Shaping a Generic Mission Control Infrastructure into a Multi-Mission System Tailored to Specific Operational Concepts

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Space Operations of DLR (*Deutsches Zentrum für Luft- und Raumfahrt*) provides support to DLR's various missions using its established operational concepts from its mission control centre (GSOC) located in Oberpfaffenhofen near Munich. On the level of system software infrastructure DLR cooperates closely with ESA, who shares its Mission Control System infrastructure with entities from its member states. DLR integrates this infrastructure into its operational elements for more than 10 years, benefiting from correctional, feature, and platform updates, but also feeding back its own upgrades.

This paper describes how the ESA provided mission control system infrastructure is embedded into the DLR infrastructure, and how the seamless integration of DLR's own infrastructure for live monitoring, archiving of telemetry and telecommand history, mission planning, near real-time processing of grouped packets as well as a configuration check (for identifying anomalies in spacecraft telemetry) is achieved in an efficient way for the current DLR missions. Furthermore an outlook is given on the developments that are planned to meet future needs of DLR missions like AsteroidFinder and TerraSAR-X II.

I. History of the DLR SMCS

A. Early days of SCOS-2000 at DLR

Until the end of the last century different mission control systems have been used at GSOC – the German Space Operations Center of DLR. Economic aspects lead to a change in the early 2000s with the aim to use a single software solution providing an integrated Telemetry, Telecommand and Display system. The following goals should be achieved:

- reduction of operational costs provided by a standard software and hardware platform for all scientific and LEOP support missions,
- significant reduction of long term maintenance costs and costs for the implementation of new missions,
- support of new hardware and software platforms
- scale-ability of a system for small to big mission,
- simple adaption for specific mission requirements,
- support of ESAs PUS and CCSDS standards.

ESA's mission control system SCOS-2000 has been identified as one product that was fulfilling the goal above. The selection of SCOS-2000 was chosen due to its rich set of functionality, its modular architecture, and because it was available for DLR free of charge due to SCOS-2000's open license policy when it is used within an ESA member state.

SCOS-2000 was first tested in the scientific mission CHAMP (Challenging Minisatellite Payload). At that time the CHAMP spacecraft was already launched (on 15 July 2000) and the control was performed with a VMS based system. While the mission was mostly CCSDS compliant, there were several peculiarities that required the adaption of SCOS-2000 to fit into the CHAMP ground segment:

- converting the pre-existing CHAMP MIB (Mission Information Base) both for TM and TC to SCOS-2000,
- supporting the validation of the generated MIB
- converting command files from ODL (Operations Definition Language) into SCOS-2000 Saved Stack Files
- considering CHAMP specific data structures and data flows
- implementation of specifics to GSOC's Operations Concepts like the configuration check, which validates the status of the spacecraft based on rules

This work resulted in a reliably working CHAMP system operating in a hybrid configuration (Solaris on the servers, inexpensive Linux for client machines). SCOS-2000 has successfully proved its efficiency in flight operation to become the baseline for all new satellite missions operated from GSOC. SMCS has been defined as name for this system (Satellite Monitoring & Control System).

B. Follow up Missions for DLR's SMCS

The next mission planned for DLR's SMCS was GRACE (Gravity Recovery And Climate Experiment), a twin satellite mission which performs detailed measurements of Earth's gravity field. Similar to CHAMP also GRACE was launched with a different control system than SCOS-2000 (on 17 March 2002). Some specifics of GRACE showed that it would take serious effort to fully implement the required SCOS-2000 enhancements. Therefore the SMCS adaptations for GRACE were stopped and work concentrated on the next mission.

This mission was TerraSAR-X, an earth observation mission for X-band SAR-data. During the development of the spacecraft it was possible to consider in the onboard architecture some concepts of DLR's SMCS. This leads to an overall system where the spacecraft optimally first to the Mission Control System.

SCOS-2000 has not only been used for routine operations but also for AIT (Assembly Integration and Testing) and LEOP. There are several advantages of such a multi-purpose use:

- the MIB can be re-used in all phases of the spacecraft lifecycle
- the mission control system is already tested during the checkout phase
- the operational knowledge can be shared between spacecraft manufactures and spacecraft operators

ESA was working at that time for a similar approach –the checkout system and mission control system for the space observatory spacecrafts Herschel & Planck. Because some of the industrial companies have been working in parallel for TerraSAR-X and Herschel & Planck, it was possible to share a lot of synergy. Finally only DLR was able to keep the approach for TerraSAR-X of using a single system during the whole life cycle of the spacecraft.

For TerraSAR-X several new applications have been developed (e.g. Onboard Event Display, Telecommand Acknowledge Display) and a standard pattern has been identified, how to adopt the DLR SMCS for new missions: adopt the TM Packetiser, the TC Releaser, the Onboard Queue handling, and the Time handling but try to keep the rest of the system unchanged.

An additional challenge of TerraSAR-X was the specific operations concept for data security. It required the development of special add-on components to SCOS-2000 that are used during the operational mission phase. These components share technology with SCOE (Special Checkout Equipment) systems. TerraSAR-X was launched on 15 June 2007 and it is still operational.

The forth usage of the DLR SMCS is Satcom-BW (satellite based communication), a twin satellite mission for the German armed forces (Deutsche Bundeswehr). The first satellite COMSATBw-1 has been launched on 1 October 2009 and the second satellite COMSATBw-2 has been launched on 21 May 2010. Architectural details of the SMCS used in Satcom-BW are not publicly available due to the military nature of this mission.

The last spacecraft that has been launched with the DLR SMCS was TanDEM-X (TerraSAR-X add-on for Digital Elevation Measurement). TanDEM-X is a twin satellite to TerraSAR-X with a very similar architecture. The checkout system for AIT has been partly re-used from TerraSAR-X to TanDEM-X and the mission control system deployment has been done in a way that parts of the mission control system elements are shared between TerraSAR-X and TanDEM-X. In this sense the DLR SMCS has become a true multi-domain system.

From a scientific point of view the TerraSAR-X and TanDEM-X formation is an interesting mission, as the two spacecrafts build the first configurable SAR (Synthetic Aperture Radar) interferometer in space with a separation of only a few hundred metres. TanDEM-X has been launched on 21 June 2010.

C. Near future of DLR's SMCS

At the time of writing this paper, the next mission with DLR's SMCS is close to the LEOP: TET-1 (Technologischer Erprobungsträger) shall be launched in October, 2012. The satellite is equipped with 11 technology experiments to be tested in orbit during the TET-1 mission. It will allow industry and research institutes the on-orbit verification of new and innovative satellite technologies.

D. Releases of the DLR SMCS

Baseline for the DLRs SMCS in year 2000 was SCOS-2000 Release 2.1e. The figure below shows the evolution of the system until today:

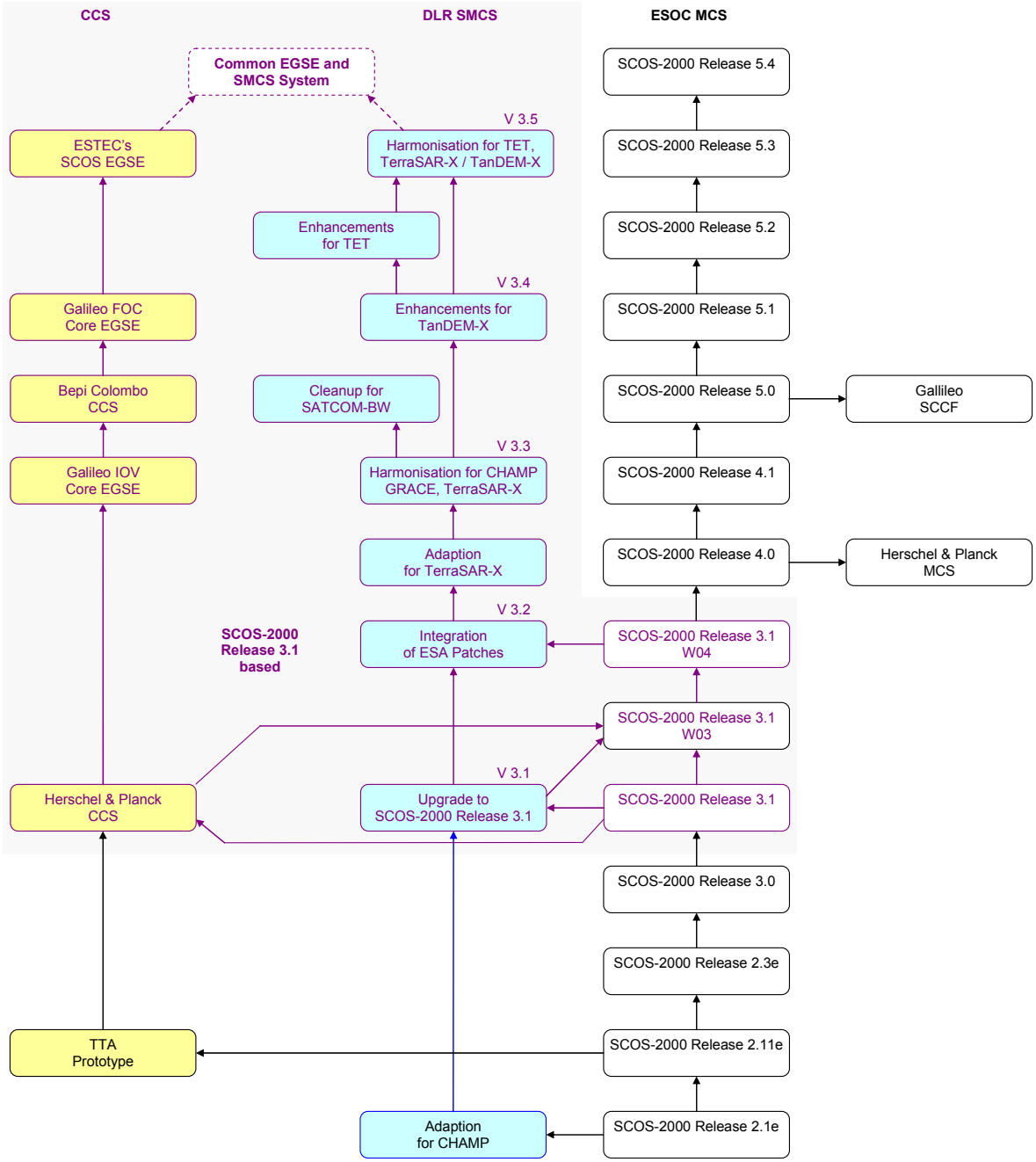

Figure 1. Releases of the DLR SMCS and of SCOS-2000.

The blue boxes in the middle of the figure are the SCOS-2000 versions of the DLR SMCS. All these versions (except the initial one) belong to the big SCOS-2000 Release 3.1. As shown in the figure, also the SCOS-2000 based checkout system (CCS) versions are members of the SCOS-2000 Release 3.1 family. The reason for this situation was the following: Starting with Release 4.0 the SCOS-2000 MCS core development at ESOC was driven from the multi-domain requirements of Galileo SCCF (Spacecraft Constellation Control Facility) that were not needed for the DLR SMCS and for the CCS systems. So these development lines remain in the SCOS-2000 Release 3.1 family.

II. Special features of the DLR SMCS

The DLR SMCS provides some unique features that are discussed in this chapter.

A. Parallel Support of Groundstation interfaces, EGSE interfaces, and Payload Analysis Equipment

As described in the previous chapter, the DLR SMCS can be used for checkout and for mission control. It allows parallel usage of the NCTRS (Network Controller and Telemetry Router System) protocol to ground stations, the TerraSAR-X EGSE (Electrical Ground Support Equipment) protocol to checkout equipment, and Payload Analysis Equipment that consumes telemetry packets.

- During the checkout phase this can be used to test the spacecraft and the ground segment in parallel.
- During mission control this can be used for monitor/control of a spacecraft and for ground segment equipment in parallel.

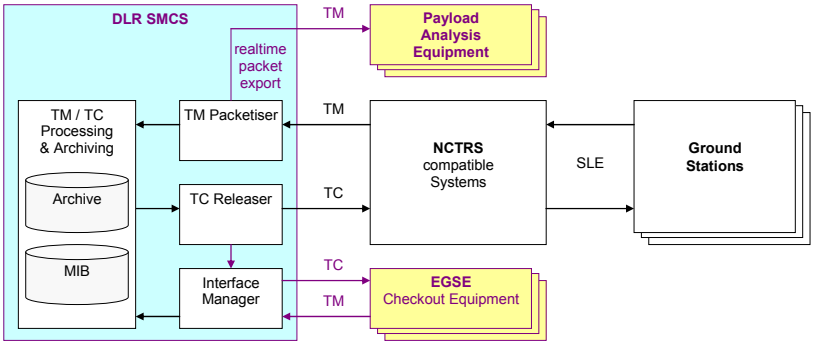

Figure 2. Parallel Support of Groundstation and EGSE interfaces.

The Interface Manager component can be simply adopted for new missions to support other EGSE protocols than the one for TerraSAR-X.

The *realtime* packet export can be used to support external system that consumes telemetry packets. Such systems are special SCOEs, GPS receivers, or payload analysis application.

B. Support for the monitoring system SATMON

SATMON is a commercial MS-Windows based spacecraft monitoring system. It is very well integrated into the DLR infrastructure and used for nearly all missions at DLR. At the time SCOS-2000 has been introduced at DLR one requirement asked that SCOE-2000 telemetry data shall be available also in SATMON. This has been solved on the SCOS-2000 side by exposing telemetry data and limit check data through the CORBA based external interfaces (EXIF) and on the SATMON side via reception of these data through a special gateway that distributes the telemetry and limits inside the SATMON system.

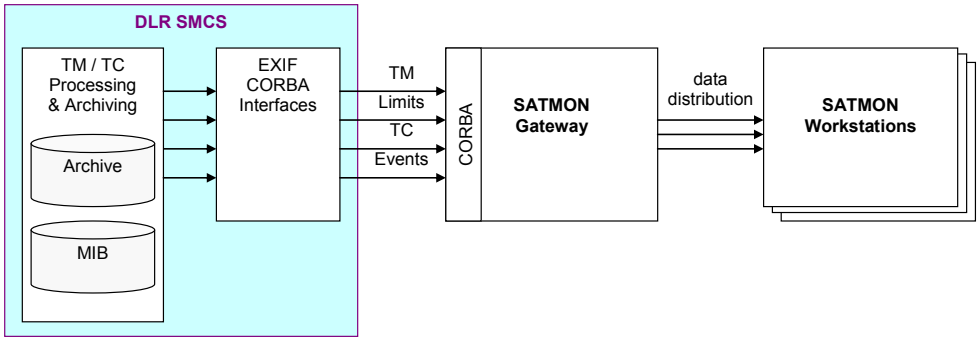

Figure 3. Interface to SATMON system.

During the evolution of the DLR SMCS further data types are exported to SATMON: telecommand data, SCOS-2000 events, and the status of the SCOS-2000 command stacks.

C. Command Supervisor

Especially during the LEOP it is important for the telecommand spacecraft controller to know in advance what kinds of telecommands are prepared by the operators. The traditional system at DLR uses a video switch system to support the monitoring of the commanding workstation displays. The disadvantage of this system is, that only on screen at a time can be monitored. The CSUP (Command Supervisor) has been developed to support command stack monitoring in an improved way.

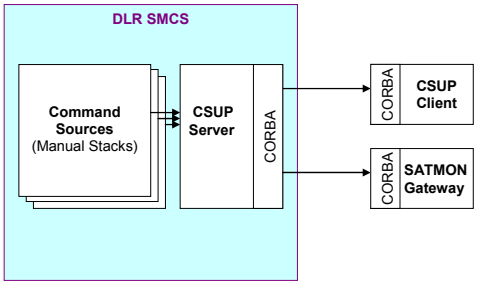

Figure 4. Command Supervisor.

All command stack displays are frequently polled by the CSUP Server and the telecommand spacecraft controller can pick up the status of the stacks in parallel – either from the CSUP Client application or from the SATMON system.

D. Product Print

During a spacecraft passage a lot of data are collected by the SMCS. Some of these data are provided to external systems for monitoring. The DLR SMCS supports this with the product print application:

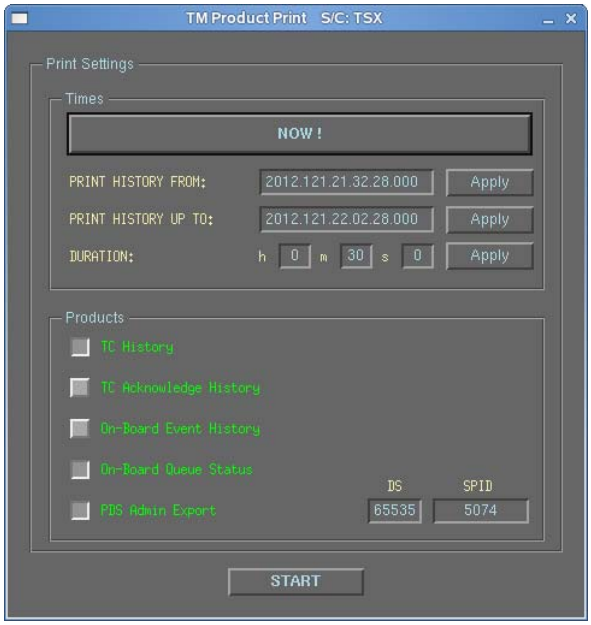

Figure 5. Product Print GUI.

The operator marks immediately before the pass the start time. After the pass the operator marks also the end time. In a second phase the tool tries to figure out from the telemetry data inside this period, when data have been

processed by the SMCS. All archived data from this interval are then extracted and written into export files at a pre-configured export-location with special file naming conventions. The files are then fetched by external applications from this place. Filters are provided to limit the export data when needed.

III. Future of the DLR SMCS

There are some activities in progress and some activities planned for the DLR SMCS to consider the needs for future missions:

- **Performance Improvements**
  New missions like TerraSAR-X-2 will require significant higher performance from the mission control system than it is for the recent missions. Higher data rates – both on the telemetry and on the commanding channels are expected. Some experiments have been performed to identify the performance bottlenecks. The results will be used to optimize the system.
- **Automated Regression Testing**
  Lot of components of the DLR SMCS are validated via manual testing, which is time consuming. Automated test procedures for the system validation are planned to speed up the test process.
- **Support for new Operating Systems**
  The Operating System baseline of the DLR SMCS is the one that has been defined by SCOS-2000 Release 3.1 - SuSE Linux 8.2 and Solaris 6. Both OS versions are not maintained anymore and there is no support for new computer hardware. The system has been ported in the meantime to SuSE Linux Enterprise Server version 10 (SLES 10) and the Solaris platform support has been dropped from the SMCS system. SLES 10 provides sufficient support for the recent computer hardware but the release is old. Successfully tests showed that a migration to SLES 11 is possible.
- **New Commanding Clients**
  A new commanding client system has been developed in cooperation with CAM that is close to finalisation. The newly designed application is an integrated manual commanding desktop and shall replace the original SCOS-2000 Manual Stacks. The application has a modern graphical user interface developed with the Qt framework and it support parallel command stacks and nested command sequences.
- **New User Interface for all Client Applications**
  The existing client applications of the DLR SMCS are developed with the C++ library IlogViews. This library is expansive and in the meantime badly maintained. There are plans to replace the presentation layer of the client applications by implementations based on Qt. The system shall also be compatible with the new commanding clients.
- **Harmonisation with ESTEC's SCOE EGSE**
  As shown in figure 1, the DLR SMCS and the CCS systems form a common family that is based on SCOS-2000 Release 3.1. After the development of the Herschel & Planck CCS the DLR SMCS and the CCS line have been developed into different directions, driven by the operational needs. A harmonisation between both version lines would allow using new features from one system in the other system like the new SQlite based archive, test procedure wizards, regression test suites, improved telemetry processing or the new command stack.

IV. Conclusion

The SMCS is a mission control and checkout system that fits perfectly to the recent needs of DLR. The new applications that have been developed as extensions to the SCOS-2000 baseline provide an important support to the DLR operations concept. Activities that are either in progress or planned will help to keep the system up-to date for future missions and future developments in the European context. It will help keeping DLR's SMCS as a corner stone of the ground system infrastructure for the following years.