CCSDS SPACE LINK EXTENSION SERVICE MANAGEMENT STANDARDS AND PROTOTYPING ACTIVITIES

John Pietras
Global Science & Technology, Inc.

ABSTRACT

The Consultative Committee for Space Data Systems (CCSDS) is developing standards for the interface through which spaceflight mission managers request tracking, telemetry, and command (TT&C) and Space Link Extension (SLE) services from TT&C ground stations and networks. The standards are intended for use not just by the spaceflight projects and networks operated by the CCSDS member agencies, but also by commercial networks and networks operated by other governmental agencies. As part of the process of developing the standards, several prototypes are under development. This paper presents a summary status of both the emerging service request standards and the prototypes that implement them.

KEYWORDS

TT&C network management, Space Link Extension, service management, and service request.

INTRODUCTION

Economic and political considerations are leading space-faring organizations to make use of shared operations infrastructures. Such infrastructure sharing is being contemplated or already taking place among space agencies of different nations, among different governmental organizations within nations (e.g., civil space, military space, and meteorological organizations), and through the time-shared use of commercial services.

A prime candidate for such a sharing arrangement is the use of the various networks of ground tracking stations by spaceflight missions. In this scenario, a spaceflight mission uses other organizations' (commercial or governmental) ground stations to provide communications between spacecraft and their associated ground-based facilities.

In order for a spaceflight mission to make use of a third-party ground station, two interfaces must be met: the space-ground link between the mission spacecraft and the ground station, and the interface between the ground station and mission ground facilities that ultimately communicate with the spacecraft (typically the mission operations center and often a payload data processing center). The earliest target (and success) of the Consultative Committee for Space Data System (CCSDS) program of standardization was the interface between the spacecraft and ground station. For twenty years, CCSDS has had in place Recommendations for radio frequency (RF), modulation, coding, and link-layer protocols (see *www.ccsds.org/CCSDS/recommandreports.jsp*).

Conformance to the CCSDS space link Recommendations has permitted and promoted interoperability between spacecraft and ground stations. However, the interface between the ground station and mission ground facilities was not addressed until the early 1990s, when CCSDS launched the *Space Link Extension* (SLE) initiative to standardize the transfer of spacecraft command and telemetry data among ground stations, mission operations centers, data processing facilities, and other parties that communicate with the spacecraft. The resulting SLE service architecture (as defined in the *Cross Support Reference Model* (CSRM) [CCSDSa] identifies two major service components: SLE *transfer services* and SLE *service management*.

SLE transfer services move CCSDS-standard space link data units (e.g., packet telemetry frames, command link transmission units) between SLE service providers (i.e., the TT&C ground stations) and SLE service users (the ground-based mission and payload control systems). SLE transfer services have been implemented by the European Space Agency (ESA), the Japanese Institute of Space and Astronautical Science (ISAS), and NASA Jet Propulsion Laboratory's (JPL) Deep Space Network (DSN). The ESA INTEGRAL and Rosetta and ISAS Muses-C missions have adopted SLE, and JPL has selected SLE as the standard interface between mission facilities and the DSN for the foreseeable future. NASA's Space Network (SN) and Ground Network (GN), as well as other national space agencies, are evaluating the adoption of SLE services as their standard for future mission support. Finally, the US Air Force has been experimenting with variations of the SLE transfer services for possible use in the Air Force Satellite Control Network (AFSCN) [Sunshine]. A more-detailed status of SLE transfer service deployment is provided in [Brosi].

The SLE transfer services must be configured for use – service user access authorization and identification authentication information must be mutually agreed ahead of time, and several quality of service parameters may be selected on a per-contact/pass basis. In the current TT&C ground station network environment, exchange of this information would need to be integrated into each provider's network-specific system of service contracting procedures and service scheduling protocols. Thus even though the use of SLE transfer services provides spaceflight missions with a common interface for exchanging spacecraft command and telemetry data with all SLE-conformant ground networks, those spaceflight missions would still need to conform to each network's proprietary service contracting and scheduling interfaces.

The lack of standards for service contracting and scheduling – not just for SLE, but also for traditional TT&C services – are an impediment to interoperability and cross support. As part of the SLE program, CCSDS has been developing standards for *SLE service management* (SLE-SM) to provide common services and interfaces to support the acquisition, scheduling monitoring, and control of the TT&C and SLE services. "SLE service management" is something of a misnomer in that it is not limited to the management of SLE transfer services. Rather, the name is an artifact of the management standard's origin in the SLE program.

SLE-SM ENVIRONMENT

The SLE service management environment is illustrated in Figure 1, which is derived from [CCSDSa]. In this model, SLE transfer services and service management provide the interfaces between a *Complex* (which provides TT&C and SLE services) and a spaceflight mission that uses the services that the TT&C/SLE Complex provides. The spaceflight mission is composed of the spacecraft and the *Mission Data Operations System* (MDOS), which represents all of the mission's ground-based functions.

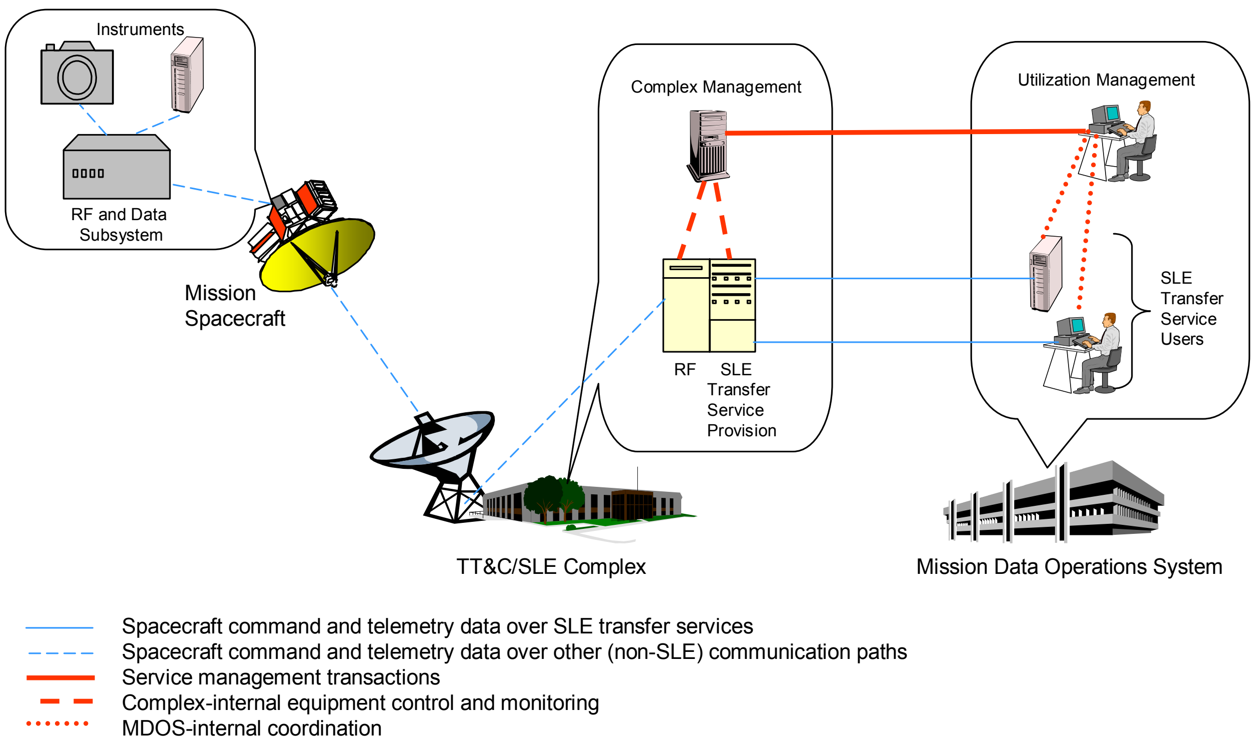

Figure 1. SLE Service Management Environment

The TT&C/SLE Complex is a collection of ground station resources under a single management authority. It may be a single ground station or a network of ground stations. In the broadest terms, the space mission uses the Complex's services so that the MDOS can communicate with and track the spacecraft.

A key concept behind the SLE architecture is that the MDOS may have multiple SLE transfer service users communicating with multiple peer entities (e.g., instruments or computer applications) onboard the spacecraft. The SLE transfer services provide individual "pipes" (represented by the thin solid lines in the figure) for these multiple connections. Each such pipe is realized as an *SLE transfer service instance*. The Complex is the SLE transfer service provider and is also the provider of the TT&C services used to communicate the data to and from the spacecraft (the thin dashed lines).

There can be multiple SLE transfer service instances associated with a single space link session. The transfer service instances rely on shared Complex resources like antennae, receivers, frame syncs, etc. To facilitate this sharing of link resources among the various transfer service users, a *Utilization Management* (UM) function within the MDOS brokers the requests for TT&C and SLE services from the Complex on behalf of the transfer service users associated with the space mission. The UM is that part of overall mission management and administration that deals with acquiring and operating TT&C and SLE services on behalf of the space mission.

The *Complex Management* (CM) function of the Complex represents the role of the Complex that:

- Establishes the service relationship with the spaceflight mission;
- Negotiates with the mission the levels of service and the length of the service agreements;
- Responds to service requests for individual space link sessions;
- Responds to requests to change configuration;
- Responds to requests from the UM for status;
- Issues status reports to the UM; and
- Interfaces with the resources of the Complex to effect service requests and collect status information.

The interactions between UM and CM (denoted by the thick solid line in the figure) are the domain of SLE service management. The transfer service interactions between the transfer service users and the SLE Complex are the subject of the CCSDS Recommendations for the three currently-defined SLE transfer services: Forward Command Link Transmission Unit (F-CLTU) [CCSDSb], Return All Frames (R-AF) [CCSDSc], and Return Chanel Frames (R-CF) [CCSDSd]. Communications across the space ground link (thin dashed lines) are subject to other CCSDS Recommendations for RF, modulation, coding, and data links (see *www.ccsds.org/CCSDS/recommandreports.jsp*). Neither the interactions between UM and transfer service users (thick dotted lines), nor those between CM and the various resources that actually provide the SLE transfer and TT&C services (thick dashed lines), are currently the subject of standardization activity.

SLE SM SERVICE REQUEST SPECIFICATIONS

SLE service management activity within CCSDS is currently focused on those interfaces and processes by which a UM requests services from a CM for individual contacts (also known as passes or tracks). The other aspects of SLE-SM – the initial establishment of service relationships, the negotiations of mission-length service agreements, and execution-time monitor and control of SLE and TT&C services – are topics for future standardization.

CCSDS is developing two Service Management specifications for this *service request* phase of cross support. The Service Request Service Specification [CCSDSe] defines the transactions between a UM and CM for purposes of requesting services (a process often referred to as scheduling) and the CM's behavior with respect to each of the transactions. The Service Request XML Schema Specification [CCSDSf] defines the messages that are exchanged in those transactions in the form of World Wide Web Consortium (W3C) eXtensible Markup Language (XML) schema [Bray et al]. XML is currently the premier standard for automated information exchange, and its use in this specification enables the automation of service request exchanges using any of a growing number of XML-based tools and technologies. These specifications are both currently CCSDS Service

Management Working Group drafts. They are scheduled for development to full CCSDS Recommendation (Blue Book) status by the end of 2004.

A detailed description of the XML schema is beyond the overview scope of this paper. However, the approach taken and functionality defined in the service specification are appropriate to this paper.

CCSDS is taking an evolutionary approach in the development of the Service Request Service Specification, based on current practices of various Agencies and TT&C service providers. These practices have been examined, and common approaches and best practices have been extracted to serve as the basis for the standard. With regard to TT&C services, the underlying functionality already exists in most legacy network scheduling systems, and what the specification brings is a standard interface to that functionality. Of course, management of SLE services will require additional functionality in the management systems of the networks that are adding SLE support.

The core of the Service Request Service Specification is the set of management transactions that can be carried out between UM and CM. The Service Request Service Specification defines four classes of service management transactions:

- Configuration Profile
- Service Request
- Trajectory Data
- Service Agreement Query

Configuration Profile A common mode of operating is to use *configuration profiles,* that is, predefined sets of parameter values for the spacecraft communication system configurations. The individual requests for service subsequently refer to the configuration profiles. The popularity of this approach derives from the increased confidence that the full set (potentially many) of parameters are properly declared for a service request, and from the compactness with which the requests for service can be created.

The SLE-SM Service Request paradigm uses this configuration profile approach. The two types of SLE-SM configuration profiles are hierarchically arranged. At the top of the hierarchy is the *carrier profile*, which captures RF, modulation, and coding parameters for a single carrier across the space-ground link. Each carrier profile also contains one or more *transfer service profiles*, each of which captures a mission-standard set of configuration parameter values for transfer services that connect the users with the Complex. The use of configuration profiles is well-suited to the majority of spacecraft that have one or more well-defined modes of TT&C operation, e.g., housekeeping, high rate instrument operation, tracking, and various combinations thereof.

UM invokes the *new carrier profile* transaction to add a new carrier profile to the set of configuration profiles on record at the Complex. CM validates each new carrier profile invocation against a previously-negotiated service agreement to determine if the new request is within the scope of the agreement. If it is, CM accepts the new configuration profile and notifies UM. If the request is invalid, CM rejects the new profile and so informs UM, citing the reason(s) for rejection.

UM invokes the *delete carrier profile* transaction to delete no-longer-needed profiles. Normally CM will comply with the invocation, delete the profile, and confirm the deletion to UM. However, under some circumstances (such as the configuration profile being cited by an active or forthcoming service request), CM will refuse to delete and will notify UM of the failure of the deletion invocation and provide the reason for failure.

UM invokes the *query carrier profile* transaction to query the content of a specified carrier profile on record at CM. This invocation provides a mechanism for validating consistency between UM and CM databases.

Service Request The SLE-SM service request class of transactions is used to request new contacts or modify or delete previously-submitted service requests. UM invokes the *new service request* transaction to request a contact at a time specified within the request (with optional lag and lead times to allow CM some latitude in fitting the request into the schedule). The service requests identify the carrier and transfer service configurations that are to be applied, and specify the (relatively few) configuration values that must be set on a per-contact basis.

One feature of the *new service request* transaction is UM's ability to incrementally schedule the resources needed to support a contact. UM may submit a new service request that identifies the needed RF resources, without detailing the characteristics of the associated transfer services. Once the RF resources have been scheduled, the details of the transfer services can be added via the *replace service request* transaction (see below).

Another feature of the new service request is UM's optional ability to specify multiple alternative service scenarios in a single service request. This capability is envisioned for use when event-driven circumstances may require different service configurations (e.g., those associated with tracking through not only a nominal spacecraft trajectory change but also any of several preplanned contingency situations [under burn/over burn/no burn]). The service request identifies the default scenario, which will be executed unless otherwise changed via an invocation of the *invoke alternate scenario* transaction (see below).

In response to a *new service request* transaction, CM can either *accept*, *reject*, or *acknowledge* the service request. Acceptance indicates that the resources needed to support the request are being held in reserve and will be applied at the specified time unless UM deletes the service request. A rejection indicates that some aspect of the service request could not be accommodated within the time window specified. Each rejection identifies the configuration parameters that are in conflict. An acknowledgement indicates that CM has received the service request and has determined that it is of the proper format, but that completion of the disposition of the request is deferred to a later time. Typically, a service request would be acknowledged when it is submitted to a CM that schedules on a periodic basis. The acknowledgement contains a expected disposition time. Acknowledgements are to be followed up with an acceptance, rejection, or updated acknowledgement at or before the expected disposition time.

UM invokes the *delete service request* transaction to remove a service request from the set of accepted service requests.

UM invokes the *replace service request* transaction to modify one or more parameters of an already accepted service request. Such a modification might be driven, for example, by an updated acquisition of signal/loss of signal calculation, or by the need to complete a partial service request with transfer service configuration details. If the replacement is accepted, the original service request is deleted and the replacement takes its place. If the replacement cannot be accepted, CM retains the original service request and notifies UM of the reason for rejecting the replacement.

UM invokes the *invoke alternate scenario* transaction to change the scenario that is to be executed when the service request becomes active, or even while the service request is active. Because CM has pre-allocated the resources to support all of the alternate scenarios in the service request, an alternate scenario can be invoked on much shorter time scale and with much higher probability of success than if UM were to submit a new or replacement service request.

UM invokes the *query service request* transaction to query the content of a specific service request on record at CM.

Trajectory Data The SLE-SM trajectory data class of transactions are used to manage the trajectory data that are used by the Complex to derive the pointing angles and doppler compensation settings needed to acquire the spacecraft. UM invokes the *new trajectory*, *replace trajectory*, and *delete trajectory* transactions to provide the CM with trajectory data, update in-place trajectory data, and delete obsolete trajectory data, respectively. The standard supports two CCSDS trajectory data formats, the Orbit Parameter Message and the Ephemeris Message [CCSDSg].

Query Service Agreement Finally, UM invokes the *query service agreement* transaction to query the contents of the service agreement. The service agreement is the "document" that establishes the service relationship between the spaceflight mission and Complex, and sets the bounds on the various configuration profiles that can be created within the context of that service agreement.

Extending SLE-SM Service Request to Non-CCSDS Resources The initial versions of the service and XML schema specifications focus on managing services that conform to CCSDS Recommendations for RF and modulation, CCSDS link coding, space link layer protocols, and SLE data transfer. However, the desirability of a standard interface for acquiring TT&C services applies to more than just "CCSDS standard" networks, and SLE-SM is being considered for adoption by users and providers of other legacy TT&C and data transfer services, such as the AFSCN.

To help broaden the potential user base, CCSDS is attempting to structure the service request standards to facilitate extensions to cover management of non-CCSDS resources. An architectural framework that can apply to non-CCSDS as well as CCSDS TT&C networks is more attractive to operators of networks that offer mixtures of service because they can consolidate their operations under a single management interface, and to developers of TT&C network management systems because they can develop a core product that can be marketed to the various kinds of TT&C networks.

SLE-SM SERVICE REQUEST PROTOTYPES

Increasingly, CCSDS is adopting the Internet approach of including prototype implementations as part of the standards development process. That approach is being applied to the development of the

SLE-SM Service Request specifications. There are four ongoing efforts to prototype the functionality specified in the draft CCSDS Recommendations for SLE service management. These prototypes have multiple purposes, but all share two goals: to expose mission operators, TT&C service providers and implementers to the emerging standards; and to validate the specifications before their final ratification as CCSDS Recommendations. The following subsections briefly describe each of these prototypes.

British National Space Centre (BNSC)/QinetiQ SLE-SM Prototype Started in 1999, the BNSC/QinetiQ SLE-SM implementation is the oldest ongoing SLE-SM prototype. Funded by BNSC and implemented by the Vega Group PLC at the QinetiQ ground tracking station in West Freugh, UK, the service management prototype is part of a larger SLE testbed that also includes implementations of the F-CLTU [CCSDSb], R-AF [CCSDSc], and R-CF [CCSDSd] transfer services. The BNSC/QinetiQ SLE testbed is currently the only testbed to automate TT&C, and SLE transfer service operations under an SLE-SM-based management system. The testbed is available for use by spaceflight missions and organizations interested in SLE-SM and/or transfer services.

The BNSC/QinetiQ SLE-SM system supports the functionality of the CCSDS service request specifications, but as of Spring 2003 it does so using a Java Remote Method Invocation (RMI) interface rather than the current XML-based approach. This is because the SLE-SM component of the testbed was developed in conformance to an older draft CCSDS service management standard. Current plans are to add an XML-based interface in the near future. Please contact Tim Wilmott (TRWillmott@space.qinetiq.com) for more information on this system.

NASA Jet Propulsion Laboratory (JPL) SLE-SM XML Prototype The JPL SLE-SM XML prototype is intended to: serve as a validation platform for the development of the service request specifications; gain implementation experience with the draft standards, leading to adoption by JPL's DSN; and gain mission user insight and feedback from the ISAS Muses-C mission and possibly other ESA and JPL flight missions. The prototype is being developed as an added capability of the existing Deep Space Mission Systems (DSMS) Service Management System. By the Spring of 2004, the JPL SLE-SM XML prototype will be capable of handling requests for DSN RF services as well as F-CLTU, R-AF, and R-CF SLE transfer services. In the intial stages of prototype operation, the prototype will receive XML-formatted requests that "shadow" real requests sent to the operational management system. JPL prototypers will then validate the outputs of the prototype against those of the operational management system.

JPL is developing the prototype on top of a COTS/open standards data architecture that incorporates (in addition to XML) the Simple Object Access Protocol (SOAP), Hypertext Transfer Protocol (HTTP), Structured Query Language (SQL), Java Database Connectivity (JDBC), Document Object Model (DOM) and Oracle 9i. Please contact Erik Barkley (Erik.J.Barkley@jpl.nasa.gov) or Emily Law (Emily.S.Law@jpl.nasa.gov) for further information.

NASA Consolidated Space Operations Contract (CSOC) SLE Management Service Request Prototype The CSOC Service Request prototype is being developed by Lockheed Martin under NASA funding as part of a larger NASA SLE testbed. The prototype is intended to provide specific and timely feedback to CCSDS as a result of implementing the draft standards in a state-of-practice TT&C operational environment, and to help NASA evaluate SLE-SM.

The CSOC Service Request prototype is being developed for requesting the services of the NASA Goddard Space Flight Center (GSFC) Wallops Flight Facility (WFF). Current plans are to use the Wide-Field Infrared Explorer (WIRE) spacecraft as a test vehicle. The CSOC Service Request prototype uses much of the same COTS/open standards (e.g., SOAP, Java DOM, Oracle) infrastructure as the JPL effort, but this prototype also addresses issues specific to the WFF operational environment. For further information please contact Andy Schreckenghost (Andy.Schreckenghost@csoconline.com).

Air Force Satellite Control Network (AFSCN) Service Management Prototype The US Air Force is sponsoring a multi-phase AFSCN Interoperability Project to explore the evolution of the AFSCN toward adoption of standards that would permit greater interoperability among the AFSCN remote tracking stations, the AFSCN user community, commercial and other governmental TT&C network operators, and (potentially) non-military spacecraft mission operators. Under subcontract to the Satellite Control Network Contractor (SCNC - a team headed by Honeywell Technology Solutions, Inc.), Global Science and Technology (GST) has developed prototype applications that allow spaceflight mission operators to develop XML-formatted Service Requests using a graphical user interface (GUI), and allow TT&C station operators to display the service request and respond (also via a GUI).

The AFSCN Service Management prototype applications are deployed at the Center for Research Support (CERES) in Colorado Springs, CO, the Honewell DataLynx Operations Center (DOC) in Columbia, MD, and the NASA WFF. The prototype applications are being used to schedule Interoperability Project contacts provided by the Johns Hopkins University Applied Physical Laboratory ground station (which is controlled via the DOC)and WFF. The Service Management prototypes differ from the other prototyping efforts in that they are not constrained to "pure CCSDS" services, but rather are used to set up services that are supported by legacy systems (i.e., the AFSCN Space-Ground Link System (SGLS)) and other non-CCSDS aspects of the Interoperability Project test configurations. Please contact John Pietras (pietras@gst.com) for more information.

Prototype Integration The initial versions of each of the aforementioned prototypes have been developed and tested in isolation. Even in isolation, they have yielded valuable feedback to the standardization effort, for example by identifying issues with implementability via COTS products, and identifying the points at which the XML schema will need to be extendable to support non-CCSDS services. But the CCSDS approach requires at least two independent implementations be developed and interoperated as a condition of ratification as a CCSDS Recommendation. To that end, plans are being made to begin to interoperate the prototypes in various combinations by the Fall of 2003. The status of the interoperability of these prototypes will be reported at ITC 2003.

CONCLUSION

CCSDS is developing SLE Service Management Service Request specifications for a standard interface for exchanging service requests and related information between TT&C networks and their spaceflight mission users. These standards apply to the management of not only SLE services but also traditional TT&C services. CCSDS is developing these specifications with Fall 2004 as the target for ratification as CCSDS Recommendations.

ACKNOWLEDGEMENTS

The author would like to thank the following for information on the service management prototypes reported on in this paper: Hugh Kelliher of Space ConneXions Limited (BNSC/QinetiQ SLE-SM Prototype), Erik Barkley of NASA JPL (NASA JPL SLE-SM Prototype), and Andy Schreckenghost of Lockheed Martin (NASA CSOC SLE Management Service Request Prototype). Funding for the author's participation in the CCSDS Service Management Working Group has been provided by the NASA Goddard Space Flight Center Data Standards Program Office. The author's participation in the AFSCN Service Management Prototype has been funded through the SCNC.

REFERENCES

Bray, Tim, et al. *Extensible Markup Language (XML) 1.0 (Second edition)*. W3C, 6 October 2000. See http://www.w3.org/TR/REC-xml.

Brosi, Fred, "CCSDS Space Link Extension (SLE) Services Overview and Status", International Telemetering Conference Proceedings, paper number 078, International Telemetering Conference, Las Vegas, NV, October 2003.

CCSDSa, Cross Support Reference Model, Part 1: Space Link Extension Services, Recommendation for Space Data System Standards, CCSDS 910.4-B-1, CCSDS, Washington, DC: May 1996.

CCSDSb, Space Link Extension – Forward CLTU Service Specification, Recommendation for Space Data System Standards, CCSDS 912.1-B-1, Washington, DC: CCSDS, April 2002.

CCSDSc, Space Link Extension – Return All Frames Service Specification, Recommendation for Space Data System Standards, CCSDS 911.1-B-1, Washington, DC: CCSDS, April 2002.

CCSDSd, Space Link Extension – Return Channel Frames Service Specification, Draft Recommendation for Space Data System Standards, CCSDS 911.2-R-2, Washington, DC: CCSDS, September 2002.

CCSDSe, Space Link Extension - Service Management - Service Request - Service Specification, Recommendation for Space Data System Standards, CCSDS 910.11, CCSDS (working group draft).

CCSDSf, Space Link Extension - Service Management - Service Request – XML Schema Specification, Recommendation for Space Data System Standards, CCSDS 910.15, CCSDS (working group draft).

CCSDSg, Orbit Data Messages, Draft Recommendation for Space Data System Standards, CCSDS 502.0-R-2, Washington, DC: CCSDS, June 2002.

Sunshine, Carl and Lance Williams, "Achieving Data Transfer and Service Management Interoperability in Satellite Control Networks", International Telemetering Conference Proceedings, paper number 087, International Telemetering Conference, Las Vegas, NV, October 2003.