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Space data and information transfer systems — Space communications cross support — Architecture requirements document

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Données spatiales et systèmes de transfert d'information - Support croisé des communications spatiales - Exigences d'architecture

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1 INTRODUCTION

1.1 PURPOSE

The purpose of this Recommended Practice is to define a set of requirements for CCSDS-recommended configurations for secure Space Communications Cross Support (SCCS) architectures. This architecture is to be used as a common framework when CCSDS Agencies 1) provide and use SCCS services, and 2) develop systems that provide interoperable SCCS services. These SCCS services include both elements on the ground and elements in space. These services cover both single-hop, space Data Link Layer services (Mission Operations Center [MOC]-to-spacecraft), and Solar System Internet (SSI), multi-hop, Network Layer services that involve data routing and internetworking using multiple space assets.

NOTE – The term 'agency' is used in CCSDS, but users of CCSDS cross support concepts include satellite operators and service providers, and the context of the cross support is not limited to a user/provider interface with an agency.

This Space Communications Cross Support—Architecture Requirements Document (SCCS-ARD) provides normative specifications and definitions; its companion Space Communications Cross Support—Architecture Description Document (SCCS-ADD) (reference [D5]) provides the descriptive information, explanatory materials, and other graphical representations that support the understanding of these requirements.

1.2 SCOPE

This document describes SCCS architecture in terms of the following:

- definitions of all key elements, on ground and in space, that are involved in space communications;
- definitions of concepts that characterize SCCS services;
- requirements on system elements and components that provide secure SCCS services;
- recommended protocol stack configurations for each element type; and
- recommended end-to-end system configurations to provide interoperable and cross-supportable space communications services.

This document does not specify:

- the details of how to implement systems that provide SCCS services;
- explicit technologies needed to implement SCCS services;
- application or mission operations protocols except for those used for data transfer;

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- mission operations except for those involved in planning, scheduling, and executing space communications;
- spacecraft onboard cross support, except for space communication services.

This document contains references to other CCSDS technical engineering and architectural recommendations describing how systems doing space communication cross support should be engineered, deployed, organized, and operated to provide interoperable SCCS services. While this document does not specify detailed internal implementation approaches, which are a private matter, it does recommend specific protocols and protocol stacks, service interfaces, element behaviors, and end-to-end architectures.

Some of the standards that are referenced in this document, especially those relating to the SSI, are still in development. They are included here so the reader gets a clear understanding of how they fit into an overall architecture.

The protocol-related parts of this document make liberal reference to the layers defined in the Open Systems Interconnection (OSI) Basic Reference Model (reference [4]). Subsection 6.2 of the Architecture Description Document (ADD) (reference [D5]) contains a discussion of the OSI stack and the functions associated with each layer.

The technical scope of single-hop cross support is the provision of Data Link Layer (Layer 2) data communications services across the Solar System in support of space mission users, using the *interoperable infrastructure of one or more space agencies*. Services above the Data Link Layer, such as CCSDS File Delivery Protocol (CFDP), Cross-Support File Service (CXFS), or Delta-Differential One-way Range (DOR), may also be provided. All mission operations application in CCSDS-compliant, interoperable, single-hop deployments are expected to utilize these underlying space link and file communications layers.

The technical scope of the SSI is the provision of internetworked (Layer 3) data communications services across the Solar System in support of space mission users, using the *confederated and interoperable infrastructure of one or more space agencies* to achieve a level of service that individual agencies would otherwise be unlikely to achieve. All mission operations application in CCSDS-compliant, interoperable, SSI deployments are expected to utilize these underlying space internetworking communications layers.

The temporal scope of this document covers current, single-hop, secure interoperable cross support installations, future deployments of an interoperable and evolving space networking infrastructure, and the transition strategies to evolve from current deployments to a future SSI state. Included in this discussion are mission-driven considerations, such as use of hybrid science/routing missions, as well as identification of optional configurations that are considered acceptable because they are in line with the transition strategies defined in this document.

Any agency that wishes to participate as a peer in the SSI should implement interoperable services and interfaces at least up to the Network Layer, along with related support services, as described in this document and specified in the relevant CCSDS and Internet standards.

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Agencies that are not yet ready to adopt the SSI themselves, but that wish to offer compliant ground station cross support services that can support SSI services, may also take advantage of this document for guidance on developing Data Link Layer services that will both meet their immediate needs and also interoperate with SSI-enabled missions.

1.3 APPLICABILITY

1.3.1 APPLICABILITY OF THIS RECOMMENDED PRACTICE

This Recommended Practice provides a set of reference architecture requirements for the development of CCSDS compatible agency systems for space communications. This Recommended Practice is applicable to all space communication systems that are involved in cross support.

The SCCS systems that are addressed in this Recommended Practice explicitly include ground stations and related systems that provide cross support services, user mission control and mission operations ground systems, and a variety of spacecraft systems. In all cases the applicability is to both single space link (ABA) and internetworked (SSI) systems. The term 'spacecraft systems' includes free-flying spacecraft, landers, rovers, and even balloons and other 'platforms' that are users of space communication services. It also includes spacecraft that are themselves providers of space communication services.

1.3.2 LIMIT OF APPLICABILITY

This Recommended Practice is not a design for real SCCS systems that may be implemented for communication with existing or future missions. It provides detailed, but broadly stated, requirements that may be tailored or adapted for use in constructing such systems.

Future CCSDS requirements (e.g., service interfaces, protocols, or data formats) that are planned, but still under development, are included for completeness so that the directions of CCSDS are clear; these are marked '[Future]' to avoid ambiguity. Any requirements that are considered optional are marked '[Opt]'. The [Opt] requirements are things like security, which may or may not be implemented by any given system. All other core standards, those that are expected to be used by the bulk of missions and implemented by the bulk of service providers, are defined as mandatory, with 'shall' rather than 'should' language. Any specific system deployment may treat these as 'shall' if they are required for that use.

Any requirements marked '[Future]' should not be relied upon in the design of current real SCCS systems. This Recommended Practice will be updated periodically. When updates of this document are published, any requirements now marked '[Future]' whose conditions are met will be reviewed and evaluated for inclusion as full requirements. Many of these future specifications are completely applicable to either ABA or SSI deployments.

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1.4 RATIONALE

CCSDS has developed a body of space communications recommendations that specify protocols and related services for specific types of functionality that are usually defined at a single layer of the OSI stack, or define how to format and exchange a specific type of information. In order to build end-to-end space communications systems that will interoperate, systems designers need to understand how to select, configure, and deploy different kinds of system elements that implement a complete stack of protocols in each element and how these are assembled to deliver end-to-end services. Single-hop communications configurations often require cross support, where one space agency develops the spacecraft and the corresponding MOC, and another agency provides the ground communications assets. This is the typical cross support configuration used today. Multi-hop communications configurations may require that space assets developed by one agency offer cross support to space elements developed by another agency, with both being supported by ground communications assets from yet another agency.

Since cross support among agencies has become the norm, and since future agency collaborative missions require elements developed by different agencies, at different times, to interoperate as a network, agreed-upon interoperable standards and architectures must be adopted in an end-to-end sense. As the only international body that defines standards to link space communication service providers with space missions, CCSDS is defining this recommended standard architecture for SCCS services, so that interoperable cross support between agencies can be defined and operated more efficiently and effectively for single-hop and multi-hop mission configurations.

Similar to existing ABA architectures, it is fundamental to the SSI concept that all full participants in the confederation must expose standard and agreed-upon cross support services at the Network Layer of the OSI communications stack, while observing common network management strategies and governance mechanisms. Agencies that provide only single-hop Data Link Layer services may still participate in the SSI if they provide compliant services at that layer.

1.5 DOCUMENT STRUCTURE

This document consists of several sections plus annexes.

- Section 1 presents the purpose, scope, and rationale of this document and lists the definitions, conventions, and references used throughout the document.
- Section 2 provides context and an overview of the SCCS architecture.
- Section 3 provides a brief overview of ABA and SSI technical architecture and some guidance on how to use the document.
- Section 4 defines top-level service requirements of ABA and SSI configurations from user and provider perspectives.

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- Section 5 defines physical requirements of spacecraft and ground system nodes that are used to create deployed ABA and SSI configurations, their allocated functions, and behavior.
- Section 6 defines communications requirements and protocol 'stacks' for the ABA and SSI node types.
- Section 7 defines end-to-end deployment requirements for representative examples of space communication configurations.
- Annexes provide a brief reference to security and Space Assigned Numbers Authority (SANA) information, a normative glossary, an acronym list, and a list of informative references.

Each of sections 4 through 7 includes a brief descriptive introduction and normative subsections that define the required elements, attributes, and behaviors for both ABA and SSI deployments. The ADD (reference [D5]) contains an extended set of descriptive materials that provide explanations and examples.

1.6 DEFINITIONS AND CONVENTIONS

1.6.1 TERMS

For the purposes of this document, the following normative definitions apply. Many of these terms are derived from other sources. Primary sources of definitions are references [1], [2], [4], [5], [6], [D6], [D7], and [D8].

NOTE – Many other terms that pertain to specific items are defined in the appropriate sections. A glossary with additional definitions can be found in annex B, and a list of acronyms can be found in annex C.

ABA: A 'single-hop' space communications configuration that involves only a single direct to/from Earth space link. Term derives from the notion of an Agency 'A' using the ground station of an Agency 'B' to communicate between its MOC and its spacecraft, hence ABA.

ABCBA: A multi-hop space communications configuration that involves multiple space and ground elements and one or more direct to/from Earth space links or space-space links. ABCBA configurations nominally include elements from three or more agencies.

Application Layer: OSI Layer 7 contains all those functions that imply communication between open systems that are not already performed by the lower layers.

building block: The set of nodes, with specific defined characteristics, that are used to describe end-to-end system configurations in this document.

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CCSDS-compliant credential: One or more CCSDS baseline recommended credentials that have the minimum recommended level of security. Higher-level security credentials (to be defined in an update to reference [7]) may be employed where required.

Coding and Synchronization sublayer: CCSDS-defined sublayer (of the OSI Data Link Layer) that provides error detection and correction for the space Data Link Layer protocols and deals with noisy, low signal-to-noise ratio, space link physical channel characteristics.

credential: A physical/tangible object, a piece of knowledge, or a facet of a person's physical being, that enables an individual to have access to a given physical facility or computer-based information system.

cross support: An agreement between two or more organizations to exploit the technical capability of interoperability for mutual advantage, such as one organization offering support services to another in order to enhance or enable some aspect of a space mission.

cross support service: A function provided by one space agency to support operations of a space mission of another space agency.

cross support service element, CSSE: A physical element involved in providing one or more cross support services (including functions for managing services).

cross support service system, CSSS: A set of CSSEs or user elements that are managed by a single authority with a single set of management policies. These may be user or provider systems.

Cross Support Transfer Service, CSTS: A family of cross support services, based upon a common framework derived from space link extension, that provides reliable, access-controlled transfer of spaceflight mission-related data between ground CSSEs and user elements. Each type of CSTS is qualified by the kind of data it transfers (e.g., telemetry frames, tracking data, monitor data).

data delivery services: The generic term for the CSTS and space link extension services used to deliver data between an Earth-Space Link Terminal (ESLT) and the ground user elements that use it.

Data Link Layer: The OSI Layer (Layer 2, often referred to as 'link layer') that provides functional and procedural means for the establishment, maintenance, and release of data link connections among Network Layer entities (where they are used) and for the transfer of data link service data units.

Earth User Node: A physical element, located on the ground, that uses a cross support service provided by a CSSS.

element management, EM: A set of functions that manage elements and interact with PM for purposes of ascertaining element resource availability, configuration and execution of element resources, and reporting status of those resources.

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forward data: Data sent from a ground element to a space element.

forwarding: The act of transferring data from its source towards its destination, which may be in space or on the ground.

functional resource: The functions or capabilities that are provided by physical resources (e.g., transmitters and receivers) of a CSSE, but not those physical resources themselves. A functional resource is a logical construct not necessarily linked to any single system component.

interface binding signature: A 'signature' that results from a service user and service provider implementing the proper stack of interface protocols in order to bind to service elements. This signature may involve Transmission Control Protocol/Internet Protocol (TCP/IP), Hypertext Transfer Protocol (HTTP), or some set of CCSDS space-communication protocols.

internetwork: A 'network of networks' (often shortened to *internet*), where two or more distinct computer networks are connected together using routing devices that allow traffic to flow back and forth between the networks.

internetworking: Practice of connecting two or more distinct computer networks or network segments together to form an internetwork, using devices which operate at OSI Layer 3 (Network Layer) to connect them together to allow traffic to flow back and forth between them.

interoperability: A property of protocols or systems whereby elements adopt a commonly defined and implemented set of protocols, data, and behaviors.

logical link: A link that shows a relationship between various types of logical objects (e.g., functions, protocols, or organizations). It may be considered separately from any particular implementation or deployment and has no physical manifestation except as part of a model.

network: One or more computers or other processing elements that are owned by a single organization, communicating using a single OSI Layer 3 protocol and sharing a single Layer-2 technology.

Network Layer: OSI Layer 3, which provides the means to establish, maintain, and terminate network connections between open systems and provides transport entities independence from routing and relay considerations.

node: A space data system physical entity operating in a physical environment. A node is a configuration of engineering objects forming a single unit for the purpose of location in space, and embodying a set of processing, storage, and communication functions. A node has some well-understood, possibly rapidly moving location, and it may be composed of two or more (sub-) nodes.

physical channel: A stream of bits transferred over a space link in a single direction.

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Physical Layer: OSI Layer 1, which provides for the transparent transmission of bit streams between data-link entities across physical connections and the mechanical, electrical, functional, and procedural means to activate, maintain, and deactivate physical connections.

protocol data unit, PDU: A unit of data which is specified in a protocol of a given layer and which consists of protocol-control information, addressing information, and possibly user data for that layer (typically defined as a Service Data Unit [SDU]).

provider system: A CSSS that provides services to a user CSSS. A provider CSSS may also be a user of other CSSS services.

provision management, PM: A set of functions of a CSSS, related to the acquisition and management of services provided by that CSSS to other CSSSes. PM interacts with the utilization management of user CSSSes to negotiate provision of services to their respective CSSSes.

Proximity link: A communications link between an element in space and another nearby element in space or on the surface of a planetary body (<1 second Round-Trip Light Time [RTLT]).

relaying: A managed process for forwarding frame, packet, or physical data that involves no decision making.

return data: Data sent from a space element to a ground element.

router: A device that forwards Network Layer PDUs between computer networks, creating an Internetwork. A router is connected to two or more data links from different subnetworks and uses address information in the PDU and information in its routing table or routing policy to direct the PDU to the next subnetwork.

routing: The process of selecting paths from origins to destinations in a network.

service management, SM: 1) The set of functions exposed by PM to utilization management for the purposes of acquiring and managing the services provided by the provider CSSS to the user CSSS. These functions include planning, scheduling, and managing the configuration of space communication service functions. 2) The specification for exchanging service management information.

service provider: The role played by a physical, functional, or organizational entity that provides a cross support service for a service user. (A single entity may play the roles of service provider and service user at the same time.)

service user: The role played by a physical, functional, or organizational entity that uses a cross support service provided by a service provider. (A single entity may play the roles of service provider and service user at the same time.)

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signal-to-noise ratio, SNR: A measure that compares the level of a desired signal to the level of background noise. The principal signal degradations in space communications are due to the loss of signal energy with distance, and to the thermal noise in the receiving system.

Solar System Internetwork, SSI: A loose confederation of independent space communications networks that all share a single Network-Layer protocol that allows them to interoperate and exchange Network-Layer PDUs, each often owned and administered by a different space agency.

space communications protocol: A communications protocol designed to be used over a space link or in a network that contains one or multiple space links.

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 extension, SLE: A set of specific cross support services that provide reliable, access-controlled transfer of spaceflight mission-related data between ground cross support service providers and user elements. Each specific SLE service is defined separately for the kind of data it transfers (e.g., telemetry frames, telecommand, Communication Link Transmission Units [CLTUs], Operational Control Field [OCF]). CSTS is a generalization of the SLE concept.

space link interface: The interface of a CSSE that uses space link protocols.

space link layer processing: Processing at OSI Layers 1 and 2 for space communications, including any needed framing, coding, and modulation.

space routing node: A physical element located in space that provides space internetworking services.

Space User Node: A physical element located in space that uses a cross support service provided by a CSSS.

supported agency: A space agency that uses cross support services.

supporting agency: A space agency that provides cross support services.

terrestrial-link interface: The interface of a CSSE that uses terrestrial link (and networking) protocols.

Transport Layer: OSI Layer 4, which has end-to-end significance, where the ends are defined as transport entities having transport associations. The Transport Layer provides transparent transfer of data between applications and relieves them from any concern with subnetwork topologies or the detailed way in which transfer of data is achieved.

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user element, UE: A physical element involved in using one or more cross support services (including functions for managing services).

user system: A CSSS that uses the services of a provider CSSS. A user CSSS may also be a provider CSSS for other CSSSes.

utilization management, UM: A set of functions of a CSSS or user system, related to the acquisition and management of services provided to that CSSS or user system by other CSSSes.

virtual channel, VC: A logical subdivision of a single physical or master channel.

1.6.2 CONVENTIONS

For the purposes of this document, the graphical conventions shown in figure 1-1 are used. They are derived from the Reference Architecture for Space Data Systems (RASDS) (reference [2]).

There are several different types of objects depicted in the diagrams in this document; they may be color coded according to the key to identify their different nature and/or associated functionality.

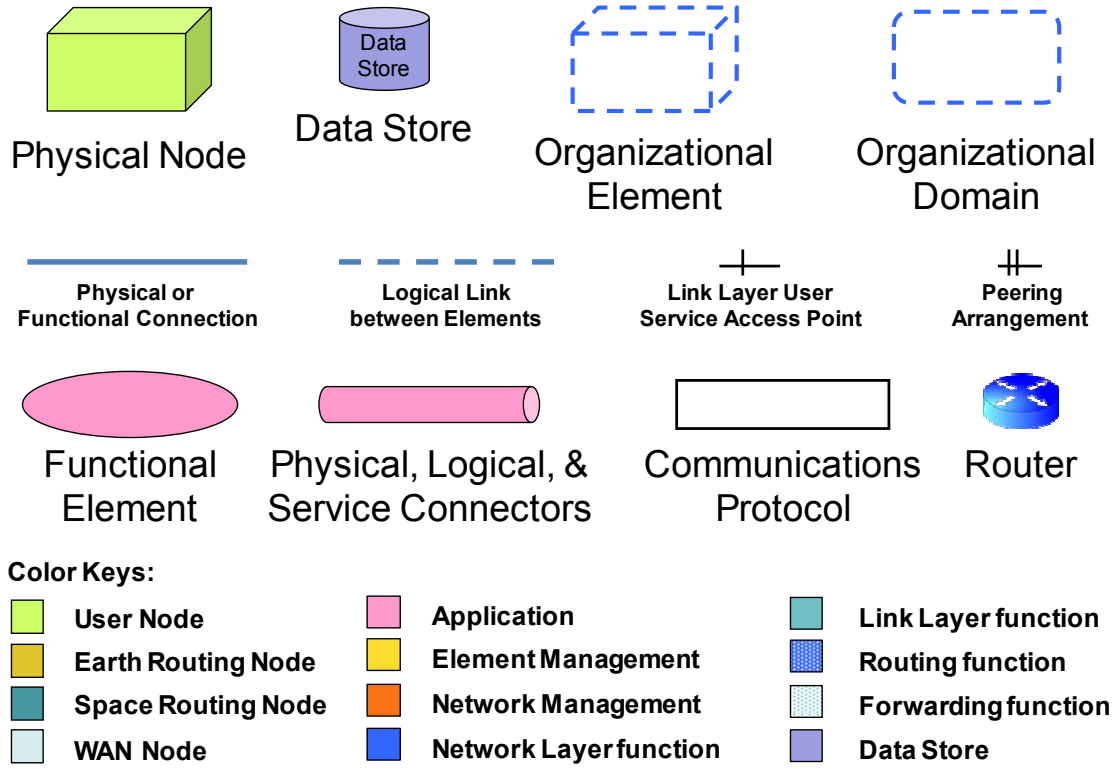

Figure 1-1: Graphical Conventions

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NOTES

1 Physical nodes (system elements) are depicted with solid three-dimensional boxes.

2 Data stores are shown as a cylinder.

3 Organizations are depicted with dashed three-dimensional boxes. Organizational domains are depicted with rounded, dashed, two-dimensional boxes.

4 Physical or functional connections are depicted with solid lines.

5 Logical links between elements are depicted with dashed lines.

6 Functional elements (aside from communications protocols) are depicted with ovals.

7 Service connections are depicted as pipes.

8 Communications protocols are depicted with two-dimensional boxes.

9 The differences between link layer user service (ABA) and peering arrangement (SSI) are distinguished as shown, where needed.

1.6.3 NOMENCLATURE

1.6.3.1 Normative Text

The following conventions apply for the normative specifications in this document:

a) the words ‘shall’ and ‘must’ imply a binding and verifiable specification;

b) the word ‘should’ implies an optional, but desirable, specification;

c) the word ‘may’ implies an optional specification;

d) the words ‘is’, ‘are’, and ‘will’ imply statements of fact.

NOTE – These conventions do not imply constraints on diction in text that is clearly informative in nature.

1.6.3.2 Informative Text

In the normative sections of this document, informative text is set off from the normative specifications either in notes or under one of the following subsection headings:

– Overview;

– Background;

– Rationale;

– Discussion.

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1.7 REFERENCES

The following documents are CCSDS, Internet, or other international standards referenced in this document. At the time of publication, the editions indicated were valid. All of the documents in this section that have CCSDS Blue or Magenta book numbers, or that have Request for Comment (RFC) or an RFC that has become a standard (STD), ISO, or other numbers are formal specifications that are valid as of the time of publication. Users of this Recommended Practice should be aware that in order to provide adequate guidance for the future, some of the documents that are referenced are still under development (CCSDS Red Books, White Books) or are otherwise in draft form, and these are so marked. There is, of course, a finite chance that some of these standards, when finalized, will not have exactly the features that are described here. A list of additional informative references is provided in annex D.

[1] *Cross Support Reference Model—Part 1: Space Link Extension Services*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 910.4-B-2. Washington, D.C.: CCSDS, October 2005.

[2] *Reference Architecture for Space Data Systems*. Issue 1. Recommendation for Space Data System Practices (Magenta Book), CCSDS 311.0-M-1. Washington, D.C.: CCSDS, September 2008.

[3] *Operations Concept for a Solar System Internetwork (SSI)*. IOAG.T.RC.001.V1. Washington, DC: IOAG, 15 October 2010.

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

[5] *Solar System Internetwork (SSI) Issue Investigation and Resolution*. IOAG.T.SP.001.V1. Washington, DC: IOAG, 1 August 2010.

[6] *Security Architecture for Space Data Systems*. Issue 1. Recommendation for Space Data System Practices (Magenta Book), CCSDS 351.0-M-1. Washington, D.C.: CCSDS, November 2012.

[7] *CCSDS Cryptographic Algorithms*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 352.0-B-1. Washington, D.C.: CCSDS, November 2012.

[8] *TC Synchronization and Channel Coding*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 231.0-B-2. Washington, D.C.: CCSDS, September 2010.

[9] *AOS Space Data Link Protocol*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 732.0-B-2. Washington, D.C.: CCSDS, July 2006.

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

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[12] K. Scott and S. Burleigh. *Bundle Protocol Specification*. RFC 5050. Reston, Virginia: ISOC, November 2007.

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[14] *Encapsulation Service*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 133.1-B-2. Washington, D.C.: CCSDS, October 2009.

[15] S. Symington, et al. *Bundle Security Protocol Specification*. RFC 6257. Reston, Virginia: ISOC, May 2011.

[16] *IOAG Service Catalog #1*. Issue 1 revision 4. Washington, DC: IOAG, June 2013.

[17] *IOAG Service Catalog #2*. Issue 1 revision 1. Washington, DC: IOAG, June 2013.

[18] *Space Assigned Numbers Authority (SANA)—Role, Responsibilities, Policies, and Procedures*. Issue 1. CCSDS Record (Yellow Book), CCSDS 313.0-Y-1. Washington, D.C.: CCSDS, July 2011.

[19] "Registries." Space Assigned Numbers Authority. http://sanaregistry.org/r/.

[20] *CCSDS Global Spacecraft Identification Field Code Assignment Control Procedures*. Issue 6. Recommendation for Space Data System Standards (Blue Book), CCSDS 320.0-B-6. Washington, D.C.: CCSDS, October 2013.

[21] *Space Link Extension—Forward CLTU Service Specification*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 912.1-B-3. Washington, D.C.: CCSDS, July 2010.

NOTE – This is an optional standard [Opt] and is to be replaced by F-Frame (reference [D14]) when that is finalized.

[22] *Space Link Extension—Return All Frames Service Specification*. Issue 3. Recommendation for Space Data System Standards (Blue Book), CCSDS 911.1-B-3. Washington, D.C.: CCSDS, January 2010.

[23] *Space Link Extension—Return Channel Frames Service Specification*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 911.2-B-2. Washington, D.C.: CCSDS, January 2010.

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[24] *Delta-Differential One Way Ranging (Delta-DOR) Operations*. Issue 1. Recommendation for Space Data System Practices (Magenta Book), CCSDS 506.0-M-1. Washington, D.C.: CCSDS, April 2011.

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[27] J. Postel. *Internet Control Message Protocol*. RFC 792. Reston, Virginia: ISOC, September 1981.

[28] *Space Link Extension—Return Operational Control Fields Service Specification*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 911.5-B-2. Washington, D.C.: CCSDS, January 2010.

[29] *XML Specification for Navigation Data Messages*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 505.0-B-1. Washington, D.C.: CCSDS, December 2010.

[30] *Orbit Data Messages*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 502.0-B-2. Washington, D.C.: CCSDS, November 2009.

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[35] *Time Code Formats*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 301.0-B-4. Washington, D.C.: CCSDS, November 2010.

[36] *Pseudo-Noise (PN) Ranging Systems*. Issue 2. Recommendation for Space Data System Standards (Blue Book), CCSDS 414.1-B-2. Washington, D.C.: CCSDS, February 2014.

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[38] *Delta-DOR Raw Data Exchange Format*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 506.1-B-1. Washington, D.C.: CCSDS, June 2013.

[39] *CCSDS File Delivery Protocol (CFDP)*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 727.0-B-4. Washington, D.C.: CCSDS, January 2007.

[40] *Conjunction Data Message (CDM)*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 508.0-B-1. Washington, D.C.: CCSDS, June 2013.

[41] *Asynchronous Message Service*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 735.1-B-1. Washington, D.C.: CCSDS, September 2011.

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[43] *Proximity-1 Space Link Protocol—Data Link Layer*. Issue 5. Recommendation for Space Data System Standards (Blue Book), CCSDS 211.0-B-5. Washington, D.C.: CCSDS, December 2013.

[44] *Proximity-1 Space Link Protocol—Physical Layer*. Issue 4. Recommendation for Space Data System Standards (Blue Book), CCSDS 211.1-B-4. Washington, D.C.: CCSDS, December 2013.

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[49] J. Postel. *User Datagram Protocol*. STD 6. Reston, Virginia: ISOC, August 1980.

[50] R. Fielding, et al. *Hypertext Transfer Protocol -- HTTP/1.1*. RFC 2616. Reston, Virginia: ISOC, June 1999.

[51] M. Degermark, B. Nordgren, and S. Pink. *IP Header Compression*. RFC 2507. Reston, Virginia: ISOC, February 1999.

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[52] *Space Link Extension—Internet Protocol for Transfer Services*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 913.1-B-1. Washington, D.C.: CCSDS, September 2008.

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[57] *CCSDS Space Link Protocols over ETSI DVB-S2 Standard*. Issue 1. Recommendation for Space Data System Standards (Blue Book), CCSDS 131.3-B-1. Washington, D.C.: CCSDS, March 2013.

And, in the context of this document, the following aggregate references may be used where needed:

[DTN] Delay Tolerant Networking suite, references [3], [D7], [12], [13], [15], [D12], [44], [D24].

[IPS] Internet Protocol suite, references [25], [46], [47], [48], [49], [53].

NOTE – Informative references are contained in annex D.

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2 OVERVIEW

2.1 BACKGROUND

Cross support is an activity of using resources of one space agency to support the operations of a space mission of another space agency. To reduce the cost of developing systems for operating space missions, multi-agency cross support arrangements have been used by many space missions. To date, most cross support has been one agency using the ground-based communications assets of another agency. This has already shifted to where agencies are providing cross support for in-space relaying of data; however, these technical and operational arrangements, to date, have been mission-specific and rather ad hoc and idiosyncratic.

To facilitate SCCS, CCSDS developed standard protocols to transfer telecommands (references [8], [9]) and telemetry (references [9], [10]) over space links, which can ensure link layer interoperability between space elements and ground elements belonging to different agencies. CCSDS also developed standard SLE services (references [1], [D6]) to transfer telecommand and telemetry data on the ground (for example, between a ground station and a spacecraft control center), and service management (reference [D10]) as the standard means to request cross support services. By using these CCSDS protocols and services, interoperability between elements of different agencies can be guaranteed to some extent at the link layer; however, coordination and negotiation for cross support is still done in mission-specific, labor-intensive ways. If space internetworking is to become a reality, with cross support and interoperability at higher protocol layers than the space data link, such as internetworking cross support in space, some new protocols and new approaches to mission design will be required.

The SCCS communications architecture defined in this Architecture Requirements Document (ARD) is intended to provide a common framework that is a basis for developing, providing, and using SCCS services. Defining a set of common concepts, common protocols and configurations, and common processes and terminology does this. This architecture is intended to 1) facilitate development of interoperable end-to-end SCCS systems, 2) describe characteristics of SCCS services, and 3) provide examples of protocol stacks for ground and space, including Data Link and Network Layers.

2.2 ROLE OF THIS ARCHITECTURE REQUIREMENTS DOCUMENT

This SCCS-ARD Recommended Practice (Magenta Book) provides the top-level requirements on the architecture elements of SCCS as shown in figure 2-1. The ARD provides concrete guidance and normative subsections that define the required elements, attributes, and behaviors for service interfaces, functional allocations at nodes, protocol stacks, and end-to-end configurations for both ABA and SSI deployments. The accompanying SCCS-ADD Informational Report (Green Book) provides descriptive materials to help understand and explain the concepts.

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Each section in this ARD starts by 1) addressing the requirements for simple, single-hop missions that form the bulk of current cross support configurations (ABA configurations), 2) adding what is required to achieve a fully internetworked 'end game'—a secure, interoperable SSI, and also 3) providing specific requirements on how to architect the building blocks for these missions. This ARD provides requirements on how to architect the building blocks for the ABA systems in a way that can directly serve existing mission modes, the future SSI, and also transitional states between them. This is especially important since these transitional configurations, when correctly constructed, will directly support the future SSI as well as offer useful services for missions that do not need to adopt the full SSI functionality.

Within each section of this document, this ARD addresses each of these operational configurations, along with any transitional information. The intent is to permit users who only require single-hop services to be able to readily find the information they need, while also providing guidance for those who are interested in progressing toward the full SSI.

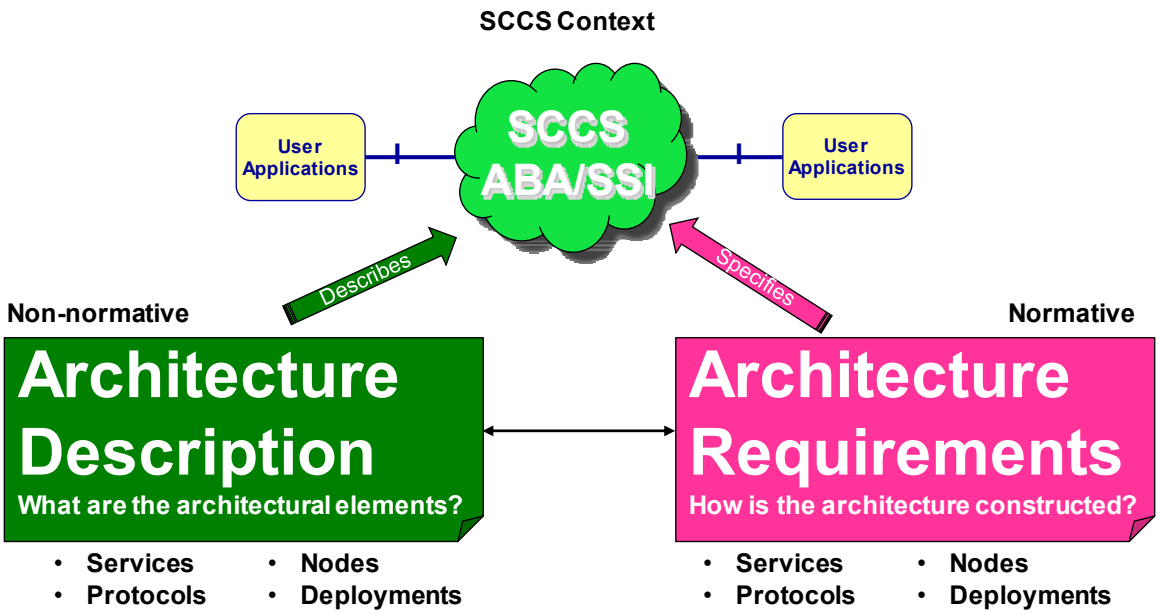

Figure 2-1: Roles of the SCCS Architecture Documents

The companion document, the SCCS-ADD Green Book (reference [D5]), provides rationale, explanatory text, and other descriptive materials. It contains an extensive set of figures that will be referenced in this ARD, and the reader is directed to that document when such additional explanatory materials, such as element architectures and a variety of end-to-end configurations are needed.

This SCCS-ARD defines requirements for developing a multi-agency, interoperable, secure technical architecture for SCCS, including single-hop and internetworked configurations. This document provides requirements on: 1) the service elements from both end-user and service-provider perspectives, 2) the physical elements and building blocks of the SSI, 3) the communications protocols that permit them to operate in end-to-end delivery of service, and 4)

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the underlying organizational principles. Section 7 provides requirements for specific end-to-end configurations for single-hop missions, for SSI missions, and for transitional strategies in getting from the present ABA operational state to the future SSI one; this includes mixed-mode states describing how SSI-compliant and non-SSI-compliant missions may interoperate in a limited fashion.

2.3 STRUCTURE OF THE ARD: FOUR VIEWS OF SYSTEM ARCHITECTURE

2.3.1 GENERAL

Large-scale system architectures are complex and must be considered from different perspectives, including both technical and operational views. An architecture that provides multi-agency SCCS services and uses service systems or elements, has many technical and organizational aspects to it. To help make each of these aspects clear, this ARD uses multiple views to define SCCS services and systems, each focusing on different aspects associated with these services and systems.

The views used in this ARD and its companion ADD are:

a) a service view;

b) a physical view;

c) a communications view;

d) an end-to-end deployment view.

These views were defined based on four of the six viewpoints of the RASDS (reference [2]), which were themselves defined based on the five viewpoints of the Reference Model of Open Distributed Processing (reference [11]). (See those documents for more background on this approach of using distinct viewpoints to describe system architectures.)

2.3.2 SERVICE VIEW

The service view is covered in section 4 and is used to define requirements on services provided by CSSSes/CSSEs and their behavioral and interface characteristics. Specifically, it addresses the topics of:

– top-level visible service interfaces for key elements;

– means for locating and binding to services;

– top-level interfaces for using services;

– top-level interfaces for managing services.

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2.3.3 PHYSICAL VIEW

The physical view is addressed in section 5 and defines requirements on the physical configuration of CSSSes/CSSEs and their functional characteristics. Specifically, it addresses the topics of:

- types of nodes and physical locations;
- allocated functionality at each node;
- physical access to the nodes.

2.3.4 COMMUNICATIONS VIEW

The communications view, which is covered in section 6 defines requirements on communications protocols used for accessing services provided by CSSSes/CSSEs. Specifically, it addresses the topics of:

- specific interface binding types for each node;
- communications protocol 'building block' stacks for each node type;
- relationships between interface bindings and internal functions.

2.3.5 END-TO-END VIEW

The end-to-end view is addressed in section 7 and defines requirements on how to configure the communications protocol building blocks to construct a set of representative mission communications configurations. Specifically, it provides a set of examples covering the following:

- ABA configurations;
- transitional configurations (limited);
- SSI configurations;
- mixed ABA and SSI configurations (limited).

The companion SCCS-ADD Informational Report (reference [D5]), provides an extended set of descriptive materials describing service interfaces, CSSE node configurations, suitable building blocks, and many more end-to-end protocol and system configurations for cross support.

2.3.6 SERVICE-VIEW RELATIONSHIPS

There is an identified relationship among the different elements that appear in each of these views:

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a) The service view shows top-level terrestrial elements that offer or use service interfaces, both terrestrial and for space communications.

b) The physical view introduces all of the different classes of physical elements (nodes) that are described and their internal functions and behavior. Their interfaces are identified in the physical view, but the interface binding signatures (i.e., the stack of protocols required to actually communicate with them) are specified in the communications view.

c) The communications view also provides the connection between the interface details and the internal functional details described in the physical views.

d) The end-to-end view shows how to assemble those nodes, and their protocol stacks, to create mission space communications deployments that will interoperate.

All of these views in this document focus only on the communications protocols up to the Link (ABA) or Network (SSI) Layer. The only Application Layer protocols that are described are those involved in transporting data (files and messages). Mission operations services and other applications protocols are not addressed in this ARD.

2.4 RELATIONSHIPS BETWEEN SCCS AND OTHER CCSDS DOCUMENTS

2.4.1 RELATIONSHIP BETWEEN SCCS AND OTHER CROSS SUPPORT SERVICE DOCUMENTS

The terminology in the SCCS for ABA configurations is derived in part from other cross support service documents, such as the Cross Support Reference Model (CSRM) (reference [1]) and Service Management (reference [D9]) CCSDS Recommended Standards (Blue Books). Because the SSI configuration introduces some new user/provider relationships, and also places cross support elements in space, some new terminology has been required.

This SCCS-ARD has introduced the terms *cross support service element*, *user element*, and *cross support service system* instead of the more limited complex and mission data-operation system terms used in the CSRM. While those CSRM terms are still relevant for ABA cross support configurations, they do not scale for the SSI.

The CSRM concept of *complex management* has been replaced here by *provision management*, which is defined as a set of functions of a CSSS, related to the acquisition and management of services provided by that CSSS to other CSSSes. PM interacts with the UMs of user CSSSes to negotiate the provision of services to their respective CSSSes.

The concept of *service management* has been extended to mean the set of functions exposed by PM to UM for the purposes of acquiring and managing the services provided by the provider CSSS to the user CSSS. Similarly, the concept of *utilization management* has been extended to mean a set of functions of a CSSS or user system, related to the acquisition and management of services provided to that CSSS or user system by other CSSSes.

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The term *element management* has been introduced to describe functions that interact with PM for purposes of ascertaining element resource availability, configuration and management of element resources, and reporting status of those resources. Elements that perform all or part of the services provided to user CSSSes have EM.

This SCCS-ARD also defines a set of nodes and different node types to support specialized CSSEs, UEs, and their functional configurations and protocol bindings. The CCSDS CSTS (reference [D6]) and next-generation extensible service management book (reference [D10]) introduce the term *functional resource*, which is defined as the functions or capabilities that are provided by physical resources (e.g., transmitters and receivers) of a CSSE, but not those physical resources themselves. A functional resource is a logical construct not necessarily linked to any single system component. Service management manages the functional resources that compose a CSSE. EM manages the elements inside a CSSE or UE that provide services or support user communications functions. Functional Resources are also referenced in the Service Control (reference [D19]) and Monitor Data (reference [D18]) specifications.

NOTE – The existing SM specification (reference [D9]) primarily defines a service request standard, message exchanges, and behavior for command and telemetry services. The new CSSM specification (reference [D10]) defines a more complete, and extensible, set of requests for all TT&C and ancillary and future services. Both are referenced in this document.

2.4.2 RELATIONSHIP BETWEEN SCCS AND OTHER CCSDS APPLICATION LAYER STANDARDS.

This document defines the suite of standards that are assumed to provide the communications services for all other CCSDS Application Layer documents such as SM&C and SOIS. These applications functions, and any other mission- or agency-specific applications, are all treated uniformly as ‘applications functions’. A separate mission operations reference architecture is proposed to be developed for these application functions that primarily run in the Earth and Space User nodes.

2.5 CROSS SUPPORT SERVICE SYSTEM ELEMENTS

2.5.1 GENERAL

In this architecture document, a CSSE is defined to be a physical element that is involved in providing one or more SCCS services, possibly together with some other CSSEs. The nodes that are CSSEs play the service-provider role and are implemented by different service-provider systems. CSSEs functioning together can provide communications and/or navigation services for any space mission element of any space agency provided that the UE conforms to the technical interface specifications and management policies specified for the CSSE.

These service-providing elements are also referred to as ‘building blocks’ because they can be assembled in various ways to provide deployed CSSS services.

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A UE is defined to be a physical element that is involved in using one or more SCCS services provided by one or more CSSEs. The nodes that are UEs play the service user role and are implemented by different service user systems. A UE may be adapted to also provide services; when this is done it is then functioning as a CSSE.

A CSSS is defined to be a set of CSSEs or UEs that are managed by a single authority with a single set of management policies. These may be provider or user systems.

2.5.2 CROSS SUPPORT SERVICE ELEMENT

A CSSE may be a landed element on the surface of a heavenly body (e.g., the Earth, the Moon, Mars, Jupiter), an element orbiting around a heavenly body (e.g., a relaying satellite), or an element in cruise through space (e.g., data management systems onboard spacecraft). Table 2-1 shows the types and nominal locations of the different CSSEs described in this document.

Table 2-1: Cross Support Service Elements and Nominal Locations

CSSE Type	Earth	Space/ Orbit	Space/ Planet
ESLT	X		
Earth Routing Node	X		
Space Routing Node		X	
Planet-Space Link Terminal (PSLT)			X
Earth/planet Wide Area Network (WAN) Routing Node	X		X

A CSSE may include a single computer or a large complex consisting of many subsystems. The internal implementation of a CSSE is not visible to its users. What is visible to the users are:

- services (functions) provided for users;
- methods for using and managing the services;
- means for locating and binding to the services;
- physical location or trajectory of the CSSE.

NOTE – For purposes of this document, the Earth is treated separately from the other planets, and the term ‘planet’ is extended to mean any other Solar System body (moon, asteroid, comet) that has missions and associated communications assets.

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2.5.3 USER ELEMENT

A UE may be a MOC, a landed element on the surface of a heavenly body (e.g., the Earth, the Moon, Mars, Jupiter), an element orbiting around a heavenly body (e.g., a science satellite), or an element in cruise through space. Table 2-2 shows the types and nominal locations of the different UEs described in this document.

Table 2-2: User Elements and Nominal Locations

UE Type	Earth	Space/ Orbit	Space/ Planet
Earth User Node	X		
Space User Node		Varies	Varies
Planet User Node			X
Earth Routing Node	X		

NOTE – The Earth routing node is included in the UE table because acts like a user of the ESLT link layer services and operates as a UE for purposes of planning, scheduling, and controlling the link to the space routing node.

A UE may include a single computer or a large complex consisting of many subsystems. The internal implementation of a UE is not visible to provider systems. What is visible to the provider systems are:

- services required by the UE;
- descriptions of the UE and its interfaces, configurations, and operating constraints;
- requests for locating and binding to the services;
- service requests made by users;
- physical location or trajectory of the UE.

2.5.4 CROSS SUPPORT SERVICE SYSTEMS

A CSSS is defined to be a set of CSSEs that are managed by a single authority with a single set of management policies. A CSSS may be a service provider, a service user, or both. Table 2-3 shows some examples of service provider CSSSes and CSSEs contained in them.

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Table 2-3: Examples of Provider Cross Support Service Systems and Related Elements

CSSS	CSSEs
Deep Space Tracking Network	Deep Space Stations, Network Control Center
Near-Earth Tracking Network	Tracking Stations, Network Control Center
Space Relay Tracking Network	Data Relay Satellites, Ground Terminals
Ground Tracking Station	Tracking Station, Station Control Center
Lunar Network	Lunar Relay Satellites
Mars Network	Mars Relay Satellites

Users of the service-provider CSSSes are service-user CSSSes, typically described as a MOC, spacecraft, lander, rover, or other mission element in space. These elements use SCCS services to accomplish their mission objectives. Table 2-4 describes some examples of service user CSSSes and the UEs contained in them.

Table 2-4: Examples of User Cross Support Service Systems and Related User Elements

CSSS	UEs
MOC	Earth User Node, Mission Control Center, Science Center
Spacecraft	Orbiter, Lander, Rover, Hybrid Science/Routing Orbiter

2.6 BASIC SYSTEM-ELEMENT CONFIGURATIONS

2.6.1 ABA SERVICE ELEMENTS—SIMPLE ABA CONFIGURATION

For the usual SCCS service, there is a service UE in space and another service UE on the ground. The ESLT in figure 2-2 is a specialized instance of the generic CSSE. Figure 2-2 shows the basic ABA configuration, with a CSSE of one agency (B) (the ABA ESLT) providing services to the Earth and Space User Nodes of another agency (A). The interface of the CSSE with the service user is called the *service-provider interface*. In this case, there is a terrestrial link service-provider interface to the Earth User Node and a space link service-provider interface to the Space User Node.

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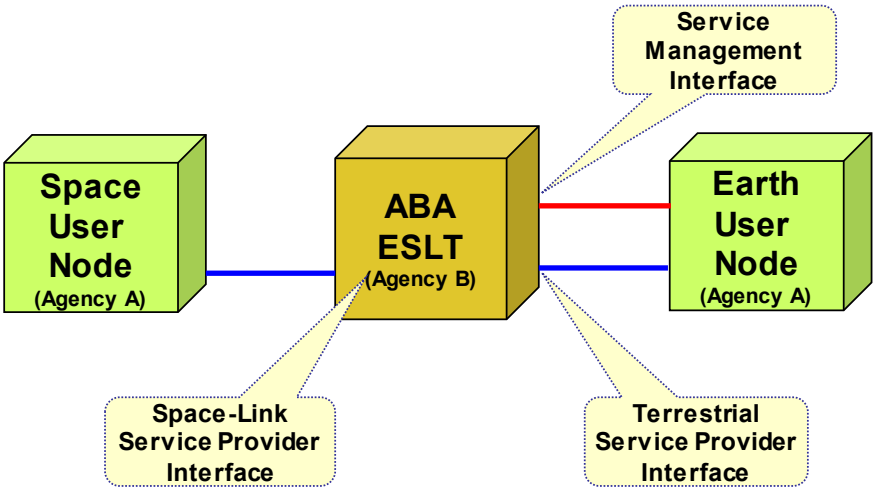

Figure 2-2: Basic ABA Configuration

The Earth and Space User Nodes shown in figure 2-2 are specialized instances of the generic UE. Within the Earth User Node, there will be a *UM element*, which manages, controls, and/or monitors the service provided by a CSSE. The UM element may be within the Earth User Node, but it can be separate, and it may be connected either directly to the interface on the CSSE that permits service management, or to another CSSE that supports the service remotely. The interface of the CSSE with the UM element is called the *service management interface*. (See definitions in 1.6.1.)

In an ABA configuration, a user's primary interfaces to the service provider are the link layer service request and service delivery interfaces either on the ground or in space. Currently the service user produces encoded space link frames for delivery and receives decoded space link frames. Once the F-Frame service is provided, this interface will be symmetric, with the user producing and consuming un-encoded frames. The activities within the service provider and the details of the service production are opaque to the service user, but a certain amount of monitor data and reporting is provided to allow the service user to determine the state of communications.

2.6.2 SSI SERVICE ELEMENTS—CORE SSI CONFIGURATION

In the SSI, there are cases in which a Space User Node and an Earth User Node are supported by two or more CSSEs. Figure 2-3 shows such an example, in which a Space User Node (a spacecraft) and an Earth User Node (e.g., a spacecraft mission control center) are supported by a space routing node (a relay satellite), the ESLT (a communications ground station), and a terrestrial WAN connection. The WAN is really an infrastructure element, and aside from providing Internet Protocol (IP) or Bundle Protocol (BP) network connectivity, it has no other distinguished role in the SSI. The MOC for the space routing node also participates, since it is responsible for managing and configuring the space routing node and for managing the space link to that node that is provided by the CSSE, but it is not necessarily in the direct SSI data flow from Earth User Node to Space User Node.

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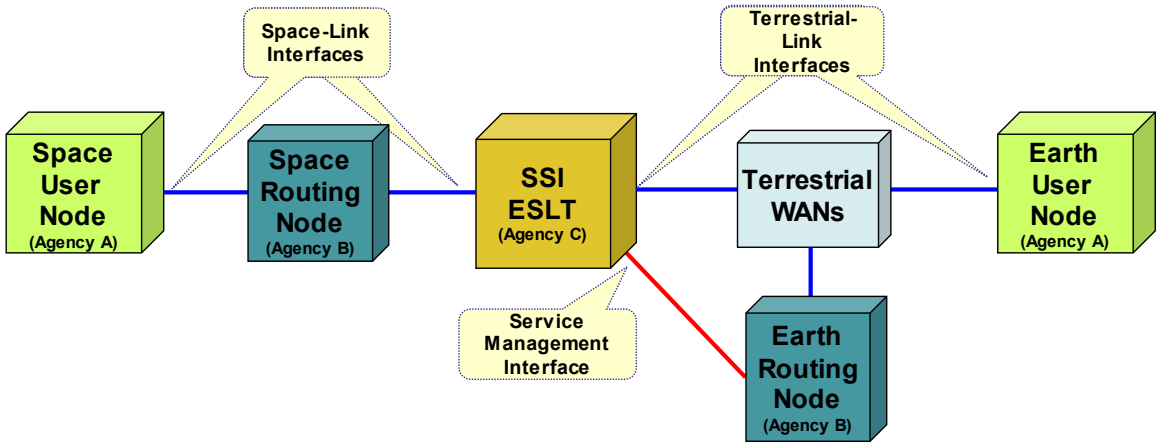

Figure 2-3: SSI Core Configuration

In this document these SSI configurations are also referred to as *ABCBA* style configurations. The notion is that the Earth User Node and the Space User Node both belong to the same agency (A), the space routing node and its MOC may belong to a different agency (B), and the ESLT may belong to yet a different agency (C). So Earth User Node *A*, gets support from the space routing node MOC *B*, connects to ESLT *C*, and then to space routing node *B*, which connects to Space User Node *A*, hence *ABCBA*. Of course, configurations are possible where all of the ABCBA elements may be owned by one agency. The terrestrial WAN may belong to either agency or be a public Internet. In practice the data may not flow directly through the space routing node MOC, but this element is certainly involved in managing the transfer and in controlling the space routing node. Much more complex SSI deployment configurations are possible, but this core SSI ABCBA configuration serves to introduce most of the necessary concepts for any SSI deployment.

2.7 NETWORK TERMINOLOGY

2.7.1 DEFINITION OF A NETWORK

A network consists of one or more computers or other processing elements (such as a spacecraft, data storage device, or other service-providing element) that are owned by a single organization, communicate using a single Layer 3 (Network Layer) protocol (see reference [4]) such as BP or IP, and share a single Layer-2 technology. These elements may communicate directly or may be connected via one or more routers that implement the Network Layer protocol and other support protocols for routing and management of the network. The underlying links from each element to another, or to the router, may differ, but the Network Layer protocol is common across the network.

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2.7.2 DEFINITION OF AN INTERNETWORK

Internetworking involves connecting two or more distinct computer networks, usually in separate management domains, together to form an internetwork (often shortened to *internet*), using routing devices that operate at Layer 3. These routing devices allow traffic to flow back and forth between the networks in a manner that is independent of how each network is implemented, and they guide traffic to its destination, routing data along a suitable path (among several different paths usually available) across the complete Internetwork. An Internetwork is therefore constructed as *a network of networks*. Internetworks may also use protocols at the boundaries of each network to manage flow from one management domain to another.

2.7.3 DEFINITION OF THE SOLAR SYSTEM INTERNETWORK

The SSI (figure 2-4) consists of a loose confederation of independent space communications networks, each often owned and administered by a different space agency. End users of the SSI are given access to internetworked data communications services by the *Solar System Internet Service Provider (SSI-SP)* with which they have established a Service-Level Agreement (SLA). 'Loose confederation' means there is no pre-agreed, planned development timeline for the full set of interoperable multi-agency assets that comprise the SSI; rather, the timeline is developed as assets are deployed by different agencies.

The participation of all assets in the SSI, from initiation until end of life, is carefully planned and managed; there is little that is 'loose' about it except for the lack of a complete, pre-agreed plan. 'Confederation' means that all agencies that choose to participate, each of which is free to act independently, voluntarily come together to collectively form what is effectively a single infrastructure. They do this by adhering to the operating guidelines, standards, protocols, and service interfaces agreed to by the confederation. Each of these independent participating networks is an SSI-SP which may consist of ground (planet or space) communications assets, dedicated routing assets, and/or hybrid science/routing assets. The SSI as a whole provides services to user missions.

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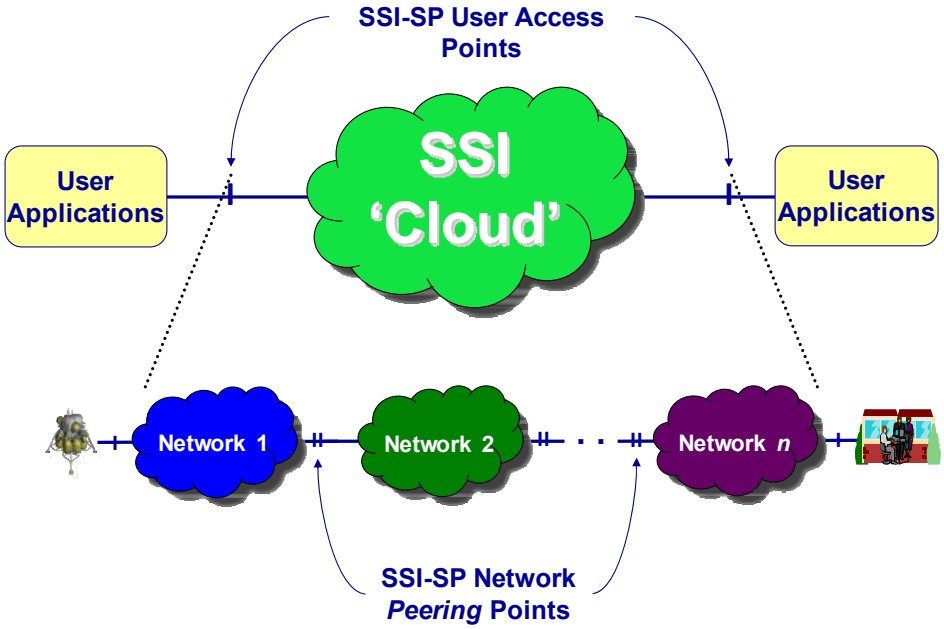

Figure 2-4: The SSI

NOTES

1 Applications are identified using Network Layer addresses.

2 All application communications go through the Network Layer.

3 To applications, there is no difference between a 1-hop, a 2-hop, or a 5-hop network path.

2.7.4 DEFINITION OF DELAY-TOLERANT NETWORKING CONFIGURATIONS

The Delay-Tolerant Networking (DTN) Protocol suite is the primary means recommended to implement the SSI because these protocols are best suited for use in all space communication configurations: deep space, near Earth, and terrestrial. In this document whenever the term 'DTN' is used, this is to be interpreted as the use of the BP (reference [12]) and all other related parts of the DTN suite that are required in that type of deployment. In the case of space links, this includes BP and the associated Store and Forward (S&F) Bundle Protocol Agent (BPA), Licklider Transmission Protocol (LTP) (reference [13]), and Encapsulation (ENCAP) (reference [14]) in order to insert BP PDUs into a CCSDS space link and to provide reliable delivery across that link. In the case of terrestrial hops, this includes BP, the bundle agent, and a convergence layer adapter providing a binding to TCP/IP or possibly User Datagram Protocol (UDP)/IP. Any references to 'Core DTN' are references to these limited DTN protocol stacks and the related functionality that may be deployed in any simple or complex mission configuration using the SSI protocols.

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The SSI architecture (reference [D7]) describes three different stages of deployments. In Stage 1 there is no expectation that SSI ESLTs or WAN nodes, with full routing and other services, will be available. In this stage SSI UEs will perform any and all SSI functions and will utilize ABA ESLTs to only provide space link access and normal link layer services. All SSI functionality is performed in the user nodes, but these may, by local agreement, provide services to other SSI UEs as well. At the time of this writing, Stage 1 SSI services have already been deployed in more than one space environment for demonstration purposes. These core DTN configurations may also use the Streamlined Bundle Security Protocol (SBSP) (reference [15]) to secure the data and Contact Graph Routing Protocol (CGRP) (reference [D11]) to describe link opportunities for DTN traffic.

For extended SSI configurations a number of additional protocols and configuration information exchanges is required. These are all described in the SSI Architecture as Stage 2 or 3 deployments, and they specifically involve the deployment of SSI functions in the ESLT and the deployment of additional DTN protocols for network management and coordination. At a minimum these extended SSI configurations will include deployment of the DTN Management Protocol (DTNMP, reference [D12]) and some new SSI planning and coordination information exchanges.

The extended SSI will use Network Service Agreements (NSAs) and Extensible Space Communication Cross Support Service Management (ESCCS-SM) requests to arrange for ESLT link layer services. The NSA covers SSI services from the service providing ESLTs, and increasingly automated exchanges for coordination among users, ESLTs, and between ESLTs. The SSI Architecture, for Stages 2 and 3, describes the specific planning and scheduling document exchanges that are to occur among coordinating authorities and within a multi-agency organization called the Coordinating Council. The SSI Architecture should be referenced for these details (see reference [D7]).

2.8 PRACTICAL LIMITS ON PROTOCOL CHOICES

In data communications, Bandwidth Delay Product (BDP) refers to the product of a data link's capacity (in bits per second) and its end-to-end delay (in seconds). The result, an amount of data measured in bits (or bytes), is equivalent to the maximum amount of data on a circuit (network or otherwise) at any given time, i.e., data that has been transmitted but not yet acknowledged. This is calculated as the data link's capacity multiplied by its RTLT.

A network with a large BDP is commonly known as a Long Fat Network (LFN). A network is considered an LFN if its BDP is significantly larger than 105 bits (12500 bytes). Ultra-high-speed LANs fall into this category, where protocol tuning is critical for achieving peak throughput, on account of their extremely high bandwidth, even though their delay is not great.

Of importance for space communications are situations where the BDP is large, such as Geosynchronous Earth Orbit (GEO) satellite connections, where end-to-end delivery time is very high and link throughput may also be high. Other examples in space include what could be called Really Long Skinny Networks (RLSNs). Examples would be IP out to GEO or almost any deep space link. Above some practical limit, like a BDP of 10^6, the high end-to-end

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delivery time makes life difficult for stop-and-wait protocols and applications that assume rapid end-to-end response. Above a BDP of 10^7, such as in almost all space applications, stop-and-wait, go-back-n, and selective repeat protocols just break, and other approaches for end-to-end reliability must be employed. Table 2-5 provides some example BDPs.

Table 2-5: Example BDPs for Different Earth and Space Applications

Application	Speed (bits/second)	RTLT	BDP
Moderate-speed GEO satellite network	512 kb/s	900 ms	512×10^3 b/s × 900×10^{-3} s = 460,800 bits
Residential ADSL[1] 2+	20 Mb/s[2]	50 ms	2×10^7 b/s × 5×10^{-2} s = 10^6 b, or 1 Mb
High-speed terrestrial network	1 Gb/s	1 ms	10^9 b/s × 10^{-3} s = 10^6 b, or 1 Mb
Earth-to-Moon network	500 Mb/s	2.6 sec	5×10^8 b/s × 2.6 s = 1.3×10^9 b, or 1.3 Gb
L1/L2 orbit	100 Mb/s	210 sec	10^8 b/s × 2.1×10^2 s = 2×10^{10} b, or 20 Gb
Earth trailing orbit	5 Mb/s	20762 sec	5×10^6 b/s × 2.1×10^4 s = 10^{11} b, or 100 Gb
Mars Reconnaissance Orbiter (MRO) to MSL	1 Mb/s	0.008 sec	10^6 b/s × 8×10^{-3} s = 8×10^3 b, or 8000 bits

What is known from real-world experience is that getting TCP/IP to run effectively over GEO satellite links requires quite a bit of acknowledgement window and buffer tuning or use of some specialized protocols like Space Communications Protocol Specification—Transport Protocol (SCPS-TP). Where drawing the distinction is required, this document will use a breakpoint BDP of 10^7 to indicate where certain families of protocols, such as the Internet Protocol Suite (IPS), will cease to work effectively and where other protocol families, such as DTN, should be selected instead. Another practical limit on protocol selection is an RTLT of greater than 2 sec, above which many terrestrial protocols time-out and assume that the link has failed.

2.9 HOW TO USE THIS DOCUMENT

2.9.1 GENERAL

This document covers the broad subject matter of space cross support and protocols, including both ABA and SSI configurations, and does so from a number of different viewpoints. This is a carefully structured architectural approach, but individual users may wish to look at the problem from a different point of view, such as 'What do I need to implement to construct a compliant ABA ESLT?' or 'What do I need to implement to build an SSI-capable spacecraft that can be supported in Stage 1 by an ABA ESLT?' There will be many such application-specific viewpoints. What this subsection tries to do is to provide a few 'slices' through the document to show how such mission or application specific questions may be answered.

[1] Asymmetric Digital Subscriber Line.

[2] From Digital Subscriber Line Access Multiplexer (DSLAM) to residential modem.

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2.9.2 DOCUMENT INTERNAL STRUCTURE

Each of the major document sections is generally structured as follows:

- ABA topics:
  - ABA Service Provider (ESLT) topics,
  - ABA Earth User topics,
  - ABA Space User topics;
- SSI topics:
  - SSI Service Provider (ESLT and other Earth and space service provider) topics,
  - SSI Earth User topics,
  - SSI Space User topics;
- Security topics.

Readers who are only interested in ABA topics may safely skip all of the SSI subsections. The reverse is not true, however, as the SSI sections make references back to the ABA ones that they are built upon. Readers who are interested in how to construct a ground station can safely read just the ESLT subsections. They should probably read about the service interfaces first (section 4) and then look at the physical viewpoint (section 5) and the protocol building blocks (section 6).

Readers who are interested in the protocols that a user spacecraft should implement are recommended to read the Space User Node physical viewpoint (section 5) to understand the allocated functionality, and then read the related protocol building blocks (section 6). If they are also concerned with the functionality expected of a spacecraft MOC, they should read the Earth User Node and ESLT service interfaces in section 4 and the related physical viewpoint and allocated functionality in section 5. Table 2-6 provides examples of mission application-specific views.

It is recommended that all readers review the security sections.

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Table 2-6: Examples of Mission Application-Specific Views

Topic	Subtopics	SCCS-ARD Sections to Read					
		ABA			SSI		
		Sec 4	Sec 5	Sec 6	Sec 4	Sec 5	Sec 6
ABA Spacecraft and MOC	ABA Spacecraft		5.2.3.3	6.3.1.6			
	ABA MOC	4.2.1 4.2.2	5.2.3.1 5.2.3.2	6.3.1.1 6.3.1.4			
ABA ESLT	ABA ESLT	4.2.2	5.2.2	6.3.1.1			
SSI Spacecraft and MOC	SSI Spacecraft		5.2.3.3	6.3.1.6		5.3.3.3	6.3.2.6
	SSI MOC	4.2.1 4.2.2	5.2.3.1 5.2.3.2	6.3.1.1 6.3.1.4	4.3.2 4.3.3	5.3.2.1 5.3.3.2	6.3.2.2 6.3.2.5
SSI ESLT	SSI ESLT	4.2.2	5.2.2	6.3.1.1			
SSI Stage 1 Spacecraft and MOC	SSI Stage 1 Spacecraft		5.2.3.3	6.3.1.6		5.3.3.3 5.3.3.4	6.3.2.6
	SSI Stage 1 MOC	4.2.1 4.2.2	5.2.3.1 5.2.3.2	6.3.1.1 6.3.1.4		5.3.2.2	6.3.2.4
	SSI Stage 1 ESLT	4.2.2	5.2.2	6.3.1.1			

NOTE – SSI Stage 1 missions will implement all of the SSI functions themselves and that they are using ABA ESLTs only to provide link layer space communications services, not any SSI services.

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3 CROSS SUPPORT OVERVIEW OF ABA AND SSI TECHNICAL ARCHITECTURE—CROSS SUPPORT BUILDING BLOCKS

3.1 OVERVIEW

There are two different, but related, types of building blocks that are used to compose space cross support systems: ABA building blocks and SSI building blocks. They differ most importantly in that the ABA building blocks are required only to support up to link layer services, where the SSI building blocks are required to support internetworking services. Service-provider building blocks may be constructed so as to support both ABA and SSI user nodes.

Figure 3-1 shows a representative end-to-end ABA configuration, using ABA building blocks and link layer functions. (See section 5 for more details on the characteristics of these building blocks.)

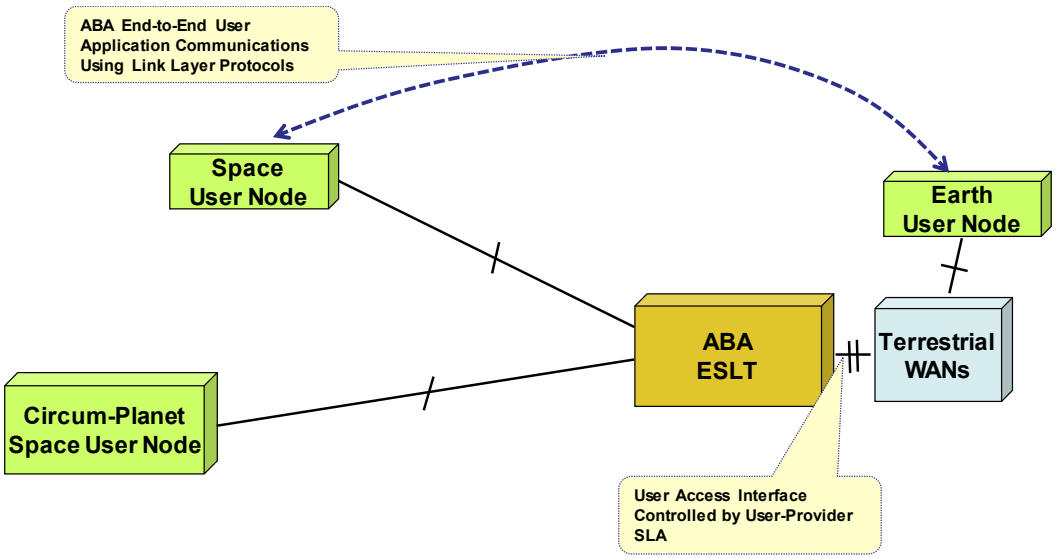

Figure 3-1: Generic ABA End-to-End Deployment

Figure 3-2 shows a representative end-to-end SSI configuration, using SSI building blocks and Network Layer functions. An SSI ESLT is also capable of supporting ABA missions, and that SSI space routing nodes and PSLTs should also be capable of supporting ABA Space User Nodes, using some defined adaptation functions.

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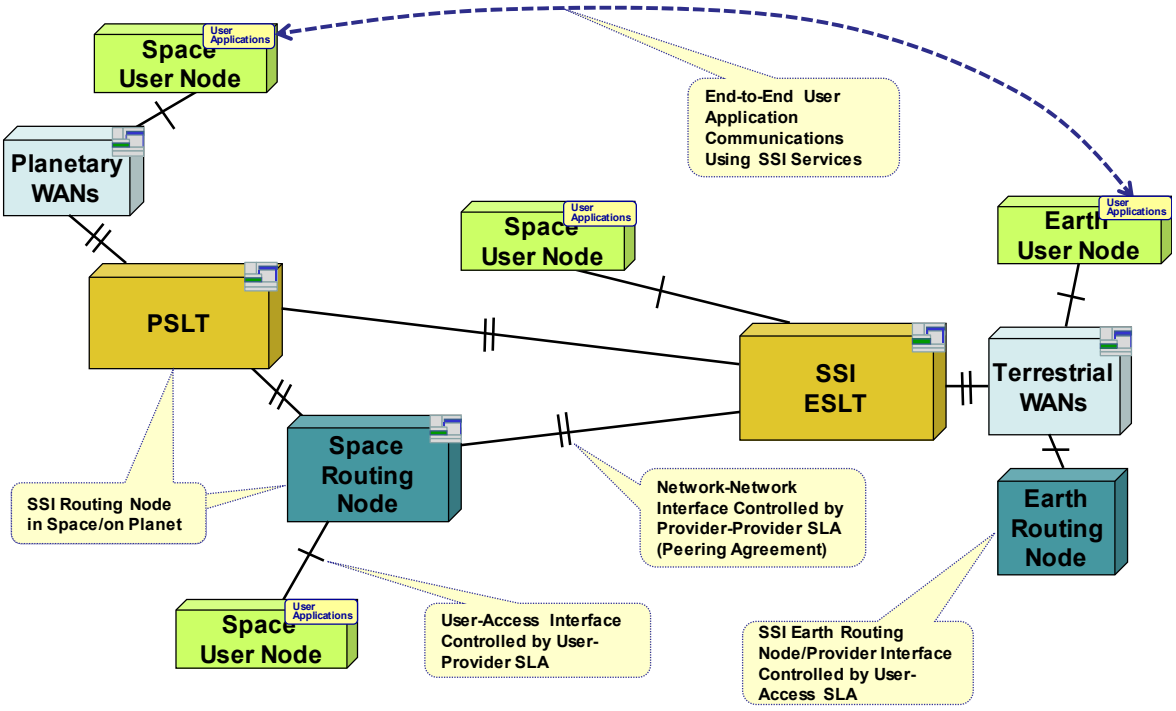

Figure 3-2: Generic SSI End-to-End Deployment

3.2 BUILDING-BLOCK FUNCTIONS

3.2.1 DISCUSSION

Each of the SCCS building blocks (CSSEs) has an associated set of basic functions that distinguishes the blocks one from another. Any of these building blocks may also incorporate other functionality, but the basic functions must be included to enable interoperability. The sets of functions identified here are suitable for both ABA and SSI configurations, but some of the functions are only required to provide SSI services; these are marked as (SSI).

3.2.2 REQUIRED BUILDING-BLOCK FUNCTIONS

The basic sets of functions required for each SCCS building block are as follows:

a) ESLTs (e.g., ABA and SSI ground stations)

- shall provide a communications link between terrestrial elements and space elements,
- shall provide interface to Radio Frequency (RF) space link,
- shall provide services to one (or possibly more) Earth User Nodes,
- shall provide full services for link layer processing and frame merging,

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- shall provide secure access control mechanisms,
- shall route data between terrestrial elements and space (SSI),
- shall provide full services for Network Layer processing and routing (SSI),
- may support last-hop emergency and non-SSI delivery services (SSI),
- shall provide a service management interface for processing requests, and for service configuration and reporting;

b) space routing nodes (SSI)

- shall provide routing among space elements,
- shall provide interfaces to two or more RF space links,
- shall provide full services for Data Link Layer and Network Layer processing and routing,
- shall provide security services across their links,
- must support last-hop emergency and non-SSI delivery services,
- should have an EM interface for configuration and reporting;

c) Earth routing nodes (SSI)

- shall operate one or more space routing nodes,
- may provide routing from Earth User Nodes to their ESLT (but this is not required),
- may provide interfaces to one or more Earth User Nodes,
- should provide full services for Data Link Layer and Network Layer processing and routing,
- must support secure essential commanding and telemetry for the space routing nodes that they operate,
- should have an EM interface for configuration and reporting;

d) PSLTs (SSI)

- shall route data between planet surface elements and space,
- shall provide interfaces to RF space link, either in situ or long haul,
- may provide interfaces to one or more planet ‘terrestrial’ links,
- should provide full services, including security, for Data Link Layer and Network Layer processing and routing,

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