An Interface Specification for Requesting Space Link Extension Services from NASA TT&C Networks

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Abstract

The Consultative Committee for Space Data Systems (CCSDS) has produced Recommendations (specifications) for several Space Link Extension (SLE) transfer services for the standardized, interoperable exchange of spacecraft telemetry and command data between a spaceflight mission's ground facilities and the tracking, telemetry, and command (TT&C) networks that are used to communicate with the mission's spacecraft. The European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) Deep Space Network (DSN) have implemented these SLE transfer services. Other space agencies are prototyping SLE services, several spaceflight missions have already adopted SLE, and JPL has adopted 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.

The type, number, and operational characteristics of the SLE services can vary from mission to mission, resulting in the need for management interaction between the mission and the supporting TT&C network. This management interaction nominally includes:

- Pre-flight agreement(s) between the mission and the TT&C network that specify the limits on types, numbers, and operational characteristics of the SLE services to be provided over the mission lifetime
- Requests for service on a per-pass basis. Such requests may contain values for SLE service parameters if those parameters have not been fixed for the lifetime of the mission in the pre-flight agreements
- Requests to modify the values of certain SLE service parameters during the pass
- Transfers of SLE service status information
- Responses to the various requests (e.g., confirmation of the original request, return of requested information, etc.)
- Notifications (e.g., change in status of ability to support service)

As a companion activity to the specification of the SLE transfer services, CCSDS has developed a detailed framework for a management interface through which a mission may request SLE services and modify and monitor their execution. This CCSDS SLE service management (SM) framework is abstract and not intended to be implemented directly. Rather, it is intended to be mapped into one more concrete specifications based on specific (management) information interchange technologies.

NASA has begun to apply and adapt the CCSDS SLE service management framework to a concrete specification written in the eXtensible Markup Language (XML). XML is emerging as the premier standard for automated information exchange, and its use in this specification will enable the automation of service request exchanges using XML-based tools and technology. The objective of this activity is to produce a specification that addresses not only the specific needs of NASA's DSN, GN, and SN, but also

(through coordination in CCSDS) the SLE service management cross-support needs of the international space community. A key component of this activity is a prototyping effort to test and demonstrate the specification's functionality, usability, and adaptability to NASA's TT&C networks. The goal is to have the specification available for implementation in the SN, GN, and DSN by autumn of 2003.

This paper provides an overview of the NASA XML-based SLE service management interface: the SLE SM service request requirements and operational concepts, the lifecycle of the relationship between the spaceflight mission and the SLE service provider, the benefits of using XML for the SLE SM service request messages, the contents of the SLE SM service request messages, progress to date, and future plans.

Background

In 1991, CCSDS began an 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) [reference 1]) identifies two major service components: SLE *transfer services* and the SLE *management service*.

SLE transfer services move CCSDS-standard space link data units (e.g., packet telemetry frames, command link transmission units) between SLE service providers (typically, TT&C stations) and SLE service users (e.g., ground-based mission and payload control systems). Of the sixteen SLE transfer services identified by the CSRM, three have been developed into CCSDS Recommendations and implemented by CCSDS member agencies: the Forward Command Link Transmission Unit (CLTU) service [reference 2], the Return All Frames (RAF) service [reference 3], and the Return Channel Frames service [reference 4]. Figure 1 illustrates a typical SLE use configuration, with a ground station providing CLTU and RCF services to the mission operations center, and RAF service to a return link processing facility that processes data for the mission. Also illustrated is the service management interface between the mission control center and the ground station, which is the topic of this paper.

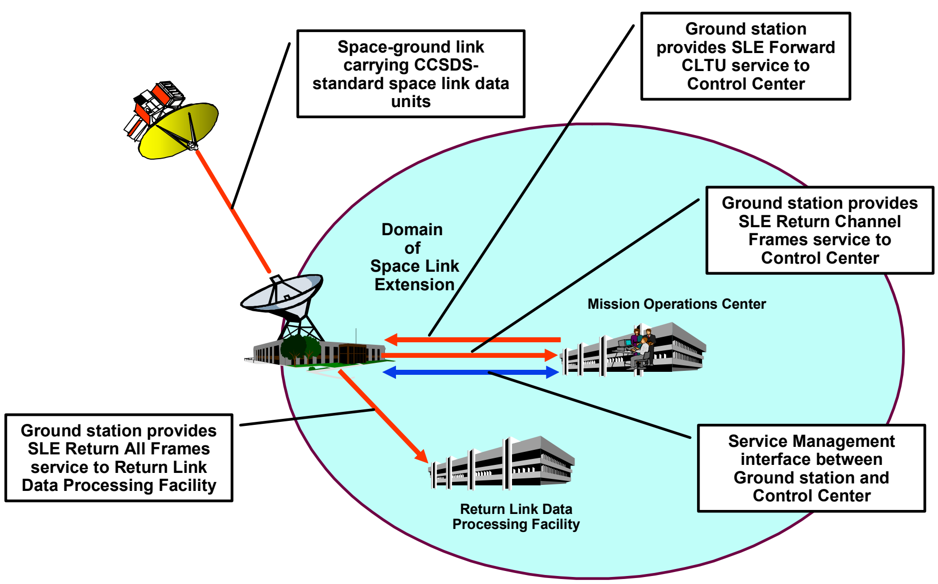

Figure 1. Typical SLE Use Configuration

JPL has already standardized on these three transfer services for all new missions supported by the DSN for the foreseeable future, and NASA is in the process of evaluating these three transfer services as the baseline set to be supported by the NASA SN and GN. More information on the overall SLE concept and the SLE transfer services in particular can be found in [references 1 - 6].

SLE service management provides an interface through which a spaceflight mission operations center can request, monitor, and (in some cases) control the execution of services received from an SLE service provider. CCSDS has been developing an SLE Service Management Specification (SLE-SM) [reference 7] and ancillary specifications that define the standard capabilities that a service provider may providefor SLE service scheduling, and monitoring and control of service execution.

The CCSDS SLE-SM encompasses all aspects of the CSRM. As such, it specifies the management information to be exchanged for *all* of the SLE transfer services identified in the CSRM. Full compliance with the CSRM also means that it supports the concept of *staging*, in which the handling of space link data may be distributed across multiple SLE service providers (e.g., a ground station delivers CCSDS transfer frames to an institutional data processing center via the SLE RAF service, which demultiplexes the contained CCSDS packets and delivers them to the user via the SLE Return Space Packet [reference 1] service). An ancillary specification defines the management information to be exchanged for scheduling, monitoring, and controlling the radio frequency (RF) and modulation services, within the framework and interfaces of SLE-SM.

The SLE-SM (the second international draft of which has recently completed review) and its ancillary specifications define object-oriented, implementation-independent management information and operations using the International Organization for Standardization's *Guidelines for the Definition of Managed Objects* (GDMO) [reference 8] and the Object Management Group's Interface Definition Language (IDL) [reference 9] standards. Various prototype implementations of subsets of the SLE-SM have been produced over the years, the most recent being the Java remote method invocation (RMI)-based implementation produced under British National Space Centre funding [reference 10].

SLE Service Request Framework

In reviewing the current SLE-SM draft for suitability to the DSN, SN, and GN, NASA determined that a subset of the features and scope of the SLE-SM, along with some enhancements to support specific DSN, SN, and GN needs, meet NASA's requirements for the foreseeable future. Furthermore, a more focused version of the SLE-SM would not only serve NASA's needs, but the needs of many (possibly most) prospective SLE service providers, at least in the near term. Under the auspices of CCSDS, NASA has begun to develop a version of the SLE-SM that focuses on this set of management capabilities. NASA has dubbed this focused version as the SLE *Service Request* (SLE-SR) specification.[1] The SLE-SR specification provides the capabilities of the SLE-SM specification for the three supported transfer services, and draws heavily from that broader-scoped document.[2]

The process adopted for developing the SLE-SR specification involves clarifying the requirements and operational concepts that bound the capabilities to be provided by the specification, the development of the SLE-SR specification, and a program of prototyping to validate the specification and discover additional requirements.

SLE Service Request Requirements and Operational Concepts

This section summarizes some of the key requirements and operational concepts for the SLE-SR framework. The CCSDS SLE Service Request Operations Concept White Book [reference 11] contains a more complete description.

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[1] In CCSDS it is sometimes referred to as the SLE-SM *Lite* specification. In this paper, the Service Request terminology is used.

[2] CCSDS has affirmed the intention to include in the SLE-SM Specification those Service Request capabilities that are not supported by the current version of the draft standard, such that the Service Request Specification will eventually be a proper subset of the SLE-SM Specification.

Like the CCSDS SLE-SM, the domain of SLE-SR encompasses the configuration of RF and modulation services, the standard CCSDS protocol processing performed by the SLE service provider, and the provision of the CCSDS-standard SLE services. However, the initial version of the SLE-SR specification addresses only the management of the SLE CLTU, RAF, and RCF services. Although the scope of SLE-SR does not explicitly address the other SLE services named in the CSRM nor specific non-SLE services (e.g., legacy delivery of undelimited bitstreams, or possibly future Internet Protocol (IP) routing/gatewaying functions supporting IP access to the spacecraft), the SLE-SR framework is intended to be extensible to support the addition of such services.

The SLE-SR service is intended to apply to all TT&C networks that provide SLE transfer services. For the service to achieve such universal applicability, the interface represented by the SLE-SR specification must be confined to the exchange of service-oriented information; that is, from a management perspective, the service provider system appears as a "black box" to the user. This "black box" perspective is aided by the fact that the current scope of the SLE-SR concept ignores the notion of staging. That is, all SLE services are assumed to be provided by TT&C networks, and not distributed serially across multiple SLE service providers.

While the goal is to make the SLE–SR service universally applicable, it is recognized that different TT&C networks have today and will continue to have different capabilities, and the Service Request framework must accommodate the management of those different capabilities. To accommodate such variability, the SLE Service Request information is modular in structure, with modules defined such that they can be included, excluded, or substituted depending on the service being provided. While the goal is to define the smallest number of such modules possible and encourage as much commonality as is practical and realistic, the modular structure of management information avoids forcing TT&C networks and service users to interact through a "one size (sort of) fits all" interface.

Another key concept is the minimization of exchange of management information between the mission control center and the service provider, which results in the use of a reference framework. For most spaceflight missions, much of the management information associated with the SLE and TT&C services provided to a given mission is fixed for the life of the spacecraft, either in a single configuration or a small number of pre-defined configurations. The service request information architecture exploits this fact by including commonly-used service configuration sets or profiles of SLE and TT&C service parameters and values for the mission, which is information shared by the mission control center and the service provider. The mission operations center can create service requests by reference to the identifiers of those configuration sets, rather than submitting all of the parameter values contained in those sets. The reference framework also supports the creation and sharing of pre-planned sequences of events, which are essentially scripts that specify relative or absolute time-based sequences of service parameter changes (e.g., data rate) to be executed by the service provider without real-time interaction with the mission control center. Other capabilities for minimization of management information exchanged can be found in [reference 11].

Spaceflight Mission – SLE Service Provider Transaction Timeline

The SLE service request model is structured in terms of transactions between a spaceflight mission and an SLE service provider. Different transactions occur at different times during the lifecycle of the relationship between the spaceflight mission and the service provider.

Today in TT&C networks, the transactions in the early stages of this lifecycle occur between network and mission administrators, and are documented in plain language. If any automation exists today, it occurs primarily in the transactions associated with requesting particular individual service support periods referred to as *space link sessions* (also known as contacts, passes, tracks, or TDRSS events), and exchanging service performance data and (in some cases) service reconfiguration requests during the execution of the space link session. However, the level of this automation varies from network to network, and the nature of the management interface is essentially unique to each network. The SLE Service Request operational concept anticipates increasing automation across the lifecycle of the relationship between a spaceflight mission and an SLE service provider (this lifecycle is summarized later in this paper). However, initially the emphasis is on standardizing the process for submitting and confirming service requests for individual space link sessions.

Figure 2 illustrates the classes of transactions against a timeline related to the provision of service during a single service package (where T0 is the start of the service package, and T1 is the end of the service package). A *service package* identifies all of the RF, modulation, data handling, and SLE transfer services that are to be provided during the specified period. Even though the current emphasis is on the service request-related transactions, it is important to establish broadly the scope and content of the transactions that occur in the other phases of the lifecycle. The transactions in the registration and mission service agreement phases establish the context for the service request transactions, and the transactions during and following the execution of the service packages will depend on the information exchanged in the service requests.

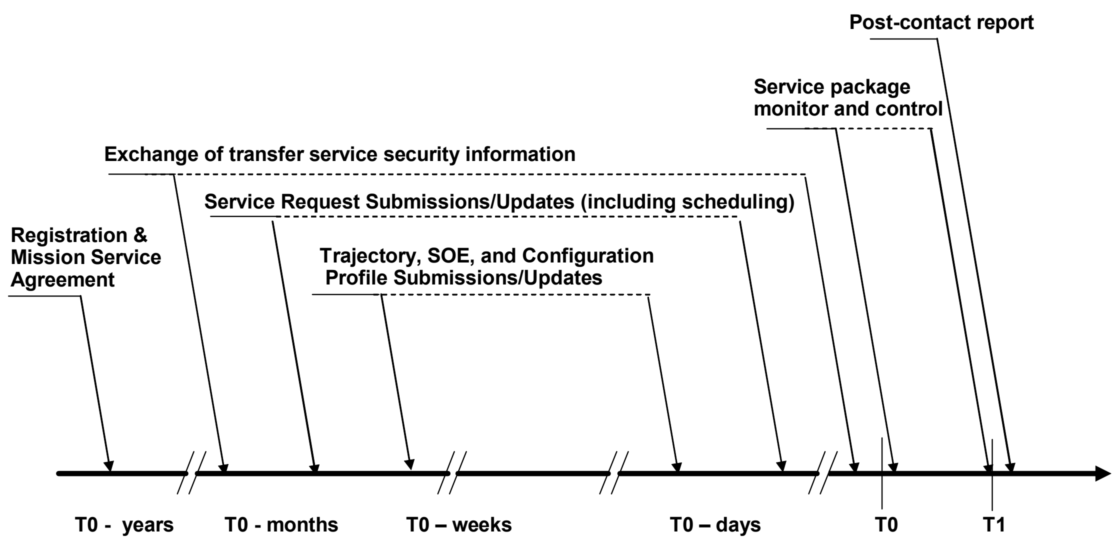

Figure 2. Spaceflight Mission – Service Provider Transaction Timeline

Consistent with the CSRM and the current state of practice, the SLE service request model concentrates the authority and capability for requesting SLE and TT&C services in an SLE service *utilization management* role that is nominally performed by the mission operations center for a spaceflight mission. Similarly, the model concentrates the authority and capability for configuring and controlling the real resources of an SLE service provider in an SLE service *complex management* role that is nominally performed by the network control center for the service provider. This paper refers to the "user" of the SLE-SR service as the mission operations center, and the "provider" of the SLE-SR service as the service provider (with the understanding that the service provider provides both SLE and TT&C services).

A mission operations center must first register with a service provider before any other transactions can occur. The information exchanged in this set of transactions includes security and authentication credentials (including expiration dates and re-authentication criteria), human and machine points of contact, and general bounds and constraints for subsequent mission service agreements. The initial point of contact and establishment of security/authentication credentials is left to the discretion of the agencies involved.

Upon successful registration, a mission operations center can enter into mission service agreements[3]. A mission service agreement is limited in scope to a single mission[4]. The information exchanged in this set of transactions includes the spacecraft communication characteristics, static/default mission profile parameters for the services provided, and bounding constraints for subsequent service requests. Among other purposes, the mission service agreement forms the initial frame of reference for service requests. The registration and mission service agreement transactions typically take place on the order of years before the first space link session.

With a mission service agreement in place, a registered mission operations center can request instances of services from the service provider. A service package comprises the instances that are to be provided during a given service support period. The transactions associated with requesting a service package are referred to as the *service request* transactions. The information exchanged in this set of transactions includes scheduling information, specific service identifiers, service instance parameters that vary from one space link session to the next, temporal sequencing (sequence of events), commitment status, and SLE transfer service binding parameters.

A supporting set of transactions is available to communicate enabling information for the service requests. The information exchanged in this set of transactions includes ephemeris, and configuration profiles which the mission operations center defines and to which both mission operations center and service provider can refer. These configuration profiles form part of the spaceflight mission reference framework.

The model includes a real-time/near-real-time monitoring and limited control capability. This set of transactions occurs during execution of the service package, and includes the exchange of status information, performance statistics, and updated configuration parameters.

In addition to the major set of transactions outlined, transactions for queries and notifications will allow confirmation and verification, and reporting on anomalous events respectively. The query transactions will also play a role for statement of conformance, capabilities offered, etc.

All of the transactions outlined above contain sufficient information for authentication, credentials, and general security concerns. Ancillary transactions are envisioned to update the security information that must be shared between the mission operations center and the service provider.

Use of the eXtensible Markup Language (XML)

As mentioned earlier, the formal CCSDS SLE-SM specification uses ISO GDMO and OMG IDL. When the SLE-SM initiative was started, ISO GDMO was being touted not only as an abstract, object-oriented management information specification language, but as an implementation-ready specification language that would be readily compilable and executable by any number of management middleware suites. The SLE-SM specification would be most directly implemented using the ISO Common Management Information Protocol (CMIP), which uses GDMO as its native specification language. Unfortunately, CMIP and GDMO did not attain the envisioned broad acceptance, and instead became niche players in telecommunications circuit management. COTS CMIP-based management systems are available but expensive, and expertise in CMIP and GDMO is relatively rare. Now GDMO's main usefulness outside of its niche is as an abstract management information specification language. A real implementation of a GDMO-based specification (such as the CCSDS SLE-SM specification) usually requires that the GDMO be first translated into a format suitable for exchange between systems executing real management middleware (e.g., IDL or Java RMI). CCSDS, recognizing the abstract nature of GDMO, has always planned to create one or more "concrete" SLE-SM specifications derived from the GDMO-based SLE-

[3] In terms of practical implementation, a sharp distinction between registration and mission service agreement transactions may not be necessary.
[4] However, a single mission may comprise a cluster or array of spacecraft.

SM specification. These so-called "mapping" specifications are to define how the SLE-SM management information is to be represented for use with a given management software technology.

The SLE-SR specification can be viewed as one such mapping specification, in that it specifies the management information within its scope using an interface language that can be readily generated and interpreted by available software solutions. Thus NASA selected the World Wide Web Consortium's (W3C) XML [reference 12] as the specification language for the SLE-SR specification. Intended for the creation of information interchange languages tailored to specific domains, XML is currently the premier language for information interchange, with new applications rising continuously. It supports loose coupling between systems, which is appropriate to the service-information-only, black-box approach that SLE service management in general and SLE-SR in particular support. It can be used with legacy systems, which is particularly attractive when attempting to combine management of existing TT&C RF and modulation resources with "new" SLE services.

Openness of specifications is always a valued attribute to standards-making bodies such as CCSDS, because it minimizes the chance that a small group can monopolize a specification once it has been adopted as a standard. XML is platform- and vendor-independent, with the core standards readily available though W3C.

XML's success has a positive feedback effect. The more popular it has become, the more development tools have become available, and the more aggressive for-profit concerns have become in developing XML technology. Both of these effects have in turn increased the popularity of XML even further. The growing availability of tools and commercial off-the-shelf (COTS) products provides the space communication community with growing opportunity to leverage these developments for SLE service management.

Prototype Example of SLE Service Request Message

As of the writing of this paper (July 2002), the SLE-SR specification is in the early stages of development. As such, the XML messages that have been defined should be viewed as draft or prototype messages. Figure 3 illustrates the top-level structure of the current SLE Service Request message prototype. In this simplified illustration, only the element identifiers are shown, not the data content of the message. The first group of elements identifies: the message as pertaining to SLE service management; the particular format (schema revision) that this part of the message follows; and the submitting agency, with appropriate credentials for authentication.

The second group of elements serves as the "header" for one transaction (a service request message may contain multiple transactions). This header identifies the particular format (schema revision) of the transaction header, and provides a transaction tracking identifier that allows both parties to correlate subsequent message references to this transaction.

The third group of elements identifies the transaction as a service request, the particular format of the service request, and the mission service agreement under which this service request is being submitted. The service request-specific portion of the transaction message also contains:

- A unique identifier for the service request, to be used in subsequent references to the service request
- The type of operation to be performed (e.g., add, modify, delete)
- The reference to the previously-sent ephemeris file that is to be used to support this requested service package
- The reference to the sequence of events definition to be used (optional)

- The set of SLE services instances that are to be provided as part of the service package, each of which contains a start and stop time and references to appropriate sets of service-related parameter definitions.

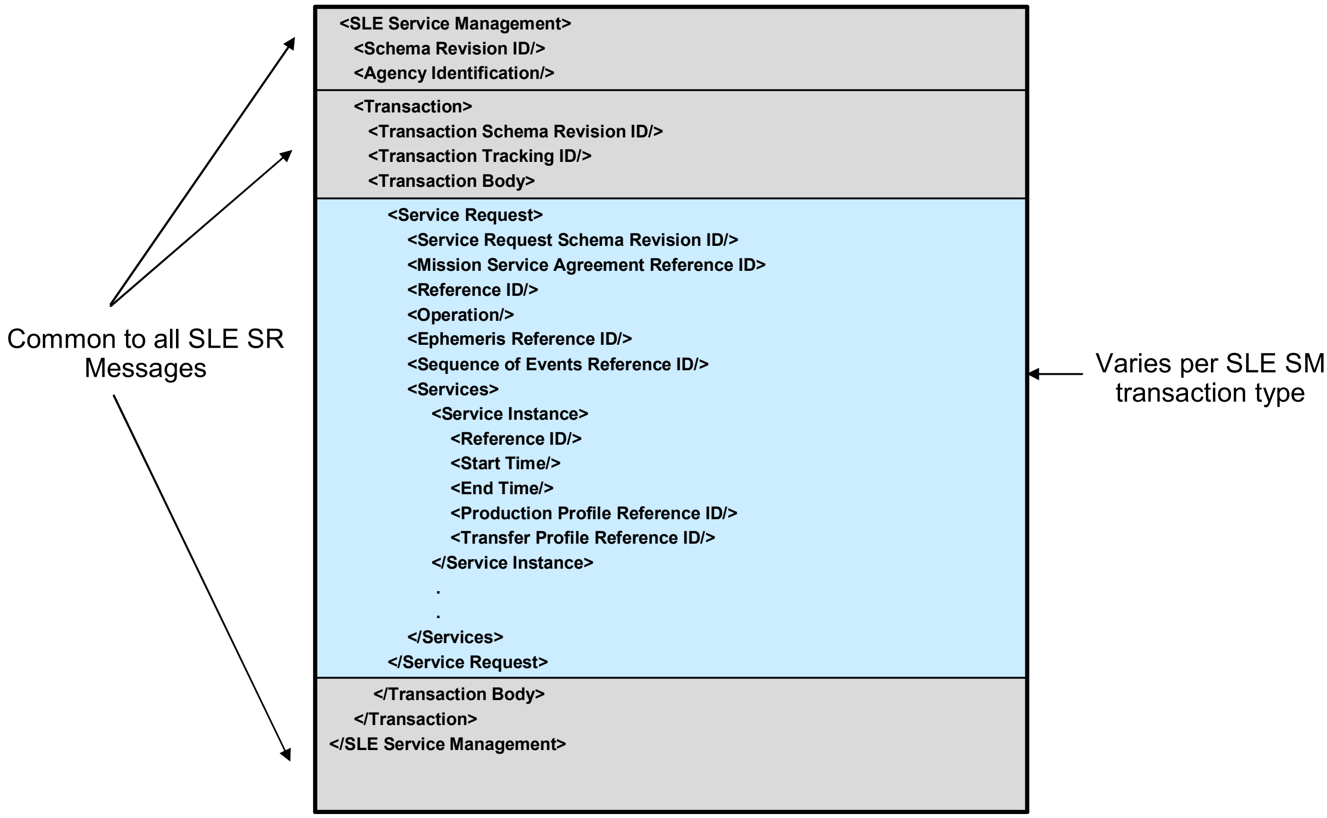

Figure 3. Prototype SLE Service Request Message

The service request transaction message conforms to the XML *content model* for SLE service management messages being defined as part of the SLE-SR specification. The content model defines the allowable content, sequencing, and repetition of schema elements in an XML file. Figure 4 illustrates the top-level content model for SLE service management transactions as defined in the SLE-SR specification. Figure 4 also identifies the particular set of schema elements that combine to form the service request message shown in figure 3. In content model illustration, all SLE service management messages contain the SLE Service Management root element, followed by the sequence of an SLE SM Schema Revision ID element, an Agency Identification, Credentials, and Authorization element, and one or more SLE SM Transaction elements. Each SLE SM Transaction element contains a sequence of an SLE SM Transaction Schema Revision ID element, an SLE Transaction Tracking ID element, and an SLE SM Transaction Body element. The content of SLE SM Transaction Body element varies according to the class of the transaction, with the allowable options represented by *substitution groups*, each with its defined *substitution head element*. The transaction being illustrated is a service request as sent from the mission operations center to the service provider, so the SLE SM Request substitution head element is used (indicating that is a request from the user to the provider). The SLE SM Request class itself has a number of subclasses, each represented by a substitution group. In this case, one or more SLE SM Service Request substitution group can be present. Although not illustrated in figure 4, the fully-developed content model goes on to define the content of the SLE SM Service Request substitution group and other substitution groups.

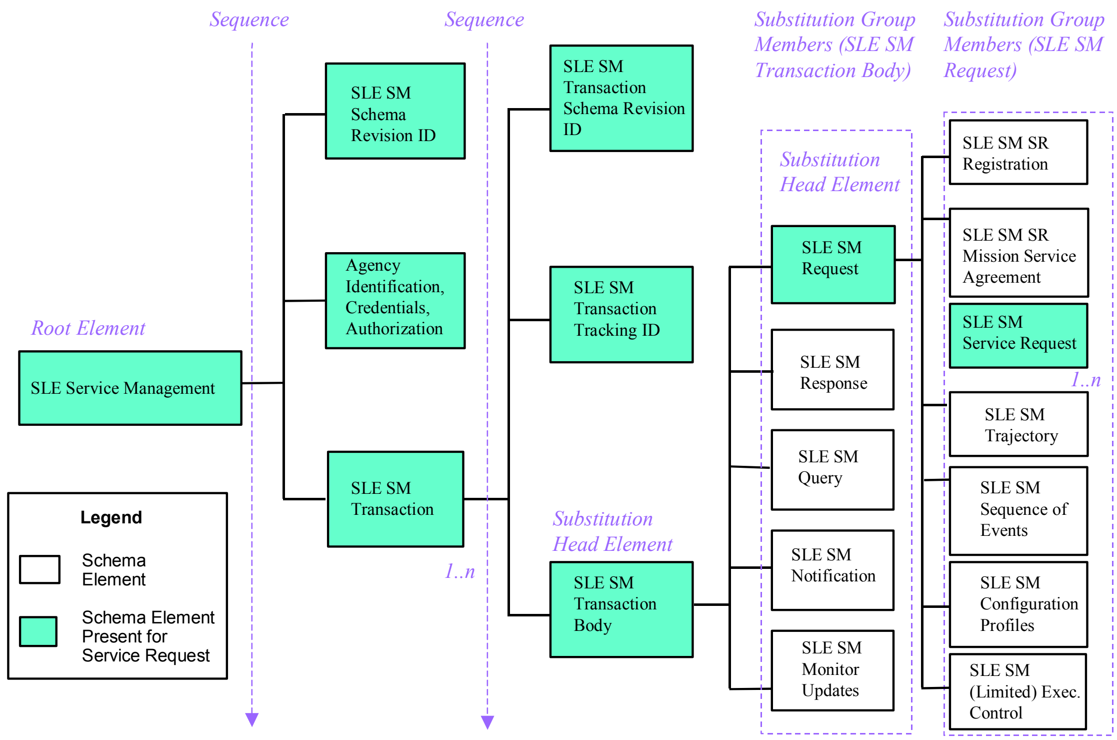

Figure 4. XML Content Model for SLE Service Management Messages

Progress to Date and Future Plans

The CCSDS SLE Service Request initiative began in April 2002 as an ambitious fast-track activity, leveraging the existing SLE Service Management specifications and knowledge base, and known capabilities, constraints, and plans for the NASA TT&C networks. As of the writing of this paper (July 2002), the draft CCSDS Report *Space Link Extension – Service Request Operations Concept* [reference 11] is under CCSDS working group review, with an update to be issued at the October 2002 CCSDS Panel 3 Workshop.

The CCSDS Recommendation *SLE Service Request Specification* is currently under draft development. The October 2002 draft (White Book) version will address the content model and schema for the SLE Service Request transaction class. The target is to have a stable, implementable version of the Service Request class of transaction schemas defined by autumn of 2003.

The DSN will be providing SLE transfer services to the Japanese Institute of Space and Astronautical Science (ISAS) Muses-C (November - December 2002 launch) mission, which will also be a pathfinder user of the SLE Service Request interface. To that end, a DSN and ISAS have begun a prototyping effort to implement key elements of the SLE Service Request specification. JPL is also currently evaluating other JPL missions to select a second user for the Service Request interface. The SLE Service Request Specification Recommendation will reflect the results of the prototyping activity. Over time, JPL plans to evolve the prototype into a fully-functional Service Request interface.

The Goddard Spaceflight Center (GSFC)-operated GN is slated for a management system upgrade in the next few years, and the SLE service request interface is a candidate for that upgrade. Sufficient progress and applicability of the service request specification must be demonstrated in 2003, however, before NASA will commit to it as the solution. NASA has recently begun to build an SLE Testbed for the use of

SLE services by the GN and the SN. While the initial emphasis of the Testbed is on SLE transfer services, the scope is expected to expand in FY2003 to include prototyping of Service Request transactions for the management of GN and SN services.

Over the longer term (2 – 5 years), the other service management transaction classes will be addressed and standard specifications developed. A likely candidate for early follow-on development is the specification of the transactions and schemas for real-time/near-real-time service package monitoring and (limited) control. The SN management interface currently supports equivalent transactions.

JPL has expressed interest in further automating the processes for registering spaceflight missions with service providers and for developing service agreements between missions and providers. Developments in these areas would be accompanied by rigorous specification of the associated transactions.

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