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SPACE PACKET PROTOCOL

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FOREWORD

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

This document is a draft CCSDS Report, which contains background and explanatory material to support the CCSDS Recommendation on the Space Packet Protocol (reference [1]).

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DOCUMENT CONTROL

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CONTENTS

1 INTRODUCTION

1.1 PURPOSE

This Report has been developed to present the concept and rationale of the CCSDS Recommendation on the Space Packet Protocol (reference [1]).

It has specifically been prepared to serve the following purposes:

a) To provide an introductory overview on the concept of the Space Packet Protocol;

b) To provide information on how the Space Packet Protocol should be used by end users to efficiently develop their mission systems (including onboard instruments and ground support systems);

c) To provide information on how the Space Packet Protocol should be deployed in space data systems to efficiently develop multi-mission infrastructures (including both onboard and ground infrastructures).

1.2 SCOPE

The information contained in this Report is not part of the CCSDS Recommendation on the Space Packet Protocol (reference [1]). In the event of any conflict between the Recommendation and the material presented herein, the Recommendation 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 Space Packet Protocol is and how it should be used by end users to develop instruments, monitor and control systems, etc.;

c) Section 3 shows how the Space Packet Protocol is deployed in space data systems and how it should be used to develop multi-mission infrastructures;

d) Section 4 presents frequently asked questions and their answers;

e) Annex A lists all acronyms used within this document.

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.

destination user application: a user application (see below) that receives application data using the Space Packet 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: a protocol specified in reference [1], which has been developed to transfer space application data from one user application to one or more user application(s).

Space Packet Protocol entity: a functional entity that performs all of a portion of the functions of the Space Packet Protocol.

Subnetwork: a local network that connects two or more Space Packet Protocol entities.

user application: a functional entity that sends or receive application data using the Space Packet Protocol.

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

[2] *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.

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

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

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

[6] *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.

[7] *Cross Support Reference Model: Part 1 - Space Link Extension Services.* Recommendation for Space Data System Standards, CCSDS 910.4-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 1996.

[8] *CCSDS File Delivery Protocol.* Recommendation for Space Data System Standards, CCSDS 727.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, October 2002.

[9] *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.

[10] *Advanced Orbiting Systems, Networks and Data Links: Architectural Specification*. Recommendation for Space Data System Standards, CCSDS 701.0-B-3. Blue Book. Issue 3. Washington, D.C.: CCSDS, June 2001.

[11] *Packet Telemetry*. Recommendation for Space Data System Standards, CCSDS 102.0-B-5. Blue Book. Issue 5. Washington, D.C.: CCSDS, November 2000.

[12] *Telecommand, Part 3 Data Management Service: Architectural Specification*. Recommendation for Space Data System Standards, CCSDS 203.0-B-2. Blue Book. Issue 2. Washington, D.C.: CCSDS, June 2001.

2 WHAT IS THE SPACE PACKET PROTOCOL? *- FROM USERS' PERSPECTIVE*

2.1 BASIC CONCEPTS

2.1.1 LOGICAL DATA PATH (LDP)

The Space Packet Protocol (reference [1]) was developed to transfer space application data from one user application (called the source user application) to one or more user application(s) (called the destination user application(s)). User applications are typically processes used for (1) controlling onboard instruments and subsystems and (2) generating and processing mission (observation or experiment) data.

The conceptual path that connects the source and destination user applications is called a Logical Data Path (LDP). Figure 2-1 shows a source user application, a destination user application, and a LDP between the two user applications.

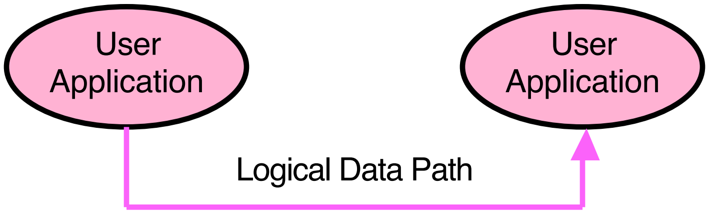


Figure 2-1: User Applications and a Logical Data Path

In most cases, one of the user applications connected with an LDP is located on a spacecraft and the other user applications on the ground. But there may be cases in which all of the user applications connected with an LDP are on a single spacecraft or on multiple spacecraft flying in formation.

LDPs are formed by entities of the Space Packet Protocol and subnetworks that connect the entities of the Space Packet Protocol (see Figure 2-2). Each data unit provided by the source user application is transferred by the Space Packet Protocol through the underlying subnetworks packed in a standard data unit called the Space Packet.

Each LDP is identified with a Path ID, which usually consists of an Application Process Identifier (APID) and a Spacecraft Identifier (SCID). Further, another parameter called the Packet Type is used to indicate the direction of each LDP (i.e., whether telemetry or telecommand).

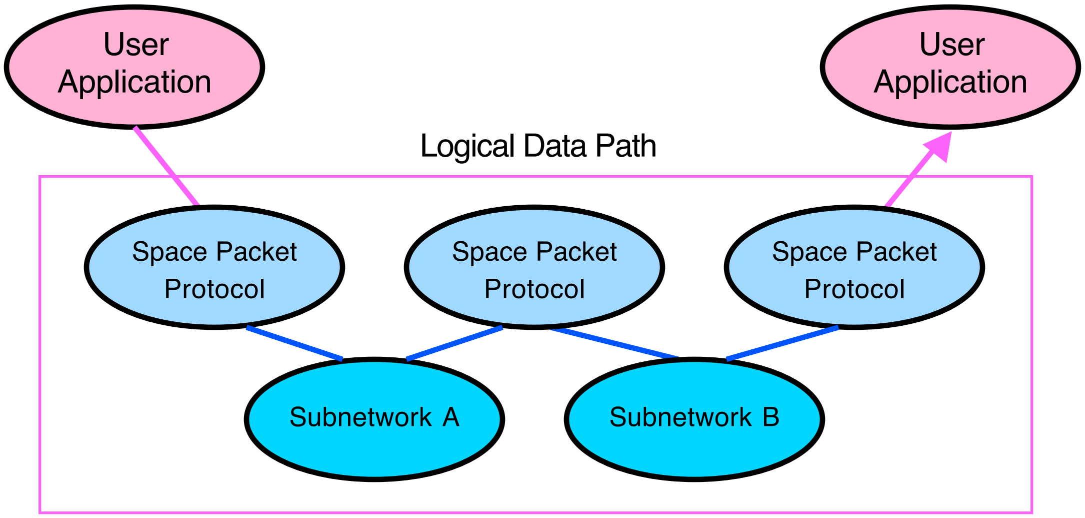


Figure 2-2: Conceptual Construction of an LDP

2.1.2 SPACE PACKET PROTOCOL AND SUBNETWORKS

The actual configuration of LDPs varies depending on the configuration of the entire system, but they typically consist of onboard subnetworks, onboard data handling systems, space-to-ground RF links (hereafter called space links for short), ground data handling systems and ground subnetworks. The methods for transferring Space Packets through the underlying subnetworks is determined for each subnetwork based on the characteristics of the subnetwork because the characteristics of the subnetworks involved in space systems varies significantly from subnetwork to subnetwork.

For transferring Space Packets over space links, the Space Data Link Protocols developed by CCSDS (references [3]-[6]) are usually used together with appropriate physical protocols. Therefore, only two layers are used to transfer Space Packets over space links and this helps save the bandwidth of space links. In ground and onboard subnetworks, a set of appropriate communications protocols is selected for each subnetwork. Both space-oriented protocols and commercially available protocols are used in onboard and ground subnetworks. In ground subnetworks, application services like the CCSDS Space Link Extension Services (reference [7]) are usually used on top of Internet protocols. How LDPs are physically configured will be explained in detail in Section 3.

Since spacecraft are not constantly in contact with the ground, source user applications are not connected with destination user applications through LDPs all the time. When portions of LDPs (usually space links) are disconnected or do not have a sufficient bandwidth, the LDPs provide capabilities for temporarily storing Space Packets. These storage capabilities are usually provided at places where relaying or Space Packet Protocol is performed (see 3.2).

The specification of the Space Packet Protocol is independent of the data transfer methods of the underlying subnetworks and actual transfer capabilities are provided by the subnetworks. The Space Packet Protocol is therefore a "thin" protocol which only provides end-to-end connectivity and actual data transfer is performed by each subnetwork using technologies suitable for the subnetwork. Therefore, if new data transfer technologies become available in a subnetwork, they can be introduced in the subnetwork without affecting the Space Packet Protocol.

The services provided to user applications by the Space Packet Protocol are independent of the data transfer and storage methods used in LDPs. Although the underlying physical elements may impose constrains on the performance of the services provided by the Space Packet Protocol, the methods used inside LDPs are invisible from user applications.

2.2 BENEFITS OF THE SPACE PACKET PROTOCOL

The following are benefits given by the Space Packet Protocol to the users.

2.2.1 INDEPENDENCE

Before the Space Packet Protocol was invented, many activities on spacecraft had to be synchronized with the process of generating telemetry frames, and coordination on telemetry generation rate and timing among the instruments onboard the same spacecraft was necessary. However, the Space Packet Protocol hides such physical mechanisms from user applications because it is independent of the data transfer methods of the underlying subnetworks as explained in 2.1.2. By using the Space packet Protocol, 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 instruments.

Independence form 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 Space Packet Protocol can be used as a basis for developing standard applications that do not depend on specific projects. Therefore, the Space Packet Protocol will greatly contribute to the reduction of development cost of space missions.

2.2.2 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 LDP, the user can decide what data to send at what rate and timing, within the allocated resources. On one LDP, for example, a user application that sends images taken by an onboard instrument can send images whenever it desires. The volume of each image does not need to be the same and the user application can use any data compression scheme. On a different LDP, another user application that monitors the status of the instrument can send status data periodically. A third user application that controls the instrument can receive commands through a third LDP. All of these cases of data transfer can be realized with the Space Packet Protocol and the users do not have to devise special data transfer schemes that suit their user applications.

2.2.3 MANAGEABILITY

Each LDP is identified with a Path ID, which is assigned by the project management. Each Space Packet is identified with a Packet Sequence Count or a Packet Name, which is assigned by the Space Packet Protocol. The values of these identifiers do not change while Space Packets traverse the entire network. Although the Space Packet Protocol does not guarantee the completeness of the transferred data (see 2.3.2), many users use these identifiers to manage their application data. For example, whether data units sent from the source of an LDP have arrived at the destination(s) can be examined using these two identifiers. (If the Packet Sequence Count is not sufficient for identifying Space Packets, a time code is used together with the Packet Sequence Count.)

Whatever kind of data is transferred, data units can be managed with these identifiers. The Space Packet Protocol does not have a capability of managing data units, but a simple data management scheme applicable to any instrument and any data type can be devised from the Space Packet Protocol. End-to-end management of data is a key issue for space data systems because important data may be transferred over not-so-reliable communications links and because data may be stored at temporary storages and/or transferred through multiple routes. One of the advantages of using the Space Packet Protocol is that it can be used as a basis for developing standard data management schemes.

2.3 FEATURES OF THE SPACE PACKET PROTOCOL

The following are features of the Space Packet Protocol as a communications protocol.

2.3.1 PRE-CONFIGURED

LDPs must be configured before actual transfer occurs. That is, the project must establish what user applications send data to what user applications and prepare necessary resources to support data transfer before data transfer begins. The Space Packet Protocol does not have in-line mechanisms to configure LDPs and LDPs must be configured by management activities. This is not a big disadvantage because the configuration of data flows to and from spacecraft do not frequently change during the mission lifetime. Further, the overhead incurred by the Space Packet Protocol is very small because it only supports pre-configured data flows. Pre-configuration of LDPs also helps save the bandwidth of space links.

It is not possible to dynamically configure LDPs with the capabilities of the Space Packet protocol, but it is possible, to some extent, to change the physical configuration of LDPs by management activities. For example, a spacecraft may be controlled by a system in the main control room during the launch and early orbit phases, but it may be controlled by another system in a dedicated control room during the science phase. In this case, the physical configuration of the LDPs for this spacecraft is changed by management activities when the science phase starts. However, the user applications are not affected by this configuration change because the physical configuration of the LDPs is not visible from them.

2.3.2 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 that the source sent.

When there is a need to provide a confirmation to the source, to perform retransmission of lost data, or to 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 (like commands), using another LDP in the opposite direction. CCSDS does not have a standard for sending back confirmation or performing retransmission with the Space Packet Protocol, but it has developed a file transfer protocol known as the CCSDS File Delivery Protocol or CFDP (reference [8]) that can be used on top of the Space Packet Protocol to perform reliable data transfer.

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 they may choose to rely on a retransmission capability provided by the underlying Data Link Layer. If reliability of data is the most important requirement for the mission, a higher layer protocol like CFDP should be used on top of the Space Packet Protocol.

2.3.3 UNIDIRECTIONAL (ONE-WAY)

Each LDP only provides one-way transfer from a source user application to one or more destination user applications. User applications onboard spacecraft usually receive commands from other user applications, and they send telemetry back to the original user applications that send commands. In such cases, the LDPs for sending telemetry are separate form the LDPs for sending commands.

The Space Packet Protocol does not provide two way communications between peer user applications over a single LDP, 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 more larger than that of user applications that send commands to the same spacecraft) and it is easier to manage one-way LDPs than to manage two-way LDPs.

2.4 TYPICAL EXAMPLE

An example illustrating how the Space Packet Protocol is used to operate an onboard instrument is shown in this section.

2.4.1 CONFIGURATION OF USER APPLICATIONS

Let us suppose that an instrument on a spacecraft takes images and send them to an image analysis system which is 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 pre-processing (e.g. compression, etc.) taken images. The image pre-processing process communicates with an image analysis process in the analysis system, and the monitor and control process with an instrument operations process in the control system.

The configuration of the user applications of this system is shown in Figure 2-3. In this figure, there are three physical entities, which are 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.

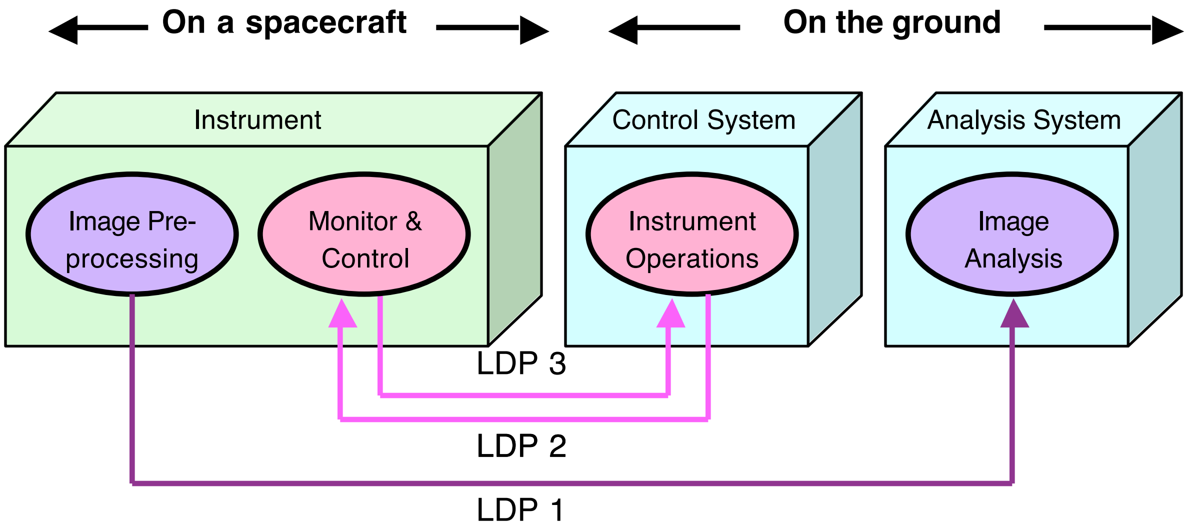


Figure 2-3: Configuration of User Applications (An Example)

There are other elements that are involved in this mission but they are not shown in this figure. For example, there are other instruments and subsystems on the spacecraft and other supporting facilities (like a tracking network) on the ground. Figure 2-3 only shows elements that directly perform the operations of this instruments. As explained in 2.2.1, the user applications for this instrument can be designed almost independently of the other elements involved in the mission. The elements that support the communications between user applications shown in the figure will be explained in Section 3.

2.4.2 COMMUNICATIONS BETWEEN USER APPLICATIONS

The image pre-processing process of the instrument sends pre-processed images to the image analysis process on the ground through LDP 1. Images are transferred by the Space Packet Protocol packed in Space Packets. However, since the size of taken 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 pre-processing process in this case) must segment 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 the limit, the onboard pre-processing process can send images of whatever size at the timing it desires to send. Therefore, the pre-processing process can compress images with a suitable method and send them whenever they have images to send.

The instrument operations process on the ground sends commands to control the instrument to the monitor and control process of the instrument through LDP 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 LDP 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 or not. While the spacecraft is not in contact with the ground, images and status data are temporarily stored in a recorder 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 within the LDP and the instrument need not be aware of whether data are being transferred to the ground in real-time or stored in the onboard recorder.

The user applications for this instrument are designed with these assumptions on how to use the LDPs but the instrument designer does not have to be concerned about how Space Packets are physically transferred through the underlying subnetworks or where and how they are temporarily stored. The mechanisms of data transfer and storage will be explained in detail in Section 3.

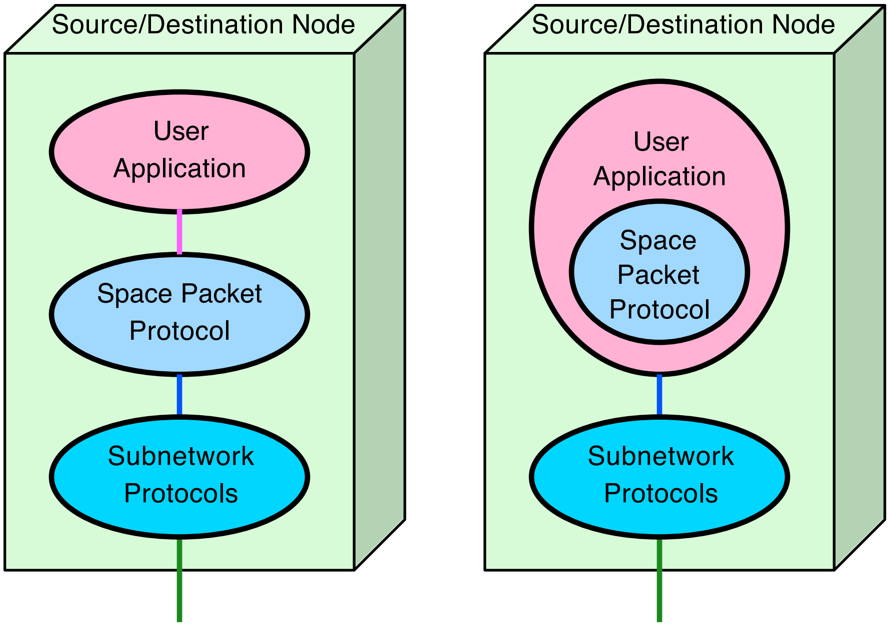
3 HOW IS THE SPACE PACKET PROTOCOL DEPLOYED? - *FROM DEVELOPPERS' PERSPECTIVE*

3.1 SOURCE AND DESTINATION NODES

Let us call physical elements that constitute a system (e.g., computers, instruments, etc.) Nodes. Physical elements that generate and consume Space Packets will be called Source Nodes and Destination Nodes, respectively. The instrument, the control system and the analysis system shown in Figure 2-3 are all Source or Destination Nodes.

There are basically two ways to implement the Space Packet Protocol at Source and Destination Nodes.

The first way is to use a software library or a hardware device to process the Space Packet Protocol that has been developed separately from the user applications (see Figure 3-1 (a)). In this case, source user applications give application data units to the library or device, which generates Space Packets and send them through the underlying subnetwork (e.g., an onboard bus if the Node is on a spacecraft or a LAN or WAN if the Node is on the ground) to the next Node that handles the Space Packet Protocol.



(a) Using a common library **(b) Embedded in the application**

Figure 3-1: Space Packet Protocol at Source/Destination Nodes

The second way is to implement the Space Packet Protocol embedded in the user applications (see Figure 3-1 (b)). In this case, source user applications pack application data to be transferred into Space Packets and send them through the underlying subnetwork to the next Node that handles the Space Packet Protocol.

The advantage of the first way is that the Space Packet Protocol does not have to be implemented for each user application separately and therefore the development cost can be saved. The advantage of the second method is that some fields in the header of the Space Packet can be used by user applications for identifying and managing application data units and therefore the user applications do not have to define a data structure for identifying and managing application data units.

3.2 INTERMEDIATE NODES

If two or more subnetworks are used to support LDPs, intermediate Nodes must be used to connect the subnetworks and relay Space Packets originated at the source Nodes toward the destination Nodes.

For example, onboard instruments and subsystems are usually connected to an onboard subnetwork but, in order for them to communicate with the ground, there must be a Node (a physical element) that performs gateway functions between the onboard subnetwork and the space link. This Node, which will be called an Onboard Gateway, relays Space Packets from the onboard subnetwork to the space link and vice versa. It may also temporarily store Space Packets destined for the ground when the space link is not available or the amount of the Space Packets to be relayed exceeds the capacity of the space link. Stored Space Packets are transferred to the ground when the link becomes available or does not have much traffic. Likewise, a Ground Gateway is needed to connect the space link with the ground subnetwork,

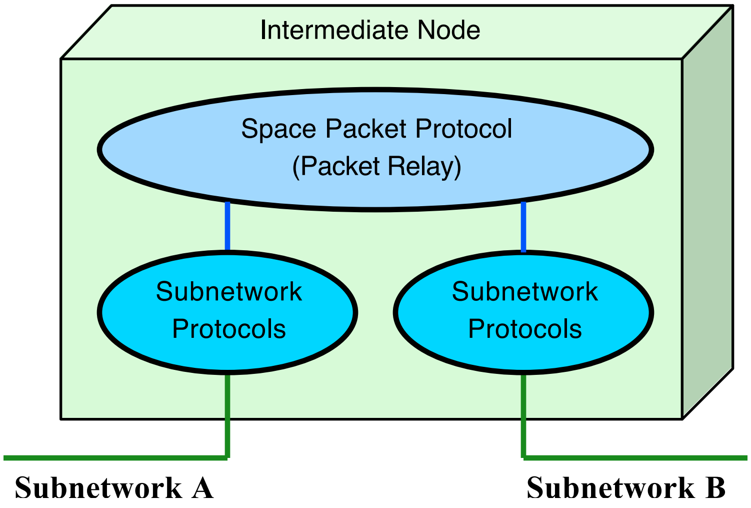


Figure 3-2: Space Packet Protocol at Intermediate Nodes

which may also temporarily store Space Packets for later delivery. The conceptual configuration of such intermediate Nodes is shown in Figure 3-2.

LDPs can have multiple destination user applications. In such cases, intermediate Nodes generate multiple copies of the same Space Packets and send them to multiple destinations.

3.3 END-TO-END CONFIGURATION

A typical end-to-end configuration with an Onboard Gateway and a Ground Gateway is shown in Figure 3-3, which is an engineered version of Figure 2-2. In reality, some more Nodes are usually used on the ground (see 3.4), but the system configuration principles do not change regardless of the number of Nodes used in the system.

In the system shown in Figure 3-3, the Onboard and Ground Gateways provide gateway capabilities for all of the LDPs used for this spacecraft and thus can be considered part of the project infrastructure.

It is usually the case that software libraries that implement the Space Packet Protocol are distributed by the project to users so that they can be used as part of the Onboard and Ground End Nodes. If the Space Packet Protocol and the underlying subnetworks are all implemented by the project as an infrastructure and only the user applications are developed by the users, the infrastructure portion of the system can be seen as a virtual network that supports various LDPs used by the project (see figure 3-4). The users are only concerned with the services provided by the Space Packet Protocol, and the technologies used within

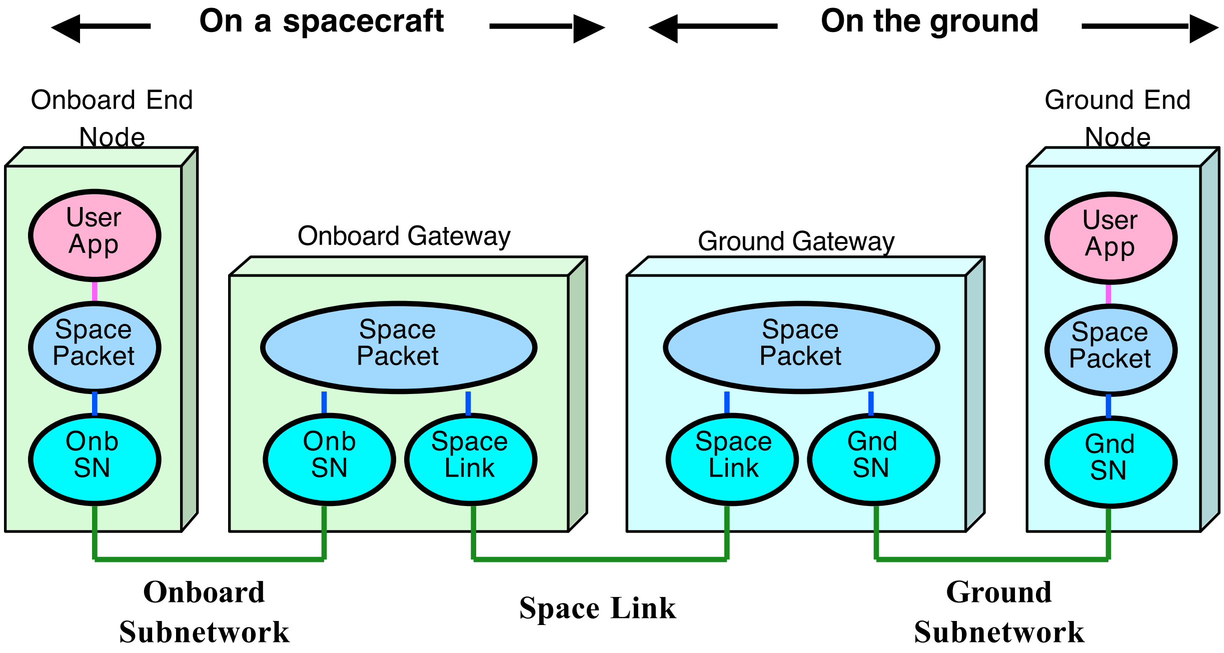


Figure 3-3: End-to-end Configuration of Nodes for an LDP

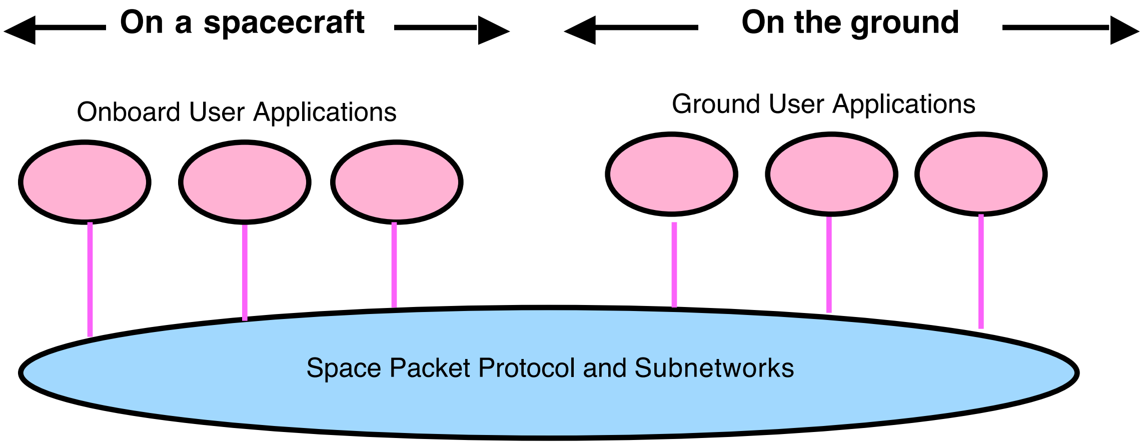


Figure 3-4: Virtual Network Provided by the Space Packet Protocol

the Space Packet Protocol and the underlying subnetworks are invisible to the users.

3.4 AN EXAMPLE OF GROUND CONFIGURATION

Figure 3-5 is another example of ground configuration to support an LDP, in which three Nodes are used on the ground: a Ground Station, a Control Center and a Ground End Node. In this example, the Ground Station relays Transfer Frames (protocol data units of Space Data Link Protocols specified in references [3], [4] and [5]) received from the spacecraft to

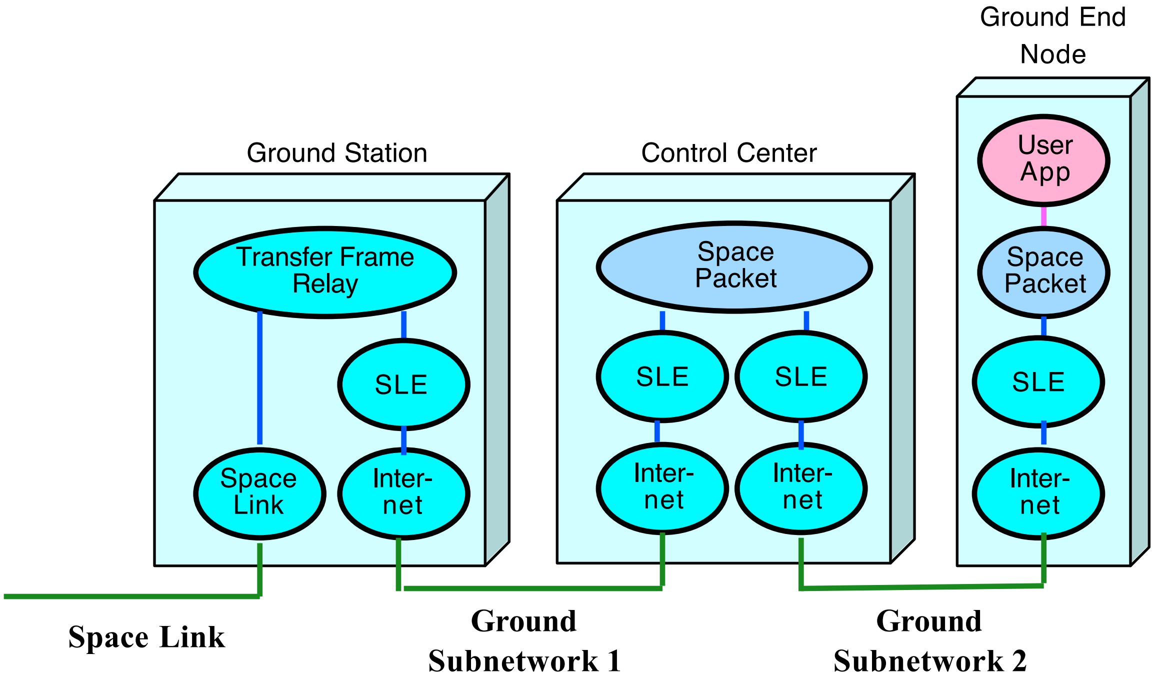


Figure 3-5: An Example of Ground Configuration

the Control Center using an SLE Service to transfer Transfer Frames (reference [7]). At the Control Center, Space Packets are extracted from the Transfer Frames and delivered to the Ground End Node using another SLE Service to transfer Space Packets. To support the operations of the SLE Services, the Internet protocol suite (i.e., TCP/IP) is used.

4 FREQUENTLY ASKED QUESTIONS ON THE SPACE PACKET PROTOCOL

4.1 TO WHAT LAYER DOES THE SPACE PACKET PROTOCOL BELONG?

The Space Packet Protocol is introduced as a Network Layer protocol in the CCSDS Report of “Overview of Space Link Protocols” (reference [9]), because it is used directly on top of a Data Link Layer protocol over a space link and it provides a capability of routing Space Packets through the network. However, most users and systems use it as an Application Layer protocol for the following reasons.

First, the Space Packet Protocol provides a routing capability through the entire network, which consists of different subnetworks, but some of the subnetworks may have a routing capability suited to routing within those subnetworks. In such cases, the Space Packet Protocol is used to route Space Packets from subnetwork to subnetwork, while a local Network Layer protocol is used to route Space Packets within individual subnetworks. Therefore, routing can be performed in a hierarchical way and the Space Packet Protocol performs routing at the Application Layer. Further, the addresses (i.e., Path IDs) used by the Space Packet Protocol identify applications, rather than hosts, which are usually identified by addresses of the local Network Layer protocol used in the subnetwork that the hosts belong to. Multiple applications that reside in a single host are individually identified by Path IDs.

Secondly, the Space Packet can be used as the standard data unit for identifying and managing application data in the entire system. End-to-end management of data is a key issue in space data systems because important data may be transferred over not-so-reliable communications links and because data may be stored at temporary storages and/or transferred through multiple routes. Since the networks used for space projects consist of various kinds of subnetworks (onboard buses, space-to-ground RF links, the Internet, etc.), the data unit used for end-to-end management must not depend on any technology used in the subnetworks. The Space Packet is frequently used as the standard data unit for end-to-end management by space projects because it is neutral to data transfer technologies. It is also used as the standard data unit for store and forward delivery because it is neutral to file systems or directory structures.

By using the Space Packet Protocol as an Application Layer protocol, different network technologies, each suited to one of the environments encountered in the system, can coexist in the entire system under the Space Packet Protocol, and applications can be built on top of the Space Packet Protocol independently of the underlying network technologies. On the space link, however, Space Packets are directly transferred by the Space Data Link Protocols (references [3], [4] and [5]) without any intermediate layers, and therefore high bit-efficiency is achieved.

4.2 CAN THE SPACE PACKET PROTOCOL CO-EXIST WITH INTERNET TECHNOLOGIES?

As discussed in 4.1, Internet technologies can be used as subnetwork technologies while the Space Packet Protocol can be used as an end-to-end technology.

Telemetry and Telecommand are activities in the Application Layer and they need a protocol and a data structure in the Application Layer. The Space Packet Protocol provides an end-to-end data transfer capability in the Application Layer and Internet technologies can be used to support the operations of the Space Packet Protocol in the Transport and Network Layers.

LDPs formed by the Space Packet Protocol represent logical passes between applications and are implemented with technologies provided by subnetworks. The Internet Protocol (IP) can be used for routing among Space Packet Protocol entities through subnetworks (for a discussion on Space Packet Protocol entities and subnetworks, see Section 3). In such a case, the Path ID that identifies an LDP is mapped to the IP addresses of the computers that host the Space Packet Protocol entities. If different sets of computers are to be used for the same LDP during different mission phases, just the mapping from the Path ID to the IP addresses need to be changed and the user applications are not affected at all by these changes.

Combining space-oriented technologies like the Space Packet Protocol with commercially available technologies like Internet technologies is an efficient and flexible way of building space data systems and this has been proven by many existing systems.

4.3 IS THE SPACE PACKET PROTOCOL DIFFERENT FROM PACKET TELEMETRY?

The specification of the Space Packet Protocol was developed from the Path Protocol defined in the CCSDS AOS Recommendation (reference [10]). However, since the same Packet structure was used in the Packet Telemetry Recommendation (reference [11]) and the Telecommand Recommendation, Part 3 (reference [12]) as well, the Space Packet Protocol was developed to unify these protocols that use the Packet concept.

The Packet Telemetry and Telecommand Recommendations defined the Packet as a data structure to send telemetry and commands, respectively, but the Space Packet Protocol defines the Packet as a protocol data unit that traverses a network, as the AOS Recommendation did. This way of looking at the Packet is actually closer to the way in which the Packet is used in real missions. Therefore, the projects that use the Packet Telemetry and Telecommand Recommendations are compliant with the Space Packet Protocol, with a few exceptions explained in the next paragraph.

The AOS, Packet Telemetry and Telecommand Recommendations used the same Packet structure, but there were a few differences among the Packet specifications of these Recommendations. In order to define a single protocol from these Recommendations, there are a few differences in technical contents and terminology between the Space Packet Protocol and the old Recommendations. These differences are listed in Annex C of reference [1].

4.4 HOW CAN SPACE PACKETS BE TRANSMITTED RELIABLY?

As explained in 2.3.2, the Space Packet Protocol does not perform retransmission to recover lost Space Packets.

When there is a need to perform reliable transfer with the Space Packet Protocol, an upper layer protocol that performs reliable transfer, such as CFDP (reference [8]), must be used on top of the Space Packet Protocol, or the user applications must perform retransmission themselves.

Although it does not provide complete reliability, users can rely on reliable transfer services provided by the subnetworks to some extent, in case implementing one more protocol in the spacecraft is not feasible. For example, the TC Space Data Link Protocol (reference [4]) provides a reliable data transfer service over a space link and retransmission of lost data is automatically performed by this protocol. The probability of losing data can be reduced by using a reliable service in each of the subnetworks in LDPs. However, end-to-end reliability is not guaranteed by this method because data lost within Nodes (physical entities like computers) cannot be recovered.

4.5 IS THE SPACE PACKET PROTOCOL SUITABLE FOR REAL-TIME OPERATIONS?

The Space Packet Protocol does not guarantee a minimum delay in data transfer from source to destination since it is an asynchronous protocol, but there are ways to transfer real-time data as speedily as possible through LDPs.

One way is to use high-priority services of the underlying subnetworks when Space Packets are transferred over subnetworks. When Space Packets are transferred over space links, the CCSDS Space Data Link Protocols (references [3]-[6]) 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 can be set up for transferring high-priority data, then Space Packets for real-time operations can be transferred over those Virtual Channels. In some cases, the Space Packet Protocol entities themselves can prioritize Space Packets by controlling the order of sending out Space Packets over subnetworks.

Space Packets for real-time operations will be identified with their Path IDs. Therefore, real-time operations must be performed over dedicated LDPs.

4.6 ISN'T THE SPACE PACKET PROTOCOL TOO COMPLEX FOR SMALL SPACECRAFT?

It is true that the Space Packet Protocol is somewhat more complex than traditional Time Division Multiplexing (TDM) telemetry schemes. However, if data of variable lengths (such as compressed data) is to be transferred or data is to be transferred at irregular intervals, accommodating such data flows efficiently in traditional TDM telemetry is very difficult and requires a complex scheme.

Therefore, whatever the size of the spacecraft is, the Space Packet Protocol is a good buy if processed data is to be transferred over space links.

4.7 ISN'T THE SPACE PACKET TOO SMALL FOR SENDING IMAGES AND MEMORY DATA?

It is true that the maximum size of the Space Packet (i.e., approximately 65k octets) is sometimes too small for images and memory uploads/downloads. In such cases, an application data unit (an image or a chunk of memory data) that does not fit into a single Space Packet must be transferred with 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 header to identify the first and last segments of a group, and reconstruction of the original application data unit at the destination is possible with 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 Sequence Flags and the Packet Secondary Header, see reference [1]).

ANNEX A

ACRONYMS

This annex lists the acronyms used in this Report.

AOS	Advanced Orbiting Systems
APID	Application Process Identifier
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
ID	Identifier
IP	Internet Protocol
LDP	Logical Data Path
SCID	Spacecraft Identifier
SLE	Space Link Extension
TC	Telecommand
TM	Telemetry