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The evolution of the EDRS control centre for automated operations of EDRS-C

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Abstract

The European Data Relay System (EDRS), also known as SpaceDataHighway, provides high speed data links between ground stations and satellites in low earth orbit. The SpaceDataHighway is a public–private partnership between the European Space Agency (ESA) and Airbus, with the laser terminals developed by Tesat-Spacecom and the DLR German Space Administration. Commercial services for the SpaceDataHighway are provided by Airbus, which owns the System. The satellites' operations of EDRS are conducted by the German Space Operations Centre (GSOC) at Oberpfaffenhofen. In January 2016 the first node EDRS-A has been launched and is in routine operations since mid-2016. Presently, up to 400 links per day are commanded by the ground-system established at GSOC via EDRS-A only. This high command load is beyond the capabilities of a classical operational concept with manual operations. Therefore, an automated system has been implemented at the so-called Devolved Payload Control Centre (DPCC), with human interaction only necessary in case of an anomaly either in the ground processing or the space segment. EDRS-A is realized as a hosted payload on the Eutelsat 9B satellite, and therefore the platform operations are carried out by Eutelsat's control centre in Paris. In August 2019, EDRS-C, the second satellite of the system has been launched. Since EDRS-C is now the first entire satellite dedicated to the SpaceDataHighway mission, the control centre at GSOC has to be capable of not only operating the EDRS payload, but must take care of the entire satellite operations, which comprises additionally a hosted communications payload owned by London-based satellite communications operator Avanti. The DPCC ground segment was designed to be independent of the particular spacecraft platform. This is realized via a layered system architecture centred on the core Monitoring Control System (MCS), with layer 1 consisting of the commanding front-end and automation engine, while layer 2 comprises the Link Management System (LMS) and interface to the external ground segment partners. This layered architecture has been designed to ensure a seamless phase-in of EDRS-C, with no software changes required for layer 2 and only minor upgrades to components of layer 1. Differences in the platform shall be masked through the versatility of the core MCS. This paper will present the evolution of the DPCC system for EDRS-A to the Satellite Control Centre (SCC) for EDRS-C. While an utmost reuse of heritage components has been basis for the system design, the actual arrangement of the components had to be revised after an assessment of the DPCC's performance.

Keywords: European Data Relay System (EDRS), spacecraft operations, automated operations, SpaceDataHighway

Abbreviations

DPCC	Devolved Payload Control Centre
DSSS	Dynamic Satellite Simulator System
EDRS	European Data Relay System
GCU	Ground Crypto Unit
GSOC	German Space Operations Centre
LCT	Laser Communication Terminal
LMS	Link Management System
MCS	Monitoring and Control System
MIB	Mission Information Base
MOC	Mission Operations Centre
SCC	Spacecraft Control Centre
TC	Telecommand
TM	Telemetry
TT&C	Telemetry, Tracking, and Command

1. Introduction

The European Data Relay System (EDRS), also known as SpaceDataHighway, is designed primarily to both reduce the delays in transmission of data from low earth orbiting satellites and also to vastly increase the amount of data transmitted over a given period. The system is composed of two geostationary satellites positioned over Europe for in-orbit redundancy. The first (EDRS-A) is realized as a hosted payload on Eutelsat's EB9B satellite and has been launched in January 2016. The second (EDRS-C) is a dedicated spacecraft based on the SmallGEO platform developed by OHB System launched in August 2019. Both satellites are equipped with a Laser Communication Terminal (LCT) by Tesat-Spacecom to provide high speed optical links of up to 1800 Mbit/s. In addition, the EDRS-A satellite carries a Ka-band inter satellite antenna to establish links to LEO satellites or the International Space Station. Both link types are using common RF equipment to relay the received data to the ground via Ka-band.

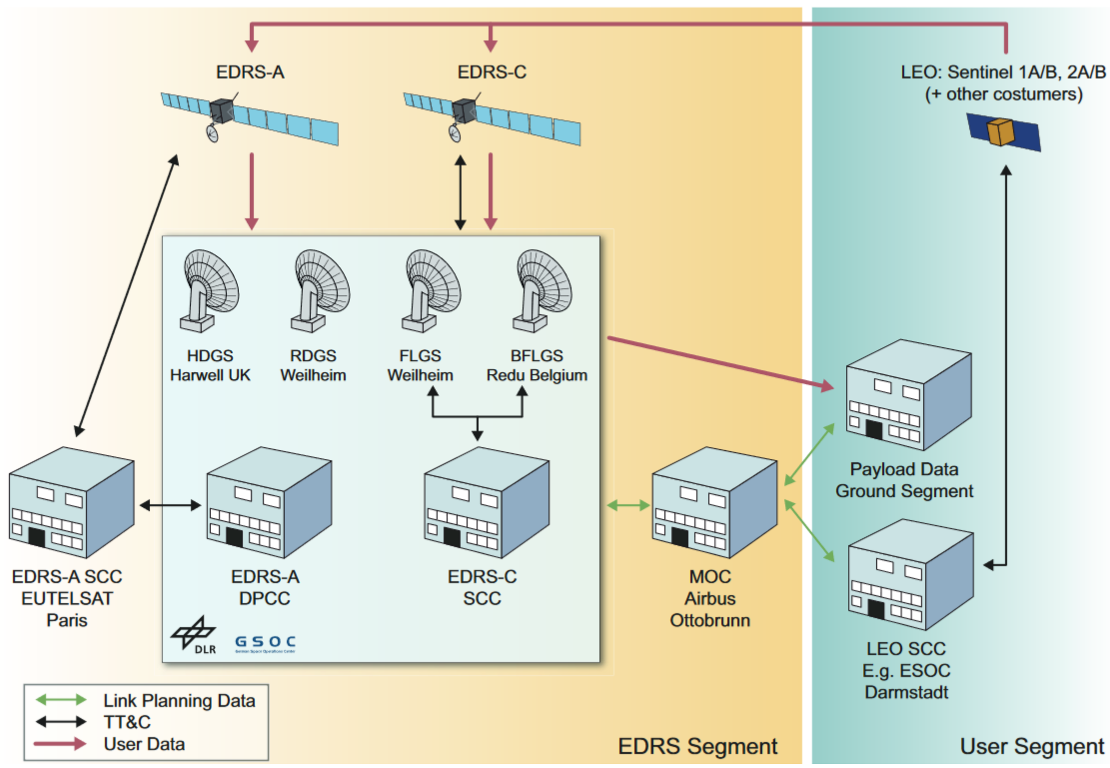

Figure 1. EDRS system overview

The central part of the EDRS ground segment shown in Figure 1 is the Mission Operations Centre (MOC) located at Airbus Defence and Space. It interfaces with all other components and coordinates the overall mission. The MOC receives the link orders which are requests for data transmissions between the LEO satellites and EDRS-A or EDRS-C from the different users. It schedules the mission timeline for both EDRS satellites taken all known constraints into account and sends requests for the scheduled links to the German Space Operations Centre (GSOC). Within the scope of GSOC, four ground stations based at Harwell, Redu, and two at Weilheim are part of the system. These ground stations receive the user data from both EDRS satellites and deliver the data to the users as well as being used for the telemetry, tracking and command (TT&C) link to EDRS-C.

The Devolved Payload Control Centre (DPCC) is responsible for operating the EDRS-A hosted payload. A file-based interface with Eutelsat's SCC, which is operating the EB9B satellite, is used for commanding. The telecommands of typically one flight operations procedure are combined into one TC set file, transferred to the SCC in Paris, and released within Eutelsat's commanding system. For monitoring, two separated telemetry streams are received within the DPCC. One forwarded by the Eutelsat SCC, including all satellite telemetry, and one received at an EDRS dedicated antenna containing only LCT related data. The system is designed to perform up to 400 links per day, 200 with the optical LCT channel and 200 via the steerable Ka-band inter-satellite antenna.

Such a high command load combined with a required on-board autonomy of eight hours and a capability for late requests is beyond the capabilities of manual operational concepts. Only with the assistance of automated systems these high demands can be economically fulfilled. For the DPCC an automatic command and control system to operate the EDRS-A payload in its routine operations phase has been developed. This innovative system commands the payload during nominal conditions entirely without human interaction.

The EDRS-C satellite on the other hand is dedicated to the EDRS mission. It is equipped with an LCT identical to the EDRS-A equipment, but no Ka-band inter-satellite antenna. In addition, two hosted payloads are embarked on-board the spacecraft: the Hylas-3 communications payload owned by London-based satellite communications operator Avanti as well as the Next Generation Radiation Monitor (NGRM) experiment of the European Space Agency. For the EDRS-C operations a Spacecraft Control Centre (SCC) has been established at GSOC, not only executing the payload operations but controlling the entire spacecraft. For this, the design of the DPCC's components has already been developed with the reuse for the SCC in mind. The main drivers in the design of the ground segment can be summarized as follows [1]:

- A single system design for the control centre, applicable to both EDRS-A and EDRS-C, despite the differences in satellite platform and commanding concepts.
- Fully autonomous routine operations to manage the high level of payload utilization, with no need for continuous operator supervision.
- Seamless integration in the existing multi-mission environment and reuse of already available software components, as far as possible.
- Ease of system updates and maintenance without service interruption over the complete operational lifetime of 15 years.

In chapter 2 of this paper the basic design of the SCC will be presented, including the different abstraction layers on which the shared components are based on. It will specify the differences between DPCC and SCC, within the reused components as well as the need of different components. In chapter 3 the redesign of the redundancy concept within the control centre will be detailed. As the redundancy concept of the DPCC based on different independent chains has not shown the desired flexibility, the concept has been significantly changed for the SCC.

2. Flight Operations System Design

The design of the EDRS-A DPCC has already taken into account the most possible re-use for the implementation of the EDRS-C SCC. For that, the system has been designed with components in two categories: Category 1 (shown in blue within the SCC in Figure 2) are components that have to undergo implementation changes or are new in the SCC while category 2 (shown in green in Figure 2) are components that only require configuration changes to be used either in the DPCC or the SCC.

2.1 Category 1 components

GECCOS MCS

The main functions of the Monitoring and Control System (MCS) are the encoding and transmission of TCs (either to the ground station during real operations or to the Dynamic Satellite Simulator System (DSSS) during simulations), and the reception, processing and monitoring of incoming TM data from the correspondent source. It also has to provide data interfaces to other applications and components. TM (raw data) is received and processed by the MCS. The contained raw TM parameters are encoded and, in case required, calibrated and checked for limit violations. Additionally parameters derived from TM (synthetic parameters) are calculated and made available. All relevant definitions are obtained from the Mission Information Base (MIB).

The MCS to be used at the SCC is the DLR-SMCS "GECCOS" (GSOC Enhanced Command & Control System for Operating Spacecraft) which is based on ESA SCOS-2000 [2]. While most other components of the SCC are based on the heritage of EDRS-A, GECCOS has been adapted and used in the HAG-1 mission operated in LEOP and IOT by GSOC. This mission uses the same spacecraft bus "SmallGEO" by OHB System. With this adaption being proven through the HAG-1 mission it has been favoured to extend the system in some aspects to the peculiarities of the SCC's operations instead of adapting the DPCC's MCS to the peculiarities of the EDRS-C spacecraft.

Automation Engine

The Automation Engine provides an automation front-end to the core MCS. It assists the operator in routine operational tasks and enables the SCC to autonomously process payload configuration requests received from the MOC. Its main function is to keep track of flight operational procedures sent to the S/C via the MCS and to verify their successful execution. Additionally, the Automation Engine retrieves and monitors telemetry from the MCS, providing real-time data to other ground-segment services in order to ensure their functionality. The retrieval of telemetry can be periodic, scheduled via flight procedures or triggered by events and operational scenarios, e.g. the generation of reports for each link session.

While a similar implementation consisting of two separate components is used in the DPCC the functionality is combined into a single component at the SCC. With the experience gained during EDRS-A, it was possible to take the first step into operations based on the execution of procedures within one tool, providing the capability of automated execution as well as semi-automatic execution [3]. The resulting Procedure Tool Suite (ProToS) [4] is used as the Automation Engine in the SCC. It provides an increased flexibility and usability compared to the setup of the DPCC.

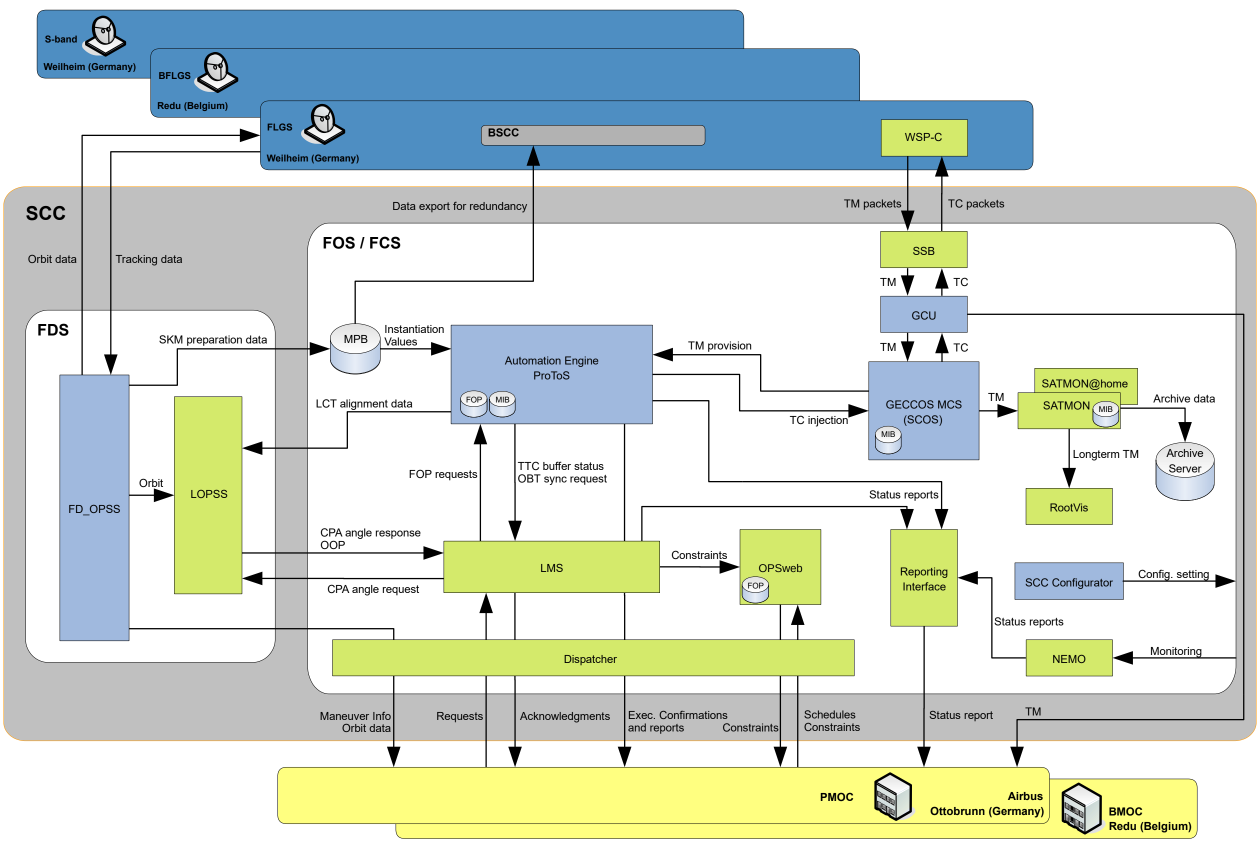

Figure 2. EDRS system architecture

SCC Configurator

A central component called SCC Configurator supports operators and administrators in monitoring and configuring the SCC environment. It provides an overview over incoming requests and of all processing chains, and allows configuration of chain roles (active or simulation, more will follow in chapter 3). The functionality comprises:

- Setting of redundancy chain switches (SCC processing chain selection)
- Remote monitoring of Dispatcher component on each chain
- MOC request status overview on each chain
- Transfer directory status on each chain
- Injection of test files to simulate operational scenarios (single requests and complex test scenarios)

A similar tool, the DPCC Configurator, has already been implemented for EDRS-A but the significant changes in the redundancy design required a re-implementation of the tool.

2.2 Category 2 components

Link Management System

The Link Management System (LMS) is responsible for scheduling and management of configuration and deletion requests received from MOC [8]. It is based on the existing planning and scheduling software suite available at GSOC, together with EDRS specific interface components. More specific, the LMS accepts payload configuration requests, forward data requests and deletion requests from the EDRS MOC, schedules them on the timeline as well as archives them on the SCC archive. The LMS furthermore keeps track of the time tag TC buffer of the EDRS-C satellite and the uplink time budget and exports command files depending on the current available capacity. The LMS schedules additional routine procedures, such as on-orbit propagator uplinks and on-board time synchronization procedures. At all stages, corresponding report messages are generated that allow the MOC to keep track of the status of its requests.

The implementation of the LMS for both the DPCC and the SCC only differ in their configuration of the flight operations procedures to be used and the constraints of their interactions [9].

Satmon

Although GECCOS is offering a TM display user interface, the GSOC preferred solution is using an in-house developed product called SATMON. This application is jointly developed together with an external supplier. It is used in all GSOC missions as the telemetry user interface for distributing display information to workstations.

Any number of display pages can be opened in the application window. SATMON features an internal archive that allows instant access to data history including a replay function. Colour-coding is allocated to parameters to indicate current status. Alarm displays are a special type of alphanumeric display page which maintain lists of parameters whose values currently exceed predefined limits. Graphical plots are used to monitor the critical status of parameters against time. Historical values are held by the system for all data that appears on a time plot. Options allow the user to modify the history region visible on a particular page. Online scaling of the plots is also possible. The following features are additionally implemented to the standard display pages:

- Hot links provide fast access to display pages
- Desktop header and footer lines provide general parameters, which are relevant for all display pages
- Size and fonts of the display pages are scalable
- The display database can be located on a central server or it can be stored on the local workstation
- Snapshots of the actual pages can be stored on the workstation for later view
- Layouts of the screen can be saved and reloaded at start-up
- There is a function to record playback of the telemetry data
- Display pages can be edited by authorized persons in the central database. A feature is implemented to get a quick information of all characteristics and location of a desired parameter
- Monitoring of GECCOS components, e.g. the command stack and the TC history can be displayed

On-call personal from outside of the SCC operational environment can access the telemetry via the satmon@home feature. This feature of SATMON allows access to the TM close to real time. It is an authenticated and encrypted connection over Internet.

Dispatcher

The Dispatcher is the interface component controlling all workflows between the SCC and the MOC. It is controlling all incoming and outgoing communication and taking care of the workflows' sequence counters and messages' validity. Two separate instances of the Dispatcher are actively connected to the MOC serving both the SCC and the DPCC, and managing their own set of message counters. Messages are received in dedicated SCC input folders and sent to dedicated SCC output folders. Additionally, their source and destination tag, which is contained in every message, takes either "MOC", "DPCC" or "SCC" as values. With this, the software is based on the identical implementation for both.

OpsWeb

This component is an internal website that provides a centralized access to all mission information, many tools and documentation. Examples are Action Item tool, Project Calendar, Anomaly Reporting, Timeline, Constraints and Flight Dynamics Products access. The OpsWeb is widely used in most GSOC missions. It is accessible both from the offices and the control rooms. While most tools of the OpsWeb are generic over all GSOC mission, some specific tools for the EDRS mission have been added, e.g. for the handling of messages and requests exchanged with the MOC.

NEMO

GSOC uses its own monitoring and control system for IT infrastructure. It's called NEMO (NEtwork MOnitoring) but is not limited to network monitoring. NEMO is a highly modularised, component based distributed IT Infrastructure monitoring and control system. It is very flexible and highly configurable. It is used in GSOC to ensure reliable operations for most missions.

NEMO provides real time end-to-end monitoring available for the situational awareness of the SCC's operators [5]. It is monitoring all components of the SCC via probes on the dedicated machines as well as via messages provided by the components to NEMO.

Reporting Interface

The Reporting Interface is a web based status information providing the high level operational status of the SCC to the MOC. Input are gathered from NEMO concerning the status of the system components, from the LMS, concerning the current state of the timeline as well as from the Automation Engine, concerning some telemetry based information.

RootVis

RootVIS is used for offline analysis of mission telemetry data. It stores an archive of all telemetry received during the mission in an efficiently organized binary container format. Due to the space efficient format with fast access it is well-suited for long-term telemetry analysis. Pre-defined plots are produced in regular intervals. A flexible configuration syntax allows for easy setup of the desired plot contents and options. Several graphing modes are implemented, e.g. evolution of parameters over time, x-y plots, histograms or plots with a secondary time axis to spot periodic features in the data. The set of graphing modes can be enhanced to cater special analysis needs. The data can be processed through several algorithms before being displayed, e.g. an averaging algorithm to display a long time interval in a readable fashion. The engineers can supply additional implementations of algorithms to perform any kind of data analysis (e.g. change detection). RootVis is based on the ROOT framework published by CERN [6].

3. Redundancy Concept

The SCC system provides sufficient redundancy to ensure safe and uninterrupted operations of the EDRS-C payload and platform, even in cases of site emergencies, hardware failures, software upgrades and other maintenance.

3.1 General concept

The DPCC redundancy concept has been based on a three processing chain setup [1]. All three chains are set up identically and only one branch is needed to fulfil the functional requirements. In order to provide maximum redundancy and seamless operations, one chain is operational while one other chain is dedicated to be in hot-stand-by, ready to take over in case of hard- or software failure on the active chain. The third chain is used in the frame of simulations, tests and software upgrades. The chains are composed of stand-alone software components tied together by an automated file distribution system with minimum set of cross-connections between chains. Any implemented component has no information about the chain it is allocated to or the role of that chain. Since the communication between DPCC components is file based for the most part, redundancy switching is realized via the use of symbolic links in the file system. These links can be switched between actively populated directories and a dead directory. The central DPCC Configurator allows the operator to view and change the switch settings of all chains in a single step. This design of the DPCC's redundancy concept has proven its reliability over the years of EDRS-A operations, but also shown its drawbacks. Although the parallel processing in the operational and the hot-standby chain should theoretical provide identical results, small delays of file transfers in the magnitude of milliseconds generate deviations between the chains that need to be solved by human interaction. Especially in case of a maintenance on one chain while the other remains in operations generates these kind of deviations and the clean-up of the system after an update of a single component takes more time than the actual update.

In order to gain this flexibility the SCC chain setup has been separated into two different redundancy concepts on the telemetry and telecommand chains and on the processing chains as shown in Figure 3. The grouping is following a concept based on the context of the role the components are performing within the SCC. Three contexts are defined: The components currently performing the mission are composing the MIS context. Beside that, two contexts for simulation purposes are defined as SIM1 and SIM2. Each TM/TC chains as well as each processing chain can be configured to each context.

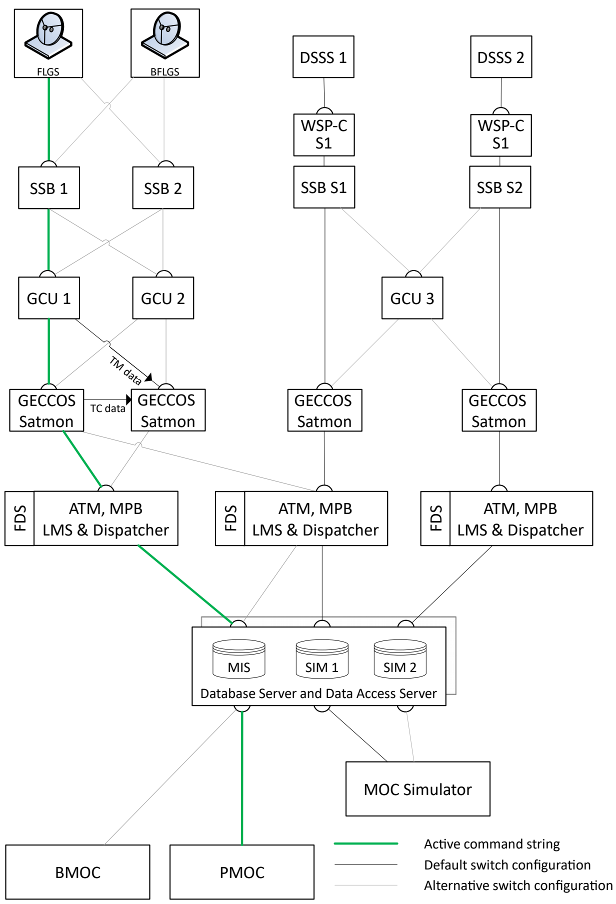

Figure 3: SCC chain setup

The configuration of these redundancies is conducted via the SCC Configurator tool. This tool provides a graphical overview over the current configuration of the SCC as shown in Figure 4. It verifies all possible connections between the redundancy parts and displays these via round lights in the graphical user interface. Further more it provides the possibility to change the configuration via drag-and-drop of the component groups within the user interface and performing the needed operations via command line tools in the background.

3.2 TM/TC chain redundancy concept

The TM/TC components group in the redundancy concept is build out of the MCS GECCOS with a fix connected SATMON server instance, represented by the GECCOS box in Figure 3, in a classical hot redundancy setup. Four independent TM/TC groups, numbered A to D, are available in the SCC. The group interfaces to the Ground Crypto Units (GCU) towards the ground stations with an NCTRS based TM/TC interface. The prime operational TM/TC chain (chain A in Figure 4) is connected to the GCU in TM and TC. The hot redundant chain (chain B in Figure 4) is connected to the GCU only receiving TM. With that, no interruption in the TM processing will occur in case of an outage of the TM/TC chain A. Only chain A is able to send telecommands towards the spacecraft. For the hot redundant chain B being able to take over immediately, the history of the sent telecommands is mirrored from the GECCOS in chain A to the GECCOS in chain B.

Beside the hot redundant setup of chain A and B in the MIS context, the chains C and D are configured for simulation purposes. Each has a connection to the Dynamic Satellite Simulator System (DSSS) and can independently be used. A third GCU is available for simulation purposes as well and can be used from chain C or D. In case of a major outage of the chains A or B, first chain C and finally chain D can be configured to act as prime or hot redundant chain within a short timespan.

3.3 Processing chain redundancy concept

The processing chains are using a very different redundancy concept. Three independent process groups, numbered 1 to 3, are available. Each of these groups is composed of an LMS, an Automation Engine, a Dispatcher, a

Reporting Interface and an MPB instance. Via the configuration files of the single components, the entire group is designated to be in MIS, SIM1 or SIM2 context. While the installed instance of the software is on a dedicated server, the runtime model of the components is not. The software loads its runtime model from a common data store, i.e. a database server set up as a high-availability cluster with two cluster nodes. The database server contains one database for every context and the software configuration determines which database is chosen from the data store. All file-based I/O operations are performed on a shared file server which is also set up as a two-node cluster. Identical directory trees exist for each context and the software configuration determines which tree is used for its file operations. The transfer of files from a software component's output directory to another component's input directory is realized via an automated file transfer. The use of a common data store for this tool chain allows a hot-redundant setup without designated backup servers. As a result, there is no need to sync the chains. Only one tool chain receives, processes and distributes operational products, while the other two chains may be used for tests and simulations. In case of a major issue on the process chain currently in MIS configuration, the impacted chain is disconnected from the database server using the SCC Configurator. One of the redundant chains is then stopped, configured via the SCC Configurator to be in MIS context, and brought back online. It will on start-up connect to the MIS context on the database server and connect to the interfaces of the TM/TC chain being in MIS configuration.

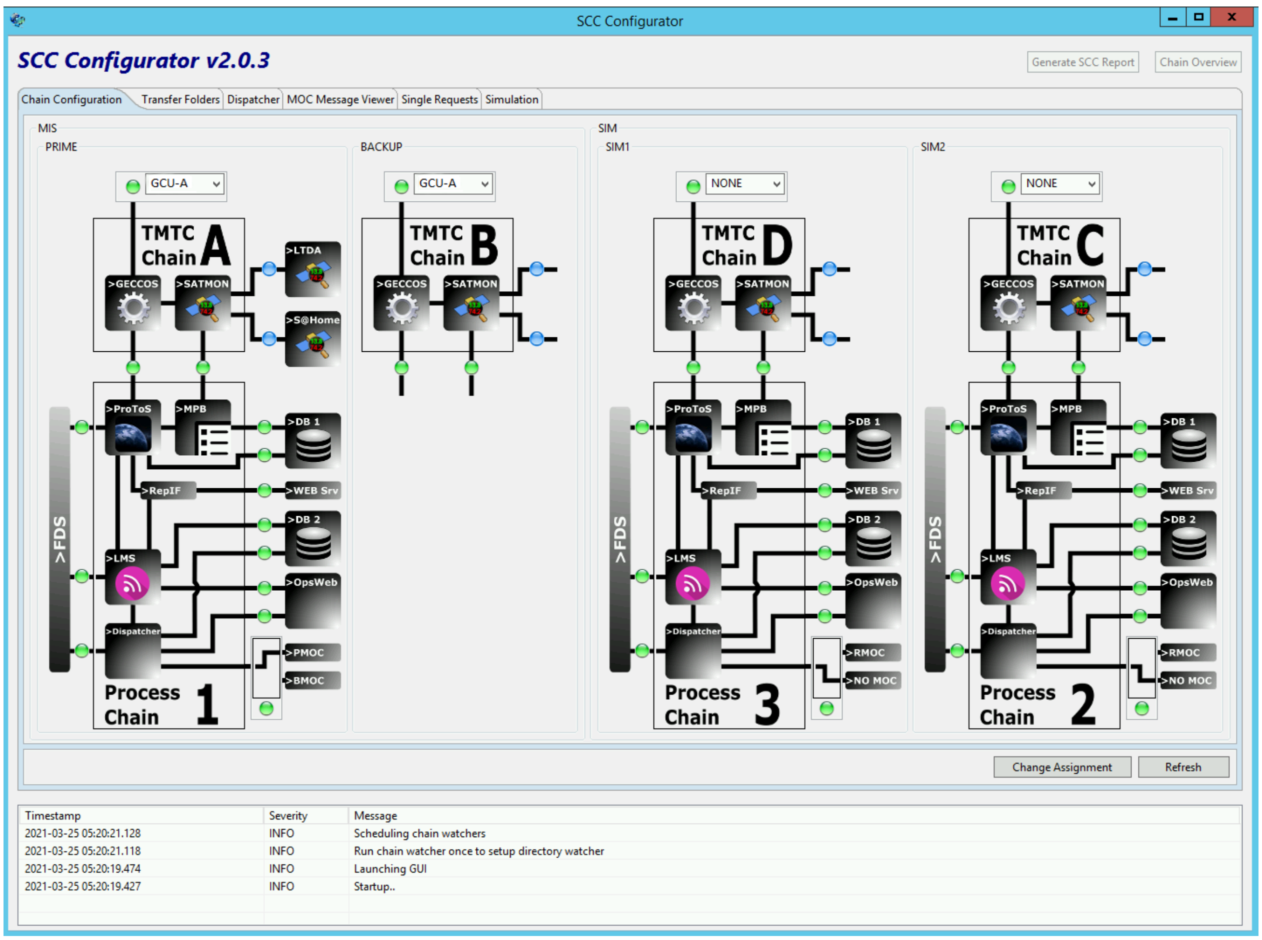

Figure 4. SCC Configurator

4. Conclusion

The EDRS mission poses challenges, on technical level for the ground segment as well as on the management level [7]. Although the design and implementation of the EDRS-A DPCC has been capable of facing the challenging operational concept by automating the main payload operations, the evolution to the SCC of EDRS-C presented in this paper marks the next step in automatization, flexibility and versatility. With the system presented, the SCC will further increase its grade of automatization on the spacecraft operations. With an additional focus on the automatization of the platform operations, the system will soon be used for the execution of station keeping manoeuvres without human interaction.

References

[1] Beck, T., Schmidhuber M., and Scharringhausen J.-C., Automation of Complex Operational Scenarios – Providing 24/7 Inter-Satellite Links with EDRS, AIAA 2016-2417, 14th International Conference on Space Operations, Daejeon, Korea, 16 – 20 May 2016.
[2] Stangl, C., Braun, A., and Geyer M., GECCOS - the new Monitoring and Control System at DLR-GSOC for Space Operations, based on SCOS-2000, AIAA 2014-1602, 13th International Conference on Space Operations, Pasadena, USA, 5 – 9 May 2014.
[3] Scharringhausen J.-C. and Beck T., Automated Procedure Based Operations for the European Data Relay System, IAC-17-B6.1.2, 68th International Astronautical Congress (IAC), Adelaide, Australia, 25-29 September 2017.
[4] Beck T., Schlag L., and Hamacher J., ProToS: Next Generation Procedure Tool Suite for Creation, Execution and Automation of Flight Control Procedures, AIAA 2016-2374, 14th International Conference on Space Operations, Daejeon, Korea,16 – 20 May 2016.
[5] Scharringhausen J.-C., Kolbeck A. and Beck, T., A Robot on the Operator’s Chair –The Fine Line Between Automated Routine Operations and Situational Awareness, AIAA 2016-2508, 14th International Conference on Space Operations, Daejeon, Korea, 16 – 20 May 2016.
[6] ROOT Data Analysis Framework, ROOT Team, https://root.cern/ (accessed April 1st 2021).
[7] Rossmanith G., Faller R., Bernonville S. and Schmidhuber M., EDRS-C – Challenging Way of Bringing the Second Orbital Node into Space, SpaceOps-2021,1,x1419, 16th International Conference on Space Operations, Cape Town, South Africa, 3 – 5 May 2021 (submitted for publication).
[8] Göttfert T., Grishechkin B., Wörle M., Lenzen C., The Link Management System for the European Data Relay System, AIAA 2016-2645, 14th International Conference on Space Operations, Daejeon, Korea, 16 – 20 May 2016.
[9] Göttfert T., Wörle M., Prüfer S., Lenzen C., Operating and Evolving the EDRS Payload and Link Management System, AIAA 2018-2688, 15th International Conference on Space Operations, Marseille, France, 28 May – 1 June 2018.