CCSDS SPACE LINK EXTENSION
PROPOSAL FOR A NASA WIDE GROUND DATA SERVICE STANDARD
Nascom Block Phase Out Working Group

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ABSTRACT

Today, the primary National Aeronautical Space Administration (NASA) ground data communications (Nascom) architecture is based on Nascom Internet Protocol (IP) transition data format and protocol. The Nascom IP transition protocol distributes data encapsulated in the legacy Nascom block data structure using an IP infrastructure and the User Datagram Protocol (UDP-Multicast). Nascom block is a NASA unique fixed length data format which is an artifact of the days when data communications consisted of point-to-point communications interfaces. Over the past two decades, many new mission programs have elected to utilize other reliable data protocols and data structures. The result is that mission operation user facilities must have unique hardware and/or software implementations for each different ground data service they need to use. This is a costly trend for programs needing to utilize NASA ground data service facilities.

NASA and the CSOC formed a multi NASA center study working group to investigate the phasing out of NASA ground communications services based on Nascom blocks and to propose a new data services for NASA ground facilities and commercial ground facilities. A major goal is to have a standardized data service used by all NASA ground data facilities to facilitate interoperability between NASA facilities and international customers. The Nascom block phase out working group evaluated the key requirements anticipated for future mission, and also evaluated selected data protocols and standards currently in use today. The working group concluded that Consultative Committee for Space Data Systems (CCSDS) Space Link Extension (SLE) transfer services has become the predominant internationally accepted standard for interoperability between ground data service and mission user facilities. Based on this investigation, the Nascom Block Phase out working group agreed to propose a NASA wide data standard based on CCSDS SLE services for the ground data communications requirements as the first step toward phasing out Nascom Blocks. This paper presents the conclusions and recommendations of the Nascom Block Phase Out working group. This paper also presents a proposed NASA wide ground data service architecture model and requirements based on CCSDS SLE Services being implemented by the European Space Agency (ESA) and NASA Jet Propulsion Laboratory (JPL) Deep Space Network (DSN) for the ESA INTErnational Gamma Ray Astrophysics Laboratory (INTEGRAL) mission. The proposed NASA standard includes optional considerations to facilitate initial installations at NASA Space Network (SN) and Ground Network (GN) facilities.

1. BACKGROUND

The primary NASA ground data communications used today between a typical NASA ground tracking site and the ground data user is the Nascom IP transition protocol. The Nascom IP

Protocol effectively tunnels NASA legacy Nascom block data formats through the IP Transition protocol. The Nascom block data structure is a NASA unique fixed length 4800 bit or 1200 bit data block which is used to carry spacecraft bit stream data asynchronously or ground data messages such as tracking messages, site status messages, etc. The Nascom block levies no framing structure for the data packed into the data fields of the Nascom block data structure. Thus, the ground tracking site performs no processing on the spacecraft data and packs the data into the Nascom bock asynchronously. NASA ground tracking site for the NASA Space Network (SN), and ground network (GN) utilize specialized equipment such as Nascom Block Programmable Telemetry Processors (PTP), Small Converter Devices (SCD), and enhanced Multiplexer/Demultiplexer (MDM) equipment to support the Nascom IP Transition protocol and the legacy Nascom block data structure. The PTP/SCD devices provide conversion between the legacy Nascom Block protocol and the Nascom IP Transition protocol. The use of the Nascom block PTP/SCD and MDM equipment minimized changes to many legacy user facilities based on Nascom block point-to-point communication protocol. Many spacecraft mission user facilities have modified their ground system to connect directly to the Nascom IP Transition networks so they did not need to utilize the Nascom IP PTP/SCD, but this architecture embedded the custom Nascom block data structure and protocol into the user software systems. Today, the primary ground data service for the NASA SN ground station at the White Sands Complex (WSC) is provided by the Nascom IP enhanced MDM system. The enhanced MDM system is the prime NASA Integrated Service Network (NISN) interface connection for the NASA Johnson Space Center (JSC) Mission Control Center (MCC). As such, the Nascom block data structure is deeply embedded into the NASA communication infrastructure and hinders new low cost missions the capability to move to a more robust COTS communications technology which is readily available today.

Many new mission programs using NASA ground facilities have elected to use other reliable data protocols based on COTS technology or other proprietary data structures. Other data standards, such as the Standard Formatted Data Unit (SFDU) data structure, have been developed and are being used for some NASA missions. Due to the wide ranges of mission requirements, several variations of SFDU data formats are in use today to meet specific mission requirements. Some mission programs elected to develop custom proprietary data structures. JPL Deep Space Network (DSN) also uses unique DSN Data Delivery (DDD) data headers/trailers and protocol communication layer. Figure 1 illustrates several of the major NASA ground communications data structures and protocols in use to day. There are also NASA programs investigating various COTS IP protocols for space links and for ground communication networks. In summary, there are many different proprietary and standard data interfaces between the major ground based systems and user sites in use today. Some new protocols require special equipment to be installed at each ground tracking site and at user sites for each mission specific data communications design. While this fosters new technology development through competition between mission projects, it is costly and does not provide for a common communication interface to the ground network sites which are required for interoperability.

2. NASCOM BLOCK PHASE OUT WORKING GROUP

NASA formed a study team to investigate the phasing out of NASA ground-to-ground telecommunications services based on Nascom blocks and to propose a new replacement data services for all NASA ground facilities and commercial ground facilities. A major goal was to have a standardized data service used by all NASA ground data facilities to facilitate interoperability for NASA user facilities and international customers.

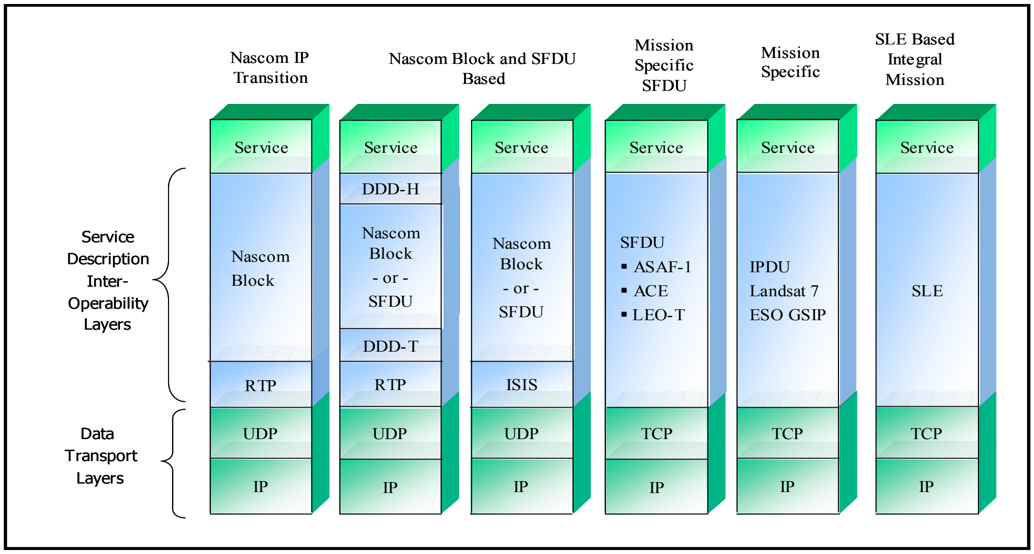

Figure 1. Major NASA Ground Data Structures and Protocols in Use Today

The Nascom Block Phase Out working group defined a set of requirements based on current and future mission requirements. The plan was to use these requirements to identify and define a new NASA wide standard data service to replace data services based on Nascom block data structures and protocols. The Nascom Block Phase-out working group looked at the known major standards and data structures in used today by NASA missions and found that CCSDS SLE was the only protocol in use today which is being pursued as an internationality accepted standard with the potential to meet the interoperability requirement.

The Nascom Block Phase Out working group investigated CCSDS SLE and concluded that SLE benefits included the following:

- First step toward phasing out Nascom block communications
- Common ground data service standard for future science missions
- Cross support (interoperability) among NASA sites and with international agencies
- Builds upon the wide spread adoption of many CCSDS recommendations in use by missions already using CCSDS standards for their space links
- Places no additional requirements on spacecrafts that are already using CCSDS space link protocols
- Offers cost savings potential through the use of common equipment at all ground stations and a standard user interface

The Nascom Block Phase-out working group also found some shortcomings with CCSDS SLE:

- Not intended to support the many NASA legacy data communications data structures and protocols in use to day
- CCSDS SLE is still in the early stages of maturity
- Several challenges have to be overcome for implementing CCSDS SLE at the existing NASA ground network and space network ground tracking stations
- Security considerations related to SLE operations concept needs to be further developed to operate over the NASA networks

The Nascom Block Phase-out working group concluded that CCSDS SLE Services being implemented for the INTEGRAL missions could meet the requirements identified for most future Goddard Space Flight Center (GSFC) science missions and JPL Deep Space Missions (DSN). The working group also concluded that most of the shortcomings will be resolved with further SLE testing and proposed enhancements. The general consensus of the Nascom Block Phase Out working group is to proceed with CCSDS SLE services for ground data communications requirements for future GSFC Science Missions and JPL Deep Space Missions.

3. CCSDS SPACE LINK EXTENSION OVERVIEW

The Consultative Committee for Space Data Systems (CCSDS) is an international standards organization of space agencies cooperating in development of data standards to promote interchange of space related information. The CCSDS cross support panel, made up with international representation, has defined and released a cross support reference model[1]. This model defined a set of recommended services for ground link standards called Space Link Extension (SLE) for inter-agency cross support. SLE services complements existing CCSDS recommendations that apply to space links based on packet telemetry, packet telecommand, and Advanced Orbiting Systems (AOS) recommendations. SLE "extends" the existing CCSDS recommendations for space links to include the exchange of spacecraft data between ground elements. CCSDS SLE has become a widely accepted standard that supports interoperability between mission user facilities and ground station facilities owned and managed by different organizations (space agencies, commercial sites, universities, etc.).

Figure 2 illustrates a high level view of the CCSDS SLE service model as defined in the CCSDS cross support reference model SLE services recommendation[1] and the SLE service specifications. The service model includes data transfer services and management services. Transfer services provide a standard means to transfer spacecraft forward and return data between the ground tracking station (provider site) and the Mission Control Center (user site). SLE management supports the means to allocate and configure resources under management authorities within the SLE complexes (SLE service provider sites). The cross support model describes the management interactions within the SLE Complexes and the SLE utilization management on behalf of the Mission Control Center within the domain of the SLE architecture model.

The CCSDS Cross Support Reference Model Part 1 Space Link Extension Services[1] describes eight return data services and ten forward data services. To date, the CCSDS SLE Panel has defined and released draft service specifications for only the following five of the eighteen data services defined in the Cross Support Reference Model

- Return All Frames (RAF) data service[2]. Provides data service to transfer all return link frames to the user center
- Return Channel Frames (RCF) data service[3]. Provides data service to transfer pre-agreed selected virtual channels to the user center.
- Forward Command Link Transmission Unit (CLTU) data service [4]. Provides forward command service from the user control center to the provider site.
- Forward Space Packet (FSP) Service[5]. Provides service for user control center to send forward telecommand packets to the provider site.
- Telecommand Frame Service[6]. Provides service for user control center to send forward telecommand frames to the provider site.

Other services defined in the SLE Cross Support model include services for CCSDS Advance Orbital Systems (AOS) and bit stream space links, but additional interest is required before these specification are fully developed by the CCSDS SLE panel.

Of these, only the RAF, RCF, and CLTU services are being implement by JPL for the DSN sites and are the services selected by the Nascom Block Phase out working group for the initial proposed NASA wide data service standard. Figure 2 illustrates the RAF, RCF, and CLTU data services within the Provision and User SLE transfer service functions.

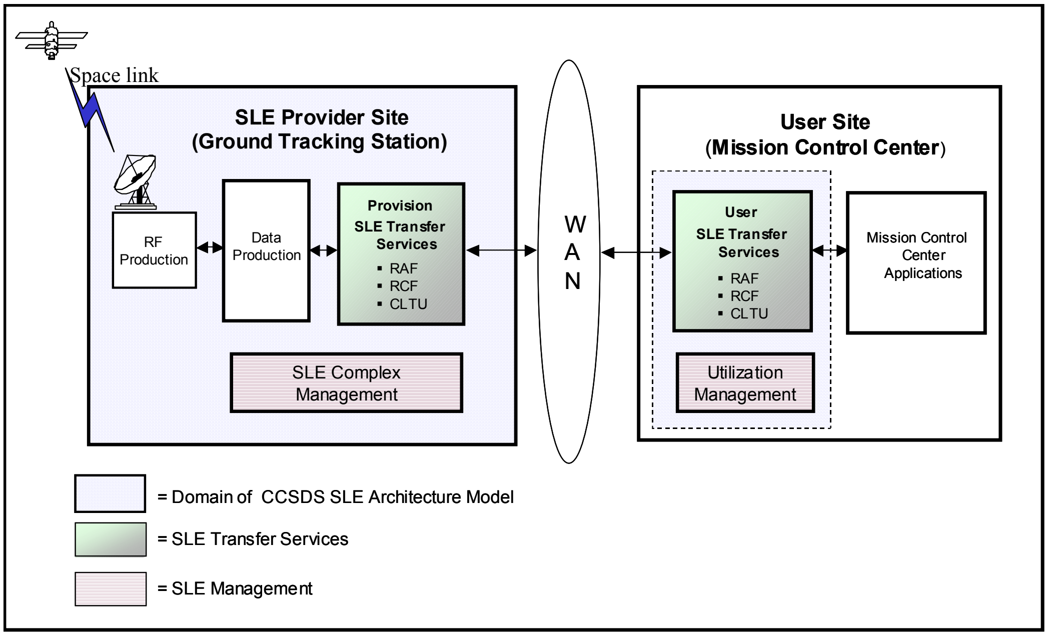

Figure 2. CCSDS SLE Reference Model Elements

The provision service resides at the SLE provider facility (tracking station), and the SLE user service resides at mission control facility. These transfer services operate at the application level at each site and establish a communications relationship between the user and the provision transfer service to set up the ground communications link via the NISN Wide Area Network (WAN). *(Note: It is not the intent of this paper to describe CCSDS SLE operational concept. See reference material for a description of the SLE services.)*

For cross support of the INTEGRAL mission, ESA and NASA/JPL have agreed on the specification and implementation of an Application Program Interface (API) for SLE transfer services between the provider site and the user site. It was initially published as an ESA specification and was presented to the CCSDS SLE panel as a joint ESA and NASA proposal for recommendation. The CCSDS SLE panel has released the following APIs as first draft specifications (white books) for review and intends to release these in the future.

- SLE Core Specification API for Transfer services, Draft Recommendations for Space Data Systems Standards[7]. The purpose of this recommendation is to define a C++ API for CCSDS SLE transfer services which is independent of any other specific technology used for communications between SLE service user and an SLE service provider.
- SLE Core Specification API for Transfer Services, Technology Mapping for Space Data Systems Standards[8]. The purpose of this specification is to define an API proxy using

the Internet protocols TCP (Transmission Control Protocol) and IP (Internet Protocol) for data transfer and the Abstract Syntax Notation One (ASN.1) for data encoding.

- SLE Core Specification API for Return Services[9]. The purpose of this specification is to specify a C++ API for the CCSDS return transfer services.
- SLE Core Specification API for Forward Services[10]. The purpose of this specification is to specify a C++ API for the CCSDS forward CLTU and FSP transfer services.

As illustrated in figures 2 and 3, the return link data production process receives return link telemetry from the RF production function at the provider site. The provider return link data production function includes frame synchronization, de-randomization, error detection and correction, virtual channel sorting per CCSDS packet processing standards. The data production routes framed data with ground receipt time stamp and data quality information to the SLE RAF and RCF return provision service. The return link data production function also includes data capture and playback for line outage recording and playbacks via the SLE RAF and RCF transfer services.

The forward link data production receives the CLTUs from the SLE forward CLTU provision service, and applies the forward service physical link operations procedure (PLOP) to build the command stream to the Radio Frequency (RF) forward production for transmission to the space-link. The PLOP defines the carrier modulation sequences including

- Idle fill between commands
- Leading pattern for each command
- Trailing pattern for each command
- Minimum spacing between commands

The forward data production also performs required buffering and interface required at the tracking site for RF production.

4. SLE IS BEING DEPLOYED TODAY

JPL is deploying SLE services in the Deep Space Network (DSN) to support several upcoming missions including INTEGRAL, MUSES-C, Rosetta, CONTOUR, and others. JPL has successfully deployed an initial delivery of CCSDS SLE RAF, RCF, and CLTU services for the DSN stations. JPL is tentatively planning to phase out legacy telemetry and command services and has a goal to utilize SLE for all new missions in the future. John Hopkins Advanced Physics Laboratory (APL) has also implemented SLE for the "CONTOUR" mission which was recently launched.

ESA currently has deployed CCSDS SLE in their Network control and telemetry routing system and at their simulator system. ESA plans to deploy CCSDS SLE services in the ESA ground station network by 2003. SLE will allow an ESA control center to use NASA DSN Ground Station to compliment the ESA ground stations.

Many other international space agencies are either investigating or deploying CCSDS SLE capability. They include Japan (NASDA and ISAS), British National Space Centre (BNSC), Italy (ASI), and France (CNES). In addition the United States Air Force is also investigating CCSDS SLE for the Air Force Satellite Control Network (ASFCN). The US Air Force is also investigating interoperability options with NASA ground stations based on CCSDS SLE with the possibility of evolving to a common standard.

5. LEGACY MISSION SUPPORT

SLE transfer services are defined for missions using CCSDS conformant Packet Telemetry standards for the return space link, and for missions using CCSDS telecommand standards for the forward space link. However, many legacy missions were built before the CCSDS space-link were defined and implemented. Many legacy mission use time division multiplex (TDM) telemetry, unframed telemetry, and CCSDS AOS space links which are not currently supported by an SLE transfer service. However, the Nascom Block Phase-out team determined that CCSDS SLE services could potentially be configured to support legacy missions with some minor requirement extensions.

SLE transfer services for CCSDS Advanced Orbiting Systems (AOS) are defined in the CCSDS SLE Service Model but have not been developed. However, it was concluded that missions that utilize return links with CCSDS AOS telemetry recommendations (such as Space Station) can utilize SLE transfer service since they have production processes that are compatible with the SLE RAF and RCF transfer services. It was also concluded SLE RAF transfer service could support TDM synchronous telemetry and encrypted stream by providing a data production capability to block TDM frames or block unframed data units into SLE protocol data units (PDUs) format at the provider site. The mission control center user site could use standard SLE RAF transfer service to receive the TDM frames without need for frame synchronization function. For unframed encrypted data, the mission control center user site would be required to have a re-serialize function, and telemetry processing function.

Missions which utilize CCSDS AOS forward service for the space link, require a continuous synchronous bit stream uplink which is not supported by CCSDS SLE CLTU service as currently defined. However, CCSDS SLE CLTU data service does not levy any requirements on the CLTU data structure. The SLE CLTU data service and the provider site forward service production only sends the CLTU data structure to the spacecraft as it was formatted by the SLE user along with the start and stop patterns and fill bits defined by the telecommand PLOP configuration parameters. To support synchronous bit stream service, the mission user could block the bit stream into SLE CLTU data structure. The provider CLTU transfer service can be configured to route the CLTU back-to-back to recreate the serial stream by utilizing a special PLOP configuration setting. The Nascom Phase Out working group concluded that the CCSDS SLE CLTU could potentially support legacy forward bit steams services including CCSDS AOS forward service with minor requirement extensions. While this is not an ideal architecture, it could provide a transition option while there are legacy missions which continue to use these legacy space links.

6. SLE MATURITY

While SLE data transfer services are being implemented by many space agencies, it is far from just a turn key implementation. Draft SLE transfer services specifications have been developed and should be released as CCSDS full approved recommendation (CCSDS Blue Book release) in 2002, but several space agencies are already discussing future changes. The transfer service is expected to continue to evolve for the next few years. Also SLE management standards were released for review, but due to complexity, they are being revised by CCSDS SLE panel to simplify for near future implementations.

The Nascom Block Phase out working group also identified other requirements not yet fully explored by current CCSDS SLE implementations and requirements. These include the following areas:

- SLE has not been tested to support mission with high data rate space links.
- Efficient routing of high rate data to multiple user sites in real time as data is being received by the ground tracking stations (such as multicast protocols)

Some missions require that the same mission data be routed to multiple user sites in real time. The current implementation of SLE requires multiple instances of CCSDS SLE RAF or RCF transfer services (one for each user) to service multiple centers with the same spacecraft data concurrently.

CCSDS SLE COTS products are expected to be available in the near future. Several companies offer SLE products and services, but only under a development contract or as a special order. ESA and JPL SLE APIs have been developed and are available, but each is tailored to the current ESA and JPL unique implementation. Additional software integration for specific site architectures is required.

In summary, the Nascom Block Phase out working group concluded that the SLE transfer service provides a good initial deployment. It was also decided to make SLE management optional for initial SLE implementations at NASA GN and SN sites until after the CCSDS SLE managements requirements become more mature.

7. SLE CHALLENGES FOR NASA SN AND GN INTEGRATION

For interoperability, all ground sites used by NASA missions need to support CCSDS SLE. JPL is currently integrating CCSDS SLE RAF, RCF, and CLTU transport services into the DSN Sites, but major challenge still remains for installation of SLE in the NASA Space Network (SN) and Ground Network (GN). This includes adding SLE capability to commercial ground tracking sites supporting NASA space missions.

The NASA Space Network is composed of two primary ground sites for supporting spacecraft communications via multiple NASA Tracking Data Relay Satellites (TDRS). The SN can support several spacecrafts simultaneously using the TDRSS satellites. The NASA Ground Network consists of several NASA sites and commercial sites for communicating directly with the spacecrafts. All NASA ground tracking sites currently have RF production, data handling, data routing, site scheduling systems, and site configuration and management systems in place and these are well ingrained into NASA data service operations concepts. NASA ground data systems were developed separately and many are uniquely designed. Incorporating all objectives of the SLE model and specifications is expected to be costly. But the use of common SLE equipment at all the ground facilities offers a cost savings opportunity. Plus SLE implementation costs could be offset if implemented as part of the planned equipment obsolesce replacement for existing NISN equipment as described in section 2 of this paper.

Implementing SLE Management will require major change in the way site scheduling and management are done today. Scheduling and management for the NASA SN and for the NASA GN sites are different and very integrated into the existing ground site configuration and management systems. It was concluded that the initial installation would not implement SLE Management and would utilize existing site scheduling and management operations concepts and systems until the SLE management becomes more mature.

The existing ground tracking sites are required to continue to support existing legacy missions with space links which utilize Time Division Multiplexed (TDM) telemetry, unframed telemetry formats, and CCSDS AOS forward data services. Legacy missions could be supported by existing equipment for a transitional period or implemented with SLE capability extensions as discussed in section 5 of this paper.

NASA engineering at GSFC is investigating SLE for SN and GN ground tracking sites.
New low earth orbit and medium earth orbit missions have not yet committed to SLE. SLE is still very new and is currently not supported by existing tracking stations. NASA needs to commit to SLE with the issuance of an NASA wide policy statement. New missions managers need to see commitment and understand the risk through prototyping demonstrations and availability.

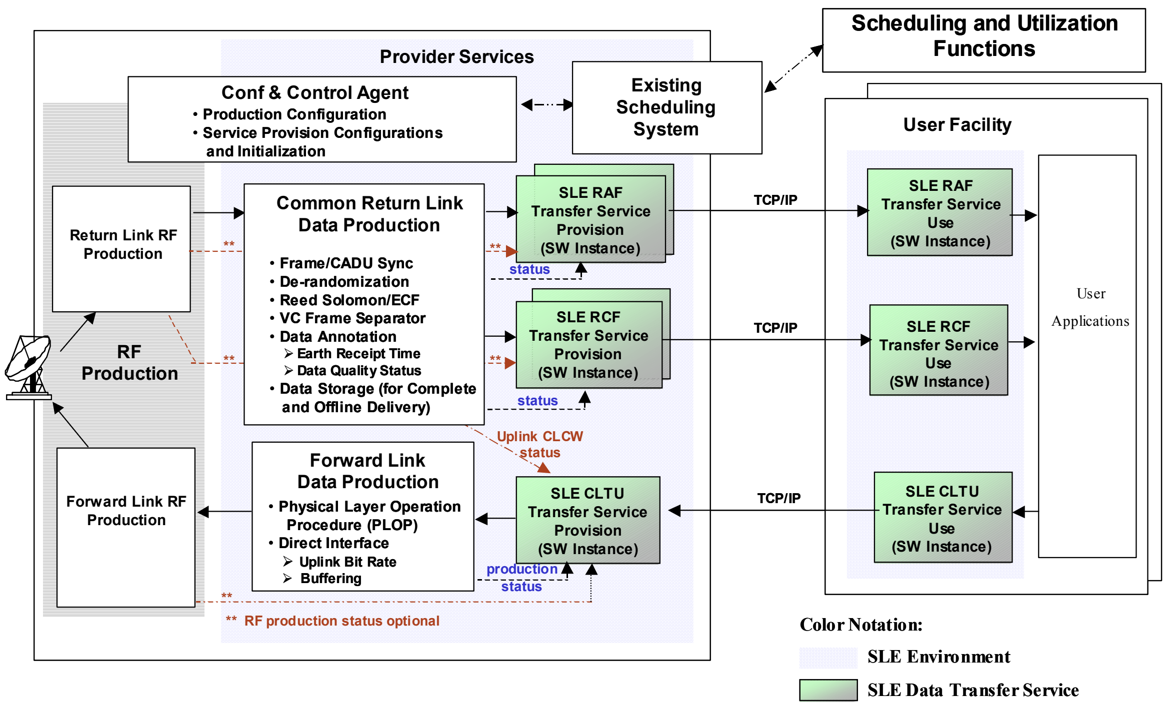

Figure 3, Proposed NASA SLE Service Model – Initial Phase

8. PROPOSED NASA RECOMMENDED STANDARD AND MODEL

Figure 3 illustrates a more detailed view of the SLE Model being proposed for the initial SLE implementation for SN and GN sites. The initial delivery shows use of the existing site scheduling, resource configuration system, and RF systems. It adds CCSDS data production and SLE RAF, RCF, and CLTU transfer services at the ground tracking sites as described in section 3 of this paper. The initial SLE implementation will utilize the SLE APIs developed by ESA and JPL for the INTEGRAL mission and which utilized standard TCP/IP protocol. As SLE management requirements mature and site equipment is replaced, the full SLE model can be deployed.

9. FORWARD PLAN

CSOC is continuing to work the objectives outlined in the Nascom Block Phase-out plan. These include:

- Finalizing and releasing a proposed NASA wide specification based on the CCSDS SLE model described in this paper
- Conduct CCSDS SLE prototyping to evaluate performance and promote and gain NASA wide acceptance for SLE.

CSOC is currently developing a test laboratory project to demonstrate SLE capabilities for SN and GN missions. The objective is to demonstrate and validate CCSDS SLE as described in this paper and to set up the infrastructure to test with NASA control center test facilities and the Air Force Satellite Control Network Space Operations center. The development system is based on an Avtec Systems, Inc. standard telemetry and command process with SLE capability, and on a SLE system developed by Global Science and Technology, Inc. for the Air Force. One of these systems will be installed at a NASA Wallops test facility in 2002, and one is planned to be installed at the NASA SN ground facility in 2003. Plans are on the way to conduct demonstration and validation test with NASA control center facilities and with Air Force Space Operations Center starting in 2003. The goal is to conduct performance and demonstration tests to help promote CCSDS SLE for future missions.

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