The Consultative Committee for Space Data Systems

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Consultative Committee for Space Data Systems

REPORT CONCERNING SPACE DATA SYSTEM STANDARDS

OVERVIEW OF SPACE LINK PROTOCOLS

CCSDS 130.0-G-1

GREEN BOOK

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FOREWORD

This document is a CCSDS Report that contains an overview of the space link protocols recommended by CCSDS. A space link is a communications link between a spacecraft and its associated ground system or between two spacecraft. A space link protocol is a communications protocol designed to be used over a space link, or in a network that contains one or multiple space links. Please note that a space link protocol is not necessarily a protocol of the Data Link Layer of the OSI Basic Reference Model (reference [2]).

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1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this report is to provide an architectural overview of the space link protocols recommended by CCSDS and to show how these protocols are used in space mission data systems.

A space link is a communications link between a spacecraft and its associated ground system or between two spacecraft. A space link protocol is a communications protocol designed to be used over a space link, or in a network that contains one or multiple space links. Please note that a space link protocol is not necessarily a protocol of the Data Link Layer of the OSI Basic Reference Model [2].

This report only presents a top-level overview of the space link protocols and does not contain the specification or rationale of each protocol. The specification of a space link protocol developed by CCSDS is contained in a CCSDS Blue Book, and its rationale is described in a CCSDS Green Book that accompanies the Blue Book.

1.2 DOCUMENT STRUCTURE

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

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

b) section 2 provides a brief introduction to the space link protocols;

c) section 3 presents major features of the space link protocols;

d) section 4 shows some examples of how space link protocols are used in space data systems;

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

1.3 DEFINITIONS

1.3.1 DEFINITIONS FROM OSI BASIC REFERENCE MODEL

Most of the CCSDS space link protocols are defined using the style established by the Open Systems Interconnection (OSI) Basic Reference Model [2]. This model provides a common framework for the development of standards in the field of systems interconnection. It defines concepts and terms associated with a layered architecture and introduces seven specific layers. The concepts and terms defined in this model are extensively used in the Blue Books that define CCSDS space link protocols. If the reader is not familiar with this model, an excellent introduction can be found in a textbook on computer networks such as [3].

The following terms used in this Report are defined in [2]:

a) Application Layer;

b) Data Link Layer;

c) layer;

d) Network Layer;

e) Physical Layer;

f) protocol data unit;

g) service;

h) Transport Layer.

1.3.2 TERMS DEFINED IN THIS REPORT

For the purposes of this Report, the following definitions also apply.

octet: an 8-bit word.

Physical Channel: a stream of bits transferred over a space link (see below) in a single direction.

space link: a communications link between a spacecraft and its associated ground system or between two spacecraft. A space link consists of one or more Physical Channels in one or both directions.

space link protocol: a communications protocol designed to be used over a space link (see above), or in a network that contains one or multiple space links. A space link protocol is not necessarily a protocol of the Data Link Layer of the OSI Basic Reference Model [2].

1.4 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] *Procedures Manual for the Consultative Committee for Space Data Systems*. CCSDS A00.0-Y-7. Yellow Book. Issue 7. Washington, D.C.: CCSDS, November 1996.

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

[3] Andrew S. Tanenbaum. *Computer Networks*. 3rd ed.. New Jersey: Prentice-Hall, 1996.

[4] *Space Packet Protocol*. Draft Recommendation for Space Data System Standards, CCSDS 133.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

[5] *TM Space Data Link Protocol*. Draft Recommendation for Space Data System Standards, CCSDS 132.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

[6] *TC Space Data Link Protocol*. Draft Recommendation for Space Data System Standards, CCSDS 232.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

[7] *AOS Space Data Link Protocol*. Draft Recommendation for Space Data System Standards, CCSDS 732.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

[8] *Channel Coding and Synchronization—Part 1: Synchronous*. Draft Recommendation for Space Data System Standards, CCSDS 131.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

[9] *Channel Coding and Synchronization—Part 2: Asynchronous*. Draft Recommendation for Space Data System Standards, CCSDS 231.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

† At time of publication, several documents referenced in this list had not yet been approved by the CCSDS for final release. For such documents, current draft versions have been referenced, even though in some cases those draft versions may not be generally available. For all draft CCSDS documents referenced, users of this Report are advised to substitute released versions as soon as they become available.

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

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

[12] *Space Communications Protocol Specification (SCPS)—Security Protocol (SCPS-SP)*. Recommendation for Space Data System Standards, CCSDS 713.5-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 1999.

[13] *Space Communications Protocol Specification (SCPS)—Transport Protocol (SCPS-TP)*. Recommendation for Space Data System Standards, CCSDS 714.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 1999.

[14] *Space Communications Protocol Specification (SCPS)—File Protocol (SCPS-FP)*. Recommendation for Space Data System Standards, CCSDS 717.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 1999.

[15] *CCSDS File Delivery Protocol (CFDP)*. Draft Recommendation for Space Data System Standards, CCSDS 727.0-R-5. Red Book. Issue 5. Washington, D.C.: CCSDS, August 2001.

[16] *Lossless Data Compression*. Recommendation for Space Data System Standards, CCSDS 121.0-B-1. Blue Book. Issue 1. Washington, D.C.: CCSDS, May 1997.

[17] *Proximity-1 Space Link Protocol*. Draft Recommendation for Space Data System Standards, CCSDS 211.0-R-2. Red Book. Issue 2. Washington, D.C.: CCSDS, January 2000.

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

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

[20] S. Deering and R. Hinden. *Internet Protocol, Version 6 (IPv6) Specification*. RFC 1883, December 1995.

‡ Internet Request for Comments (RFC) texts are available on line in various locations (e.g., http://ietf.org/rfc/). In this list, Internet Standards are identified by 'STD' followed by the number of the standard, and RFCs are identified by 'RFC' followed by the number of the RFC. RFCs comprised by Internet Standards are given in square brackets following the citation.

CCSDS HISTORICAL DOCUMENT

[21] J. Postel. *Transmission Control Protocol*. STD 7, September 1981. [RFC 793]

[22] J. Postel. *User Datagram Protocol*. STD 6, August 1980. [RFC 768]

[23] J. Postel and J. Reynolds. *File Transfer Protocol*. STD 9, October 1985. [RFC 959]

[24] *Communications Operation Procedure-1*. Draft Recommendation for Space Data System Standards, CCSDS 232.1-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, June 2000.

[25] *Space Link Identifiers*. Draft Recommendation for Space Data System Standards, CCSDS 135.0-R-1. Red Book. Issue 1. Washington, D.C.: CCSDS, November 2000.

[26] *Space Packet Protocol—Encapsulation Service*. CCSDS 133.1-W-1. White Book. [Under development]. n.p.: n.p, n.d..

[27] Space Link Extension Service Specifications. [Space Link Extension Service Specifications are in various stages of development. Current issues of CCSDS documents are maintained at the CCSDS Web site: http://ccsds.org.]

[28] *Space Data Link Protocols—Summary of Concept and Rationale*. Draft Report Concerning Space Data System Standards, CCSDS 130.2-G-0.1. Draft Green Book. Issue 0.1. Sagamihara, Japan: ISAS, n.d.

[29] *Channel Coding and Synchronization—Part 1: Synchronous—Summary of Concept and Rationale*. Draft Report Concerning Space Data System Standards, CCSDS 130.1-G-0.1. Draft Green Book. Issue 0.1. Sagamihara, Japan: ISAS, n.d.

[30] *Channel Coding and Synchronization—Part 2: Asynchronous—Summary of Concept and Rationale*. Draft Report Concerning Space Data System Standards, CCSDS 230.1-G-0.1. Draft Green Book. Issue 0.1. Sagamihara, Japan: ISAS, n.d.

[31] *Space Packet Protocol—Summary of Concept and Rationale*. Draft Report Concerning Space Data System Standards, CCSDS 130.3-G-0.1. Draft Green Book. Issue 0.1. Sagamihara, Japan: ISAS, n.d.

[32] *Space Communications Protocol Specification (SCPS)—Rationale, Requirements, and Application Notes*. Draft Report Concerning Space Data System Standards, CCSDS 710.0-G-0.4. Draft Green Book. Issue 0.4. Washington, D.C.: CCSDS, October 1997.

[33] *CCSDS File Delivery Protocol (CFDP)—Part 1: Introduction and Overview*. Draft Report Concerning Space Data System Standards, CCSDS 720.1-G-0.8. Draft Green Book. Issue 0.8. n.p.: n.p., July 2001.

[34] *Lossless Data Compression*. Report Concerning Space Data System Standards, CCSDS 120.0-G-1. Green Book. Issue 1. Washington, D.C.: CCSDS, May 1997.

2 INTRODUCTION TO SPACE LINK PROTOCOLS

2.1 HISTORY OF SPACE LINK PROTOCOLS

Traditionally, telemetry transmitted from the spacecraft was formatted with a Time Division Multiplexing (TDM) scheme, where data items were multiplexed into a continuous stream of fixed-length frames based on a predefined multiplexing rule. To design and implement a data system for spacecraft, each project was forced to develop a custom system used by that project alone, with the exception of the ground tracking network, because of the lack of established standards in this field.

The advent of microprocessor-based spacecraft instruments and subsystems, however, enabled telemetry systems to become more flexible and have greater throughput so that data processed by onboard software could be transmitted efficiently.

In the early 1980s, CCSDS developed an international standard for a Packet Telemetry protocol capable of sending processed telemetry efficiently using a variable-length data unit called the Source Packet. Source Packets generated by various instruments and subsystems on a spacecraft are transmitted to the ground in a stream of continuous, fixed-length Transfer Frames. This standard has been used by many space projects enabling them to share onboard and ground data processing equipment.

Based on a similar concept, another international standard on Telecommand was developed by CCSDS, shortly after Packet Telemetry, for sending commands to a spacecraft with a data unit known as the TC Packet. TC Packets destined for various instruments and subsystems on a spacecraft are transmitted from the ground in a stream of sporadic, variable-length Transfer Frames.

In the late 1980s, CCSDS extended the above standards to meet the requirements of the Advanced Orbiting Systems, such as the International Space Station, and came up with a third standard known as AOS. The AOS standard added to the Packet Telemetry standard services for transmitting various types of online data (such as audio and video data). And it may be used on both space-to-ground and ground-to-space links. The AOS uses the same packet structure as the Packet Telemetry standard but the frame format is slightly different.

These three standards (Packet Telemetry, Telecommand, and AOS) were later restructured by CCSDS in order to define the protocols in a more structured and unified way, and the following standards replace the original standards:

a) Space Packet Protocol (reference [4]);

b) TM/TC/AOS Space Data Link Protocols (references [5], [6], and [7], respectively);

c) TM/TC Synchronization and Channel Coding (references [8] and [9], respectively).

As an international standard for the Radio Frequency (RF) signal between a spacecraft and a ground station, CCSDS developed a standard called Radio Frequency and Modulation Systems [10]. This standard specifies the characteristics of the RF signal used to carry Packets and Frames.

In the 1990s, CCSDS developed another set of protocols collectively known as Space Communications Protocol Specifications (SCPS), which include SCPS Network Protocol (SCPS-NP) [11], SCPS Security Protocol (SCPS-SP) [12], SCPS Transport Protocol (SCPS-TP) [13], and SCPS File Protocol (SCPS-FP) [14]. The SCPS protocols are basically based on Internet protocols. But modifications and extensions to the Internet protocols are incorporated in the design of the SCPS protocols to meet the specific needs of space missions.

In response to the needs of space missions to transfer files to and from an onboard mass memory, CCSDS has developed a protocol called the CCSDS File Delivery Protocol (CFDP) [15]. This protocol provides the capability to transfer files reliably and efficiently over an unreliable protocol (for example, the Space Packet Protocol).

In the area of data compression, CCSDS has developed a Lossless Data Compression standard [16] either to increase the science return or to reduce the requirement for onboard memory, station contact time, and data archival volume. This standard guarantees full reconstruction of the original data without incurring any distortion in the process.

Recently CCSDS has developed a protocol called Proximity-1 Space Link Protocol [17] to be used over proximity space links. Proximity space links are defined to be short range, bi-directional, fixed or mobile radio links, generally used to communicate among fixed probes, landers, rovers, orbiting constellations, and orbiting relays. This protocol defines a data link protocol and RF and modulation characteristics.

2.2 PROTOCOL LAYERS

2.2.1 SUMMARY

A communications protocol is usually associated with one of the seven layers defined in the OSI Basic Reference Model [2]. Although some space link protocols do not fit well with the OSI seven-layer model, this report uses this model for categorizing the space link protocols.

The space link protocols are defined for the following five layers of the ISO model:

a) Physical Layer;

b) Data Link Layer;

c) Network Layer;

d) Transport Layer;

e) Application Layer.

As in most terrestrial networks, protocols of the Session and Presentation Layers of the OSI model are rarely used over space links.

Figure 2-1 shows the space link protocols categorized into the five layers listed above. Figure 2-2 shows possible combinations of these protocols.

In figure 2-1, there are two protocols that do not correspond to a single layer. CCSDS File Delivery Protocol (CFDP) has the functionality of the Transport and Application Layers. Proximity-1 Space Link Protocol has the functionality of the Data Link and Physical Layers.

Although CCSDS does not formally define Application Program Interfaces (APIs) for the space link protocols, most CCSDS standards provide service definitions in the form of primitives following the conventions established by ISO (see reference [18]). A primitive is an abstract representation of an API that does not depend on any implementation technology and thus should be used as the baseline for an API.

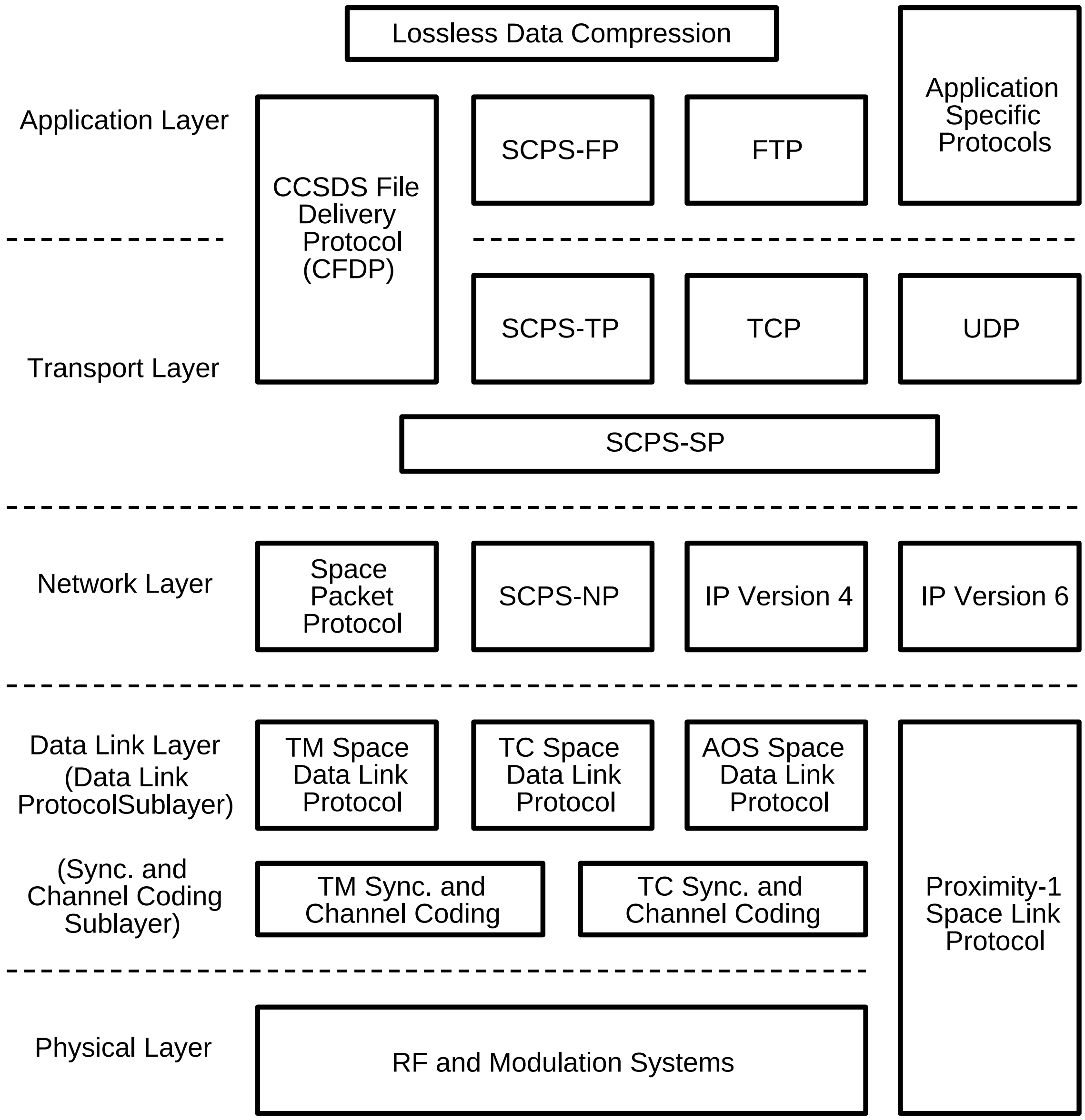

Figure 2-1: Space Link Protocols

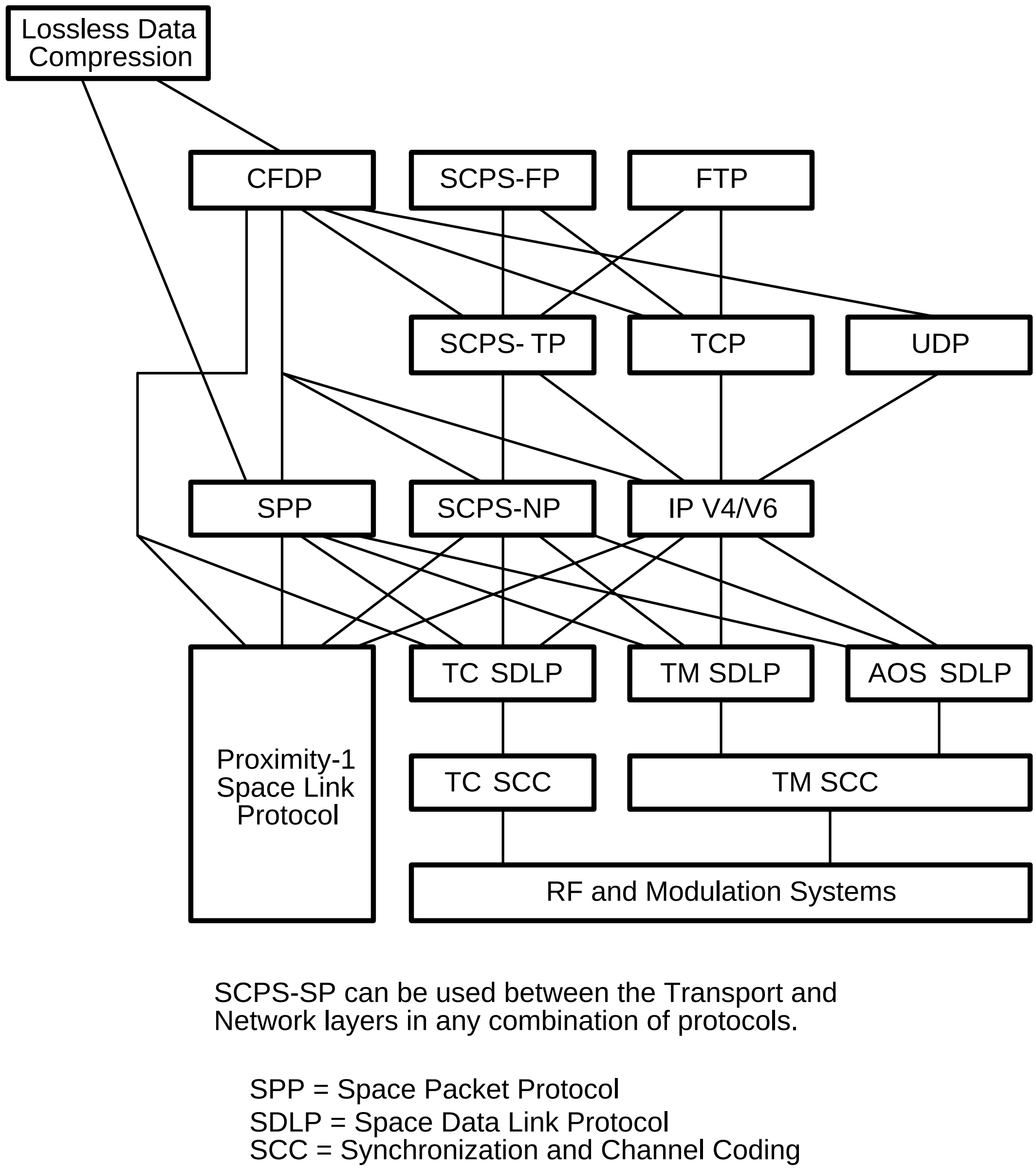

Figure 2-2: Possible Combinations of Space Link Protocols

In the following subsections, the protocols shown in figure 2-1 are briefly introduced. Major features of these protocols will be explained in section 3.

2.2.2 PHYSICAL LAYER

CCSDS has a standard for the Physical Layer called the Radio Frequency and Modulation Systems [10] to be used for space links between spacecraft and ground stations. The Proximity-1 Space Link Protocol [17] also contains recommendations for the Physical Layer of proximity space links.

2.2.3 DATA LINK LAYER

CCSDS defines two Sublayers in the Data Link Layer of the OSI Model: Data Link Protocol Sublayer and Synchronization and Channel Coding Sublayer. The Data Link Protocol Sublayer specifies methods of transferring data units provided by the higher layer over a space link using data units known as Transfer Frames. The Synchronization and Channel Coding Sublayer specifies methods of synchronization and channel coding for transferring Transfer Frames over a space link.

CCSDS has developed three protocols for the Data Link Protocol Sublayer of the Data Link Layer:

a) TM Space Data Link Protocol [5];

b) TC Space Data Link Protocol [6];

c) AOS Space Data Link Protocol [7].

The above protocols provide the capability to send data over a single space link.

CCSDS has developed two standards for the Synchronization and Channel Coding Sublayer of the Data Link Layer:

a) TM Synchronization and Channel Coding [8];

b) TC Synchronization and Channel Coding [9].

TM Synchronization and Channel Coding is used with the TM or AOS Space Data Link Protocol, and TC Synchronization and Channel Coding is used with the TC Space Data Link Protocol.

The Proximity-1 Space Link Protocol [17] also defines a protocol of the Data Link Protocol Sublayer together with the synchronization and channel coding methods to be used by this protocol.

The TM, TC and AOS Space Data Link Protocols and the Data Link Protocol Sublayer portion of the Proximity-1 Space Link Protocol are called the Space Data Link Protocols in this document.

2.2.4 NETWORK LAYER

Space link protocols of the Network Layer provide the function of routing higher-layer data through the entire data system that includes both onboard and ground subnetworks.

CCSDS has developed two protocols for the Network Layer:

a) Space Packet Protocol [4];

b) SCPS Network Protocol (SCPS-NP) [11].

In some cases, Protocol Data Units (PDUs) of the Space Packet Protocol are generated and consumed by application processes themselves on a spacecraft, instead of being generated and consumed by a separate protocol entity, and in these cases this protocol is used both as a Network Layer protocol and as an Application Layer protocol.

PDUs of a Network Layer protocol are transferred with Space Data Link Protocols over a space link.

The following protocols developed by the Internet can also be transferred with Space Data Link Protocols over a space link, multiplexed or not-multiplexed with the Space Packet Protocol and/or SCPS-NP:

a) Internet Protocol (IP), Version 4 [19];

b) Internet Protocol (IP), Version 6 [20].

2.2.5 TRANSPORT LAYER

Space link protocols of the Transport Layer provide users with end-to-end transport services.

CCSDS has developed the SCPS Transport Protocol (SCPS-TP) [13] for the Transport Layer. The CCSDS File Delivery Protocol (CFDP) [15] also provides the functionality of the Transport Layer, but it provides some functions (i.e., functions for file management) of the Application Layer as well.

PDUs of a Transport Layer protocol are usually transferred with a protocol of the Network Layer over a space link, but they can be transferred directly with a Space Data Link Protocol if certain conditions are met.

Transport protocols used in the Internet (such as TCP [21] and UDP [22]) can also be used on top of SCPS-NP, IP Version 4, and IP Version 6 over space links.

SCPS Security Protocol (SCPS-SP) [12] may be used with a Transport protocol to provide end-to-end data protection capability.

2.2.6 APPLICATION LAYER

Space link protocols of the Application Layer provide users with end-to-end application services such as file transfer and data compression.

CCSDS has developed two protocols for the Application Layer:

a) SCPS File Protocol (SCPS-FP) [14];

b) Lossless Data Compression [16].

The CCSDS File Delivery Protocol (CFDP) [15] provides the functionality of the Application Layer (i.e., functions for file management), but it also provides functions of the Transport Layer.

Each project (or Agency) may elect to use application-specific protocols not recommended by CCSDS to fulfill their mission requirements in the Application Layer over CCSDS space link protocols.

PDUs of an Application Layer protocol (excluding CFDP) are usually transferred with a protocol of the Transport Layer over a space link, but they can be transferred directly with a protocol of the Network Layer if certain conditions are met.

Applications protocols used in the Internet (such as FTP [23]) can also be used on top of SCPS-TP, TCP and UDP over space links.

3 MAJOR FEATURES OF SPACE LINK PROTOCOLS

3.1 PHYSICAL LAYER

The CCSDS Recommendation on Radio Frequency and Modulation Systems [10] recommends the characteristics of the RF and modulation systems used for communications over space links between spacecraft and ground stations.

The Proximity-1 Space Link Protocol [17] also contains recommendations for the Physical Layer of proximity space links.

3.2 DATA LINK LAYER

3.2.1 GENERAL FEATURES OF DATA LINK PROTOCOLS

CCSDS has developed four protocols for the Data Link Protocol Sublayer of the Data Link Layer:

a) TM Space Data Link Protocol [5];

b) TC Space Data Link Protocol [6];

c) AOS Space Data Link Protocol [7];

d) Data Link Protocol Sublayer portion of Proximity-1 Space Link Protocol [17].

These protocols (collectively known as 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 knows as packets (i.e., protocol data units of protocols of the Network Layer such as the Space Packet Protocol, SCPS-NP and IP).

Each packet format transferred by the Space Data Link Protocols must have a Packet Version Number (PVN) authorized by CCSDS. A list of the Packet Version Numbers presently authorized by CCSDS is contained in reference [25]. Packets with authorized Packet Version Numbers can be transferred by the Space Data Link Protocols directly, but CCSDS has another mechanism to transfer other packets with a service called the Encapsulation Service, defined in reference [26]. With this service, packets are transferred by the Space Data Link Protocols encapsulated in either Space Packets defined in reference [4] or Encapsulation Packets defined in reference [26].

The TM Space Data Link Protocol is usually used for (but not limited to) sending telemetry from a spacecraft to a ground station (i.e., on a return link). The TC Space Data Link Protocol is usually used for (but not limited to) sending commands from a ground station 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 Proximity-1 Space Link Protocol is to be used over proximity space links, where proximity space links are defined to be short range, bi-directional, fixed or mobile radio links, generally used to communicate among fixed probes, landers, rovers, orbiting constellations, and orbiting relays.

The protocol data units used by the Space Data Link Protocols are called Transfer Frames. The TM and AOS Space Data Link Protocols use fixed-length Transfer Frames to facilitate robust synchronization procedures over a noisy link, while the TC Space Data Link Protocol uses variable-length Transfer Frames to facilitate reception of short messages with a short delay. The Proximity-1 Space Link Protocol uses either fixed-length or variable-length Transfer Frames.

A key feature of the Space Data Link Protocols is the concept of 'Virtual Channels'. The Virtual Channel facility allows one Physical Channel (a stream of bits transferred over a space link in a single direction) to be shared among multiple higher-layer data streams, each of which may have different service requirements. A single Physical Channel may therefore be divided into several separate logical data channels, each known as a Virtual Channel (VC). Each Transfer Frame transferred over a Physical Channel belongs to one of the Virtual Channels of the Physical Channel.

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), which is defined in a separate document (reference [24]). (This function does not necessarily guarantee end-to-end complete delivery). The Proximity-1 Space Link Protocol also has a similar function called COP-P, which is defined in the same document as the protocol. 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/TC/AOS Space Data Link Protocols are used on top of the Recommendation on Radio Frequency and Modulation Systems [10]. The Proximity-1 Space Link Protocol [17] contains recommendations for the Physical Layer in the same book.

A summary of concept and rationale of the TM/TC/AOS Space Data Link Protocols is contained in reference [28].

3.2.2 ADDRESSING OF DATA LINK PROTOCOLS

The Space Data Link Protocols provide some addresses (or identifiers) to identify data streams. All the Space Data Link Protocols have the following three identifiers: Transfer Frame Version Number (TFVN), Spacecraft Identifier (SCID), and Virtual Channel Identifier (VCID). The concatenation of a TFVN and a SCID is known as a Master Channel Identifier (MCID), which is used for identifying a spacecraft associated with a space link.

All Transfer Frames with the same MCID on a Physical Channel constitute a Master Channel (MC). A Master Channel consists of one or more Virtual Channels, each of which is identified with a VCID. In most cases, a Physical Channel only carries Transfer Frames of a single MCID, and the Master Channel will be identical with the Physical Channel. However, a Physical Channel may carry Transfer Frames with multiple MCIDs (with the same TFVN). In such a case, the Physical Channel consists of multiple Master Channels.

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

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

Figure 3-1 shows the relationship among the channels of the Space Data Link Protocols.

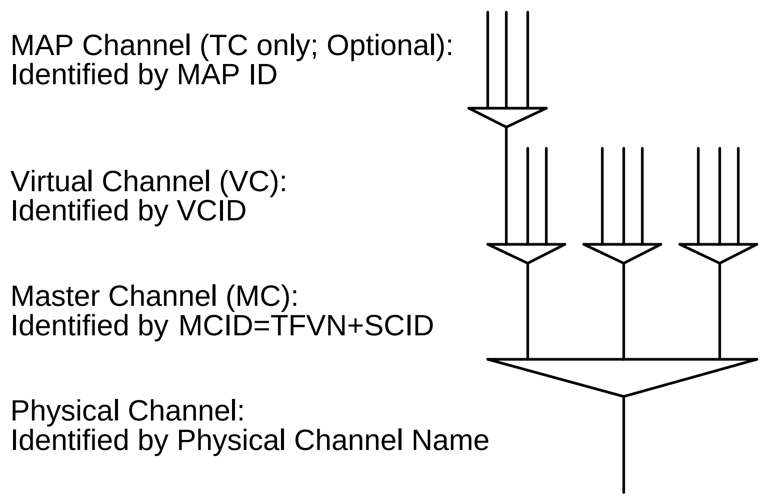

Figure 3-1: Relationships between Channels of the Space Data Link Protocols

The Proximity-1 Space Link Protocol has another identifier called the Port Identifier that is used to route user data internally (at the transceiver's output interface) to specific logical ports, such as applications or transport processes, or to physical ports.

Table 3-1 summarizes the addressing capability of the Space Data Link Protocols.

Table 3-1: Addressing Capability of Space Data Link Protocols

Address	TM Space Data Link Protocol	TC Space Data Link Protocol	AOS Space Data Link Protocol	Proximity-1 Space Link Protocol
Transfer Frame Version Number (TFVN)	Always 1 (binary encoded number is 00)	Always 1 (binary encoded number is 00)	Always 2 (binary encoded number is 01)	Always 3 (binary encoded number is 10)
Spacecraft Identifier (SCID)	0 to 1023	0 to 1023	0 to 255	0 to 1023
Virtual Channel Identifier (VCID)	0 to 7	0 to 63	0 to 63	0, 1
Multiplexer Access Point Identifier (MAP ID)	N/A	0 to 63	N/A	N/A
Port Identifier	N/A	N/A	N/A	0 to 7

3.2.3 SERVICES PROVIDED BY DATA LINK PROTOCOLS

The Space Data Link Protocols provide several services to transfer a variety of data on a space link. The most important service is a service to transfer variable-length data units known as packets (i.e., protocol data units of protocols of the Network Layer). In addition to this service, the Space Data Link Protocols provide services to transfer fixed- or variable-length data units with private (non-CCSDS) formats, short fixed-length data units for reporting or real-time functions, and bit streams.

Table 3-2 shows a summary of the services provided by the TM/TC/AOS Space Data Link Protocols categorized by the types of data transferred by the services. For complete definition of these services, refer to references [5], [6] and [7].

NOTE – The Proximity-1 Space Link Protocol is not included in this table because no service definition is given in the current draft Recommendation (reference [17]).

Table 3-2: Summary of Services Provided by Space Data Link Protocols

Type of Service Data Units	TM Space Data Link Protocol	TC Space Data Link Protocol	AOS Space Data Link Protocol
Packets (NOTE 1)	Packet Service, Encapsulation Service	MAP Packet Service, VC Packet Service, Encapsulation Service	Packet Service, Encapsulation Service
Fixed-length private data	VC Access Service	(None)	VC Access Service
Variable-length private data	(None)	MAP Access Service, VC Access Service	(None)
Short fixed-length data	VC FSH Service (NOTE 2), MC FSH Service, VC OCF Service (NOTE 3), MC OCF Service	(None)	Insert Service, VC OCF Service (NOTE 3)
Bit stream	(None)	(None)	Bitstream Service
Transfer Frames	VC Frame Service, MC Frame Service	VC Frame Service, MC Frame Service	VC Frame Service, MC Frame Service

NOTES

1 Packets directly transferred by the Space Data Link Protocols must have Packet Version Numbers authorized by CCSDS. A list of authorized Packet Version Numbers is found in reference [25]. Other packets can be transferred using the Encapsulation Service defined in reference [26].

2 FSH = Frame Secondary Header.

3 OCF = Operational Control Field.

3.2.4 SYNCHRONIZATION AND CHANNEL CODING

The standards of the Synchronization and Channel Coding Sublayer provide some additional functions necessary for transferring Transfer Frames over space links. These functions are delimiting/synchronizing Transfer Frames, error-correction coding/decoding, and bit transition generation/removal. CCSDS has two standards for Synchronization and Channel Coding:

a) TM Synchronization and Channel Coding [8];

b) TC Synchronization and Channel Coding [9].

TM Synchronization and Channel Coding is used with the TM or AOS Space Data Link Protocol, and TC Synchronization and Channel Coding is used with the TC Space Data Link Protocol. The synchronization and channel coding schemes used with the Proximity-1 Space Link Protocol are defined in the document that defines the protocol (reference [17]).

Table 3-3 summarizes the functions and schemes provided by the Synchronization and Channel Coding standards.

Table 3-3: Functions of Synchronization and Channel Coding Standards

Functions	TM Synchronization and Channel Coding	TC Synchronization and Channel Coding	Proximity-1 Space Link Protocol
Error Correction	Convolutional Codes* Turbo Codes* Reed Solomon Codes*	BCH Code*	Convolutional Code* Reed Solomon Code*
Error Detection/ Frame Validation	Reed Solomon Codes* Frame Error Control Field* (see NOTE 2)	BCH Code Frame Error Control Field* (see NOTE 2)	Reed Solomon Code* Attached Cyclic Redundancy Code*
Pseudo-Randomization	Cyclic Pseudo-noise Sequence*	Cyclic Pseudo-nose Sequence*	(Not used)
Frame Synchronization	32-bit Attached Sync Marker	16-bit Start Sequence	24- or 32-bit Attached Sync Marker

NOTES

1 '*' in the table denotes an optional function.

2 The Frame Error Control Field is defined in the Recommendations on the TM/TC/AOS Space Data Link Protocols, and not in the Recommendations on Synchronization and Channel Coding.

Summaries of concept and rationale for TM and TC Synchronization and Channel Coding are contained in references [28] and [30], respectively.

3.3 NETWORK LAYER

3.3.1 GENERAL FEATURES OF NETWORK PROTOCOLS

CCSDS has developed two protocols for the Network Layer:

a) Space Packet Protocol [14];

b) SCPS Network Protocol (SCPS-NP) [11].

These protocols are developed to transfer data (1) from a source on a spacecraft to one or multiple destinations on the ground or on (an)other spacecraft, or (2) from a source on the ground to one or multiple destinations on one or multiple spacecraft. When protocol data units of these protocols traverse the data system of a space mission (i.e., onboard networks, onboard data handling system, ground stations, control centers), the address(es) attached to each packet is used for determining the route of that packet.

The Space Packet Protocol provides the capability to efficiently transfer processed data over space links and the capability for routing data through a space data system. SCPS-NP provides a variety of addressing and routing capabilities, some of which are compatible with the Internet, and can be used with SCPS or Internet upper-layer protocols.

The protocol data units of the Space Packet Protocol are called Space Packets, while the protocol data units of SCPS-NP are called SCPS-NP datagrams.

These protocols do not provide a function for retransmitting lost or corrupted data, so retransmission should be done by a higher-layer protocol if complete delivery of data is required.

Over a space link, protocol data units of these protocols are transferred with Space Data Link Protocols.

A summary of concept and rationale of the Space Packet Protocol is contained in reference [31]. A summary of concept and rationale of SCPS-NP is contained in reference [32].

The Space Data Link Protocols have the capability to carry the protocol data units of the following protocols developed by the Internet, multiplexed or not-multiplexed with the Space Packet Protocol and/or SCPS-NP:

a) Internet Protocol (IP), Version 4 [19];

b) Internet Protocol (IP), Version 6 [20].

Protocol data units (datagrams) of IP Version 6 are transferred by Space Data Link Protocols using Encapsulation Packets defined in reference [26] in order for the Space Data Link Protocols to process IP Version 6 datagrams efficiently. Other protocols can also be transferred with the Space Data Link Protocols using the Encapsulation Service defined in reference [26].

3.3.2 ADDRESSING OF NETWORK PROTOCOLS

Two types of addresses are used by the Network Layer protocols: Path Address and End System Address. A Path Address identifies a logical data path in the network from a source to one or multiple destinations. Configuration of logical data paths is done by management activities, and not by the protocol that transfers data. An End System Address identifies a single end system or a group of end systems. When an End System Address is used, a pair of End System Addresses must be used to identify both source and destination end systems.

Table 3-4 shows the addressing capability of the Network Layer protocols.

Table 3-4: Addressing Capability of Network Protocols

Protocol	Address Name	Address Type	Address Length	Note
Space Packet Protocol	Application Process Identifier (APID)	Path Address	11 bits	When APIDs have to be uniquely identified in a global network, the Spacecraft Identifier (SCID) is used to qualify APIDs.
SCPS-NP	Extended End System Address	End System Address	4 octets + 4 octets	IP addresses or SCPS address family addresses
	Extended Path Address	Path Address	4 octets	SCPS address family addresses
	Basic End System Address	End System Address	1 octet + 1 octet	SCPS address family addresses
	Basic Path Address	Path Address	1 octet	SCPS address family addresses
	IPv6 Address	End System Address	16 octets + 16 octets	IP version 6 addresses
IP Version 4	IP Address	End System Address	4 octets + 4 octets	
IP Version 6	IP Version 6 Address	End System Address	16 octets + 16 octets	

NOTES

1 The SCPS address family addresses are a subset of the IP version 4 address space with the first octet fixed to the decimal value of 10. They can be truncated to one octet (Basic Addresses) when there is no ambiguity in interpretation of the addresses.

2 Any of the five addresses shown above may be used for a SCPS-NP datagram.

3.4 TRANSPORT LAYER

CCSDS has developed the SCPS Transport Protocol (SCPS-TP) [13] for the Transport Layer. The CCSDS File Delivery Protocol (CFDP) [15] also provides the functionality of the Transport Layer, but it provides some functions (i.e., functions for file management) of the Application Layer as well.

SCPS-TP supports end-to-end communications between applications and is designed to meet the needs of a broad range of space missions. It is based on TCP and UDP of the Internet and is intended to be used on top of SCPS-NP, IP Version 4 or IP Version 6. A summary of concept and rationale of SCPS-TP is contained in reference [32].

CFDP is designed to meet the needs of space missions to transfer files to and from an onboard mass memory. It is a file transfer protocol, but it also provides the functionality of the Transport Layer for detecting and retransmitting corrupted or lost data. It can be used on top of any protocol of the Network Layer (e.g., Space Packet Protocol, SCPS-NP, IP Version 4 or IP Version 6), or directly on top of the TC Space Data Link Protocol or Proximity-1 Space Link Protocol if a Virtual Channel, a MAP or a Port is dedicated to CFDP. In some circumstances it can be used on top of UDP, TCP or SCPS-TP. A summary of concept and rationale of CFDP is contained in reference [33].

Transport protocols used in the Internet (such as TCP [21] and UDP [22]) can also be used on top of SCPS-NP, IP Version 4 and IP Version 6 over space links.

SCPS Security Protocol (SCPS-SP) [12] can be used with the above protocols to provide end-to-end data protection capability. A summary of concept and rationale of SCPS-SP is contained in reference [32].

3.5 APPLICATION LAYER

CCSDS has developed two protocols for the Application Layer:

a) SCPS File Protocol (SCPS-FP) [14];

b) Lossless Data Compression [16].

The CCSDS File Delivery Protocol (CFDP) [15] also provides the functionality of the Application Layer (i.e., functions for file management), but it provides functions of the Transport Layer as well.

SCPS-FP provides a file transfer service and is designed to meet the needs of current and future space missions. It is based on FTP of the Internet and is intended to be used on top of SCPS-TP or TCP. A summary of concept and rationale of SCPS-FP is contained in reference [32].

The Lossless Data Compression standard was developed to increase the science return as well as to reduce the requirement for onboard memory, station contact time, and data archival volume. It is intended to be used together with the Space Packet Protocol or CFDP. A summary of concept and rationale of Lossless Data Compression is contained in reference [34].

Applications protocols used in the Internet (such as FTP [23]) can also be used on top of SCPS-TP, TCP and UDP over space links.

Each project (or Agency) may elect to use application-specific protocols not recommended by CCSDS to fulfill their mission requirements in the Application Layer over CCSDS space link protocols.

4 EXAMPLES OF PROTOCOL CONFIGURATIONS

4.1 GENERAL

This section shows some examples of how space link protocols of various layers are used in space data systems.

Five examples of protocol configurations are shown in this section. There are many other combinations of protocols that can be used in space data systems, but it is not the intention of this Report to enumerate all possible combinations of protocols. The following examples are selected to illustrate the basic functionality of the space link protocols.

For each example in this section, two diagrams are shown. The first diagram shows a stack of protocols used over a space link (i.e., a link between a spacecraft and a ground station or between two spacecraft).

A space data system consists of one or more onboard subnetworks, one or more space links, and one or more ground subnetworks. In this section, however, a simple space data system consisting of four major elements (see figure 4-1) is used to illustrate how space link protocols are used in an end-to-end space data system. It will be shown that some space link protocols are used for end-to-end communications between onboard and ground end systems, and some space link protocols are used only for communications over the space link.

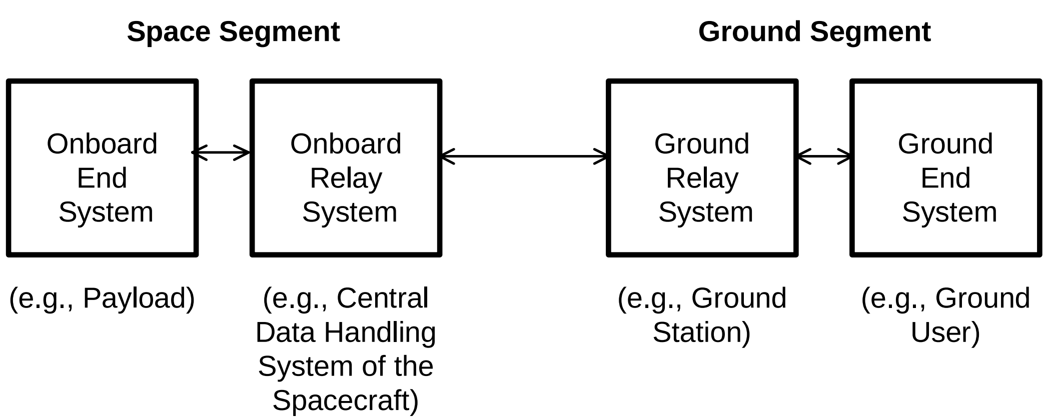

Figure 4-1: Simple Space Data System Model

The primary difference among the five examples shown in this section is the selection of the protocol used for end-to-end routing. In a space data system, user data traverse subnetworks (i.e., one or more onboard subnetworks, one or more space links, and one or more ground subnetworks). One of the protocols used in a space data system provides the capability of routing user data from a source to a destination through these subnetworks. This functionality is called ‘end-to-end routing’ in this Report.

The following protocols are used for end-to-end routing in the following examples:

a) Space Packet Protocol;

b) SCPS-NP and IP (version 4 or 6);

c) IP version 4;

d) IP version 6;

e) CFDP.

NOTES

1 In the following figures, ‘Prox Space Data Link Protocol’ denotes the Data Link Layer portion of the Proximity-1 Space Link Protocol. When the Proximity-1 Space Link Protocol is used in the Data Link Layer, it is also in the Physical Layer.

2 In the following figures, the Synchronization and Channel Coding standards are omitted for simplicity reasons.

4.2 SPACE PACKET PROTOCOL FOR END-TO-END ROUTING

In this example, the Space Packet Protocol is used for end-to-end routing. The Space Packet Protocol was designed by CCSDS to meet the requirements of space missions for efficient transfer of processed data over space links. This configuration is suited to space missions that require the simple addressing and routing capabilities provided by the Space Packet Protocol.

Figure 4-2 shows an example of protocol configuration on a space link, and figure 4-3 shows an example of protocol configuration in an end-to-end space data system.

When the Space Packet Protocol is used for end-to-end routing, Space Packets are usually transferred with a Space Link Extension (SLE) Service (see reference [27]) in the ground subnetwork.

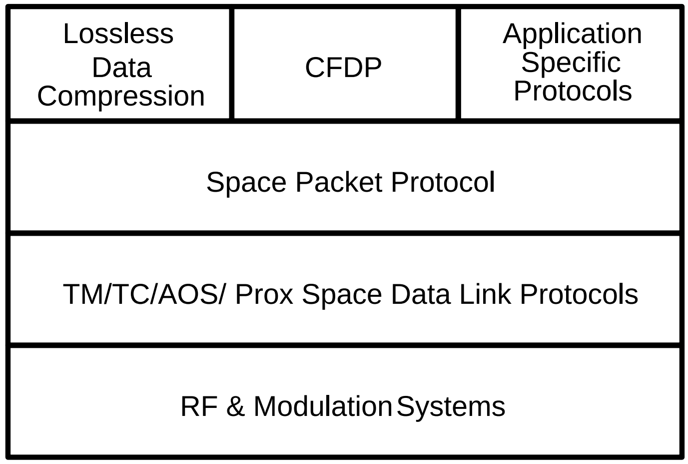

Figure 4-2: Protocol Configuration on a Space Link When Space Packet Protocol Is Used for End-to-End Routing

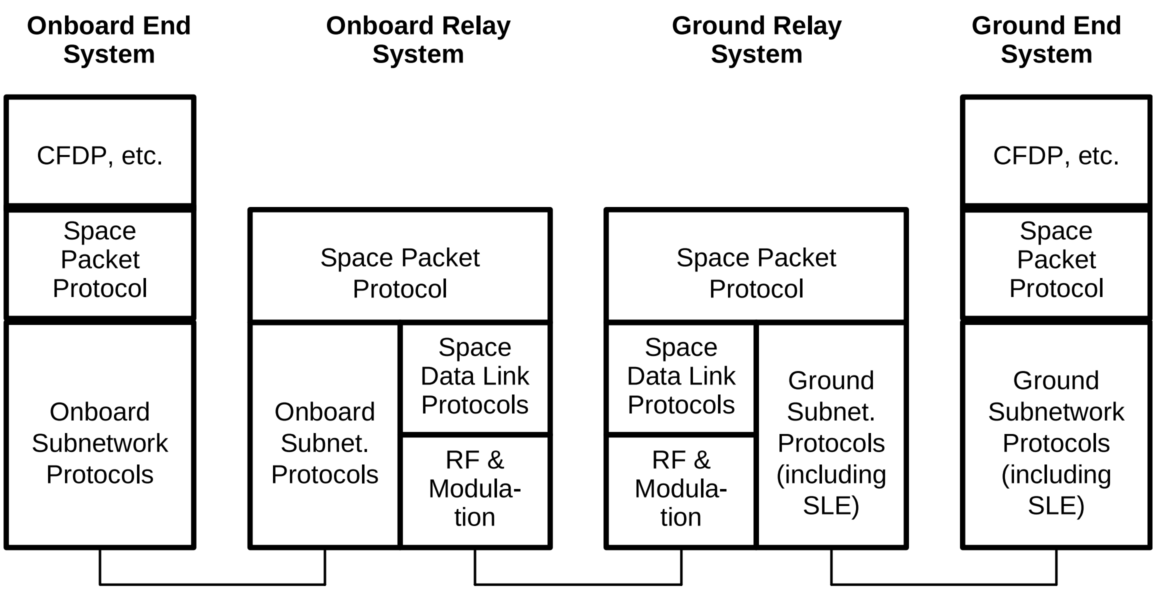

Figure 4-3: Protocol Configuration in a Space Data System When Space Packet Protocol Is Used for End-to-End Routing

4.3 SCPS-NP AND IP FOR END-TO-END ROUTING

In the second example, SCPS-NP and IP (either version 4 or 6) is used for end-to-end routing. This configuration is suited to space missions that require the extended addressing and routing capabilities provided by SCPS-NP and/or need to use SCPS or Internet upper-layer protocols.

Figure 4-4 shows an example of protocol configuration on a space link, and figure 4-5 shows an example of protocol configuration in an end-to-end space data system. In this configuration, SCPS-NP is used for routing except in the ground subnetwork where IP is used for routing. A gateway at the ground relay system performs protocol conversion between SCPS-NP and IP.

Most SCPS and Internet end-to-end protocols can be used on top of SCPS-NP and IP. SCPS-TP can be converted to TCP/UDP at a relay system. More information on this configuration is found in reference [31].

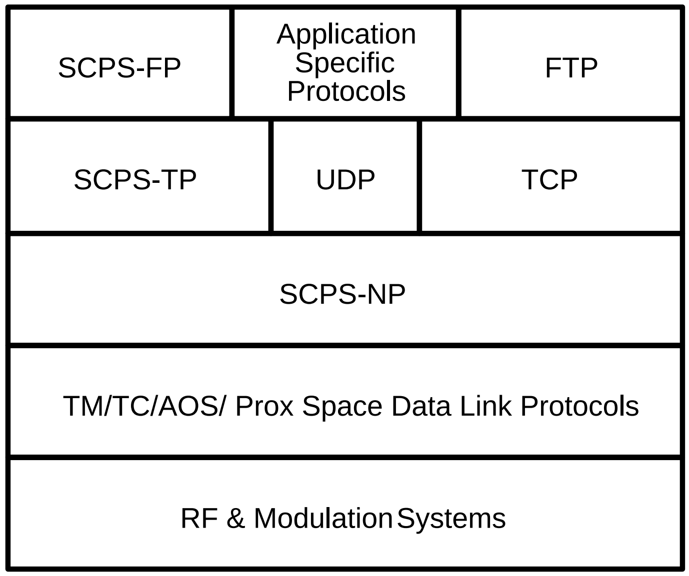

Figure 4-4: Protocol Configuration on a Space Link When SCPS-NP and IP Are Used for End-to-End Routing

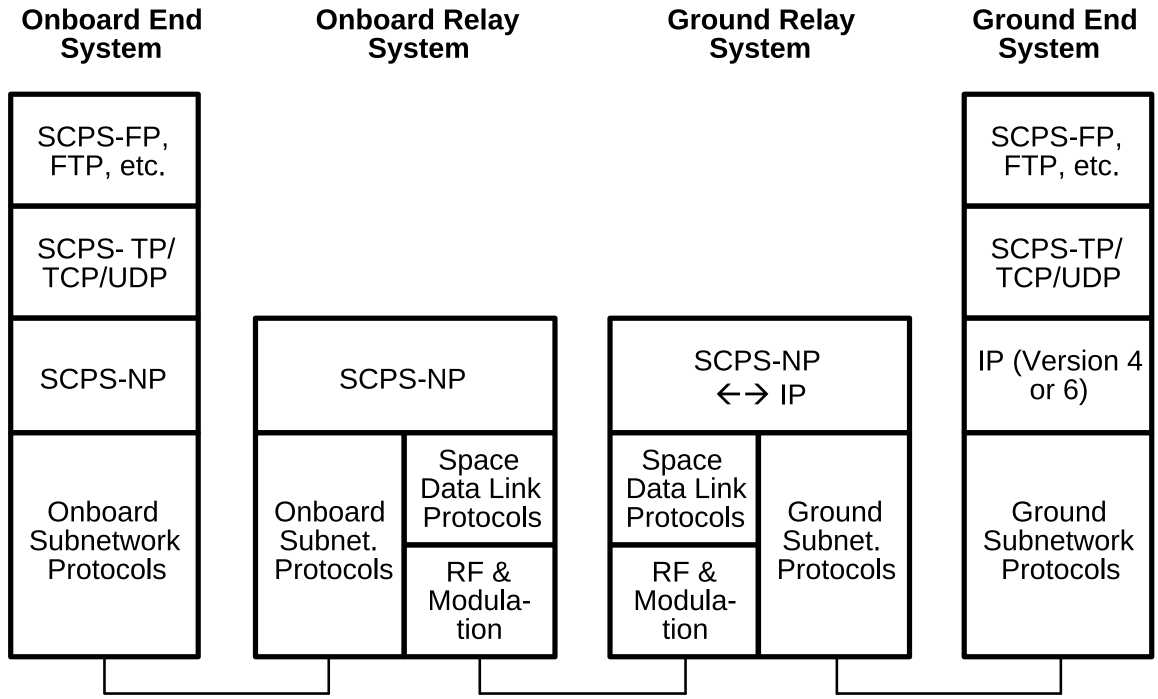

Figure 4-5: Protocol Configuration in a Space Data System When SCPS-NP and IP Are Used for End-to-End Routing

4.4 IP VERSION 4 FOR END-TO-END ROUTING

In the third example, IP version 4 is used for end-to-end routing. IP Version 4 is the protocol used for routing in the Internet, but it can also be carried by a Space Data Link Protocol over a space link. This configuration is suited to space missions that require integration of their space segments into the Internet.

Figure 4-6 shows an example of protocol configuration on a space link, and figure 4-7 shows an example of protocol configuration in an end-to-end space data system.

In this example, it is assumed that the Internet is directly extended into the space segment. Most Internet end-to-end protocols and SCPS-TP can be used on top of IP Version 4. SCPS-TP can be converted to TCP/UDP at a relay system.

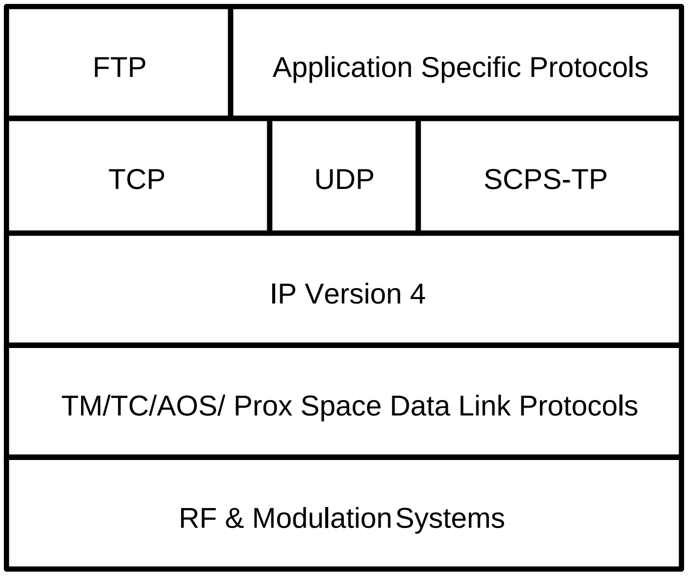

Figure 4-6: Protocol Configuration on a Space Link When IP Version 4 Is Used for End-to-End Routing

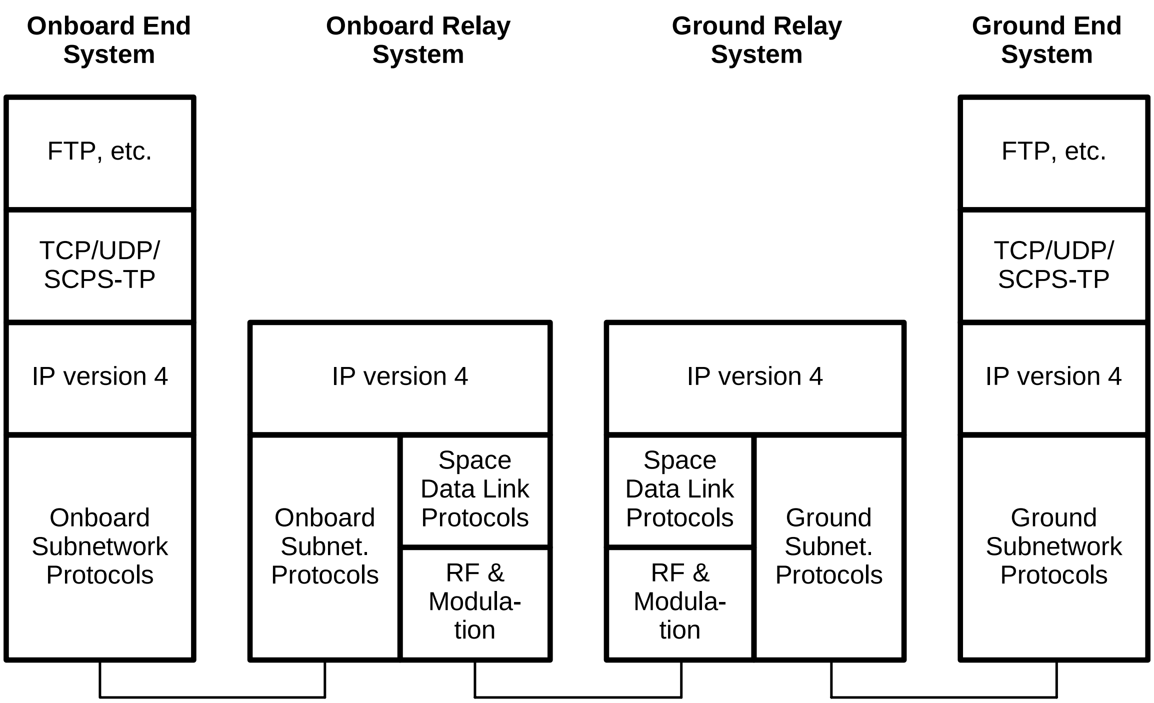

Figure 4-7: Protocol Configuration in a Space Data System When IP Version 4 Is Used for End-to-End Routing

4.5 IP VERSION 6 FOR END-TO-END ROUTING

In the fourth example, IP Version 6 is used for end-to-end routing. IP Version 6 is an upgraded version of IP Version 4 and is expected to replace the latter in the near future in the Internet. This configuration is suited to space missions that require integration of their space segments into the Internet when IP Version 6 is deployed.

Figure 4-8 shows an example of protocol configuration on a space link, and figure 4-9 shows an example of protocol configuration in an end-to-end space data system.

Protocol data units (datagrams) of IP version 6 are transferred by Space Data Link Protocols using Encapsulation Packets in order for the Space Data Link Protocols to process IP Version 6 datagrams efficiently.

In this example, it is assumed that the Internet is directly extended into the space segment. Most Internet end-to-end protocols and SCPS-TP can be used on top of IP Version 6. SCPS-TP can be converted to TCP/UDP at a relay system.

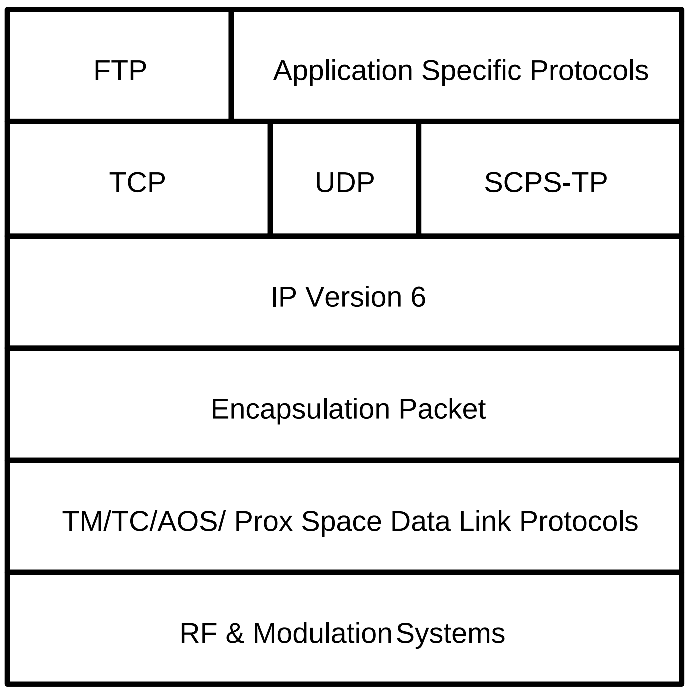

Figure 4-8: Protocol Configuration on a Space Link When IP Version 6 Is Used for End-to-End Routing

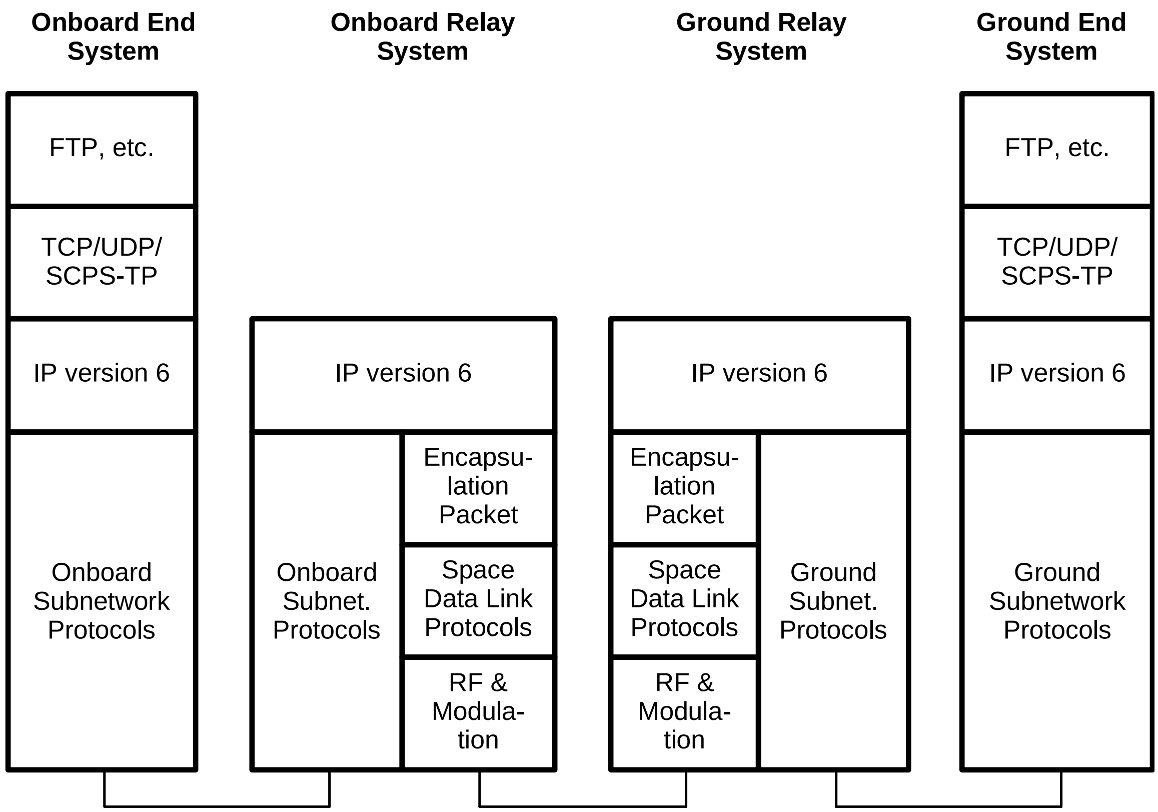

Figure 4-9: Protocol Configuration in a Space Data System When IP Version 6 Is Used for End-to-End Routing

4.6 CFDP FOR END-TO-END ROUTING

In the final example, CFDP is used for end-to-end routing. CFDP is a file transfer protocol, but it also has the capability to route files through a space data system. This configuration is suited to space missions in which most data are transferred as files.

Figure 4-10 shows an example of protocol configuration on a space link, and figure 4-11 shows an example of protocol configuration in an end-to-end space data system.

In this example, it is assumed that protocol data units of CFDP are carried by the Space Packet Protocol over the space link, but they can also be carried by SCPS-NP, IP Version 4 or IP Version 6. They can also be carried directly by the TC Space Data Link Protocol or Proximity-1 Space Link Protocol if a Virtual Channel, a MAP or a Port is dedicated to CFDP.

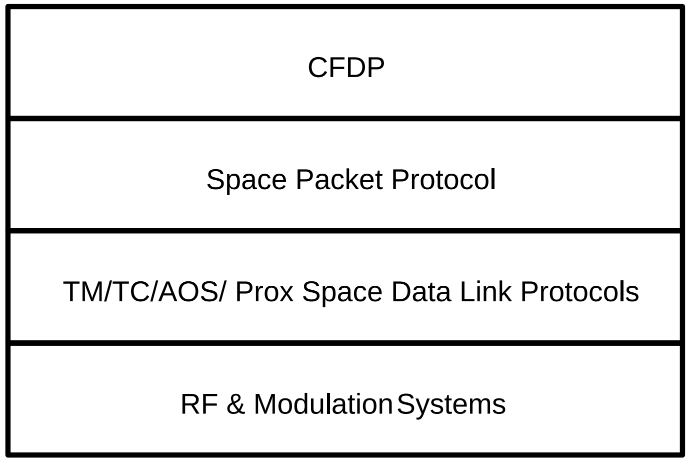

Figure 4-10: Protocol Configuration on a Space Link When CFDP Is Used for End-to-End Routing

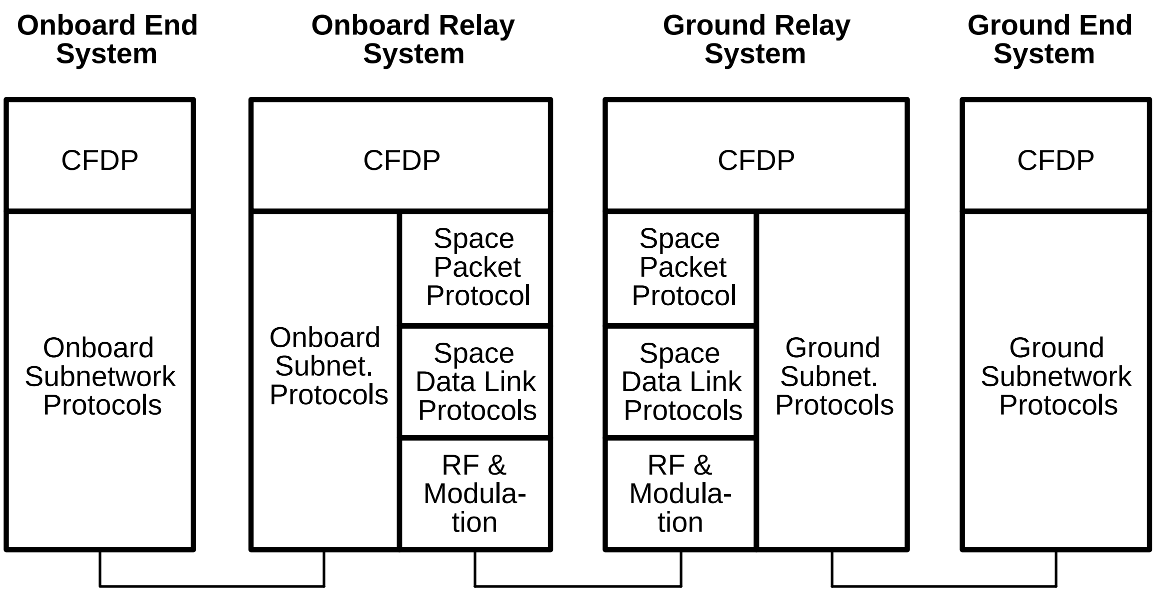

Figure 4-11: Protocol Configuration in a Space Data System When CFDP Is Used for End-to-End Routing

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
FSH	Frame Secondary Header
FTP	File Transfer Protocol
IP	Internet Protocol
MAP	Multiplexer Access Point
MC	Master Channel
MCID	Master Channel Identifier
N/A	Not Applicable
OCF	Operational Control Field
PVN	Packet Version Number
SCID	Spacecraft Identifier
SCPS	Space Communications Protocol Standards
SCPS-FP	Space Communications Protocol Standards File Protocol
SCPS-NP	Space Communications Protocol Standards Network Protocol
SCPS-SP	Space Communications Protocol Standards Security Protocol
SCPS-TP	Space Communications Protocol Standards Transport Protocol
SLE	Space Link Extension
TC	Telecommand
TCP	Transmission Control Protocol
TFVN	Transfer Frame Version Number

TM	Telemetry
UDP	User Datagram Protocol
VC	Virtual Channel
VCID	Virtual Channel Identifier

CCSDS HISTORICAL DOCUMENT