NASA/Lockheed Martin-CSOC
Ground Network and Space Network Interoperability Testbed

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1.0 Introduction

Lockheed Martin-CSOC, a prime contractor for NASA ground systems, has been supporting in the development of plans for the evolution of NASA's Ground Network (GN) and Space Network (SN), and where possible, synchronizing those plans with plans for the evolution of the Deep Space Network (DSN). Both organizations want those networks to have certain key attributes. Among the desired attributes are: 1. A common interface for all NASA networks to allow users to reduce development and operations costs by using common standards-based system interfaces; 2. Network interoperability to allow the sharing of resources among space agencies and other government agencies; and 3. Provide a common interface for integrating commercial ground network providers and network users.

A multi-center and multi-contractor study team led by Lockheed Martin-CSOC concluded that the Space Link Extension (SLE) set of Consultative Committee for Space Data Systems (CCSDS) recommendations has the desired attributes. The team recommended that NASA and Lockheed Martin-CSOC set up an interoperability testbed to show how most future NASA missions can use CCSDS SLE and that SLE could meet NASA's interoperability goals.

NASA's involvement with SLE started with its support for the development of SLE as the primary interface for future Deep Space Network missions. The current effort, including the buildup of an SLE interoperability testbed, centers on proving that SLE can also be used for both legacy and future GN and SN science missions. In addition, a proposed testbed effort intends to show that SLE can be applied to ground systems supporting Human Space Flight missions (International Space Station and Space Shuttle).

Inter-agency interoperability plays a major role in the plans for the SLE testbed. NASA has a program for interoperability with the Air Force Satellite Control Network (AFSCN). As part of this program, the SLE testbed set up connectivity between a ground station at NASA's Wallops Flight Facility (WFF), a National Oceanic and Atmospheric Administration (NOAA) ground station, and an AFSCN control center to allow downlinks and uplinks using NASA and DoD test satellites. Integrating commercial network providers using SLE services into the testbed remains a future objective.

The SLE testbed is a proof of concept showcase for new GN and SN science missions and for legacy missions assessing the use of SLE. The scope of testing in the SLE interoperability testbed includes testing CCSDS packet-based SLE Transfer Services on the GN. Encrypted Bitstream and TDM over SLE Transfer services were tested with the GN, NOAA, and the AFSCN.

SLE Management Services Request as defined by the CCSDS Panel 3 Operations Concept White Paper is being prototyped in the SLE testbed. As part of this activity, we plan to submit automated SLE Service Requests to a Wallops Flight Facility test ground station from an AFSCN and a Lockheed Martin-CSOC test operations center. One final product of this testing activity is to support the development of CCSDS SLE recommendations by providing inputs and results on our testing and prototyping activities to the CCSDS Panel 3 SLE standards committee.

1.1 Background

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 a 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. This is a costly trend for programs needing to utilize NASA's ground data service facilities.

NASA and the Lockheed Martin-CSOC formed a multi NASA center work group to investigate the phasing out of NASA ground communications based on NASCOM blocks services on the Ground and Space Network and to propose new data services. The NASCOM block Phase-Out work group evaluated the key requirements for current and future missions, and also evaluated many data protocols and standards currently in use.

The work group concluded that CCSDS SLE transfer services has become the predominant internationally accepted standard for interoperability between ground data services and mission user facilities. Based on this investigation, the NASCOM Block Phase-Out work group agreed to propose a NASA wide data standard based on CCSDS SLE for ground data communications as the first step toward phasing out NASCOM Blocks.

1.2 Current Architecture

The primary NASA ground data communications used 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's 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. The ground tracking site performs no processing on the spacecraft data and packs the data into the NASCOM bock asynchronously. NASA's ground tracking sites for the SN and 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.

The primary ground data service for the NASA SN ground station at the White Sands Complex (WSC) is the NASCOM IP enhanced MDM system. The enhanced MDM system is the prime NASA Integrated Service Network (NISN) interface for connecting with the NASA Johnson Space Center (JSC) Mission Control Center (MCC). The result is that the NASCOM block data structure is deeply embedded into the NASA communication infrastructure and this does not give new low cost missions the capability to move to a more robust COTS communications technology.

Many new missions using NASA ground facilities have elected to use other reliable data protocols based on COTS technology or proprietary data structures. NASA programs are also investigating various COTS IP protocols for space links and for ground communication networks. 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. Figure 1 shows several of the major NASA ground communications data structures and protocols in use today.

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 that special equipment be installed at each ground tracking site and at user sites for each mission specific data communications design. This is a costly trend and does not provide for a common communication interface to network sites.

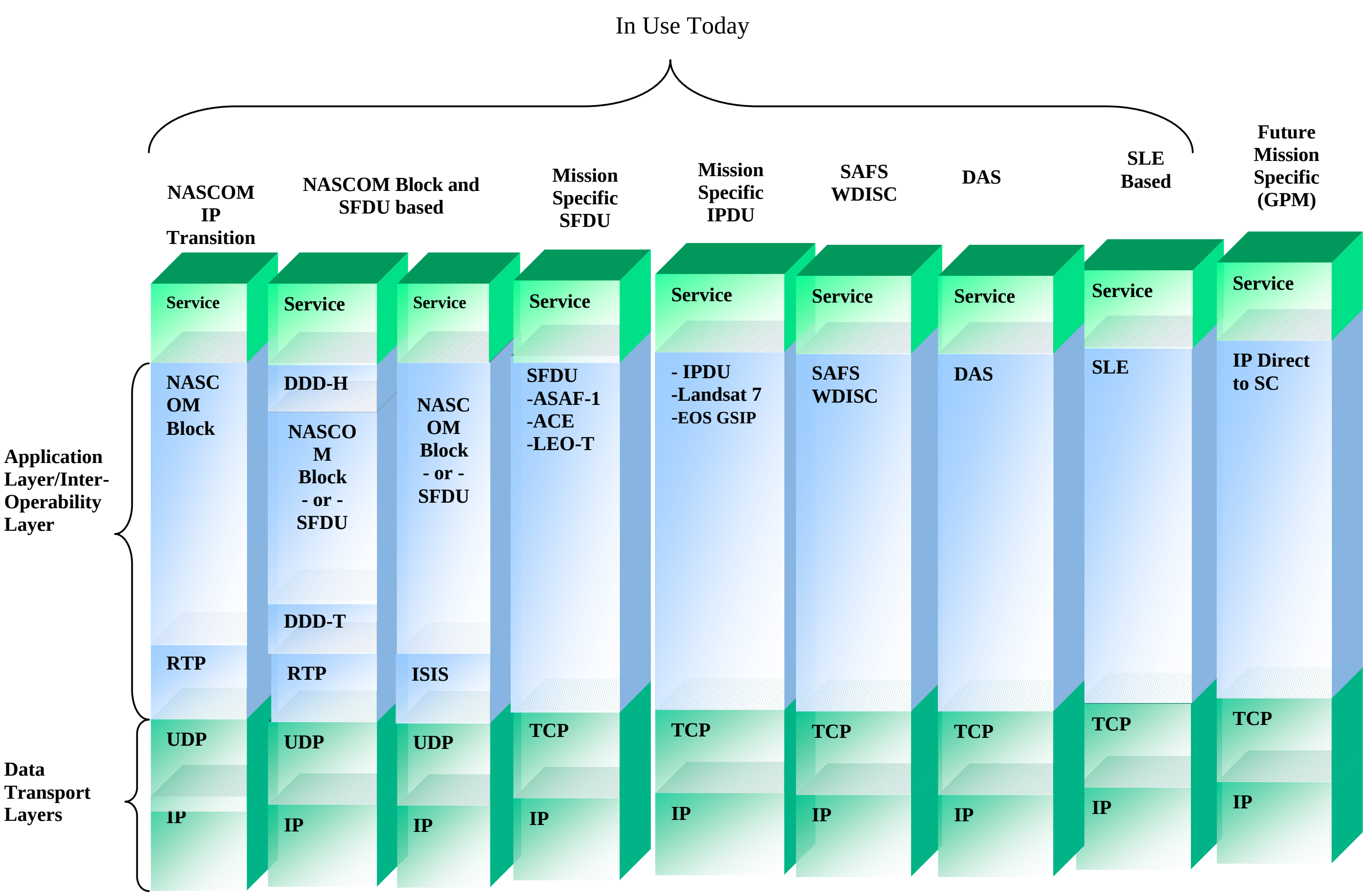

Figure 1. Major NASA Ground Data Structures and Protocols in Use Today

2.0 NASCOM Block Phase-Out Working Group Recommendations

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 data service for all NASA ground facilities and commercial ground facilities. A major goal was to have a standardized data service that can be used by all NASA ground data facilities to facilitate interoperability for NASA user facilities and international customers.

The NASCOM Block Phase-Out work group defined a set of requirements based on current and future missions and identified a new NASA wide standard data service to replace data services based on NASCOM block data structures and protocols. The NASCOM Block Phase-Out work group investigated the known major standards and data structures in use today and found that CCSDS SLE was the only protocol in use that is an internationality accepted standard with the potential to meet the interoperability requirement.

The NASCOM Block Phase-Out work group found the benefits of SLE included the following:

- SLE can be a common ground data service standard for future SN and GN science missions.
- SLE can provide cross-support (interoperability) among NASA sites and with international agencies.
- SLE builds upon the wide spread adoption of many CCSDS recommendations in use by missions already using CCSDS standards for their space links.
- SLE places no additional requirements on spacecrafts that are already using CCSDS space link protocols.
- SLE offers cost savings potential through the use of common equipment at all ground stations and a standard user interface.

The NASCOM Block Phase-Out work group also found some shortcomings with CCSDS SLE. Among them:

- As designed, SLE is not intended to support the NASA legacy data protocols communications data structures and protocols in use to day.
- SLE is still in the early stages of maturity.
- Several challenges have to be overcome for implementing CCSDS SLE at the existing NASA GN and SN tracking sites.
- Security considerations related to SLE need to be further developed to operate over the NASA networks.

The NASCOM Block Phase-Out work group concluded that the CCSDS SLE Services being implemented for the INTEGRAL mission could meet the requirements identified for most future Goddard Space Flight Center (GSFC) SN and GN science missions. The work 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 work group was to proceed with CCSDS SLE services for ground data communications requirements for future GSFC SN and GN Science Missions.

2.1 CCSDS SLE Service Reference Model

Figure 2 shows a high level view of the CCSDS SLE service reference model as defined in the CCSDS cross-support reference model[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 a 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 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.

Of these, only the RAF, RCF, and CLTU services are being implement by JPL for its DSN sites these same services were selected by the NASCOM Block Phase-Out work group for the initial proposed NASA wide data service standard. 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 specifications are fully developed by the CCSDS SLE panel.

Figure 2 shows the RAF, RCF, and CLTU data services within the SLE transfer services Provider and User functions. The provider 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 provider transfer service to set up the ground communications link via a Wide Area Network (WAN).

As shown 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.

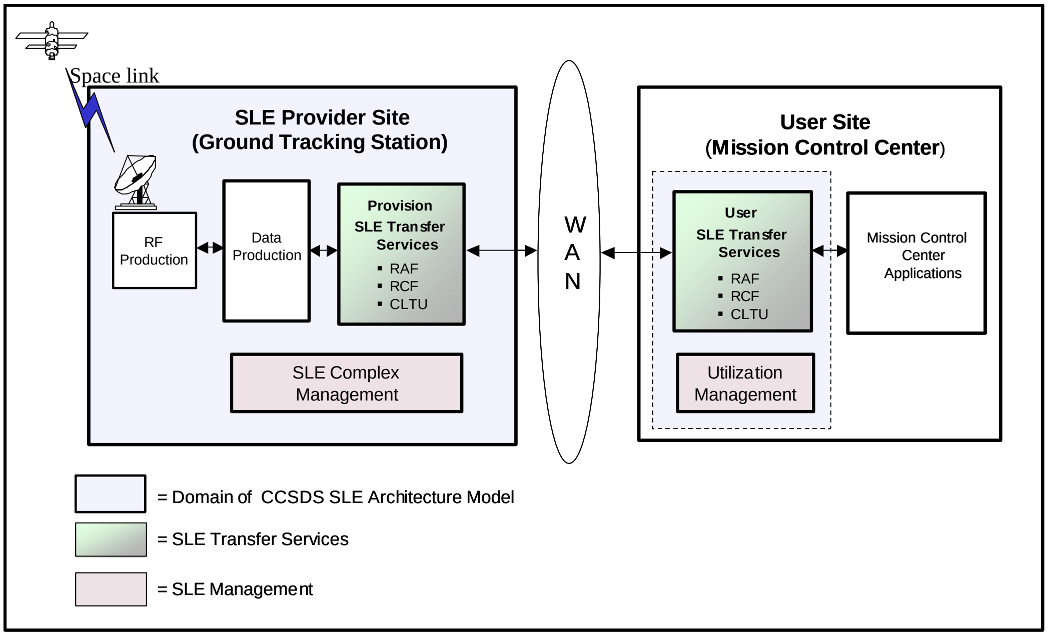

Figure 2. CCSDS SLE Reference Model

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.

2.2 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. The NASCOM

Block Phase-Out work group 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. The NASCOM Block Phase-Out work group 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. Additionally, the work group 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 utilizing CCSDS AOS forward service for the space link require a continuous synchronous bit stream uplink, a service that is not supported by CCSDS SLE CLTU service. 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 Block Phase-Out work 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 not an ideal architecture, it could provide a common hardware and software platform transition option while there are legacy missions which continue to use these legacy space links.

2.3 SLE Maturity

While SLE data transfer services are being implemented by many space agencies, it is far from just a turnkey implementation. Final (Blue Book) SLE transfer services specifications have been developed but several space agencies are already discussing future changes. The transfer service is expected to continue to evolve for the next few years. SLE management standards were released for review and are being revised by CCSDS SLE panel to simplify future implementations.

The NASCOM Block Phase-Out work 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. The group 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.

2.4 Proposed NASA Recommended Standard and Model

All ground sites used by NASA missions need to support CCSDS SLE for interoperability. JPL is currently integrating CCSDS SLE RAF, RCF, and CLTU transport services into its DSN Sites, but major challenges still remain for installation of SLE in the NASA SN and GN. This includes adding SLE capability to commercial ground tracking sites supporting NASA space missions.

The NASA SN 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 GN 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. Also, SLE implementation costs could be offset if implemented as part of the planned equipment obsolesce replacement for existing NASA equipment as described in 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 GN sites are different and very integrated into the existing ground site configuration and management systems. Initial SLE installations will not implement SLE Management and will utilize existing site scheduling and management operations concepts and systems until the SLE management becomes more mature.

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.

Figure 3 illustrates a more detailed view of the SLE Model being proposed for the initial 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 a previous section 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.

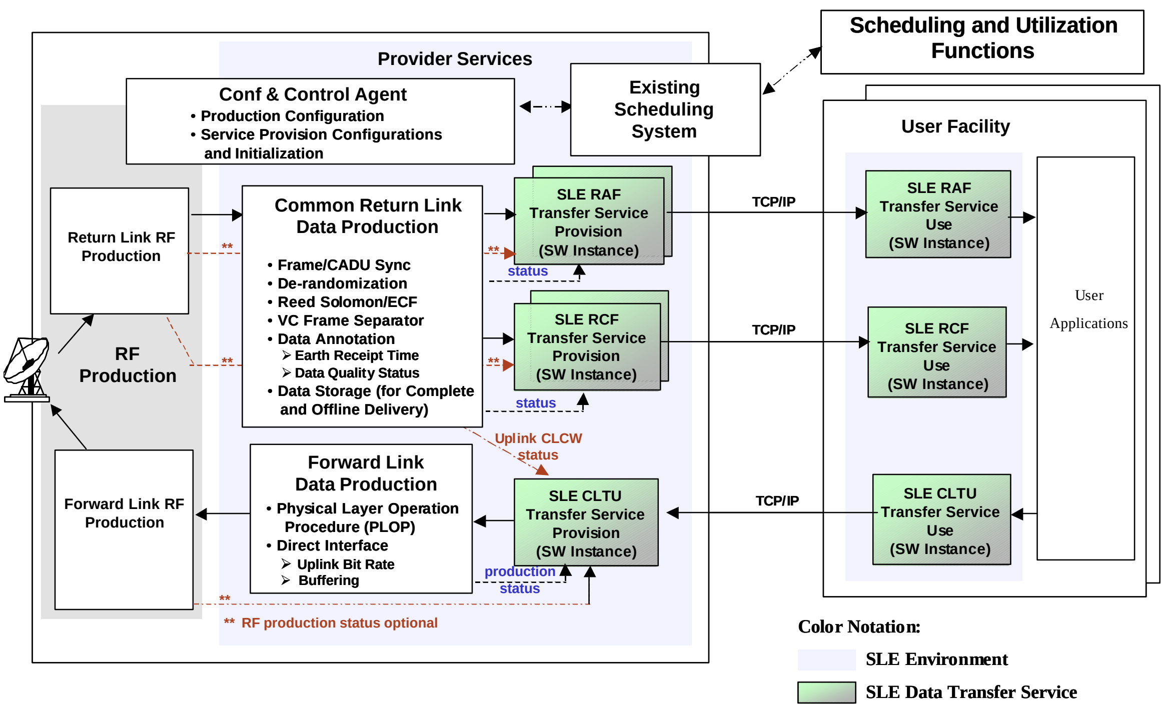

Figure 3. Proposed NASA SLE Service Model – Initial Phase

3.0 Lockheed Martin-CSOC SLE Testbed

This section describes the current status of the Lockheed Martin-CSOC SLE testbed, its architecture and how it interfaces to NASA and AFSCN facilities. Project status and the findings to date will also be described.

SLE has been identified by NASA as a key area of interest, and the agency has been exploring SLE definition and implementation for several years. Although new GSFC low earth orbit and medium earth orbit missions have not committed to SLE, and SLE is not currently supported by GN or SN operational tracking stations, NASA and contractor personnel are testing and investigating the use of SLE on SN and GN ground tracking sites.

Lockheed Martin decided to put to use CSOC's expertise in ground station operations and technical standards implementation and proposed that NASA fund an SLE interoperability testbed to further define and explore the recommendations made by the NASCOM Phase-Out work group for the SN and GN. The SLE testbed project is sponsored by John Rush of NASA HQ, and promotes NASA's use of the SLE protocol within the GN and SN and it helps define the architecture for future interoperable communications and cross support with other national and international agencies and organizations.

Lockheed Martin-CSOC has assumed a major leadership role in the investigation of SLE on the SN and GN and ensures that GN and SN SLE activities are technically compatible with the implementation of SLE on the DSN. Lockheed Martin-CSOC has also taken on the role of SLE clearinghouse for information relating to SLE on the GN and SN and has supported GSFC and JSC investigations of SLE. Lockheed Martin-CSOC has also provided the leadership and support for the development of SLE interoperability demonstrations.

The primary goal of the SLE testbed is to demonstrate the use of SLE for GN and SN science missions and for potential cross-support between NASA and the Air Force Satellite Control Network (AFSCN). Additional high-level goals include:

- Demonstrate, test, and promote CCSDS SLE as proposed by the NASCOM Block Phase-Out work group.
- Gain experience in the CCSDS SLE APIs developed by Jet Propulsion Laboratory (JPL) and the European Space Agency (ESA) for the INTErnational Gamma Ray Astrophysics Laboratory (INTEGRAL) mission.
- Conduct interagency interoperability testing using CCSDS SLE.
- Evaluate Commercial Off The Shelf (COTS) CCSDS SLE products from Avtec Systems.
- Investigate SLE service management.
- Monitor on-going SLE service management working group activities.

To meet these goals, Lockheed Martin-CSOC has installed SLE provider systems at two operating ground station antennas, installed an SLE user system at Lockheed Martin-CSOC facilities in Houston, and coordinated satellite testing with both NASA and DoD space vehicles.

An SLE "user" refers to the entity that is receiving telemetry from and/or issuing commands to the spacecraft, typically the mission operations center. The SLE "provider" refers to the antenna ground station. The provider tasks are broken into provision and production. Provision is the actual SLE interface that exchanges data with the SLE user via the communications network. Production refers to the other tasks performed by the ground station equipment, such as bit synchronization, error correction, time-stamping, etc. The SLE testbed houses two instances of two different SLE user/provider systems.

The first user/provider system is based on a collection of SLE user tools and a COTS Telemetry/Command processor (See Figure 4). The SLE user tools were developed by Jet Propulsion Laboratory (JPL) and Lockheed Martin-CSOC. They are based on the JPL SLE API set. The SLE user tools provide the forward and return service user applications. The COTS processor provides the SLE Forward Command Link Transmission Unit (CLTU) service. The Return All Frames (RAF) and Return Channel Frames (RCF) services were initially provided by in-house software based on the JPL SLE API set, but following a software upgrade in January 2003 the COTS processor provides all three services. End-to-End tests using telemetry and command generators were conducted in a laboratory environment to demonstrate the functionality of the SLE implementations.

The second user/provider system is a prototype developed by Global Science and Technology, Inc. under AFSCN sponsorship. Since DoD space vehicles do not use CCSDS protocols, this system performs additional production processing to break the encrypted bit stream interface into arbitrary data blocks to be passed to the SLE provider service. This supplemental production processing also packages additional timing information with the data to meet the stringent time correlation requirements for the data delivery to the end-user equipment. This system successfully proved the feasibility of delivering the AFSCN data stream over a packet switched network while meeting time-stamping and delivery requirements.

One instance of each of the above SLE provider systems has been installed at a development and test ground station at the NASAWallops Flight Facility (WFF). The second instance of these systems was installed at a National Oceanic and Atmospheric Administration (NOAA) Command and Data Acquisition (CDA) Station. Satellite testing at WFF began in February 2003. Current tests exercise the NASA and AFSCN systems independently and show cross-support by relaying telemetry from a DoD engineering test satellite to an AFSCN control center via the WFF ground station. The WFF test does not include commanding because the site does not have a modulator compatible with the DoD uplink. The NOAA station demonstrates both the command and telemetry flows. The satellite tests use the Wide-field Infra-Red Explorer (WIRE) and COsmic Background Explorer (COBE) satellites to represent NASA missions as well as a DoD engineering test satellite to represent DoD missions.

The current test configuration is shown in Figure 4, FY03 Final Architecture. The main elements of the final architecture are:

- NASA Wallops SLE provider system located at the Wallops telemetry development microwave system laboratory.
- NOAA WCDA provider system.
- Common SLE user test tools located in the Houston SLE laboratory The common SLE user test tools are be used to test the NASA Wallops SLE provider system and the NOAA WCDA station SLE provider system.
- Air Force Center for Research Support (CERES).

The Wallops SLE provider system is being tested with the common SLE user test tools via a NISN Standard IP network interface.

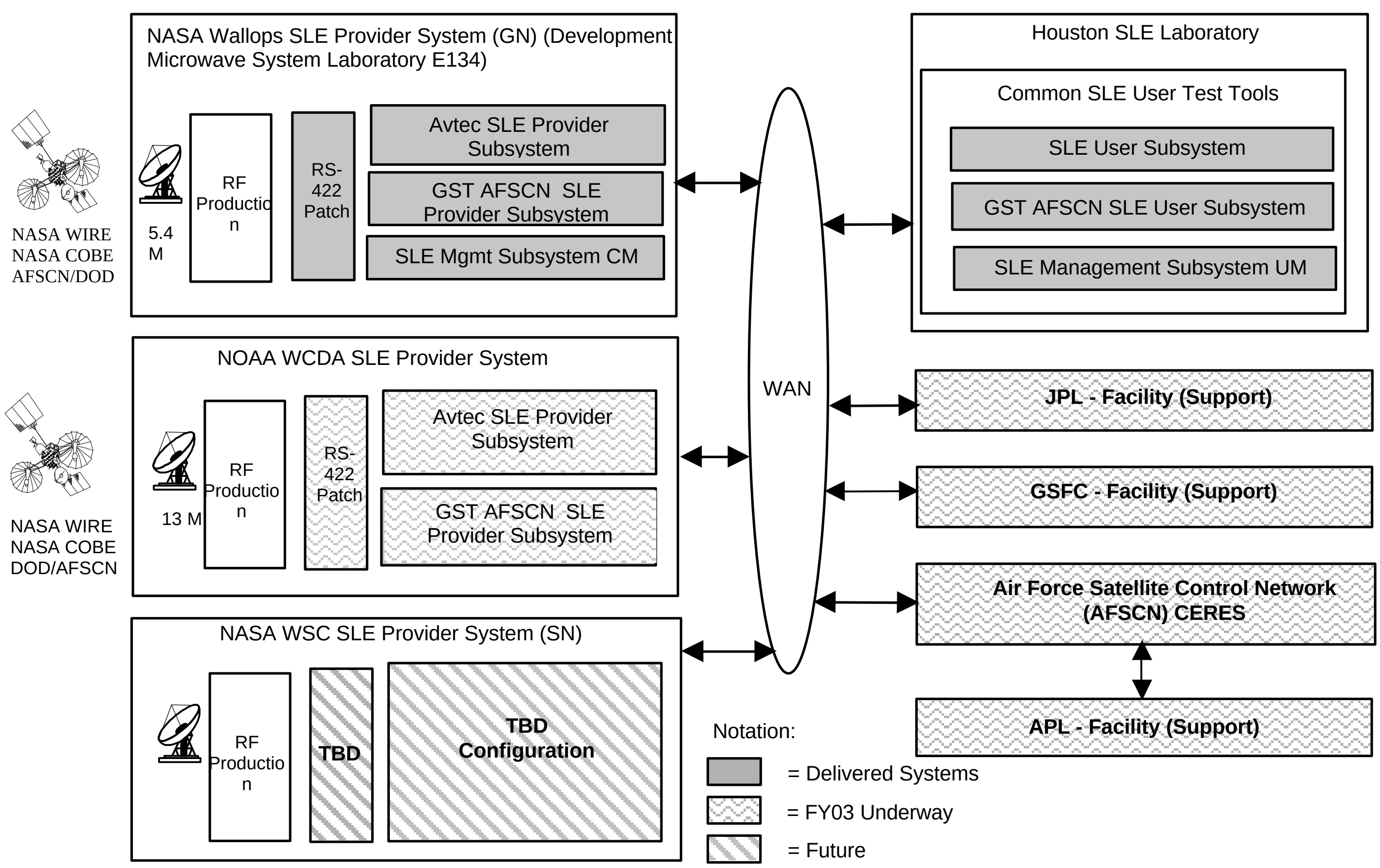

Figure 4. FY03 Final Architecture

3.1 NASA Wallops 5.4 m station SLE Provider system

The NASA Wallops 5.4 m station SLE provider system consists of the following elements:

- Avtec Programmable Telemetry Processor (PTP) SLE provider subsystem shown in Figure 5.
- The GST Air Force Satellite Communications Network (AFSCN) SLE provider subsystem shown in Figure 6.

3.2 Avtec PTP SLE Provider Subsystem

The Wallops Avtec PTP SLE provider subsystem is shown in Figure 5. Full requirements for the Avtec PTP SLE provider system are contained in the CCSDS SLE Telemetry and Telecommand Processor Specification. The Avtec PTP provider subsystem was specified to meet the functional requirements of the existing Programmable Telemetry Processors (PTPs) currently installed at NASA GN sites supporting many NASA space missions. In addition, the Avtec PTP includes the updated software released for CCSDS SLE Return All Frames (RAF), SLE Return Channel Frames (RCF), and SLE Command Link Transmission Unit (CLTU) transfer services.

The Avtec SLE PTP subsystem consists of the following functional elements:

- Avtec Inc SLE PTP Processor.
  - CCSDS Telemetry (TLM) Production. The Avtec PTP performs return link processing for space links conforming to CCSDS packet standards and PCM telemetry for data rates up to 5 Mb/s. Capabilities include frame synchronization, Reed-Solomon error detection and correction, virtual channel sorting, ground receipt time stamping, and data quality monitoring.
  - SLE RAF and RCF Transfer Services. The Avtec PTP includes software to support SLE RAF and RCF Transfer services. The SLE RAF and RCF functions receive return link data, ground receipt time, and data quality data from the Avtec PTP telemetry production, and support communications with the mission control center using SLE RAF and RCF protocols. RAF and RCF provide standardized communications to send return link data and status from the Avtec PTP to the mission user site.
  - SLE CLTU Command Production. The Avtec PTP performs forward link processing for spacecraft conforming to CCSDS telecommand recommendations. It is specified to support forward data rates up to 2

Mb/s. The SLE CLTU transfer service provides standardized communications with the mission control center.

- Space Downlink (Return Link) Data Simulator. The Avtec PTP includes a limited capability spacecraft downlink data test generator that serves as the data source for the return link test defined in this document. It is configured to generate a simulated CCSDS Advance Orbital System (AOS) return link with nine simulated virtual channels (where one channel is designated as the fill data channel) at selectable data rates up to 5 Mb/s.

- Uplink (Forward Link) Command Receiver. The Avtec PTP includes the capability to receive, collect limited data quality statistics, and log telecommand data streams for uplink test verification.

- IP-Sec Router (Linux PC). This platform performs software IP routing with basic firewall capability. It provides for future evaluation of an IP-Sec package to support AFSCN interoperability testing.

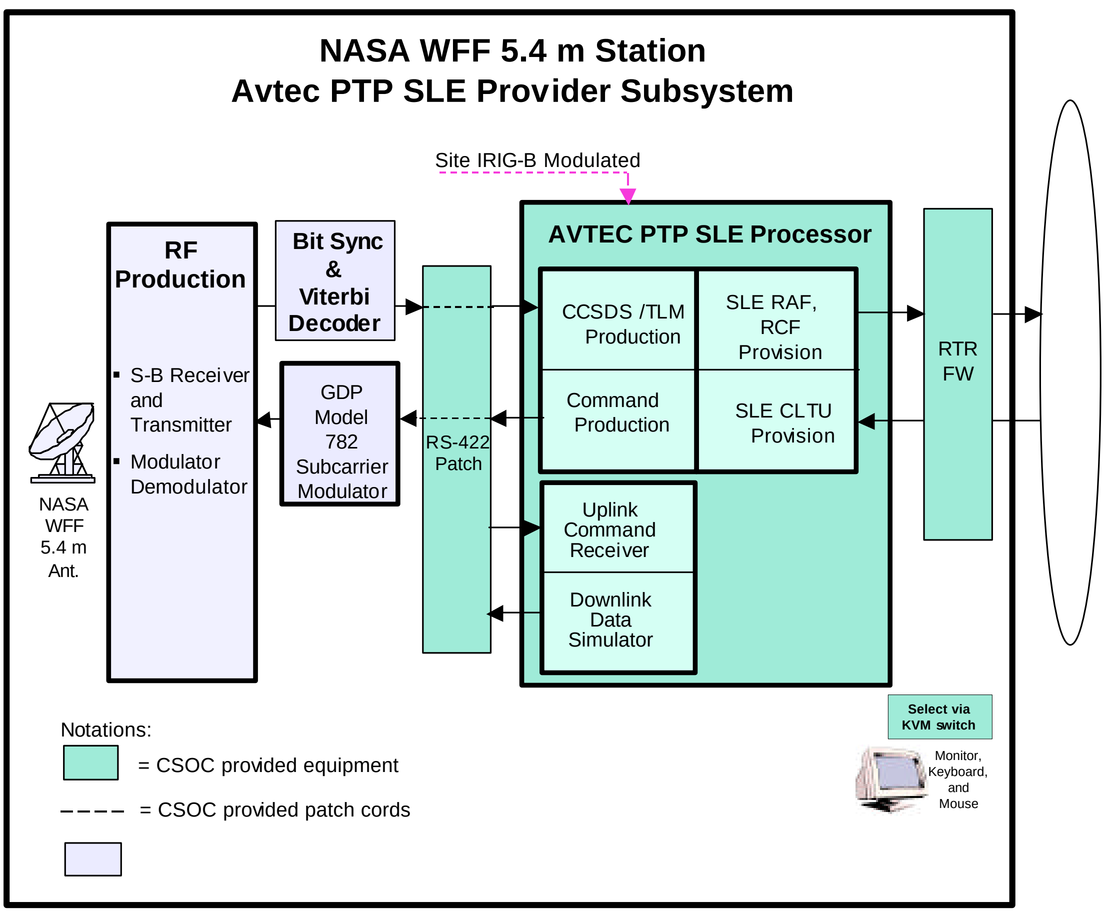

Figure 5. NASA WFF 5.4 m Station Avtec SLE Provider System

3.3 GST AFSCN SLE Provider Subsystem

The GST AFSCN production system is illustrated in Figure 6. The system software was provided and installed by GST as GFE. The system was developed by GST for Research and Development (R&D) to test the capability to send AFSCN satellite unframed bit stream data using the CCSDS RAF transfer service via an Internet-based network. The subsystem elements of the Wallops GST AFSCN subsystem consist of the following:

- GST Test Tool: Downlink Data Simulator (Linux PC). Provides the capability to generate a serial data stream at selectable data rates. This serial data stream simulates an unframed bit stream for routing via the GST Data Blocker and Time Processing Function.

- GST Data Blocker and Time Processing (Linux PC). Provides the capability to receive an RS-422 unframed serial data stream. The data blocker blocks the unframed data into a fixed data format along with accurate time tags (ground receipt time data). The time tags are required by the user facility to recreate the time signal to an accuracy of 1 millisecond (ms) with the data interface. (**Note:** GST test tools are not provided to verify the 1-ms time accuracy.)

- GST CCSDS RAF Provision Function (Linux PC). Performs the standard CCSDS RAF transfer service for routing the framed data to the user facility. (This function runs on a SUN Solaris platform.)

- IP Sec Router (Linux PC). This platform performs software IP routing with basic firewall capability. It provides for future evaluation of an IP-Sec package to support AFSCN interoperability testing.

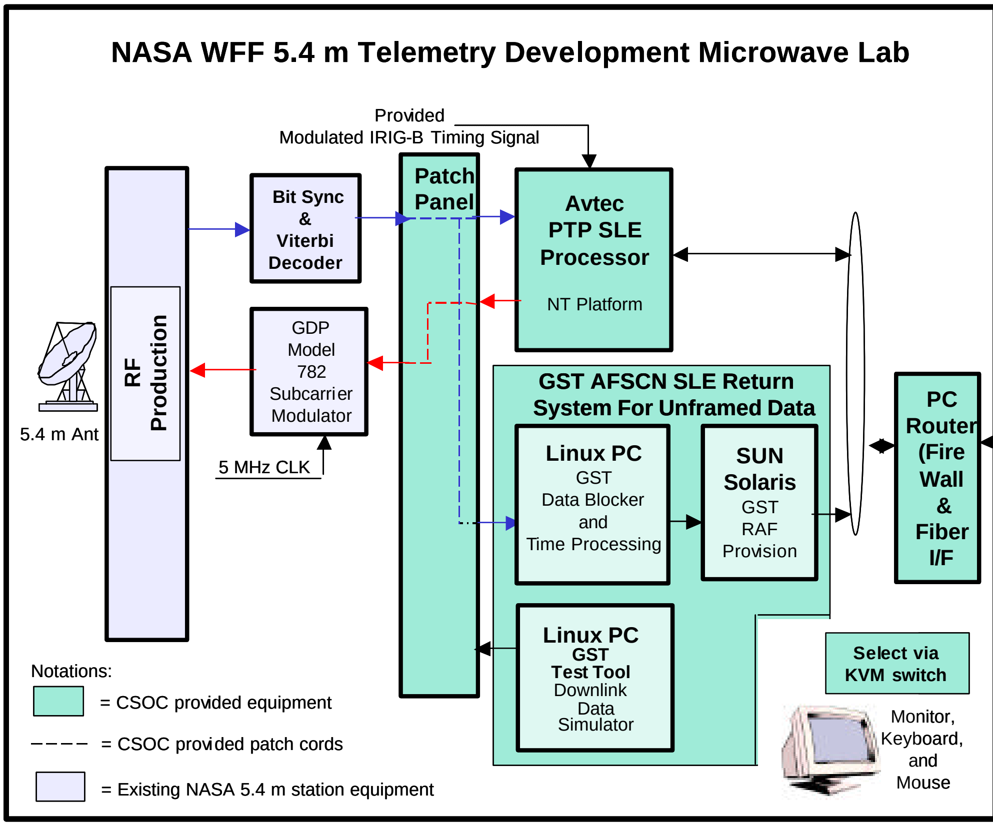

Figure 6. NASA WFF 5.4 m Station SLE Provider System

3.4 NOAA WCDA Station SLE Provider System

A second SLE provider system was installed at the NOAA WCDA station in FY03. The SLE System is identical to the NASA Wallops system. It included a GDP Space System Model 782 Subcarrier Modulator as shown in Figure 7, NOAA WCDA Station SLE System.

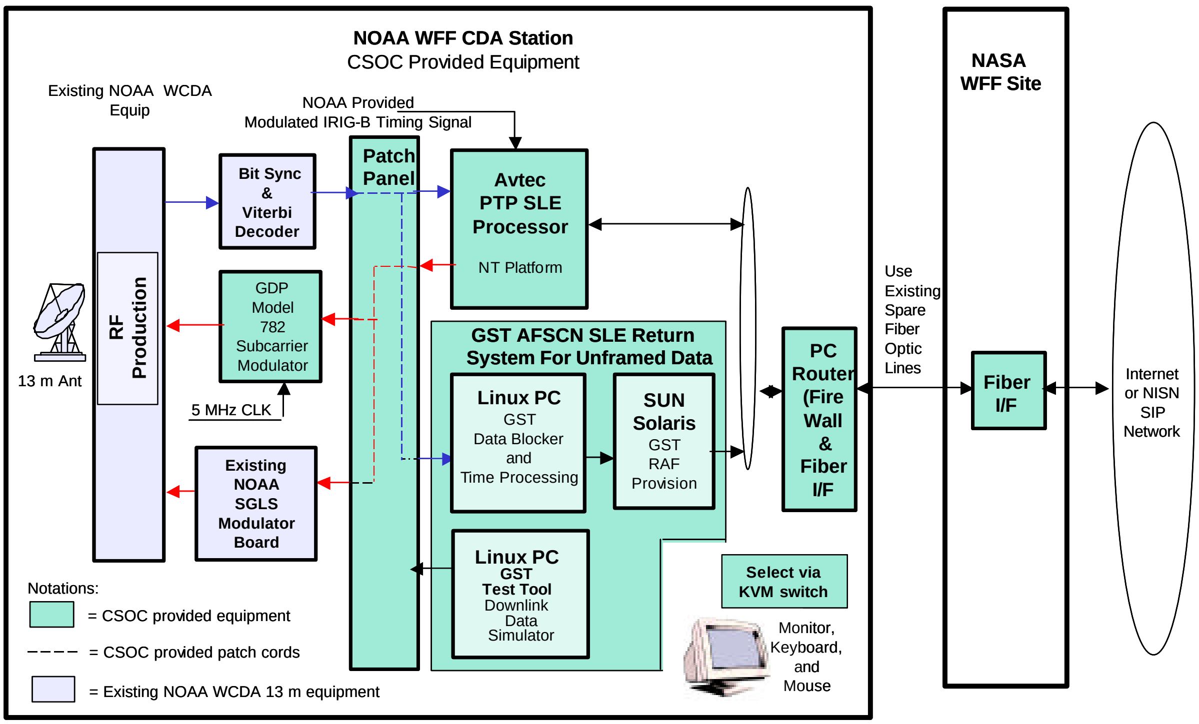

Figure 7. NOAA WCDA Station SLE System.

4.0 Space Link Extension Testbed Results

Lockheed Martin-CSOC has provided technical and management coordination to ensure successful interoperability demonstrations between NASA, National Oceanographic and Atmospheric Administration (NOAA) and the DOD/Air Force Satellite Control Network (AFSCN). Lockheed Martin-CSOC has led and participated in numerous working group meetings with NASA Wallops Flight Facility (WFF), NOAA and AFSCN personnel to coordinate installation and test planning activities. Lockheed Martin-CSOC has also provided the planning and integration skills to support interoperability across vendors, agencies and facilities.

Summaries of Lockheed Martin-CSOC's major accomplishments in the SLE testbed arena are included below:

- Supported NASA's goals for the evolution of SLE COTS products by successfully working with Avtec, an SLE products vendor, to test and verify that the Avtec SLE COTS product met all of the requirements for SLE as stated by the

CCSDS standards organization. Thus, Lockheed Martin-CSOC has made significant contributions toward the availability of an SLE COTS product to support NASA missions on the GN and SN.

- Tested the Avtec SLE COTS implementation using NASA's WIRE and COBE satellites through NASA's Wallops 5.4 m Station. This is the first time that an SLE implementation has been used on a NASA GN station thus furthering NASA interoperability goals. Lockheed Martin-CSOC successfully executed WIRE and COBE forward and return link using the Avtec COTS SLE implementation.
- Contributed successfully towards NASA's inter-agency interoperability goals on the Ground Network by designing and implementing the interoperability architecture and developing the operations concepts required to support spacecraft data exchange with DOD/Air Force Satellite Control Network (AFSCN) satellites via NASA's Wallops 5.4 m Station. Lockheed Martin-CSOC has supported numerous successful DOD/AFSCN test satellite return link passes through Wallops to an AFSCN control center using SLE.
- Contributed successfully to NASA's inter-agency interoperability goals included performing technical analysis and design to determine that SLE could be installed at the National Oceanic and Atmospheric Administration (NOAA) Wallops Command and Data Acquisition (CDA) site. Lockheed Martin-CSOC also successfully managed the installation of a second instance of an SLE system at the NOAA Wallops Command and Data Acquisition Station and led the testing of NASA's WIRE and COBE satellites through this site. This implementation also sets the stage for future forward and return link testing with NASA satellites and with DOD/AFSCN test satellites.

4.1 SLE Management Service Request Prototype

The Lockheed Martin-CSOC CCSDS Space Link Extension (SLE) Service Management prototype project is sponsored by John Rush at NASA HQ, and is part of a broader effort to develop and test the functionality of SLE Service Management standards. Current and active participants in SLE Service Management standards arena include Lockheed Martin-CSOC, NASA (JPL, GSFC), ESA, the USAF, and other US and international agencies. Among the goals of CCSDS SLE Service Management standards is the reduction of the cost of mission operations by establishing and implementing standards for use of multi-agency ground stations.

The purpose of the Lockheed Martin-CSOC Space Link Extension (SLE) Management Service Request (SR) Prototype is to advance architectural concepts and develop "lessons learned" in support of CCSDS SLE Management standards development. This prototype provides an opportunity to evaluate processes, message content, and specific eXtensible Markup Language (XML) formats including configuration profiles and service requests that have been put forth in the CCSDS SLE standards community.

To evaluate CCSDS SLE Management standards in a realistic environment, the Lockheed Martin-CSOC SLE Management SR prototype implements a COTS architecture representing a typical near-future GN telemetry service provider and consumer management environment (Figure 8). Proposed CCSDS SLE Management standards are then overlaid and evaluated. The system will ultimately be of sufficient fidelity to make specific observations on the performance, manageability, security, and general functionality of the proposed SLE Management elements under consideration. In addition, this approach is scalable to encompass the evaluation of all SLE Management functions as they are more fully described by CCSDS. Finally, the architectures and tools employed in creating a realistic GN service consumer and provider management environment will be fully documented in support developing future SLE Management reference architectures.

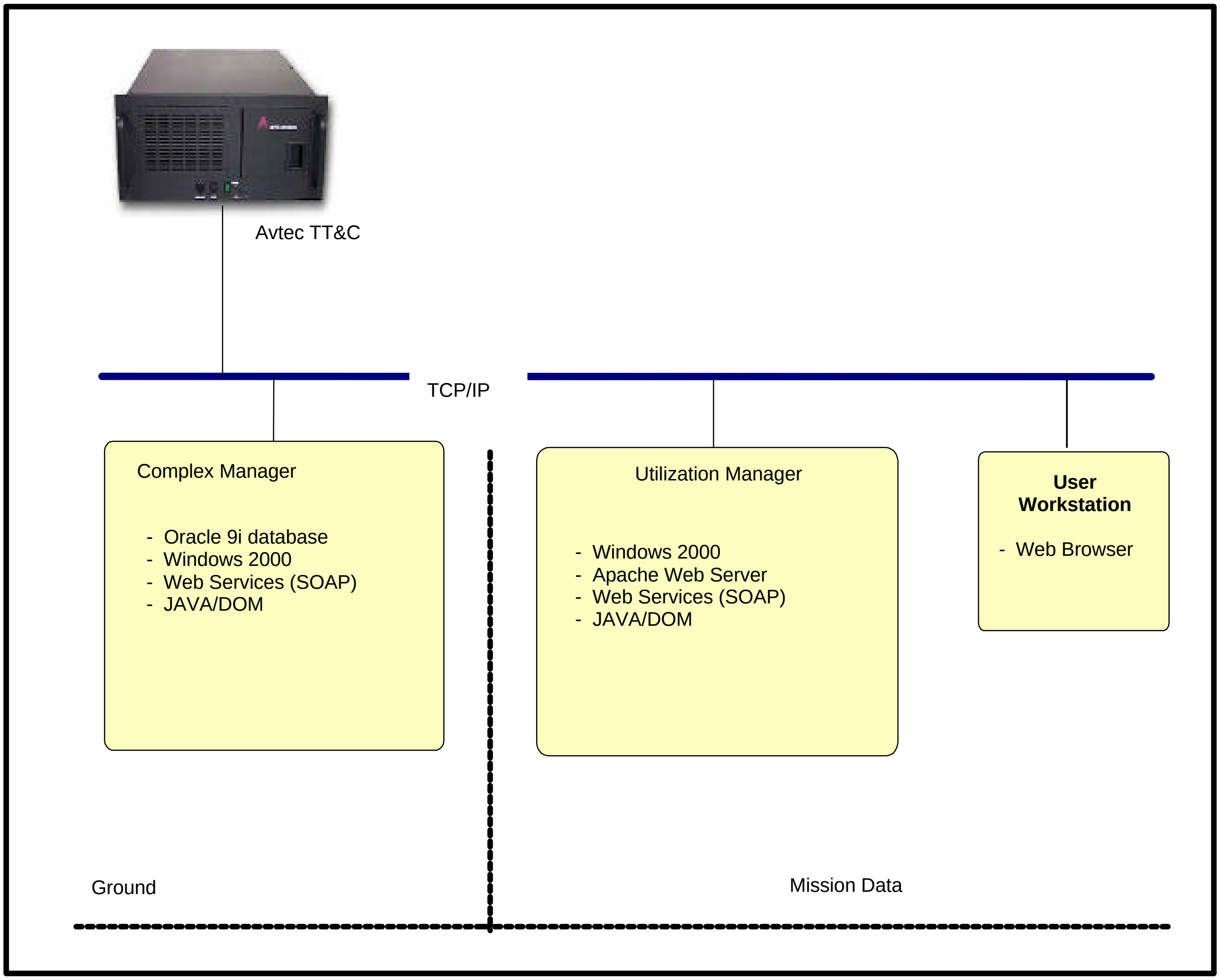

Figure 8. SLE Service Request Architecture

To assure that this prototype is as broadly useful as possible, well understood and widely available system components were utilized. The architecture is based on Web Services and fully leverages the capabilities of current XML based tools. This approach promotes interoperability, web access, self-describing services, and, to the greatest extent possible, operating system and programming language independence. The ubiquity of Web Services tools also ensures ease of use and a robust set of implementation options. The specific elements being utilized include Web Services Description Language (WSDL), Simple Object Access Protocol (SOAP), and eXtensible Stylesheet Language for Transformations (XSLT). The service user side consists of one or more mainstream user workstations running Microsoft Windows while the service provider side implements an Oracle database interfaced via a controller to telemetry-processing equipment. The transformation of hierarchical XML data representations to a relational database is explored as well as control features inherent in commanding telemetry-processing equipment. Finally, basic features of service provider and consumer operator computer interfaces are explored.

4.2 SLE Management Service Request Prototype Results

Lockheed Martin-CSOC has provided expertise in ground station operations and technical standards implementation to the CCSDS SLE Service Management standards development group. Lockheed Martin-CSOC's contributions to this group have reinforced the goals of the CCSDS SLE Service Management by infusing the group with senior technical leadership and by providing a "real world" approach and platform for testing the technical specifications being developed by the group.

Lockheed Martin-CSOC used its technical and management skills to continue the definition of the SLE Management implementation architecture and development of a proof-of-concept prototype so that it meets the goals of supporting the development of a usable CCSDS SLE Service Management specification.

Specific Lockheed Martin-CSOC contributions to CCSDS SLE Service Management standard development include:

- Successful advocacy to maintain focus on producing near term products for interoperability.
- Demonstrated how CCSDS and 'non-CCSDS' spacecraft can fit into the SLE Service Management standard.
- Developed recommendations for standard and Ops Concept extensions needed in NASA's highly reliable environments.
- Shared practical experience in web and database design and implementation, SLE COTS products integration, and Wallops RF systems integration in the NASA environment.
- Provided prototype feedback and lessons learned to the committee generating the standard.
- Provided cutting edge architecture experience on the use of emerging standards and technologies within the NASA infrastructure.

Lockheed Martin-CSOC has made several significant contributions to the development of CCSDS SLE Service Management standards by infusing Lockheed Martin-CSOC's technical and "real world" leadership and expertise.

5.0 Design/Implementation Lessons Learned

The interim RAF/RCF provider application and user application were built on top of the JPL's SLE APIs. Receiving the JPL SLE API source for the RAF/RCF implementation was essential to keeping a tight NASA schedule. This was a huge savings in time and effort. JPL engineers were also very helpful and quick to respond in assisting with understanding their source and trouble-shooting. Starting with the JPL SLE API source is highly recommended for all startup SLE Projects. Reference CCSDS SLE API for RAF (CCSDS 911.1.B.1) for details on the APIs.

The RAF/RCF API source code received from JPL was missing several pieces of software at the application layer that was unique to the JPL architecture. Instead of developing this code from scratch, the source code developed by GST was obtained to fill in the missing software pieces. This saved application software development time.

JPL used OSS Nokalva (OSS) Inc. ASN.1 (Abstract Syntax Notation) for the DER (Distinguished Encoding Rules) ASN.1 encoding package. While more expensive than other ASN versions, a decision was made to stay with the OSS ASN.1 DER package due to schedule constraints and risk concerns. However, further study is needed here to reduce the cost for future implementations.

Receiving the JPL SLE CLTU client application and CLTU provider simulator provided a major cost savings. This generic CLTU client application (which also serves as a command generator) was used in lieu of creating custom CLTU client tools. The team recommends that all SLE Projects be provided these tools to allow them to immediately start testing the SLE interface. Becoming familiar with the CLTU client was also helpful when the PTP solution was delivered, it was just swapped with the simulator. It would have been an even bigger boost if the source for the client had been provided so that the metering logic could have been adjusted for testing higher rates.

5.2 Testing Remarks

SLE hides much of the detail of the handshaking and transfer of data, so a test team needs a tool to monitor the network data flow in order to account for variances. If the network being used by an SLE project is unstable (varying bandwidth available, prone to reconfiguration changes, etc.), this could present significant problems for a program expecting a steady data flow.

The current RAF provider implementation start discarding data at the 3 Mb/s return rate. This fell short of the expected goal of 5 Mb/s. The source of the problem could not be determined and is still under investigation. It could lie with the Avtec TTP, the provider, the client, or the network.

Because an SLE vendor with a proven, stable SLE solution was not available, the growing pains of working with a newly developed product were incurred. It was essential to gain direct contact with the vendor's software development engineers. The vendor's software engineers were very responsive. This proved to be a huge time-saver in trouble-shooting problems and gaining on-the-phone training.

6.0 Acknowledgements

The work performed during this investigation depended on support provided by JPL, GST Corp., John Hopkins, AFSCN and Avtec. The testbed team would like to especially acknowledge the support provided by JPL in helping to get started with the JPL-provided SLE APIs and for providing the SLE user software. This support was a huge savings in time and effort. JPL and GST engineers were also very helpful and quick to respond in assisting with understanding their source and trouble-shooting.

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ACRONYM LIST

AFSCN	Air Force Satellite Control Network
AOS	Advance Orbital System
API	Application Program Interface
ASN	Abstract Syntax Notation
BLDG	Building
bps	bits per second
CCSDS	Consultative Committee for Space Data System
CDA	Command and Data Acquisition
CLTU	Command Link Transmission Unit
COTS	Commercial Off The Shelf
CSOC	Consolidated Space Operations Contract
DER	Distinguished Encoding Rules
DoD	Department of Defense
ESA	European Space Agency
FY	Fiscal Year
GFE	Government Furnished Equipment
GN	Ground Network
GST	Global Science and Technology
ID	Identification
INTEGRAL	INTErnational Gamma Ray Astrophysics Laboratory
IP	Internet Protocol
IRIG-B	Inter-Range Instrumentation Group-Format B
JPL	Jet Propulsion Laboratory
LAN	Local Area Network
ms	millisecond
MTU	Maximum Transmission Unit
NASA	National Aeronautics and Space Administration
NISN	NASA Integrated Service Network
NIST-NET	National Institute of Standards and Technology – Network Emulation Tool
NOAA	National Oceanic and Atmospheric Administration
OS	Operating System
PCM	Pulse Code Modulation
PTP	Programmable Telemetry Processor
RAF	Return All Frames
RCF	Return Channel Frames
R&D	Research and Development
RTT	Round Trip Time
SIP	Standard IP
SLE	Space Link Extension
SN	Space Network
SOC	Space Operation Center
SODA	Space Operations and Directive Agreement
TCP	Transmission Control Protocol

TTP	Telemetry and Telecommand Processor
VCDU	Virtual Channel Data Unit
WAN	Wide Area Network
WFF	Wallops Flight Facility
WSC	White Sands Complex
XML	eXtensible Markup Language