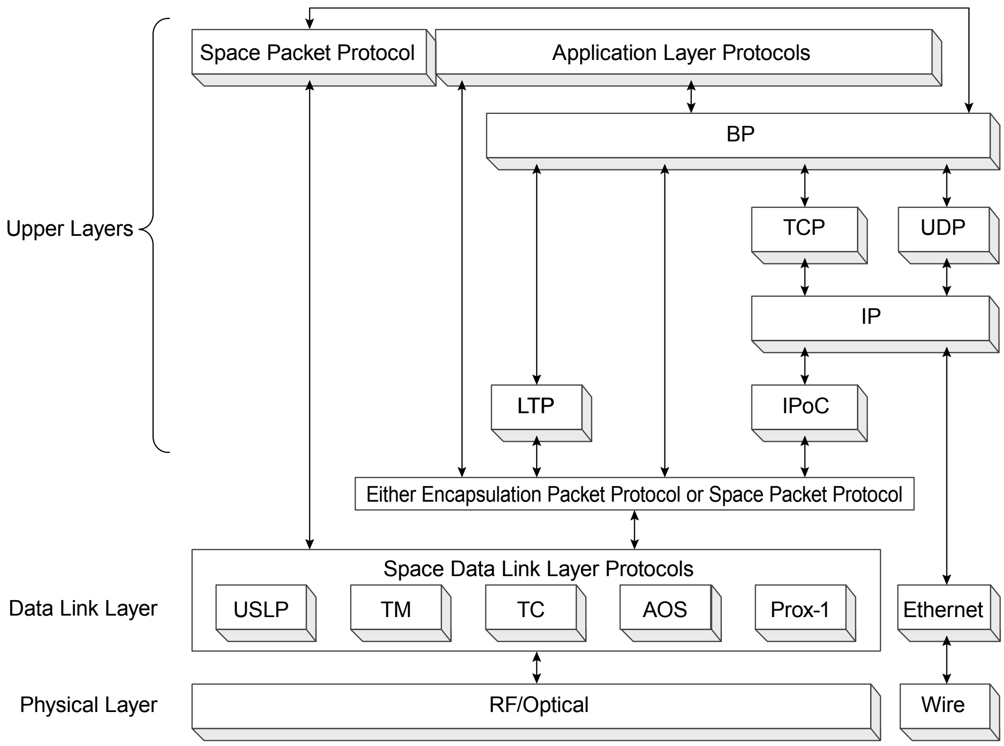

Figure 2-1: SPP Context within the CCSDS Protocol Stack

The identification of the meaning of APID as to source or destination and the path that the SPP will traverse are entirely determined by the assignment of mission-specific meaning within the context of any given deployment. Most importantly, the SPP itself defines no path, network, or routing functionality and does not provide network services. Furthermore, SPP itself has no networking capabilities and fully relies on the services provided by the applicable subnetworks.

Figure 2-1 illustrates the concept of the SPP within the CCSDS protocol stack when used over a space link. User data units are incorporated in Space Packets and are eventually transferred over a space link using either one of the Packet Services of an SDLP (references [3], [4], [5], [6], and [7]), including the Bundle Protocol (BP) service (reference [12]), which transmits a bundle to an identified bundle endpoint. Management establishes which underlying protocol and service is to be used to transfer PDUs. It should be noted that the Coding and Synchronization sublayer of the Data Link Layer is not explicitly shown in the figure.

The SPP provides a unidirectional data transfer service from a single source user application to one or more destination user applications through one or more subnetworks. The APID is the field in the packet primary header that uniquely identifies a stream of packets (indicates source, destination, or type).

The APID provides a single naming domain within a given mission deployment. The APID can be used in a variety of ways by a mission, depending on mission needs. It can be used to designate the intended destination for a stream of packets, to designate the source of a stream of packets, or to designate different types of packets. The ways that the APID are used, and the management of the APID naming domain, are mission-specific choices.

If missions wish to use the APID naming domain to service, for instance, a spacecraft that has multiple processors, a spacecraft that is 'fractionated', or even a mission that includes a deployment of multiple spacecraft, those spacecraft/missions must either manage and suballocate assignments in the single APID naming domain within the enterprise or define a way to extend it using mission-specific fields in the packet secondary header. This sort of extension is supported by the APID and the packet secondary header, but a standard APID domain naming service is not defined by CCSDS. Similarly, other mechanisms supported by transfer-frame-level services in the Space Data Link Layer protocols, such as virtual channel multiplexing/demultiplexing of transfer frames over a master channel, can be utilized.

As the data traverse the subnetworks, they are carried by subnetwork-specific mechanisms using protocols provided by the subnetworks. The selection of protocols used in the subnetworks is determined independently for each subnetwork and may not be the same throughout.

The actual path through the end-to-end data system through which the packets flow needs to be configured by design or by a management system before the data transfer occurs and can only be reconfigured through the management system. This flow is referred to as a managed data path; aside from the APID, the SPP does not define any of the mechanisms to define or manage a managed data path. Each managed data path may consist of a single source end system, one or more destination end systems, one or more subnetworks, and, if multiple subnetworks are involved, one or more intermediate systems that interconnect the subnetworks. A managed data path involves only one subnetwork only if the source and destination end systems are on the same subnetwork. The configuration details of the managed data path, and of any underlying transport services, are unknown to the SPP entity. These are all the responsibility of these underlying services, and the only information that SPP directly provides to assist in this is the APID field.

2.1.2 SPP PROTOCOL FEATURES

The SPP provides the users with abstract services to transfer space application data from a source to a destination user application. The primary function performed by this protocol is the identification and encapsulation of application data to facilitate its transfer along the managed data path through underlying subnetworks.

The PDUs employed by this protocol are Space Packets (unless otherwise stated, the term 'Packet' in this document refers to the Space Packet). They are variable in length (or may be fixed at the discretion of the user) and are transmitted at variable intervals. Aside from the SPP header that identifies the Packet, the internal data content of Space Packets is completely under the control of the user application. Each user application can define the organization and content of Packets independently of other user applications, with a minimum of constraints imposed by the transmission mechanisms of the underlying subnetworks.

The SPP entity at the source end system either generates Space Packets from Service Data Units (SDUs) supplied by the source user application or validates Space Packets provided as SDUs by the source user application. At the source system, the SPP entity examines the APID of incoming Space Packets and transfers them through appropriate subnetworks using the services provided by the underlying protocol and communication system. The behavior of intermediate nodes, and the processes to be used for forwarding data, are implementation specific and outside the scope of this document. If there are multiple destinations for a Space Packet, multicasting of Space Packets may be performed by one or more SPP entities at the source end system and/or intermediate system(s).

2.1.3 SPP ADDRESSING

The addressing feature within the SPP is the APID. APIDs are unique only in a single naming domain. An APID naming domain usually corresponds to a spacecraft (or an element of a constellation of cooperating space vehicles). Each space project establishes the allocation of APIDs to be used in its naming domain. The assignment of APIDs to managed data paths within a naming domain is controlled by the space project that owns the naming domain.

2.1.4 SPP PROTOCOL DESCRIPTION

The SPP is described in terms of

a) the abstract services provided to the users;

b) the PDUs; and

c) the procedures performed by the protocol.

The service definitions are given in the form of primitives, which present an abstract model of the logical exchange of data and control information between the protocol entity and the service user. The definitions of primitives are independent of specific implementation approaches.

The procedure specifications define the procedures performed by protocol entities for the transfer of information between peer entities. The definitions of procedures are independent of specific implementation methods or technologies.

2.2 COMMON FEATURES OF SPP SERVICES

The SPP provides users with data transfer services. The point at which a service is provided to a user by a protocol entity is called a Service Access Point (SAP) (see reference [15]). The SAP of the SPP entity accepts SPP SDUs identified with an APID.

SDUs submitted to a SAP are processed in the order of submission. No processing order is maintained for SDUs submitted to different SAPs.

NOTE – Flow control between the service user and the service provider may be required at a SAP. However, CCSDS does not define a flow-control scheme between user and provider.

The categories of services in the Recommended Standard include the following:

a) Preconfigured services: the user can send or receive data only through a preconfigured managed data path that is established by management.

b) Unidirectional (one way) services: one end of the managed data path can send but not receive data through the path, while the other end can receive but not send.

c) Asynchronous services: there are no predefined timing rules for the transfer of SDUs supplied by the service user. The user may request data transfer at any time, but there may be restrictions imposed by the provider implementation on the data generation rate.

d) Unconfirmed services: the sending user does not receive confirmation from the receiving end that data has been received.

e) Incomplete services: the services do not guarantee completeness of a sequence of SDUs, nor do they provide a retransmission mechanism.

f) Non-sequence-preserving services: the sequence of SDUs supplied by the sending user may not be preserved through the end-to-end managed data path.

NOTE – This protocol may be used for sending data from user A to user B and from user B to user A, but two separate managed data paths, one for each direction, should be used in such cases.

The actual end-to-end quality of service provided to service users will vary according to the individual qualities of service provided by the various subnetworks and links along the managed data path. The SPP does not provide any mechanisms for guaranteeing a particular quality of service; it is the responsibility of implementing organizations to ensure that the end-to-end performance of a particular service instance meets the requirements of its users.

2.3 BENEFITS OF THE SPACE PACKET PROTOCOL

2.3.1 INDEPENDENCE

Before the Space Packet Protocol was specified, many activities on board the spacecraft had to be synchronized with the process of generating telemetry frames, and coordination on telemetry generation rate and timing among the instruments on board the same spacecraft was necessary. However, the SPP hides such physical mechanisms from user applications because it is independent of the data transfer methods of the underlying subnetworks as explained in 2.1. By using the SPP, developers of instruments can design onboard applications almost independently of the underlying data transfer mechanisms and of the activities of the other instruments on the same spacecraft. Therefore instrument developers have more freedom in designing instrument data systems.

Independence from the data transfer methods of the underlying subnetworks also enables sharing or reusing of user applications among different projects that may not use the same technologies in the subnetworks. Further, the SPP can be used as a basis for developing standard applications that do not depend on specific projects. Therefore it is anticipated that the SPP will greatly contribute to the reduction of the development cost of space missions.

2.3.2 FLEXIBILITY

The Space Packet Protocol can be used to transfer any kind of application data virtually at any rate and timing. There are, of course, constraints on the transfer rate and timing imposed by the capabilities of the underlying subnetworks, but, within the resource allocation determined by the project management, user applications can send any kind of application data (commands, operation plans, housekeeping telemetry, science data, memory uploads/downloads, etc.) at the rate and timing they desire.

On each managed data path, the user can decide what data to send at what rate and timing, within the allocated resources. On a selected managed data path, for example, a user application that sends images taken by an onboard instrument can transmit images constrained by the project's end-to-end information system. The volume of each image does not need to be the same and the user application can use the available data compression schemes. On a different managed data path, another user application that monitors the status of an instrument may send status engineering data periodically. A third user application that controls the instrument may receive commands through a third managed data path. All of these cases of data transfer can be implemented using the Space Packet Protocol and the end users do not have to devise special data transfer schemes that suit their user applications.

2.4 FEATURES OF THE SPACE PACKET PROTOCOL

2.4.1 UNCONFIRMED AND INCOMPLETE

The Space Packet Protocol does not provide to the source user application a confirmation whether data units it has sent have actually arrived at the destination user application(s). Nor does it perform retransmission to recover lost data units. Therefore the destination may not receive all data units sent by the source, and the source does not know whether the destination has received all data units it sent. Further, the Space Packet Protocol may not deliver data units to the destination in the order in which the source sent them. However, at the discretion of the user, an optional field containing an error detection code may be included in the application data in order to verify that the overall integrity of the Space Packet has been preserved during the transport process.

When there is a need to provide a confirmation to the source, perform retransmission of lost data, or preserve the sequence of transferred data, the user applications must perform these functions. Actually, it is a common practice for the destination user application to send back a confirmation to the source user application when it has received important data (such as commands) using another managed data path in the opposite direction. CCSDS does not have a standard for sending back confirmation or performing retransmission with the SPP, but it has developed several higher-layer protocols on top of the SPP to perform reliable transfer of PDUs. Examples are the CCSDS Licklider Transmission Protocol (LTP) (reference [9]) for reliable transfer of LTP blocks and the CCSDS File Delivery Protocol (CFDP) (reference [8]) for reliable transfer of files.

Whether to send back confirmation or perform retransmission depends on many factors associated with the spacecraft design policies, spacecraft operations policies, and communications link performance. If simplicity is more important than performance for the mission, users may choose to perform retransmission of lost data with an action of an operator or rely on a retransmission capability provided by the underlying Data Link Layer. They may also choose to send the same data multiple times to achieve reliability if they can sacrifice efficiency. If reliability of data is the most important requirement for the mission, a higher-layer protocol like LTP or CFDP may be used on top of the SPP.

2.4.2 UNIDIRECTIONAL (ONE-WAY)

Each managed data path only provides one-way transfer from a source user application to one or more destination user applications. User applications on board spacecraft usually receive commands from other user applications, and they send telemetry back to the original user applications that sent the commands. In such cases, the managed data paths for sending telemetry are separate from the managed data paths for sending commands.

The SPP does not provide two-way communications between peer user applications over a single managed data path, but this is not a big disadvantage because data flows of commands and telemetry of space missions are not always symmetric (usually the number of user applications that receive telemetry from a spacecraft is much larger than that of user applications that send commands to the same spacecraft).

2.5 SPACE PACKET PROTOCOL NOMINAL EXAMPLE

2.5.1 INTRODUCTION

The example in figure 2-2 illustrates how the SPP is used to operate an onboard instrument.

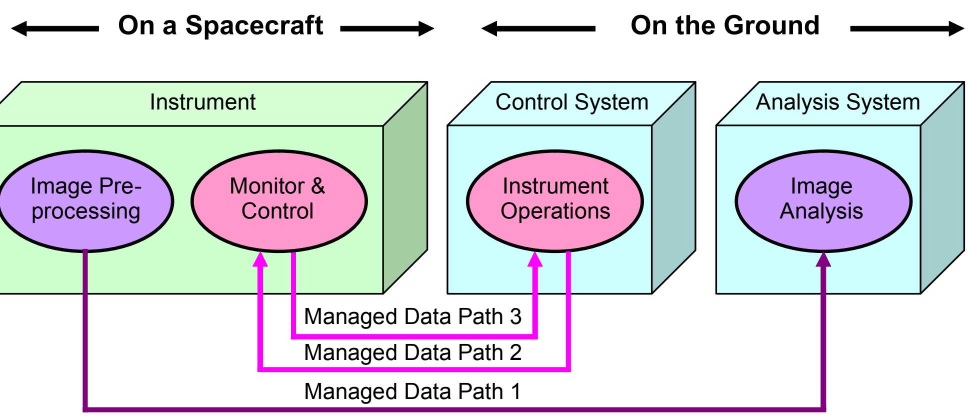

Figure 2-2: Configuration of User Applications (An Example)

2.5.2 CONFIGURATION OF USER APPLICATIONS

An instrument on a spacecraft takes images and sends them to an image analysis system located on the ground. The instrument takes images according to commands received from a control system on the ground and sends its status back to the control system.

The instrument has two user applications: one for monitoring and controlling itself and one for preprocessing (e.g., compression) acquired images. The image preprocessing process communicates with an image analysis process in the analysis system, and the monitor-and-control process communicates with an instrument operations process in the control system.

The configuration of the user applications of this system is shown in figure 2-2. In this figure, there are three physical entities, shown as boxes: the instrument, the control system, and the analysis system. The instrument is on the spacecraft, while the control and analysis systems are at a space operations center on the ground. The four user applications in this system are shown as ovals.

There are other elements involved in this mission that are not shown in this figure, for example, other instruments and subsystems on the spacecraft and other supporting facilities (like a tracking network) on the ground. Figure 2-2 only shows elements that directly perform the operations of this instrument. The user applications for this instrument can be designed almost independently of the other elements involved in the mission.

2.5.3 COMMUNICATIONS BETWEEN USER APPLICATIONS

The image preprocessing process of the instrument sends preprocessed images to the image analysis process on the ground through managed data path 1. Images are transferred by the SPP packed in Space Packets. However, since the size of acquired images is usually larger than the maximum size of the Space Packet, an image must be transferred in a group of Space Packets. The source user application (the image preprocessing process, in this case) must break images into smaller segments and make sure that each segment fits into a Space Packet. There is a limit on the transmission rate imposed by the underlying transfer mechanisms, but within that limit, the onboard preprocessing process can send images of any desired size and at any time. Therefore the preprocessing process can compress images with a suitable method and send them whenever it has images to send.

The instrument operations process on the ground sends commands to control the instrument to the instrument's monitor-and-control process through managed data path 2. When the instrument is controlled in real time from the ground, each individual command is transferred in a Space Packet. When the instrument performs observations autonomously according to the observation plans generated on the ground, each observation plan is transferred in a Space Packet.

The monitor-and-control process of the instrument periodically sends status of the instrument to the instrument operations process on the ground through managed data path 3. A set of status data taken at a time is transferred in a Space Packet.

The instrument generates images and status data regardless of whether the spacecraft is in contact with the ground. When the spacecraft is not in contact with the ground, images and status data are temporarily stored in the onboard data store on the spacecraft. Stored data are transferred to the ground when the spacecraft is in contact with the ground. These 'store and forward' operations are performed as management actions within the managed data path, and the instrument need not be aware of whether data are being transferred to the ground in real time or stored in the onboard data store.

The user applications for this instrument are designed with the above assumptions on how to use the managed data paths, but the instrument designer need not be concerned with how

Space Packets are physically transferred through the underlying subnetworks or where and how they are temporarily stored.

If the underlying subnetworks do not provide enough reliability, the user applications may implement reliable transfer mechanisms using these three, or other, managed data paths. For example, the instrument may use managed data path 3 to return to the control system an acknowledgment of receipt of each command it has received through managed data path 2 so that the control system can resend lost commands.

3 THE ENCAPSULATION PACKET PROTOCOL FROM USERS' PERSPECTIVE

3.1 BASIC CONCEPTS OF THE ENCAPSULATION PACKET PROTOCOL

The Encapsulation Packet Protocol is used to transfer PDUs, defined in SANA by CCSDS, using the SDLPs (references [3]–[7]) over an applicable ground-to-space, space-to-ground, or space-to-space communications link.

Data units that can be directly transferred by the SDLPs have a Packet Version Number (PVN) defined in SANA by CCSDS. (A list of the Packet Version Numbers presently defined by CCSDS is contained in reference [14].) The main purpose of the EPP is to provide a mechanism to transfer PDUs without an authorized PVN over a space link.

The EPP is a 'shim' protocol that utilizes the packet services of the SDLPs of the Data Link Layer defined in references [3]–[7], and therefore it is intended to be used together with one of these references.

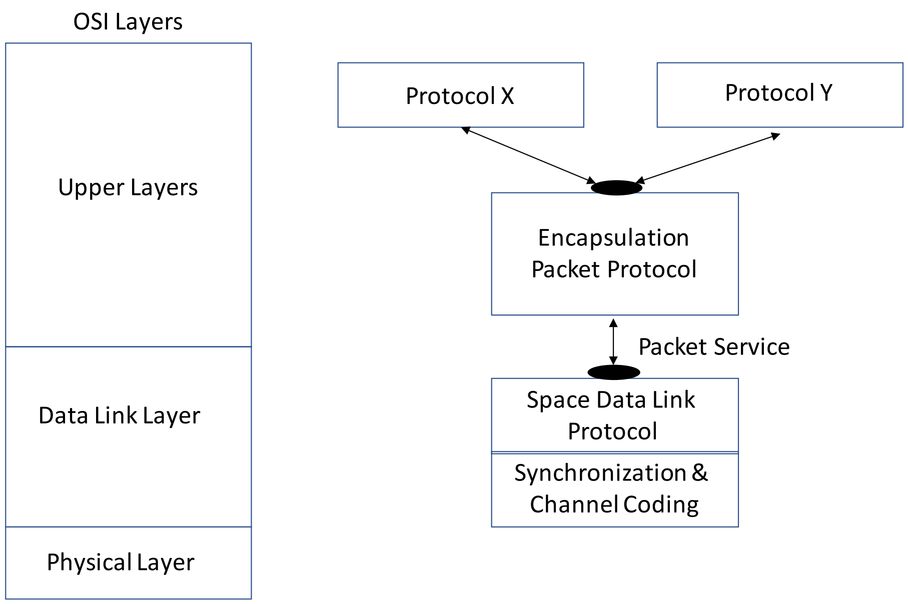

Figure 3-1: Concept of Encapsulation Packet Protocol

Figure 3-1 illustrates the concept of this protocol. PDUs of protocols X and Y, which do not have an authorized PVN, are transferred with the EPP within the Data Link Layer. PDUs of protocols X and Y are encapsulated in Encapsulation Packets and are eventually transferred using one of the VC/MAP/Proximity-1 Packet Services of an SDLP. Management establishes which SDLP is to be used to transfer encapsulated PDUs. Figure 2-1 also provides a more encompassing view of the EPP as a shim-layer protocol between the CCSDS upper-layer protocols and the CCSDS Space Data Link Layer.

3.2 FEATURES OF THE ENCAPSULATION PACKET PROTOCOL

The EPP transfers a sequence of variable-length, delimited, octet-aligned PDUs within the data field of an SDLP over a space link. A user of this protocol is a protocol entity that sends or receives PDUs that do not have an authorized PVN.

A data unit supplied by the protocol user is encapsulated unchanged into an Encapsulation Packet. One and only one data unit is encapsulated into a single packet.

The protocol permits a data unit to be of any length that is an integral number of octets and that is subject to the maximum and minimum sizes established by the project organization. Although the maximum length of a data unit that can be accommodated by an Encapsulation Packet is 4,294,967,287 octets, individual project organizations may establish the maximum and minimum sizes for the encapsulated data unit.

The point at which an instance of this protocol is provided to a user is a SAP. Data units submitted to a SAP are processed in the order of submission. No processing order is maintained for data units submitted to different SAPs.

NOTE – Implementations may be required to perform flow control at a SAP between the service user and the service provider. However, CCSDS does not recommend a scheme for flow control between the user and the provider.

Features of the EPP are as follows:

a) Unidirectional (one way) service: one end of a connection can send, but not receive, data through the space link, while the other end can receive, but not send, data through the space link.

b) Asynchronous service: there are no timing relationships between the transfer of data units supplied by the user and any data transmission mechanism within the Data Link Layer. The user may request data transfer at any time, but there may be restrictions imposed by the service provider on the data generation rate.

c) Unconfirmed service: the sending user does not receive confirmation from the receiving end indicating that data has been received.

d) Incomplete service: the service does not guarantee completeness, but the service provider may signal gaps in the sequence of data units delivered to the receiving user.

e) Sequence-preserving service: the sequence of data units supplied by the sending user is preserved through the transfer over the space link, although there may be gaps in the sequence of data units delivered to the receiving user.

3.3 ADDRESSING

A user of the EPP is identified by the Encapsulated Protocol Identifier (EPI). The Encapsulation Packet is a PDU defined in section 4 of reference [2].

Encapsulation Protocol Identifiers are registered as 'defined Protocol IDs' in the SANA registries, Protocol Identifier for Encapsulation Service (reference [16]) and Extended Protocol Identifier for Encapsulation Packet Protocol (reference [17]). A SAP is identified by the combination of a PVN, an EPI, and an SDLP channel through which the data units supplied by the user are to be transferred.

3.4 PROTOCOL DESCRIPTION

The EPP is described in terms of

a) the primitives provided to the users of this protocol;

b) the PDUs employed by the protocol for encapsulation; and

c) the procedures performed by the protocol.

The primitives present an abstract model of the logical exchange of data and control information between the service provider and the service user. The definitions of primitives are independent of specific implementation approaches.

The PDU (i.e., the Encapsulation Packet) defines the data structure in which data units supplied by the service user are encapsulated.

The procedure specifications define the procedures performed by the service provider for the transfer of data units. The definitions of procedures are independent of specific implementation methods or technologies.

3.5 ENCAPSULATION PACKET PROTOCOL DEPLOYMENT EXAMPLE

An example illustrating how the EPP is used as a shim protocol to encapsulate a CFDP PDU and transfer it across the space link using the underlying CCSDS Space Data Link Layer is shown in figure 3-2.

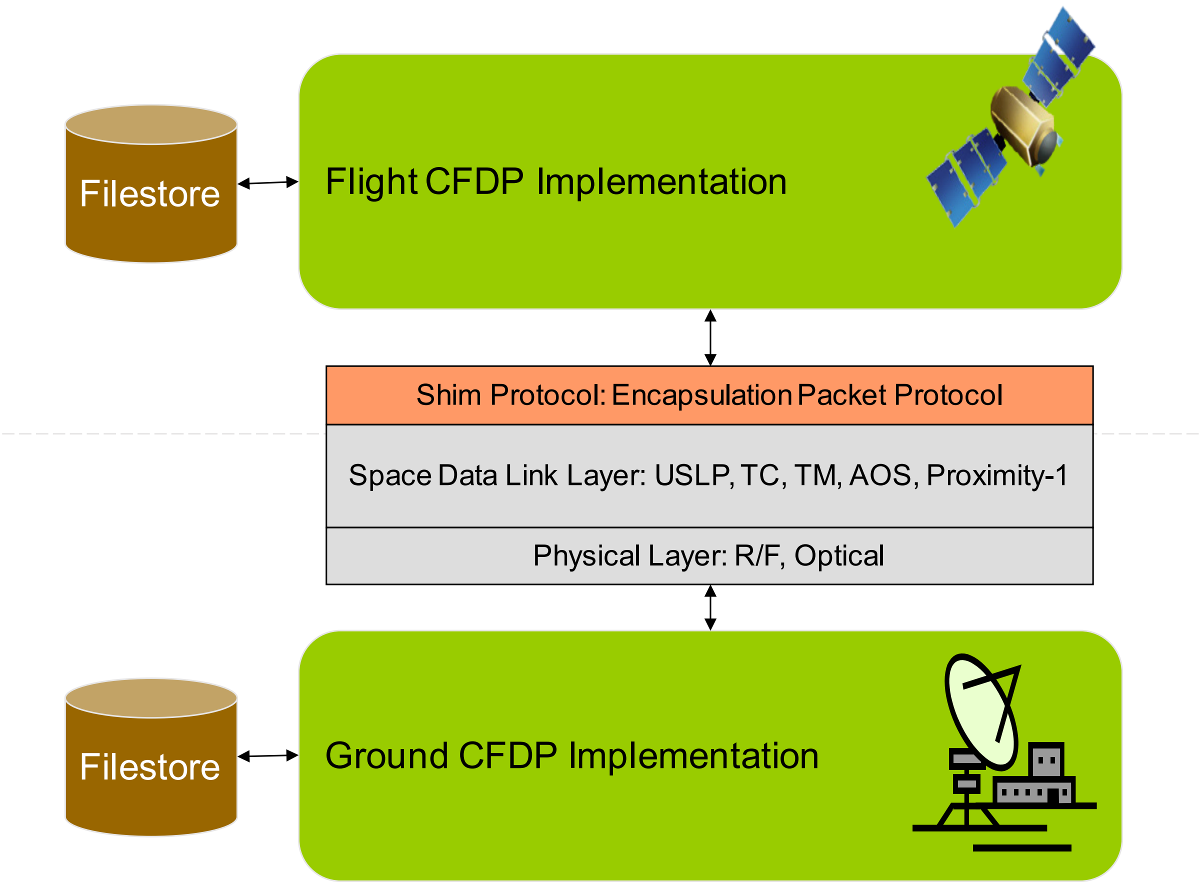

Figure 3-2: Example Deployment of CFDP over the Encapsulation Packet Protocol

In order to transfer a file in either direction shown in figure 3-2 between the filestores implemented on the ground and/or on the flight system, the user chooses CFDP as the upper layer protocol. The contents of the file is transformed into a series of CFDP PDUs, which are encapsulated one for one within an Encapsulation Packet. The EPI assigned to the Encapsulation Packet Header identifies CFDP as the encapsulated protocol so that on the receive side, the contents of the Encapsulation Packet will be routed to the receiving CFDP engine. One or more Encapsulation Packets are placed into the applicable CCSDS transfer frame for a given space data link. The Space Data Link Layer resides above the Physical Layer, that is, either RF or optical link.

4 FREQUENTLY ASKED QUESTIONS ON THE CCSDS PACKET PROTOCOLS

In what layers do the CCSDS Packet Protocols belong?

Figure 2-1 illustrates where both the SPP and the EPP can be located in the protocol stack. The SPP is able to provide the functionality of either an Application Layer protocol or a ‘shim’ protocol. For this reason, the SPP appears twice in that figure. At the Application Layer, the SPP defines the Space Packet, which can be used directly by the user to contain application data. As a ‘shim’ protocol, the Space Packet can encapsulate the PDUs of other protocols recognized by CCSDS. Additionally, the EPP exclusively provides the functionality of a ‘shim’ protocol. It also provides a mechanism of transferring PDUs of other protocols across the CCSDS SDLPs.

Can the CCSDS Packet Protocols coexist with Internet technologies and DTN?

The answer is a resounding yes. Applications, for example, telemetry and telecommand, are activities in the Application Layer, and users may choose the SPP and the associated Space Packet as the data structure with which to transport their data within the Application Layer. Delay Tolerant Networking (DTN) as well as Internet technologies can be used to support the operations of the SPP in the Transport and Network Layers in subnetworks in which either DTN or the Internet protocols provide the required end-to-end performance.

As mentioned previously, either the EPP or the SPP can be used as a ‘shim’ protocol between the upper layer DTN, CFDP, LTP, or Internet protocols and the CCSDS Space Data Link Layer protocols (references [3]–[7]). These packets can be placed directly into CCSDS Space Data Link Layer transfer frames.

The IP over CCSDS (IPoC) ‘shim’ protocol (reference [13]) is used to transfer specifically recognized Internet Protocol (IP) versions identified in the Internet Protocol Extension Header SANA registry (reference [18]) over the space link. IP PDUs are transferred by encapsulating them, one-for-one, within CCSDS Encapsulation Packets. The Encapsulation Packets are transferred directly within one or more CCSDS SDLP transfer frames. This method uses the CCSDS Internet Protocol Extension (IPE) convention defined in (reference [13]).

How can CCSDS Packets be transmitted reliably?

Neither the SPP nor the EPP has provision for recovering missing packets via a retransmission mechanism. Reliable transmission of packets can be accomplished by using an additional protocol.

By using either COP-1 (reference [11]), which supports the reliable transfer of direct-from-Earth (telecommand) transfer frames, or COP-P (reference [6]), which supports the reliable transfer of Proximity/space-to-space transfer frames, packets contained within these transfer frames can be reliably transferred point to point between nodes.

In addition, CCSDS provides several upper-layer protocols that perform reliable transfer, such as CFDP (reference [8]), which could be used to reliably transfer a file composed of packets. Furthermore, LTP (reference [9]), is another upper-layer CCSDS protocol, which could be used to transmit packets contained in LTP segments reliably across the space link. When IPoC (reference [13]) is used, Transmission Control Protocol (TCP) supplies the reliability. Finally, the user application itself could provide a reliable retransmission mechanism.

Are the CCSDS Packet Protocols suitable for real-time operations?

Neither the SPP nor the EPP guarantees a minimum delay in data transfer from source to destination, since they are asynchronous protocols. But there are ways to transfer real-time data as speedily as possible over multiple managed data paths.

One way is to use high-priority services of the underlying subnetworks when either Space or Encapsulation Packets are transferred over subnetworks. When these Packets are transferred over space links, the CCSDS SDLPs (references [3]–[7]) are typically used. These Data Link Protocols divide the capacity of a space link into multiple Virtual Channels, each of which is used for transferring a specific type of user data. If some Virtual Channels are set up for transferring high-priority data, then Space or Encapsulation Packets for real-time operations can be transferred over those Virtual Channels. In some cases, the SPP or EPP entities themselves can prioritize packets by controlling their order of transmission over subnetworks, based on the quality-of-service requirement associated with specific managed data paths.

Another method of transferring isochronous data (e.g., voice, launch-vehicle telemetry) is by using the Insert Zone Field within either the AOS (reference [5]) or USLP (reference [7]) SDLPs.

Is the Space Packet too small for sending images and memory data?

It is true that the maximum size of the Space Packet (i.e., 65536 octets) is sometimes too small to completely contain images and memory uploads/downloads. In such cases, an application data unit such as a file (an image or a chunk of memory data) that does not fit into a single Space Packet must be transferred within a group of Space Packets. The source user application must segment the application data unit into smaller segments and make sure that each segment fits into a Space Packet.

The Space Packet has fields called the ‘Sequence Flags’ in its primary header to identify the first and last segments of a group, and reconstruction of the original application data unit at the destination is possible using these flags. If the segment number of each segment needs to be transferred with the segment itself, the Packet Secondary Header can be used to send the segment number. (For the specification of the Space Packet Sequence Flags and the Packet Secondary Header, see reference [1].)

In comparison to the maximum Space Packet size, the optional 4-octet Encapsulation Packet Length field accommodates Encapsulation packet sizes up to 4,294,967,287 (= $2^{32} - 5$) octets in length (see reference [2]).

Does the Space Packet Protocol support an enterprise-wide data-management scheme based upon APID assignments?

If missions wish to share the APID naming domain amongst multiple spacecraft to service, for instance, a spacecraft that has multiple processors, a spacecraft that is ‘fractionated’, or even a mission that includes a deployment of multiple spacecraft, those missions must either manage and suballocate assignments in the single APID naming domain within the enterprise or define a way to extend it using mission-specific fields in the Space Packet Secondary Header. An enterprise-specific extension to the APID naming domain is supported by the APID and the Packet Secondary Header fields within the SPP, but a universal APID domain naming service is not defined by CCSDS. However, CCSDS does offer a better long-term approach: DTN supports an endpoint identifier, which is a type of Uniform Resource Identifier (URI) designed to meet the requirements for endpoint identification (source, destination) as defined in the BP specification (reference [12]).

Packet Secondary Header types are registered with SANA (reference [10]), and the actual contents of the secondary header are ‘managed’ at the SPP service user interface. (To view existing SPP Secondary Header formats registered with SANA or to register a new SPP Secondary Header format, see annex B, Security, SANA, and Patent Considerations, in reference [1]). From the point of view of an implementer, annex B contains a description of the registry for SPP Secondary Header format documents and also a description of structure of the SPP secondary packet data structure document registry.

What are the tradeoffs between implementing Space Packets vs Encapsulation Packets?

Both SPP and EPP can be used as ‘shim’ protocols to transfer PDUs of protocols that CCSDS recognizes across the space link. The biggest reason for choosing EPP over SPP is efficiency. The Encapsulation Packet Header size is configurable between 1 to 8 octets in length vs the Space Packet Primary Header which is 6 octets long. However, the Encapsulation Packet contains no header field for sending ancillary data (such as time) or for extending the APID domain naming space concurrent with the payload data. As stated above, the Encapsulation Packet may be provisioned to be much larger than the 65536-octet Space Packet size.

ANNEX A

ABBREVIATIONS AND ACRONYMS

AOS	Advanced Orbiting Systems
APID	application process identifier
BP	Bundle Protocol
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
COP-1	Communications Operation Procedure-1
COP-P	Communications Operation Procedure for Proximity links
DTN	Delay Tolerant Networking
EPI	Encapsulated Protocol Identifier
EPP	Encapsulation Packet Protocol
ID	identifier
IP	Internet Protocol
IPE	Internet Protocol Extension
IPoC	IP over CCSDS
PDU	protocol data unit
PVN	Packet Version Number
SAP	service access point
SDLP	Space Data Link Protocol
SDU	service data unit
SPP	Space Packet Protocol
TCP	Transmission Control Protocol
URI	Uniform Resource Identifier