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GSMC-CC, a Ground Station Monitoring & Control System based on the European Ground System Common Core

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Abstract

The ESA Tracking Network (ESTRACK) ground stations are currently monitored and controlled by two M&C systems developed in the 1990s and facing obsolescence issues.

The GSMC-CC (Ground Station M&C - Common Core) replaces the previous systems with one leveraging newer technologies and frameworks already developed by ESA, making the GSMC-CC System the first operational product that is entirely based on the EGS-CC (European Ground System - Common Core) Kernel layer. The GSMC-CC system takes advantage of the flexibility of the EGS-CC architecture, replacing the EGS-CC Reference Implementation with a new layer of components that allow communication with the ground station equipment. This Work took into consideration constraints imposed by the legacy systems and infrastructure with the goal to fully exploit re-usability of over 10.000 procedures, as well as parameter and display definitions, developed over the years for configuring ESTRACK ground stations for spacecraft support.

It is the first time that Monitoring and Control Systems from the domain of Mission Operations, Spacecraft Assembly, Integration & Validation and Ground Stations will share the same software foundation, namely EGS-CC. This offers clear advantages, but also challenges. In this paper we will present, highlight, and discuss both aspects from a perspective of the GSMC-CC. From an operational perspective it is expected that the GSMC-CC will provide the required flexibility to drive ground station automation to a new level. At the same time the effort to prepare and maintain the automation shall be reduced.

One of the many challenges that the project is trying to overcome is the quality of the network link. The GSMC-CC system will be operated using a Web user interface developed using EUD (ECOS User Desktop) framework and the operators will access the system from the ESOC NOC (Network Operations Centre) exchanging the data through the WAN (Wide Area Network) link which has high latency and low bandwidth.

The system is still under development, but it is completed with the most advanced and required features to support routine operations. In Q2-Q3 2023 the system will be deployed in the Kourou ground station. This will only mark the beginning of a one-year long deployment phase where the rest of ESTRACK ground stations will be upgraded to use GSMC-CC.

Keywords: Ground-Station, M&C, Software, ESTRACK, EGS-CC, Operations

Nomenclature

None

Acronyms/Abbreviations

CDM	Conceptual Data Model
CSMC	Computer Station M&C
EGOS-CC	ESA Ground Operations System – Common Core
EGS-CC	European Ground System - Common Core
EKSE	EGS-CC Karaf Shell Extension

EMF	Eclipse Modelling Framework
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTRACK	EGS-CC Karaf Shell Extension
EUD	ECOS User Desktop
FEC	Front-End Controller
GSMC-CC	Ground Station Monitoring & Control - Common Core
GSMC-K	Ground Station Monitoring & Control – Kourou
KAL	Kernel Abstraction Layer
M&C	Monitoring & Control
MCI	M&C Interface
NOC	Network Operations Centre
OPEN	OPEN Preparation Environment
OPEN-S	OPEN – Station
POC	Proof of concept
STC2	Station Computer 2 nd Generation
TDM	Tailoring Data Model
TTCP	Telemetry Tracking and Command Processor
UI	User Interface
WAN	Wide Area Network

1 Introduction

1.1. Legacy Systems

1.1.1. Station Computer 2nd Gen – STC2

The STC2 development started in the 90s as a successor of STC 1, which was the M&C system of the ground stations. In 1998 the first operational deployment in Ground Stations was conducted and in 2002 - 2003 a major rework was done which included the following:

- Porting to Solaris 8
- The CMIS interface was changed to Corba
- For tailoring purpose, the ONTOS database was exchanged with a Versant database

In 2004, the Corba based Ground Station Subsystem Controller (GSSC) software was introduced and began to become the reference for most sub-systems under control of the STC. Following, in 2005 an Eclipse based editor called OTTO was introduced for tailoring support. The porting to Solaris 10 and the adoption of an XML based schedule was introduced in 2008.

For many years the system was not updated except for minor bug-fixing and maintenance. Only in the year 2020 the new concept of table-based loading/saving of variables introduced, also, in view to allow simpler migration of tailoring for future systems.

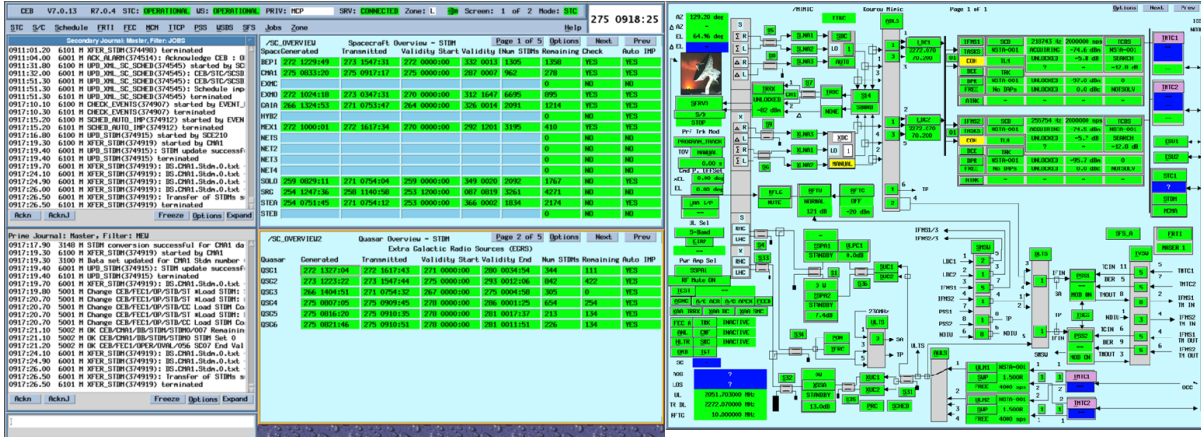


Figure 1: STC2 User Interface

1.1.2. Computer Station M&C – CSMC

The other system used only in the Kiruna ground station is called CSMC. It is a software written in QT and C++ and it was adopted instead of the STC2 due to its capability to support multi-antennas and multi passes. The main purpose of the CSMC system is, as its name states, to integrate and centralise the supervision and control in real time of the ground station equipment. It also provides tools for the management of the different types of information collected and generated by the system and the user (non-real time functions).

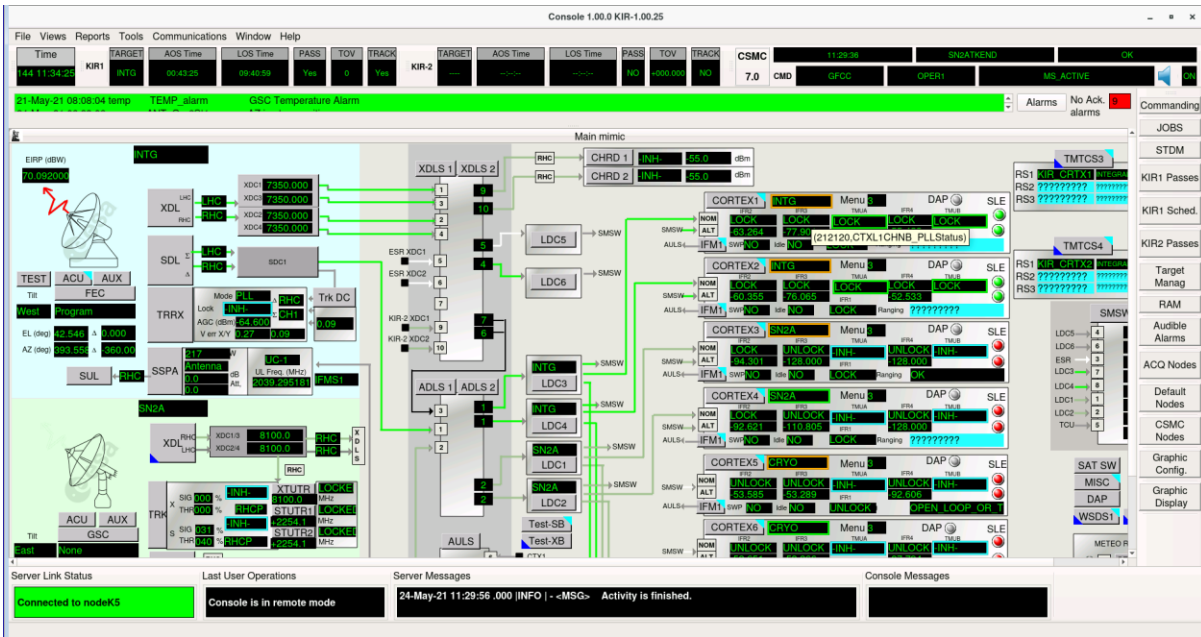


Figure 2: CSMC User Interface

It's worth noting that the CSMC system is not considered outdated. The reason for replacing it with the GSCM-CC is to standardize the M&C systems across ESTRACK ground stations and have a single software solution to support all operations.

1.2. Motivations

The obsolescence demonstrated by the systems currently used in the ESTRACK ground stations has pushed ESA to start a new project called GSMC-CC which aims to harmonise the M&C software for ground station operations. The software shall reuse the existing next generation frameworks such as EGS-CC and OPEN, respectively for the runtime online system and the offline preparation tool for tailoring data.

The GSMC-CC system is de facto the first project pushing the EGS-CC framework to be used operationally. It was decided to use the EUD framework to build a brand-new User Interface, instead of using the one provided by EGS-CC. The reason is that at the time the UI provided natively with EGS-CC was not easily extendable and it was based on Eclipse RCP without Web capabilities.

1.2.1. EGS-CC

The European Ground System Common-Core (EGS-CC) offers a generic and flexible monitoring and control framework that can be customised to support the monitoring and control of the ESTRACK ground stations. In support of this statement, ESOC has conducted a proof-of-concept activity called Ground Station Monitoring and Control - Kourou (GSMC-K). This activity has successfully proven the feasibility of implementing a series of extension components on top of the EGS-CC Kernel subsystem to cover the ground station M&C needs. EGS-CC is the new generation M&C system implemented by a consortium of European companies and Agencies to produce a highly configurable and generic framework that is able to monitor and control potentially anything. The software (currently at the very end of its consolidation phase) should be mature enough to cope with the complexity of ground stations.

The EGS-CC component architecture is very modular which makes it the perfect candidate to be used as an M&C system to replace both STC2 and CSMC. EGS-CC is a software infrastructure and framework that provides a Kernel layer, which comprises the core functionalities: support for generic monitor and control, automation, and archiving capabilities of M&C data. A system built on top of EGS-CC will have to combine any necessary domain-specific functionalities and interfaces with the EGS-CC Kernel layer.

1.2.2. OPEN-S

Every generic M&C system is based on an abstract model, referred to as tailoring data, which is often prepared offline. The GSMC-CC system is based on the EGS-CC Conceptual Data Model (CDM) - currently renamed to Tailoring Data Model TDM - that offers a common and extensible representation of the domain objects. The users therefore need a powerful offline tool to prepare and customise the tailoring data for each ground station to model every detail that the runtime system will have to monitor and control. The offline tailoring data tool OPEN-S was already partially implemented during the GSMC-K project and will be used as a starting point for the GSMC-CC activity.

OPEN-S represents the ground station data tailoring environment in the context of GSMC-CC. OPEN-S is based on the OPEN framework and several extensions covering domain-specific aspects – a high-level overview of the OPEN-S software composition are given in Figure 3.

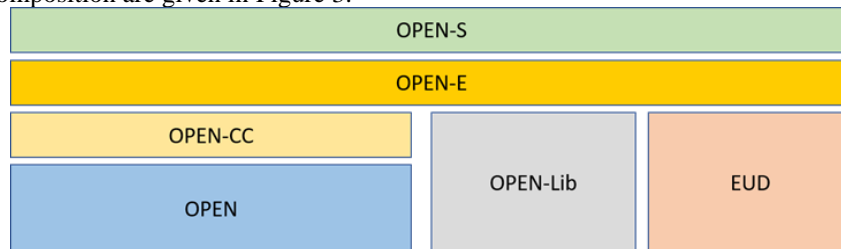


Figure 3: OPEN-S Framework and Dependencies

OPEN is a software framework for building data tailoring systems, which makes extensive use of the Eclipse Modelling Framework (EMF) and associated Eclipse frameworks and libraries for structured data modelling, editing, and analysis. The OPEN framework functionalities can be used with any EMF-based data model to develop associated data tailoring tools. Extensions for tailoring data support in line with the European Ground Systems Common Core (EGS-CC) Tailoring Data Model (TDM) and other EGS-CC related functionalities are added through the so-called OPEN-CC layer on top of the OPEN framework. Furthermore, OPEN-Lib includes a set of basic libraries, which have been extracted from the EGOS User Desktop (EUD) code base to support common concerns such as logging and log analytics and interoperability with EUD at the level of core functionalities and persistent

storage. In addition, EUD software components pertaining to the MIMIC designer, parameter displays, parameter export and EUD adapters are used, to support interoperability with the EUD, for example for User Defined Display (UDD) definitions and defining how parameters are shown on displays . The actual interoperability of the data tailoring environment with EUD is enabled through the OPEN-E layer, reconciling the OPEN(-CC), OPEN-Lib and EUD capabilities.

1.2.3. EUD based Web UI

The User Interface Framework (UIF) which is part of EGS-CC is being replaced by a custom-made Web UI, which will not be used in GSMC-CC. The reason is because the UIF component is not modular, hard to extend and most importantly it is not optimised to cope with the WAN connection constraints of the ground stations.

Instead, a frontend MMI based on the EGOS User Desktop (EUD) is utilised as a framework to build the user interface. The reason behind this is because the ESTRACK operators will have a minor impact in using the EUD interfaces since it is used at ESOC as display framework standard, instead of adapting to a completely new user experience by using a modern web application.

Within the scope of this project, a series of GSMC-CC specific displays and adapters are implemented, following an agile approach and the needs of the end-users of the system. It is important to highlight that the system is operated by the same users that have been using the STC2 and CSMC software for many decades. Hence, working together with them and reaching a high level of user friendliness of the MMI was a crucial part of this project.

Furthermore, the user will use an operation station with a 4K resolution monitor which will give for the first time a different perspective during operations. The idea is to replace four 1080p monitors with one 4K screen.

2 Material and methods

None.

3 Theory and calculation

The European Ground Operation System (EGOS) is the brand name for the ground data systems infrastructure applications managed at ESOC. For this reason, the new generation of applications based on EGS-CC has been named “EGOS-CC”. The main EGOS-CC Products and their constituent elements are shown in Figure 4 below.

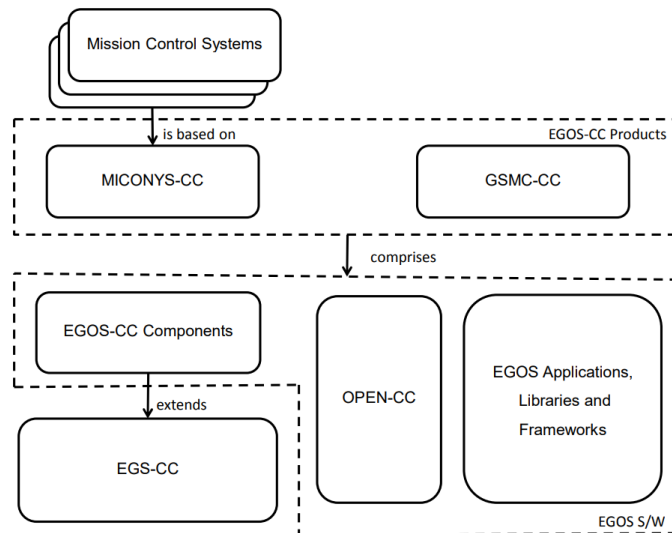


Figure 4: EGOS-CC Products

The GSMC-CC system appears among the EGOS-CC products, which was first introduced in 2017 [1].

1.3. Overall GSMC-CC Architecture

This section analyses top-down the overall GSMC-CC architecture, starting from the very high-level overview of the elements involved, ending up with the software components and their external interfaces to the various ground station equipment.

Every generic M&C system is based on an abstract data model to facilitate the creation of a concrete dataset which finally represents the states of the monitored system, referred as tailoring data, which is prepared offline. The GSMC-CC model is based on the EGS-CC Tailoring Data Model (TDM) that offers a common and extensible representation of the domain objects. OPEN-S represents the ground station data tailoring toolkit, allowing the creation of a tailoring data model, representing the equipment of the ground station in the context of GSMC-CC. OPEN-S is based on the OPEN framework and EUD and several extensions covering ground station M&C aspects.

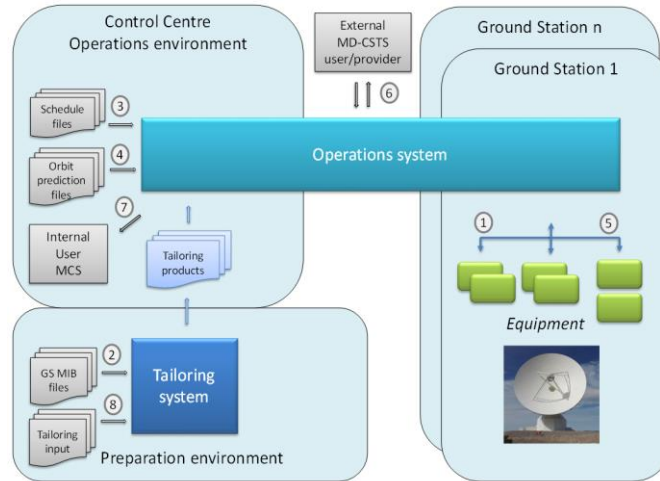


Figure 5: GSMC-CC Environment

The Figure 5 shows the GSMC-CC environment. The Operations system comprising the runtime environment has been split into GSMC-CC Kernel and GSMC-CC UI. The GSMC-CC Kernel is based on EGS-CC which offers a generic and flexible monitoring and control framework that can be customised to support the M&C activities of the ESTRACK ground stations.

The customization is usually done at several levels: it can be identified by custom tailoring data as well as software extensions that run on top of the existing OSGi components of the EGS-CC system. The GSMC-CC UI is not based on the User Interface Framework (UIF), nor on the new WebUI provided by EGS-CC. Instead, it is based on the EGOS User Desktop (EUD) framework, which has shown to be better adaptable for operational users at ESOC. Since EUD is an ESOC product that is already used on the Mission Control System side and other auxiliary systems, it gives the users an already familiar environment for operations.

The block Operations System (Figure 5) represents the core of the GSMC-CC software. The system is composed of several logical blocks that are meant to be deployed in dockerized images and run together to provide the necessary features to enable operations.

In the schema of Figure 6 the cyan blocks represent the auxiliary entities that are part of the GSMC-CC system, together with the various data archives (Zookeeper, PostgreSQL and File archive), while the grey blocks are simply representing the operator stations with the Web Browser instance that is used to access the GSMC-CC UI via HTTP protocol.

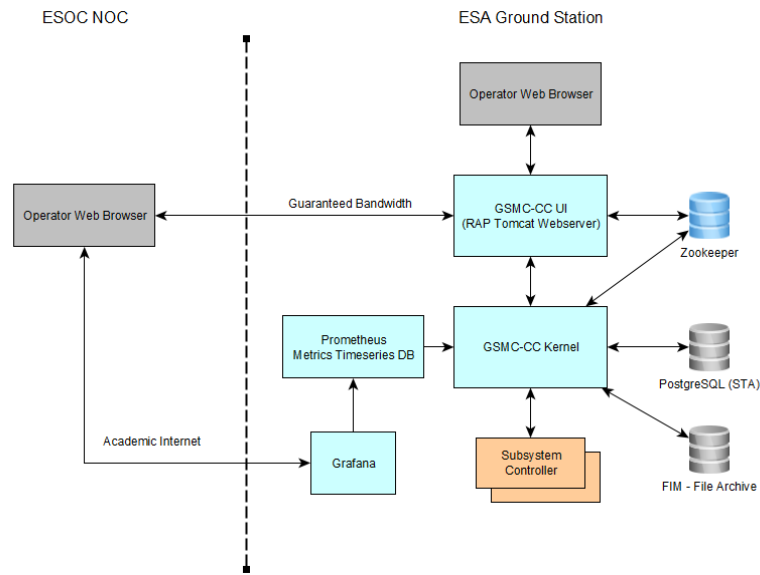


Figure 6: Auxiliary products and storage

The ESOC NOC users, as well as eventual software support, can also access the Grafana UI via Web Browser, which is able to show for every ground station the details of the hardware and software utilisation metrics. This is extremely useful when there is the need of troubleshooting issues in one or more ground stations.

Finally, the orange blocks in the diagram represent the subsystem controllers (the monitored and controlled ground station equipment) that are connected to the GSMC-CC Kernel layer via the M&C Interface (MCI) component.

Zooming-in even more, the Figure 7 shows a low-level design that illustrates components that are built on top of the EGS-CC Kernel, as well as the different interfaces with external systems. This represents the blocks GSMC-CC Kernel and GSMC-CC UI in the Figure 6 above.

The product deployed in each ground station contains the M&C adaptation components needed to communicate to the various subsystem controllers, via ESA M&C Interface and the Cortex-Interface. Both local and remote operations can be supported with the GSMC-CC UI (Web EUD based) as a user interface which is directly used by the ground station engineers and operators. The product contains the components as well for the handling of the schedule, driving the automated operations, the orbit/quasar predictions and more. The MD-CSTS provider component gives access to parameters and notifications to external users by means of the CCSDS CSTS Monitored Data Service (e.g., MCS). The tailoring products generated with OPEN-S are distributed to the different ground stations.

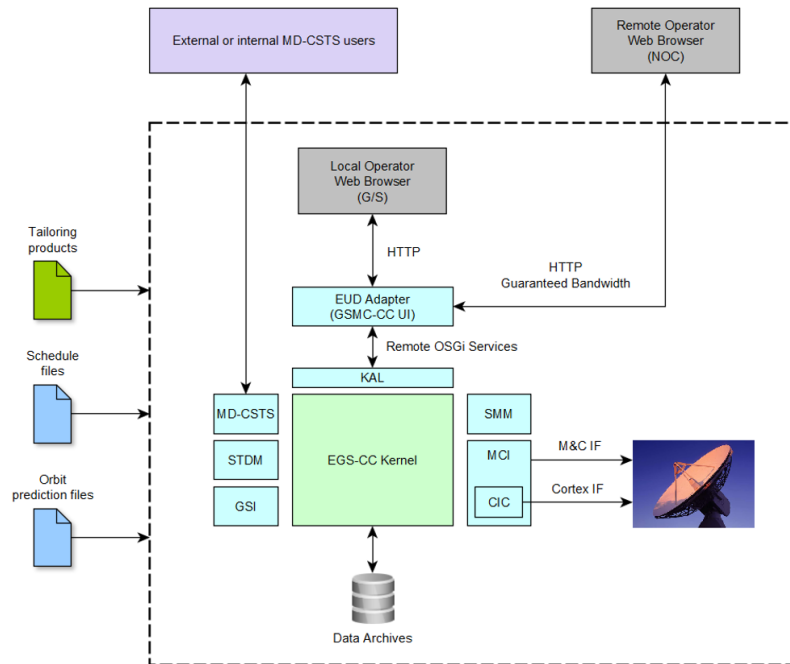


Figure 7: GSMC-CC Low-level Design and Components

1.3.1. Deployment

The GSMC-CC deliverable product is composed of a set of software parts that are all working together to reach the goal of monitoring and controlling the ground station during operations. The deliverable product contains the following applications:

- GSMC-CC Tailoring System - This is identified by the OPEN-S runtime application.
- GSMC-CC Kernel - This is the runtime Apache Karaf container that hosts all the GSMC-CC and EGS-CC OSGi components that all together represent the M&C system core, used as an operations system.
- GSMC-CC UI - This is the user interface accessed by the operators, identified by the EUD RAP application (Tomcat Web Server) that can be accessed via Web Browser.

The deployment of the system in each ESTRACK ground station is based on a set of virtual machines running Linux operating systems. On top of these, a set of Docker images are deployed, which represents the binary distribution of a given GSMC-CC runtime version. Hence, GSMC-CC is fully dockerized, including its 3rd party products. The Figure 8 shows the docker images composing the GSMC-CC M&C system and their network dependencies.

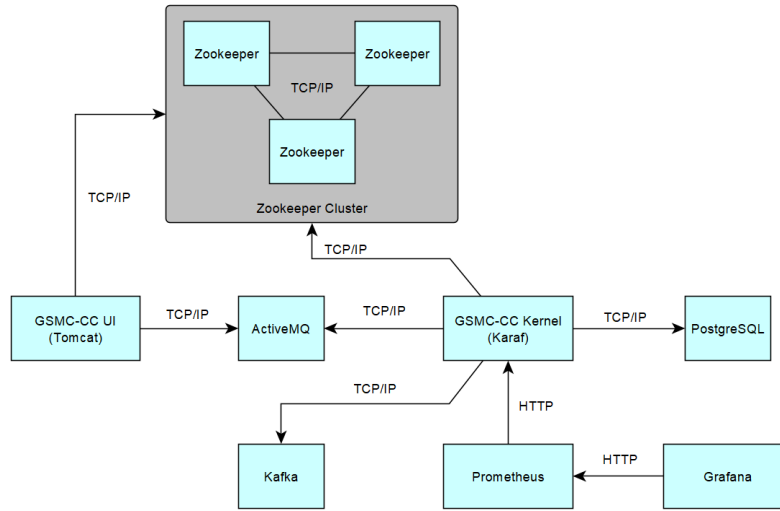


Figure 8: GSMC-CC Docker Images

The various Docker images utilise external storage volumes to store files directly on the host file system. This has a major advantage including the fact that operators can easily access files produced by the runtime systems like system logs for diagnostics, or simply change configuration files. Furthermore, the GSMC-CC system shall allow external systems to drop files in specific configured folders (e.g., Trajectory files, Quasar files, Schedule files, etc.), so that the system can inject and process these input files.

The GSMC-CC Kernel Docker container is station independent. The specific tailoring and configuration are defined for each ground station and chosen at installation/deployment time. These customisations are added by mapping external volumes to the Docker container that runs the GSMC-CC system.

1.3.2. Tailoring Data

One of the most important parts and as well the most challenging is the tailoring data. By definition, the tailoring data is the data model that tunes the GSMC-CC system to be operative on a specific setup or ground station. For ESA ground stations, the tailoring data is prepared using the OPEN-S offline tool by importing the MIB definition of the various station sub systems (FEC, TTCP, etc...). On top of this, a set of definitions are also created to ease and support the daily operations. This includes the definition of automation procedures, synthetic parameters, and auxiliary data definition for the software itself.

The tailoring preparation is a challenging activity because it requires knowledge not only on the tools to be used and the runtime constraints, but also the tailoring engineer must be aware of the operation routines and the various equipment. The Figure 9 shows OPEN-S, on the left a tree representing the structure of the station (here TST for Test Station) and in the middle an automation procedure written in the Station tailoring Language (STL).

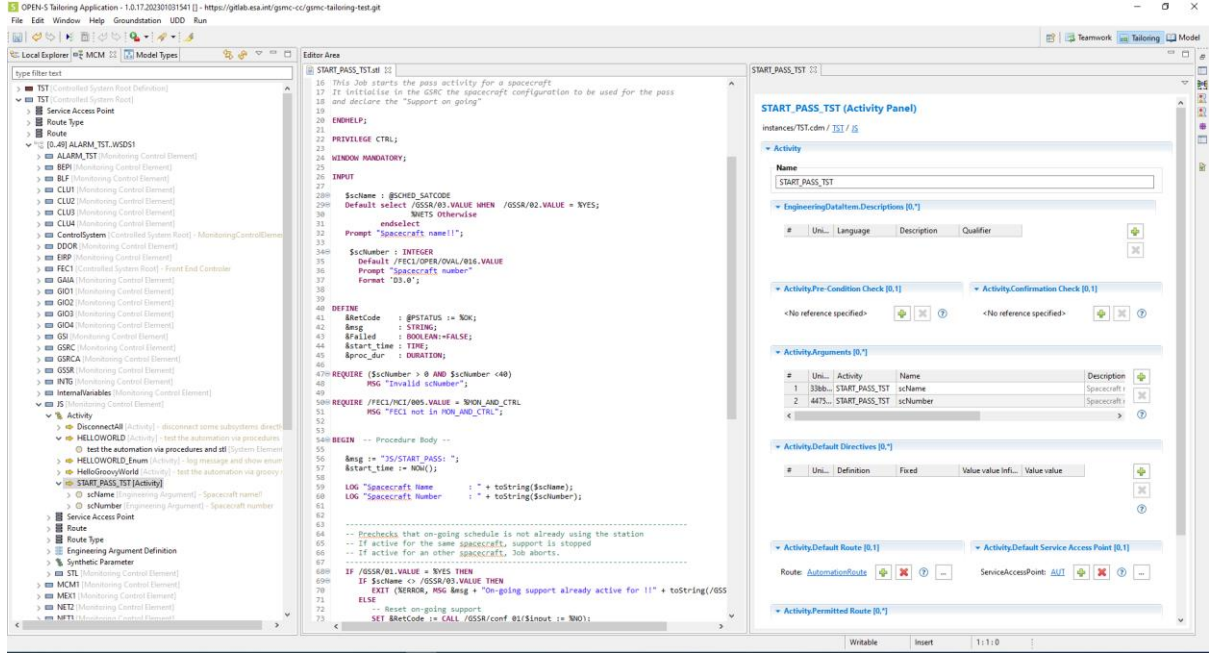


Figure 9: OPEN-S User Interface

1.3.3. Runtime

The GSMC-CC runtime system is relying completely on dockerization. The idea behind it is to compose the system for each specific ground station, by reusing binary images of the software parts and by replacing the tailoring and configuration containers which are specific to the G/S. The GSMC-CC runtime ecosystem is shown in Figure 10. Conceptually the system is divided in three macro layers: Infrastructure, Service and UI.

The infrastructure layer provides a set of 3rd party tools and applications that allow storage of the data, metrics monitoring, service discovery and message communication.

The Service layer and the UI are the two blocks that are used directly by the operators during the runtime operations. The system supports prime/backup redundancy to avoid disrupting operations in case of hardware failures. Furthermore, a Grafana user interface is accessible which exposes all the software and hardware metrics. This is particularly important to support issues troubleshooting by showing the software support engineers an overview of the status of the virtual machine hardware, the GSMC-CC software metrics at a given point in time.

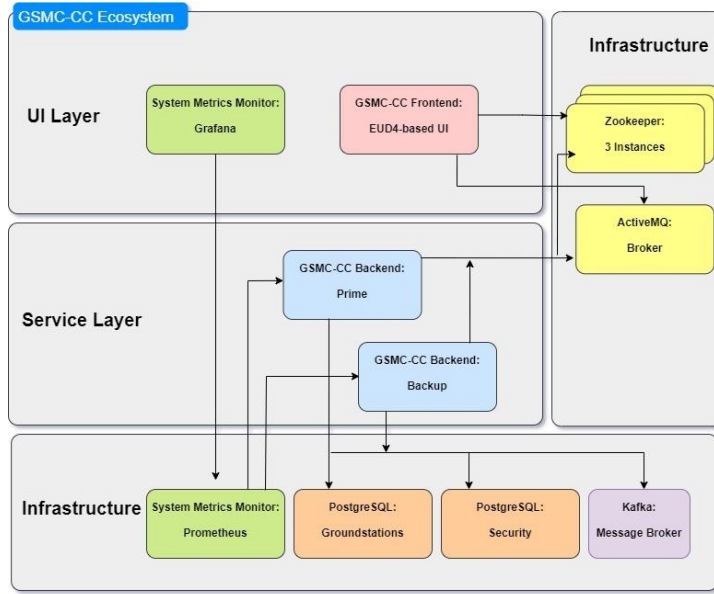


Figure 10: GSMC-CC Runtime ecosystem in layers

Finally, the operational user interface is used by the operator to monitor the routine operations in the G/S, although normally all the scheduled passes are fully automated and the operator is only acting as monitoring agent, with the possibility to manually intervene in case of contingencies or critical failures. The Figure 11 shows an example of the user interface on a 4K screen resolution.

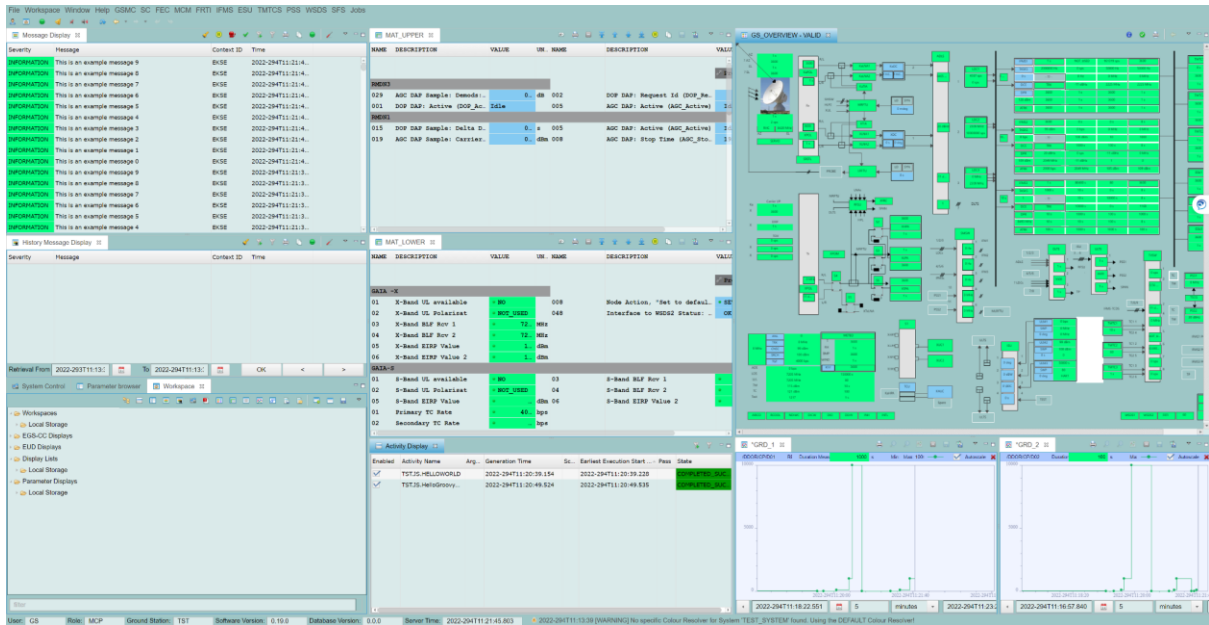


Figure 11: GSMC-CC Web User Interface on 4K resolution

4 Results

The project is currently at the end of the development phase which has lasted about two years. After the first release will be accepted (Q3 2023) a two year long deployment phase will commence where most of the ESTRACK ground stations will receive the new GSMC-CC system, ready for operations. It is also planned to train the G/S

operators on how to use the new M&C system and continue with extra development to accommodate some evolution and maintenance.

5 Discussion

1.4. Challenging features

The development of a brand-new M&C system has brought some challenges. The most complex features implemented were the following:

- Kernel Abstraction Layer component to hide the complexity of the underlying EGS-CC services. This component as well implements some complex features like the Object Selector, which is enabling pointers to monitoring objects at runtime, by switching the value of a single parameter (see Figure 12 below).

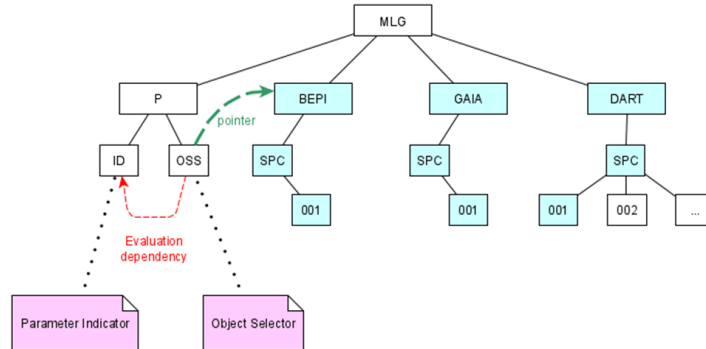


Figure 12: Object Selector

- The M&C Interface (MCI) component is a new component that is responsible for communicating with the G/S equipment via the ESA M&C I/F protocol, based on CORBA. This component is the adaptation bridge between the EGS-CC world and the ground station domain.
- To preserve over 10.000 procedures already written for the existing systems, GSMC-CC has extended the automation layer to fully support the STL procedural language. This is important to smooth the migration from legacy systems and to avoid rewriting all the procedures in a new programming language.
- The communication bandwidth between the ESOC Control Centre and the G/S is generally very weak (100-200 kbps), furthermore the latency (round-trip) can be in the order of 500ms. A POC phase was therefore conducted to minimise the consumption of the bandwidth between the Web user interface and the browser used by the operators.
- Due to the limitation of available free time slots in the ground stations, the deployment phase of the project is critical. This phase must follow a well-defined process and must avoid at all costs the scenario where the ground station remains unavailable.

1.5. CI/CD

The EKSE (EGS-CC Karaf Shell Extension), part of the EGOS-CC product, offers an integrated end-to-end testing framework which can be used to validate the GSMC-CC Kernel functionality (its M&C core) and tailoring products without the UI components. These tests run directly on a deployed instance of GSMC-CC and execute a battery of pre-defined script-based tests. This is the closest test to mimic the real operations routines in an automated way. To do so, the GitLab CI/CD pipeline is defined in such a way that it is able to deploy the system on a target virtual machine, and trigger the execution of the end-to-end tests, via EKSE. This is typically performed in nightly builds. The Figure 13 shows the details of such CI/CD pipeline.

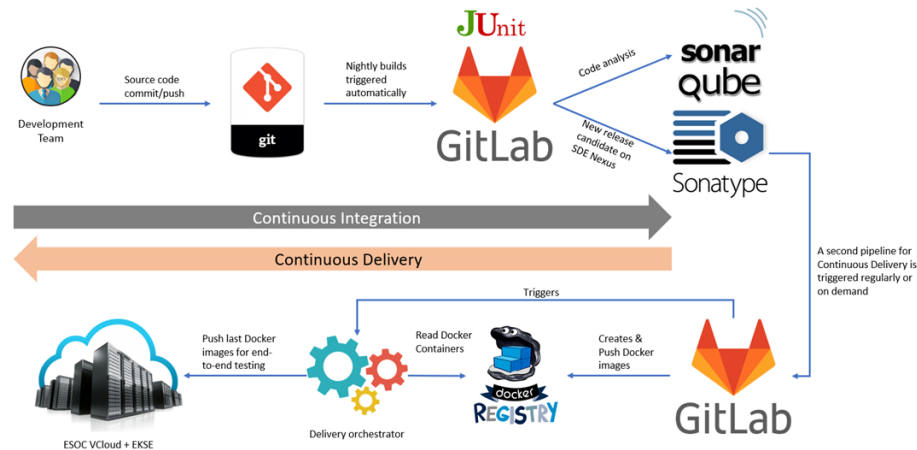


Figure 13: GSMC-CC CI/CD Pipeline

Such a complex pipeline has allowed fast integration and development of new features in a very closed loop, following a Scrum agile approach.

6 Conclusions

The project's main objective is to replace obsolete M&C systems in the ESTRACK ground stations, reusing technologies and software already developed by ESA. The modularity of the selected frameworks (OPEN, EUD, EGS-CC) has allowed the GSMC-CC Consortium to implement very specific scenarios already supported by the legacy systems and in many cases offering a better user experience to the operators. The extensibility of the selected underlying technologies will enable future improvements and evolutions.

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[1] M. Pecchioli, A. Walsh, “The EGS-CC based Mission Control Infrastructure at ESOC” SESP 2017, Noordwijk.