SLE is going Operational

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CCSDS has developed a set of Recommendations for Space Link Extension (SLE) Services with the aim to provide a uniform cross support capability for agencies who develop interfaces to their facilities in accordance to these Recommendations. SLE services are specified in terms of operations at application level and associated data structures for exchanging space data units between cross-supporting Agencies.

ESOC and JPL, initially in the context of cross support of the ESA Integral mission using NASA DSN stations, have implemented a basic set of these recommendations. This consists of the Return All Frame (RAF), and the Return Channel Frame (RCF) services for the return link and the Command Link Transfer Unit (CLTU) service for the forward link.

Beyond the Integral project, these services will also be used for the cross support between ESA and NASA/JPL of future missions, and particularly, in 2003, of Rosetta and Mars Express.

Although during the parallel ESOC and JPL development, the two Agencies have adopted respectively the role of “service user” (ESA) and “service provider” (NASA), the development concept adopted is based on the potential interchangeability of the kernel software (the API element) for the implementation of both “user”/”provider” interfaces. Thus for example, ESA also developed a “provider” capability for installation in its simulator, essential for test purposes.

The CCSDS SLE management Recommendations required for the operation of the SLE services is not yet available and so ESOC and JPL have devised a private (*ad hoc*) management scheme to support the necessary SLE operational set-up. This is based on the definition, for each support period, of a Sequence Of Events (SoE) and set of defined “Service Instances” (SIs) derived from it. The definition of the latter is supported by a management tool called the Service Instance Configuration Manager (SICM).

The implementation of the above services and service management has been completed and is undergoing an intensive testing and operational validation campaign.

During the operational validation process, certain system engineering issues arose. These issues and their consequent design considerations are discussed in this paper with the aim of providing a useful guidance to future implementations of the SLE services.

The SLE services will soon support Integral, Rosetta and Mars Express operations. This paper presents the status as of July 2002.

Keywords: Space Link Extension, Cross Support, Interoperability.

BACKGROUND

In the past TT&C cross-support between ESA and NASA/JPL invoked installing and operating user equipment at the provider side – a common approach to interfacing to the user's Mission Operations Center. The idea of implementing the innovative SLE concept, started to mature in the mid-90's as a result of the progress made in this area by CCSDS Panel 3. A groundbreaking milestone for the Space Link Extension (SLE) services development came in December 1996 when an early decision was made by the ESA INTEGRAL mission to adopt SLE for the cross-support from the DSN stations. This boosted the activities within CCSDS to complete the SLE related Recommendations. It also resulted in the parallel development at ESOC and JPL of the basic SLE transfer service implementation, specifically of the CLTU, RAF and RCF services, i.e. CLTU in the forward ground-to-space link and RAF and RCF in the return space-to-ground link.

In 1999 at the Inter-Agency Plenary attended by seven space agencies, the above three services were reaffirmed as the basic capability needed by future missions for cross-support. These missions include ESA's Mars missions, Rosetta, and Bepi Colombo, all NASA's deep space missions launched in or after 2002;and ISAS's MUSES- C, Lunar-A, and Solar-B. They will all benefit from the INTEGRAL's pioneering contribution to interoperability. The development, finalized in the year 2000, underwent a thorough progressive validation program (initially back-to-back in Europe and then cross Atlantic between ESOC and JPL). This was successfully concluded in April 2001. The deployment and validation of the SLE services for INTEGRAL, ROSETTA and MARS EXPRESS are nearing completion, in time for the INTEGRAL launch in October 2002.

SYSTEM ASPECTS

During the operational validation process, certain system engineering issues were raised. These issues and their consequent design considerations are discussed below with the aim of providing a useful guidance to future implementations of the SLE services. These issues are fully discussed in reference [3]. These are only outlined in this document, as these are important issues for end-to-end test and validation.

Access point of the SLE service provision. The initial implementation of the SLE transfer services at JPL represents mixture of the two approaches. The CLTU implementation takes an integrated approach whereas for the RAF/RCF services the two functions are allocated to two separate physical elements.

Interface between the SLE service layer and transport layer. The current implementation is based on TCP/IP. All data interchange between JPL and ESOC is connection-oriented with the connection exclusively established from the ESOC end. The concept of TCP socket communication applies to the SLE based transfer of Telemetry Transfer Frames and (Telecommand) Command Link Transmission Units. As concerns non-SLE data, secure FTP is applied to the interchange of trajectory (EPM) and tracking (ODF) data. For the voice transfer this is based upon the connectionless User Datagram Protocol (UDP). Cisco routers at either end of the interface convert from analog voice signals to digital data streams and vice versa.

Figure 1 gives an overview of the Rosetta Interfaces

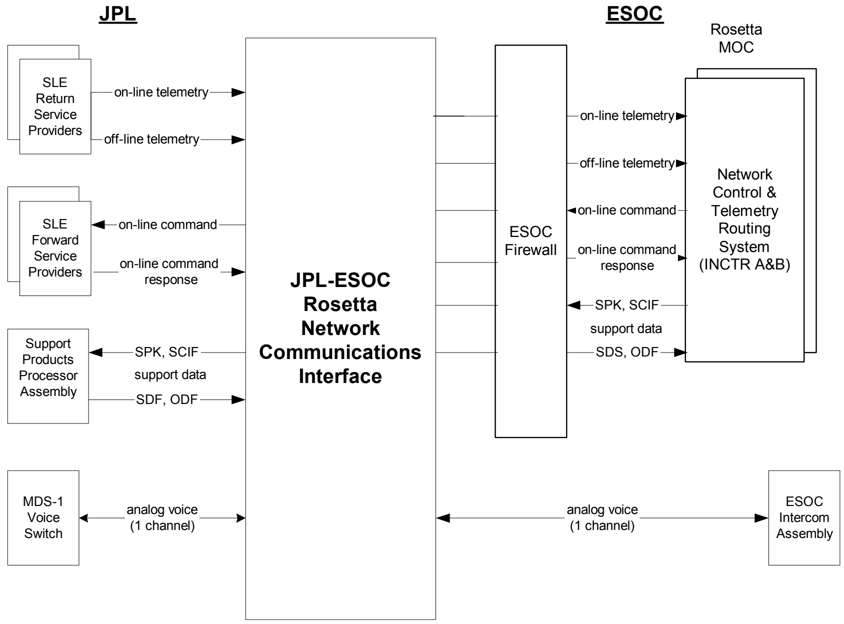

Figure 1 Rosetta Interfaces

INTERFACE NETWORK TOPOLOGY

The European Space Agency operates a network of ground stations for tracking, telemetry and telecommanding known as ESTRACK, with a space mission operations dedicated communications network known as OPSNET. The wide area data communications within this system have traditionally been based on the X.25 protocol. ESA is in the course of migrating this to the IP protocol suite (reference [1]). The SLE was introduced at ESOC at the same time as this migration and the outcome for SLE is shown in figure 2 that represent the high-level network architecture between JPL DSMS and ESOC D/TOS for the Rosetta mission.

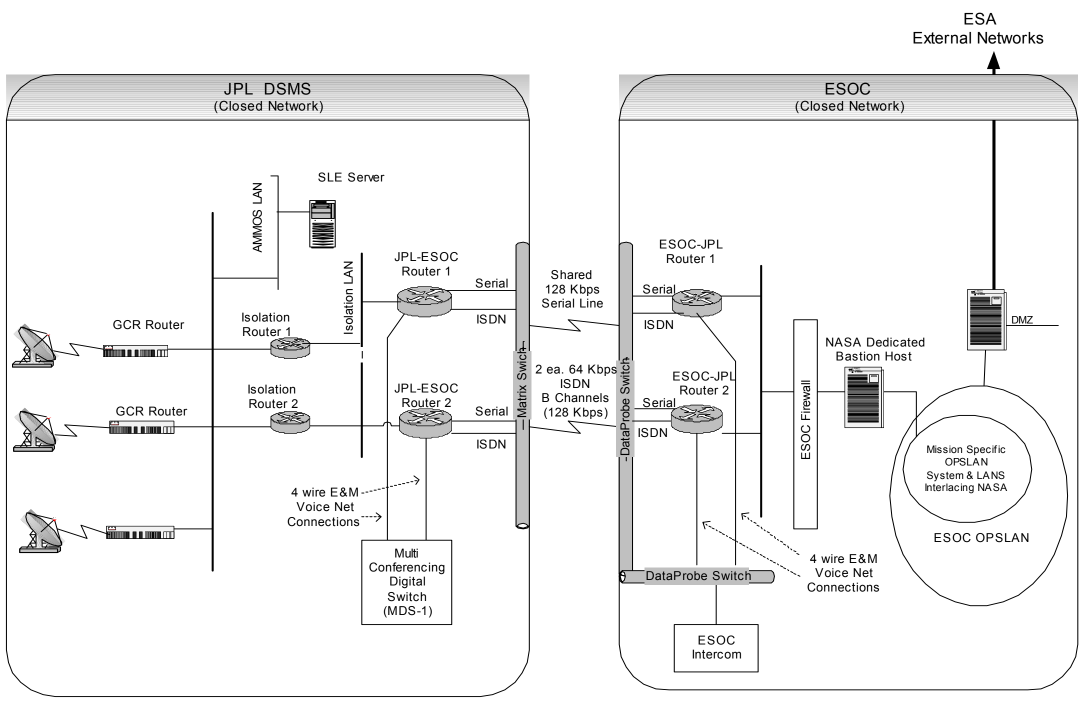

Figure 2 Rosetta Interface Network Topology

The following capabilities are implemented to satisfy the data flow needs between JPL and ESOC:

Data Throughput and Data Prioritisation **-** Many data types flow across this interface (SLE on-line telemetry, SLE off-line telemetry, SLE commands/responses, support products, etc.). It is required that all these data products can be transmitted simultaneously but with priorities. Specifically, on-line telemetry and voice-over-IP data shall be given highest priority and all other data types (off-line telemetry, and support product file transfers) shall be transmitted on a shared basis using remaining bandwidth.

SLE services recovery from communications anomalies - One of the fundamental assumptions, of which SLE protocol design has, is that the underlying communication service is 'reliable'; this means that recovery from communications anomalies is responsibility of the underlying communications service.

In case of failure of the prime line the system will activate dial-up of the ISDN lines and re-route data accordingly. Since, in the current design, two projects share a single serial line, the ISDN circuits for both projects will be brought up, regardless of actual need of the circuits.

The ISDN circuits will normally be used only if the primary serial communication link is not available (i.e. out of service or failed). All bandwidth allocations and data prioritisations that applied for the serial line path will apply equally over the backup/recovery ISDN data path. Assuming that the total bandwidth available via ISDN is the same as that of the primary serial circuit, the bandwidth-sharing situation would be same as described earlier. If less bandwidth were available, the bandwidth available to the low priority data types would naturally be proportionally less, as well.

The fail-over to the backup ISDN communications path will normally take less than a minute. However, this is not guaranteed ISDN service is part of the Public Switched Telephone Network (PSTN) and no guarantees are given by the telephone companies for dial up time or overall availability of ISDN service.

MAKING SLE OPERATIONAL

SLE services are specified in terms of operations at application level and associated data structures for exchanging space data units between cross-supporting Agencies. However an operational system needs to be integrated into existing system and it is necessary to look further than only to the interfaces and their implementation. In the following a number of points needed for an operational system are discussed, these are:

- Integration SLE into an existing operational system
- Test and Validation
- Security
- Reliability
- Operational Procedures
- Configuration Control
- Training and Simulations

INTEGRATION SLE INTO AN OPERATIONAL SYSTEM

Before SLE can be used operational one must integrate it into an operational system. SLE is a new concept/system but must work together with existing systems. For SLE this means that two main topics needs to be considered: (1) Operational Interfaces and (2) SLE Management.

OPERATINAL INTERFACES

Operational Interfaces for handling these interface operations, and general monitoring and control of the services. For the operational interfaces for handling the SLE interfaces ESOC decided to integrate into the existing system. The central system to interface between mission control system and ground stations is the so-called Network Control and Routing System (NCTRS). The NCTRS handled the different ground station equipment protocols and allowed the control center to use a simple protocol – TCP/IP. This was possible because to the open architecture of the NCTRS. The NCTRS was extended to include the SLE by adding new interface drivers that handles the SLE interfaces. For the MMI only relative small changes were necessary

SLE MANAGEMENT

One of the most valuable lessons learned during the development of SLE transfer services is the strong dependency of SLE transfer services on service management. The transfer services are in no way stand-alone or self-contained. As such, the design and implementation of transfer services must take into account the interface with service management.

Far to SLE Service Management a private (ad hoc) management scheme was implemented to support the necessary SLE operational set-up. This is based on:

- Establishment of a Service Level Agreement between ESA and NASA/JPL well in advance (in practice some 5 years)
- ESA submits contact requests to NASA/JPL well in advance (e.g. 1 year)
- NASA/JPL produces a conflict-free ground station utilization schedule of 7 days (the "7-day-schedule") that is received 3 days before the start of the covered period and defines the Space Link Session (SLS)
- The 7-day-schedule is fed as input to the Service Instance Configuration Management tool (SICM) to generate "Service Instances" based on pre-defined service-specific templates.
- The output of SICM for each contact and for each service, and is sent to NASA/JPL via the NCTRS.

The approach to the SLE Service Instance Management is based on the concept of Service Instance Configuration Files (SICFs). The SICFs are created in order to define and configure SIs. They are read by the SLE user and provider application. The Service Instance Configuration File Manager (SICM) tool will produce and distribute the SICFs to all the other applications (NCTRS, SIMSAT and other SLES providers) that call SLE services and thus need SICFs.

TEST AND VALIDATION

For the SLE API components, initial validation was done with a tailored COTS protocol validation tool. Furthermore, the interoperability of two independently developed implementations was tested. The SLE API offers comprehensive tracing and logging. In addition, the API components check invocation received from the local client and reject them if they are not permissible in the given state. This tools show to be very important tools during the testing and most problems could be diagnosed in real-time during the tests. Also it is very important that the output of such a tool is the same on both implementations.

A number of tests between JPL and ESOC have taken place. These tests have covered both the application interfaces, testing of the communications infrastructure and its required capabilities and end-to-end test and validation. Integral is the first user and therefore many tests were planned. Rosetta as the second user is therefore more representative for the effort needed to test and validate the operational SLE system. The following tests have been performed between JPL and ESOC for the Rosetta mission.

Project	Number of tests	Total duration (hours)
Rosetta	14	60

To support these tests ESOC provided to JPL the Portable Satellite Simulator (PSS) that is capable of generating representative Integral, Rosetta and Mars Express Telemetry and can accept commands for these missions. This has proven to be a very powerful tool and for the end-do-end tests such a tool is mandatory to validate that the overall system. It is strongly recommended that such a tool is used for testing of SLE.

SECURITY

Security is a major issue because the SLE underlying communication is based on TCP/IP. The overall security is based on the following measures:

1. All communications services shall be within an environment of "Closed Network" connectivity.

2. Both ESOC and JPL employs firewalls to provide further protection of the hosts within their respective domains.

3. Access controlled rooms or racks shall accommodate security sensitive elements.

4. All accounts shall be password protected.

5. The network to be established shall comply with the security requirements specified by the agency

RELIABILITY

Currently there is no real experience with reliability of an SLE system and it is assumed that this will not be different that for other existing systems. ESOC have specified the following initial figures for the overall reliability:

1. The provider shall deliver equal to or greater than 95% of available good telemetry frames.

2. The provider shall deliver telemetry data frames containing no more than eight (8) breaks per 10,000 frames for all periods of committed support.

3. The communications interface shall provide a time to restore service of no more than 5 minutes during routine operations and no more than 1 minute during critical mission events.

OPERATING PROCEDURES

When a system is operational it is important that the operators have clear procedures for how to operate the system and in particular how to handle contingencies. There is obviously a need for local procedures of how to operate the provider system and the user system but there must be agreed procedures in place on how to handle the interfaces between the service provider and the user. For this the following initial procedures have been defined:

*Declaration of the Operational Status of the Communications Network***.** Procedure to declare the established ground communications network operational and advise their staff accordingly.

*Routine Communications Network Support***.** Procedures on routine network monitor and control and maintenance.

Reporting of Service Degradation and Failures. Procedure to announce failures of degrading performances of any interface element that are observed within the area of responsibility of one agency shall be reported to the co-operating agency without undue delay.

Filing and Follow-Up on Trouble Tickets. Procedure for reported failures that result in trouble tickets and closing of a trouble ticket according to mutual agreement

Support in Fault Isolation. Procedure to support fault isolation activities.

Reports on Service Restoration. Procedure for announcing for service restoration

Coordination of Scheduled maintenance. Procedure for coordinating scheduled maintenance activities. The agreed principles are that no scheduled maintenance shall be executed without the partner's agreement, unless the entire system is unusable for mission support at that time anyway. Notification of planned maintenance activities shall be submitted, whenever possible, with a lead-time of not less than one calendar week.

CONFIGURATION CONTROL

Configuration control is extremely important for an operational SLE system. The total operational set-up of a SLE provider and user system requires correct configuration of many elements such as network, firewalls, routers and a large numbers of applications. This is also very important during the test and validation phase because if configuration control procedures are not strictly followed then test already performed might be invalidated and retesting would become necessary.

TRAINING AND SIMULATIONS

Before a system can be declared operational the operators must be trained and the overall system must go through a number of simulations. At ESOC a comprehensive training program has been established for the network operators. For the simulations ESOC and JPL has agreed to have to have a total of 3 joint simulations to exercise the system in a realistic scenarios.

LESSONS LEARNED

The lessons learned are follows:

- the best design approach on the SLE provider side is to combine service production and service provision in one physical equipment. However, in an intermediate phase, where legacy ground station equipment has to be used, separation of the two using an SLE gateway approach is a good intermediate compromise solution.

- a simple *ad hoc* approach to SLE service management was taken in the absence of agreed CCSDS standards. This approach is expected to be adequate for all major missions in the next few years.

- To make such a system operational careful considerations on "operational aspects" needs to be done. This shall include items such as:

- Integration SLE into an operational system
- Test and Validation
- Security
- Reliability
- Operational procedures
- Configuration control
- Training and Simulations

- Sufficient test tools that can generate representative Telemetry and accept Commands are mandatory for proper end-to-end test and validation.

- Configuration control is extremely important and must be strictly followed in order to ensure an SLE operational system. The whole operational system needs configuration of many parameters and this involving many systems such as the network, routers, firewalls and a large number of application programmes.

FUTURE ESOC PLANS

ESOC has a long tradition of providing cross support (reference [2]) and this will continue in the future. The final implementation of the SLE provider functions at ESA stations is planned to be ready towards the middle of the decade. The current plan is to provide the following services:

The Return Services are offered on the external interfaces based on a subset of the CCSDS SLE specification. There are two services provided

Return All Frames (RAF) **-** this service delivers all frames received from the space links and is therefore of interest for missions where elements of the frame structure do not comply with the applicable CCSDS Recommendations so that a Virtual Channel or Space Packet channel cannot be extracted from the incoming telemetry frame stream. Even if a spacecraft is designed in accordance with CCSDS recommendations, certain onboard failures may lead to a non-compliant frame content for which even Reed Solomon (RS) decoding may be impossible. The RAF service is then the only service still granting access to the telemetry for diagnosing the onboard problem.

- ***Return Channel Frames (RCF)*** **-** this service delivers Channel Frames from one Master Channel. Only good frames can be provided using this service.

On the forward service the following service will be provided:

- ***The Forward CLTU service*** **-** enables the user of the service to send Command Link Transmission Units (CLTUs) to a spacecraft, via an established forward space link channel. A forward space link channel is a physical channel carrying an asynchronous stream of CLTUs.

Pending implementation of SLE services at ESA stations, ESOC is developing a SLE gateway. This uses existing station back-end equipment for separate service production with service provision based on re-use of ESA's SLE API package and element of ESA's NCTRS (the system used to interface the control centre to the station network or SLE provider). This gateway is used to offer SLE based services from ESOC ground stations.

CONCLUSION

At the time of writing this paper the last tests between ESOC and JPL are running and after these tests are completed the SLE is ready for Launch of Integral current scheduled for 17th October 2002.

The paper has presented an overview of what is needed to make SLE operational. In general the conclusion is that that the effort needed for SLE is comparable to other systems of the same complexity. Clearly such an activity must be carefully considered and an implementation plan must be defined. For SLE it is possible to integrate this into existing operational systems and this has successfully been done at ESOC. For SLE there are new concepts that need new systems one of the major ones is the SLE management and for this ESOC has taken a pragmatic approach by implementing ad hoc solution.

ESOC is committed to SLE and will initial be able to offer such services via a gateway. The final goal is to implement the SLE services at the ground stations.

We hope that the experience gained from this first implementation can be of help for other agencies that plans to provide SLE services or use such services and we see this first SLE operational system as a major step towards a global network of SLE providers and users.

REFERENCES

[1] M. Bertelsmeier, G.Buscemi, M.Butkovic, I.Mascaraque, N. Talbot, “EXCITE – The Migration of the ESA TTC Network to TCP/IP”, Proceedings TTC 2001, 29-31 October 2001, ESA/ESTEC, Noordwijk, NL.

[2] K.-J. Schulz, N. Bobrinsky, C. Lannes, K. Capelle, “ESA’s Approach to Stations and Communication Networks Interoperability”, SpaceOps 2002, Oct. 9-12, 2002, Houston, TX.[4]

[3] Wallace Tai (1) ,Paolo Maldari ,Wolfgang Hell.= KEY SYSTEM ARCHITECTURE ISSUES CONCERNING SPACE LINK EXTENSION (SLE) SERVICES . ESA TTC Network to TCP/IP”, Proceedings TTC 2001, 29-31 October 2001, ESA/ESTEC, Noordwijk, NL