

CCSDS TELEMETRY/TELECOMMAND STANDARDS RESTRUCTURED AS COMMUNICATIONS PROTOCOLS

Takahiro Yamada

Institute of Space and Astronautical Science
3-1-1 Yoshinodai, Sagami-hara 229-8510, Japan
E-mail: tyamada@pub.isas.ac.jp

INTRODUCTION

The Consultative Committee for Space Data Systems (CCSDS) published several technical recommendations on data formats and transmission methods for telemetry and telecommand. The Packet Telemetry recommendation defines standard data units for transferring telemetry from spacecraft to the ground. The Telecommand recommendation defines standard data units for sending commands from the ground to spacecraft. The Advanced Orbiting Systems (AOS) recommendation defines standard data units for exchanging commands and telemetry between the ground and advanced space systems like the International Space Station.

With the advance of the communications technology used in ground communications networks, some spacecraft designers have started investigating the possibility of applying communications protocols developed for ground networks to communications between spacecraft and the ground. By adopting commercial-off-the-shelf software developed for ground networks, the cost of developing spacecraft and ground systems will be reduced.

However, there are two potential problems with using ground communications protocols for spacecraft. The first is that ground communications protocols may not work satisfactorily in the space environments because the characteristics of space communications links are different from those of ground communications links. The second is that it is not easy to introduce new technologies into space systems while maintaining existing infrastructures to support projects already in operation. Therefore, it may be necessary to use non-CCSDS protocols (e.g. Internet protocols) to provide advanced communications services while using CCSDS protocols to provide basic communications services. To cope with this situation, CCSDS decided to restructure their recommendations on telemetry and telecommand so that they can be used with other non-CCSDS protocols.

This paper first reviews the current structure of the CCSDS recommendations on telemetry and telecommand and presents the structure of the restructured recommendations. It then discusses major features of the restructured recommendations and introduces two additional documents that CCSDS is planning to publish together with the restructured recommendations. Finally it shows how the restructured recommendations can be used with other protocols in end-to-end space data systems.

CURRENT STRUCTURE OF CCSDS RECOMMENDATIONS ON TELEMETRY AND TELECOMMAND

The current structure of the CCSDS recommendations on telemetry and telecommand is shown in Fig. 1. There are three sets of recommendations on telemetry and telecommand: the Telemetry set, the AOS recommendation and the Telecommand set. (The current CCSDS recommendations are available at <http://www.ccsds.org>.)

The Telemetry recommendation set consists of three recommendations: Packet Telemetry (CCSDS 102.0-B-5), Packet Telemetry Services (CCSDS 103.0-B-2) and Telemetry Channel Coding (CCSDS 101.0-B-5). The Packet Telemetry recommendation defines two standard data units for sending telemetry: the Source Packet and the Transfer Frame. The Source Packet is used to pack a set of data generated by an onboard application and has functionality of the application, transport and network

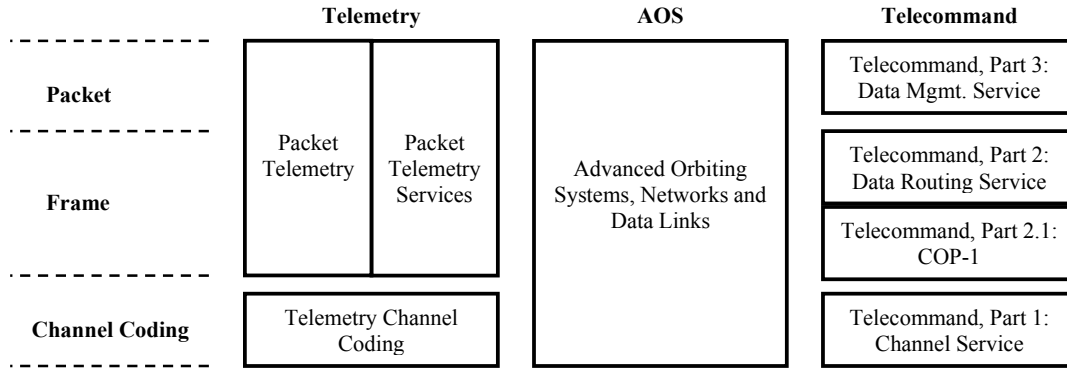


Fig. 1. Current structure of CCSDS recommendations on telemetry and telecommand

layers of the OSI reference model [1]. The Transfer Frame is used to transfer Source Packets over RF links from spacecraft to the ground and corresponds to the data link layer of the OSI reference model. The Packet Telemetry Services recommendation defines services for Packet Telemetry using the ISO conventions for defining services [2]. The Telemetry Channel Coding recommendation defines methods for synchronizing Transfer Frames and methods for correcting and detecting bit errors that occur during transfer of Transfer Frames over RF links. This recommendation covers the lowest part of the data link layer.

The Advanced Orbiting Systems (AOS) recommendation (CCSDS 701.0-B-3) was developed to meet the requirements of advanced space systems like the International Space Station. This recommendation was developed from the Packet Telemetry recommendation and uses two standard data units: the CCSDS Packet and the Virtual Channel Data Unit (VCDU). The CCSDS Packet is the same as the Source Packet defined in Packet Telemetry. The VCDU is similar to the Transfer Frame defined in Packet Telemetry, but it is different in some ways in order to accommodate services for high-speed and real-time communications (e.g. video and voice). The services and synchronization and coding methods are defined in the same recommendation.

The Telecommand recommendation set consists of four recommendations: Part 3 - Data Management Service (CCSDS 203.0-B-2), Part 2 - Data Routing Service (CCSDS 202.0-B-3), Part 2.1 - Command Operation Procedures-1 (COP-1) (CCSDS 202.1-B-2), and Part 1 - Channel Service (CCSDS 201.0-B-3). Part 3 defines a standard data unit called the TC Packet that is used for packing a command for an onboard application. The format of the TC Packet is identical to that of the Source Packet defined in Packet Telemetry. Part 2 defines a data unit called the TC Transfer Frame that is used for transferring TC Packets over RF links. Part 2.1 defines an algorithm for retransmitting lost or corrupted TC Transfer Frames. Part 1 defines a method for synchronizing TC Transfer Frames and a method for correcting and detecting bit errors that occur during transfer of TC Transfer Frames over RF links. The services for these Telecommand recommendations are defined in the same recommendations.

RESTRUCTURED CCSDS RECOMMENDATIONS AS COMMUNICATIONS PROTOCOLS

There are three problems in the structure of the CCSDS recommendations on telemetry and telecommand if these recommendations are to be used with other protocols. The first is that protocols of two layers are defined in a single recommendation (i.e., the Packet Telemetry and AOS recommendations define both packet and frame in a single recommendation). The second is that the same packet structure is defined in three distinct recommendations (i.e., Packet Telemetry, AOS and Telecommand Part 3). The third is that the three recommendation sets are defined with different styles and it is not easy to understand the similarities and differences among these recommendation sets.

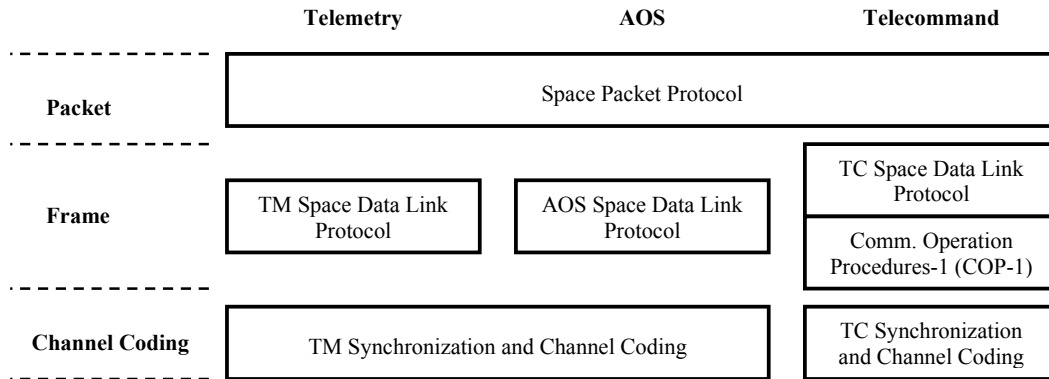


Fig. 2. Restructured CCSDS recommendations on telemetry and telecommand

In order to solve the above problems, CCSDS decided to restructure the recommendations shown in Fig. 1 so that each recommendation defines a communications protocol of a single layer (or sublayer) of the OSI reference model [1] and can be used with other CCSDS or non-CCSDS protocols of other layers. Fig. 2 shows the structure of the restructured recommendations.

In the new structure, the packet portion of the existing recommendations (i.e., the Source Packet, the CCSDS Packet and the TC Packet) is redefined as the Space Packet Protocol, which can be used over restructured CCSDS data link protocols or other appropriate protocols. The frame portion of the Packet Telemetry, AOS and Telecommand recommendations are redefined as the TM Space Data Link Protocol, AOS Space Data Link Protocol, and TC Space Data Link Protocol, respectively. These redefined data link protocols, which are collectively called the Space Data Link Protocols, can carry Space Packets and other data units authorised by CCSDS (e.g. IP datagrams). The Communications Operation Procedures-1, which is a restructured version of the Command Operation Procedures-1 (COP-1), is used with the TC Space Data Link Protocol. The TM Synchronization and Channel Coding recommendation is a restructured version of the Telemetry Channel Coding recommendation and used with either the TM or AOS Space Data Link Protocol. The TC Synchronization and Channel Coding recommendation is a restructured version of Telecommand Part 1 and used with the TC Space Data Link Protocol.

All of these restructured recommendations strictly follow the model and conventions established by ISO [1]-[2] and present the protocols in a unified way. In the restructured recommendations, there are no substantial technical changes from the current recommendations, but some technical terms used in the recommendations are changed so that a thing has a single name and similar things have similar names. For example, the Source Packet, the CCSDS Packet and the TC Packet are all called the Space Packet in the new recommendations. The VCDU (the frame used in the AOS recommendation) is called the AOS Transfer Frame in the AOS Space Data Link Protocol so that all the Transfer Frames have similar names (i.e., the TM Transfer Frame, the AOS Transfer Frame and the TC Transfer Frame).

CCSDS finished editing the restructured recommendations, and they have been published as draft recommendations (i.e. Red Books) for review by the member space agencies of CCSDS. CCSDS also has a plan to revise the Green Books (i.e., reports describing the concept and rationale of recommendations) on telemetry and telecommand with the concept used for restructuring the recommendations.

MAJOR FEATURES OF THE RESTRUCTURED RECOMMENDATIONS

Space Packet Protocol

The Space Packet Protocol is a unified protocol that defines the packet portion of the current recommendation sets (Telemetry, AOS and Telecommand). It is defined as an end-to-end protocol for transferring data between ground and onboard applications through underlying subnetworks, which include one or more onboard subnetworks, one or more space links and one or more ground subnetworks. With this protocol, an onboard application sends telemetry to one or more ground applications, and a ground application sends commands to one or more onboard applications. This protocol may also be used for transferring data between applications on a spacecraft or between applications on two or more spacecraft. The protocol data unit of this protocol is the Space Packet, which is the same as the Source Packet, the CCSDS Packet and the TC Packet defined in the current recommendations.

The Space Packet Protocol routes Space Packets through the subnetworks according to Logical Data Paths (LDPs). An LDP is a unidirectional route from a single source application to one or more destination applications. As Space Packets traverse the subnetworks included in an LDP, they are carried by subnetwork-specific mechanisms provided by the subnetworks. The mechanisms used in the subnetworks are determined independently for each subnetwork and may not be the same through the entire LDP. Over a space link, Space Packets are carried by one of the Space Data Link Protocols. In an onboard subnetwork, they are carried by onboard buses in most cases. In a ground subnetwork, they are carried with application services like the Space Link Extension (SLE) Services developed by CCSDS.

The LDPs used for a space project are configured by the project management before data transfer begins. Therefore, the configuration of LDPs is static at least during one mission phase. Every LDP is uniquely identified by a Path Identifier (Path ID). A Path ID usually consists of an Application Process Identifier (APID) and a Spacecraft Identifier (SCID). The APID is contained in the header of Space Packets, but the SCID is generally associated with Space Packets, in each subnetwork, by a mechanism provided by the subnetwork. According to this definition, an APID identifies an LDP, but it is often the case that an APID is also associated with an onboard application process that generates telemetry or consumes commands.

Space Data Link Protocols

The Space Data Link Protocols (i.e., the TM, AOS and TC Space Data Link Protocols) provide the capability to transfer various types of data on space links, but their principal function is to transfer variable-length data units known as packets. The Space Data Link Protocols can carry any packets provided that the packets have a Packet Version Number (PVN) authorized by CCSDS. The Packet Version Numbers authorized by CCSDS are registered in the Space Link Identifiers document, which is discussed below. Presently the following packets are authorized by CCSDS: Space Packet, SCPS-NP datagram, IP version 4 datagram, and Encapsulation Packet (special packet for encapsulating other data units). IP version 6 datagrams are carried by the Space Data Link Protocols encapsulated in Encapsulation Packets.

The TM Space Data Link Protocol is usually used for (but not limited to) sending telemetry from a spacecraft to the ground (i.e., on a return link). The TC Space Data Link Protocol is usually used for (but not limited to) sending commands from the ground to a spacecraft (i.e., on a forward link). The AOS Space Data Link Protocol may be used on a return link alone, or on both forward and return links if there is a need for two-way on-line communications (e.g., audio and video) between a spacecraft and the ground.

The protocol data unit used by the Space Data Link Protocols is called the Transfer Frame. The TM and AOS Space Data Link Protocols use fixed-length Transfer Frames to facilitate robust

synchronization procedures over noisy space links, whereas the TC Space Data Link Protocol uses variable-length Transfer Frames to facilitate reception of short messages with short delays.

The TC Space Data Link Protocol has a function of retransmitting lost or corrupted data to ensure delivery of data in sequence without gaps or duplication over a space link. This function is provided by a retransmission control mechanism called the Communications Operation Procedure-1 (COP-1). Neither the TM Space Data Link Protocol nor the AOS Space Data Link Protocol has such a function, so retransmission should be done by a higher layer protocol if complete delivery of data is required.

The TM Synchronization and Channel Coding and TC Synchronization and Channel Coding recommendations provide some additional functions necessary for transferring Transfer Frames over space links. They specify methods for synchronizing Transfer Frames, methods for correcting and detecting bit errors that occur over space links, and methods for generating bit transitions to facilitate the symbol synchronization process.

ADDITIONAL DOCUMENTS GENERATED WITH RESTRUCTURED RECOMMENDATIONS

Along with the restructured recommendations explained above, CCSDS plans on publishing two additional documents that are to be used with the restructured recommendations.

Space Link Identifiers

The space link protocols (i.e. protocols to be used over space links) developed by CCSDS use various identifiers to identify protocols, addresses, and data formats. Together with the restructured recommendations, a new document called the Space Link Identifiers has been developed by CCSDS in order to manage identifiers independently of the specification of the protocols. This document lists the identifiers used by the space link protocols and shows how these identifiers are managed. It also lists the values of some identifiers that are defined or reserved by CCSDS as part of the specification of the space link protocols.

Some examples of identifiers are:

- 1) Application Process Identifier (APID) used by the Space Packet Protocol,
- 2) Packet Version Number used by the Space Packet Protocol and Space Data Link Protocols,
- 3) Transfer Frame Version Number used by the Space Data Link Protocols,
- 4) Spacecraft Identifier (SCID) used by the Space Data Link Protocols, and
- 5) Virtual Channel Identifier (VCID) used by the Space Data Link Protocols.

These identifiers are categorized into three categories in terms of how they are managed.

1) The values of some identifiers are defined by CCSDS as part of the specification of protocols. Examples of this category are the Packet Version Number and the Transfer Frame Version Number. A value of the Transfer Frame Version Number, for example, is defined by a Space Data Link Protocol as part of the specification of the protocol for identifying its protocol data unit. The values of the identifiers of this category currently defined by CCSDS are listed in the Space Link Identifiers document.

2) The values of some identifiers are assigned by CCSDS upon request by Agencies. An example of this category is the Spacecraft Identifier (SCID). The procedure for assigning values of each of the identifiers of this category is defined by a separate CCSDS document, and pointers to such documents are contained in the Space Link Identifier document.

3) The values of some identifiers are managed independently by the projects that use the protocol. CCSDS does not specify how to manage these identifiers. Examples of this category are the

Application Process Identifier (APID) and the Virtual Channel Identifier (VCID). Some values of the identifiers of this category may be reserved by CCSDS to be used for some specific purposes across space projects. For example, the value 2047 of the APID is reserved for Idle Packets (i.e. Packets that do not contain valid data). The values reserved by CCSDS are listed in the Space Link Identifier document.

Space Link Implementation Chart

The CCSDS recommendations on space link protocols have several options and parameters that each space project should select, and it is necessary for a space project to describe what options and parameters are used by the project in order to be supported by ground systems. Some examples of such options and parameters are:

- 1) Whether the Segment Header of the TC Transfer Frame is used;
- 2) The decoding mode of the BCH code used for protecting TC Transfer Frames;
- 3) The length of the TM or AOS Transfer Frames;
- 4) What coding options are used for protecting TM or AOS Transfer Frames; and
- 5) Whether the randomiser for introducing bit transitions is used.

This kind of information is usually contained in an Interface Control Document (ICD) between a spacecraft and a ground system. Since there is no international standard for describing such options and parameters, each space agency has to develop their own format to be used in their ICDs.

Together with the restructured recommendations, CCSDS plans to publish a document that is tentatively called the Space Link Implementation Chart. This document contains a standard template for describing options and parameters of space link protocols implemented by a space project. By using this template, some portion of ICDs can be standardized.

COMBINATIONS OF PROTOCOLS

By restructuring CCSDS recommendations this way, space projects will be able to combine protocols more easily to create protocol stacks that match their requirements and constraints. They can use non-CCSDS protocols such as Internet protocols to provide advanced communications services while using CCSDS protocols to provide basic communications services. Some examples of combinations of protocols that can be used over space links are shown in Fig. 3.

As explained above, the Space Data Link Protocols can carry any packets as long as their Packet Version Number is authorized by CCSDS. In Fig. 3, the Space Packet Protocol, SCPS Network Protocol (SCPS-NP) and Internet Protocol (IP) are shown as protocols carried by the Space Data Link Protocols.

The SCPS (Space Communications Protocol Specification) consists of four protocols (SCPS Network Protocol, SCPS Security Protocol, SCPS Transport Protocol, and SCPS File Protocol). These protocols are based on Internet protocols, but some modifications and extensions to the Internet protocols are incorporated to meet the specific needs of space projects.

On top of the Space Packet Protocol, an efficient file transfer protocol developed by CCSDS, which is known as the CCSDS File Delivery Protocol or CFDP, can be used for reliably transferring files, but applications may directly use the Space Packet Protocol for control and monitoring purposes. On top of SCPS-NP or IP, most SCPS and Internet protocols can be used.

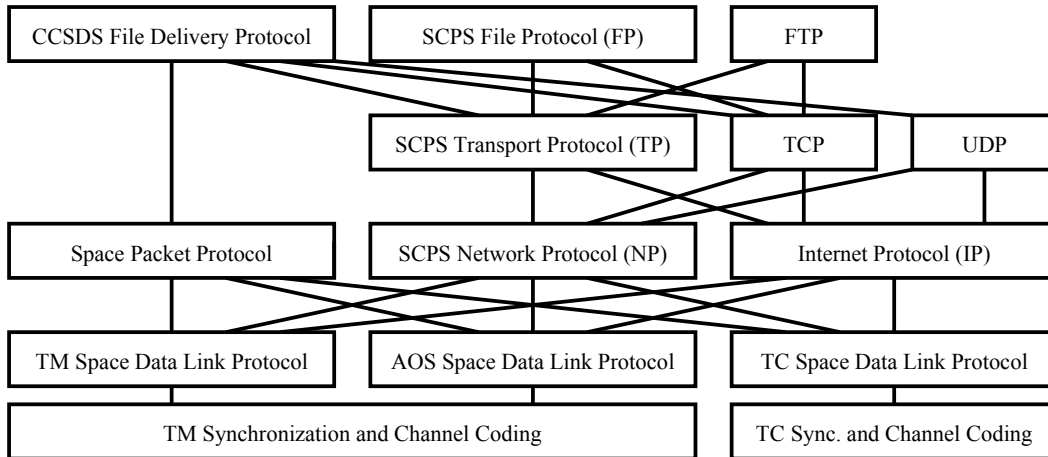


Fig. 3. Examples of possible combinations of space link protocols

END-TO-END PROTOCOL CONFIGURATIONS

End-to-end System Model

In this section, two examples are shown to illustrate how space link protocols are used in end-to-end space data systems. A space data system consists of onboard elements connected with one or more onboard subnetworks and ground elements connected with one or more ground subnetworks. The onboard and ground segments are connected with one or more space links. In this section, however, a simple space data system model (shown in Fig. 4) that consists of four elements and three subnetworks is used to present the examples of protocol configurations.

The four elements are:

- 1) Onboard end system: a payload or a subsystem of a spacecraft;
- 2) Onboard relay system: an element of the spacecraft that handles communications with the ground;
- 3) Ground relay system: a data processing element at a ground station; and
- 4) Ground end system: a user on the ground that controls the payload or subsystem.

These four elements are connected with three subnetworks (i.e., an onboard subnetwork, a space link, and a ground subnetwork) as shown in Fig. 4.

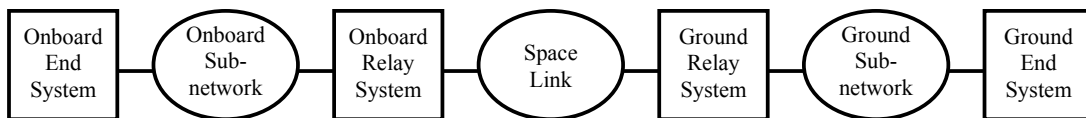


Fig. 4. An end-to-end space data system

Example 1

In the first example shown in Fig. 5, the Space Packet Protocol provides the capability of routing application data from source to destination through the subnetworks. The Space Packet Protocol was designed to meet the requirements of space projects to efficiently transfer application data in a space

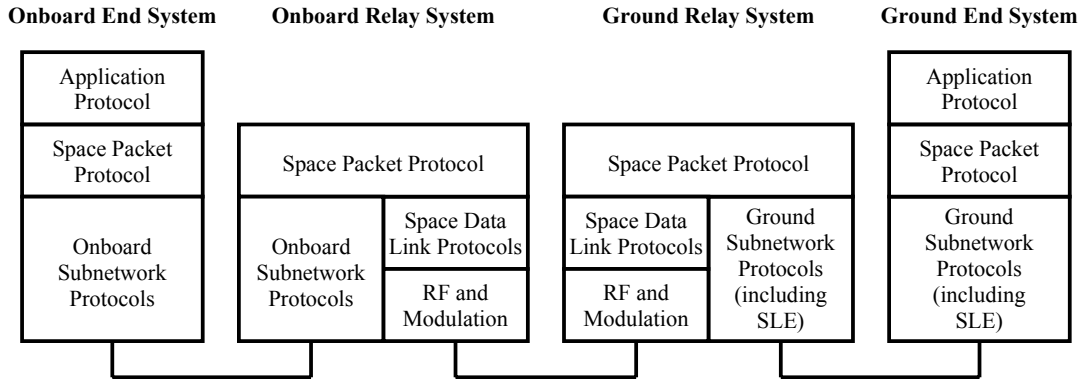


Fig. 5. Example of protocol configuration in an end-to-end space data system (Example 1)

data system, and this configuration is suited to space projects that favor the simple routing mechanism provided by the Space Packet Protocol.

In this example, the onboard end system communicates with the ground end system using an application protocol for monitoring and control or file transfer. The Space Packet Protocol transfers the application data in Space Packets between the onboard and ground end systems. Space Packets are relayed at the onboard and ground relay systems using routing information supplied by management activities. When Space Packets are transferred in the ground subnetwork, the SLE Services will be used on top of ground transport protocols (e.g., TCP/IP).

Example 2

In the second example shown in Fig. 6, the SCPS-NP or IP is used for routing through the subnetworks. In this configuration, most SCPS and Internet end-to-end protocols (e.g., SCPS-TP, SCPS-FP, TCP, UDP and FTP) can be used on top of SCPS-NP or IP. This configuration is suited to space projects that require integration of the space segments into the ground Internet and/or utilization of Internet protocols in the space segments. In this configuration, SCPS-NP can be converted to IP at some point in the network.

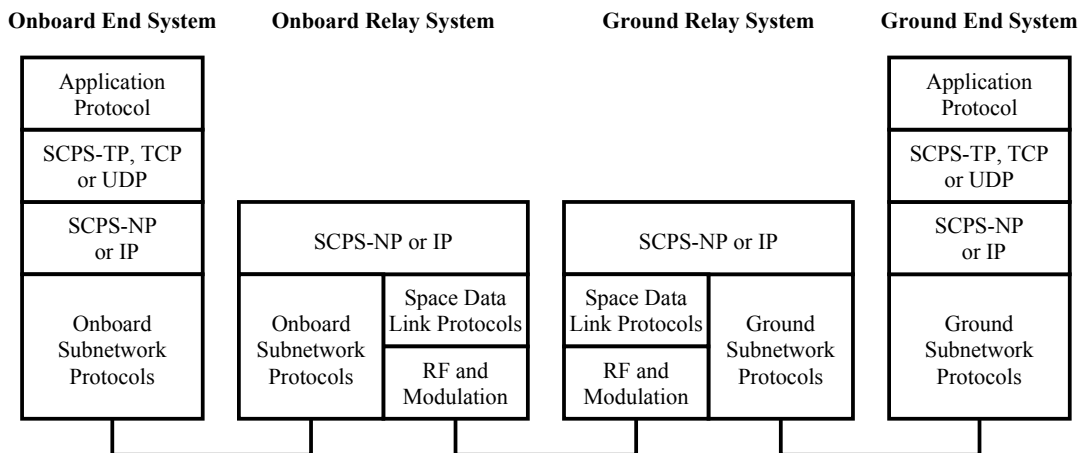


Fig. 6. Example of protocol configuration in an end-to-end space data system (Example 2)

CONCLUSION

This paper presented the on-going work of CCSDS on restructuring the current CCSDS recommendations on telemetry and telecommand as communications protocols. It showed how the current recommendations are restructured and discussed the major features of the restructured recommendations. It also showed how the restructured recommendations can be used with other protocols in end-to-end space data systems. The restructured recommendations presented here have been published by CCSDS as draft recommendations (i.e. Red Books) and available at <http://www.ccsds.org>.

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- [2] Information Technology - Open Systems Interconnection - Basic Reference Model: Conventions for the definition of OSI services, International Standard, ISO/IEC 10731:1994, ISO, 1994.

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