DOCUMENT

Convergence Towards a Unique Space Mission Simulation Reference Facility (USRF)

USRF Executive Summary Report

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1 INTRODUCTION

1.1 Purpose and Scope

The Convergence Towards a Unique Space Mission Simulation Reference Facility (USRF) project aims to conduct comprehensive End-to-End (E2E) mission-level simulations by creating a unified test facility that integrates several ESA sites and their respective assets to provide a platform for mission-level testing, verification, validation, and operations preparation. The project is initially focusing on connecting the Ground Segment Reference Facility (GSRF) at ESOC with the Avionics Test Bench (ATB) at ESTEC, enabling a robust and integrated environment for mission operations and spacecraft avionics.

This document describes the work performed and summarises the findings of the activity.

1.2 Applicable and Reference Documents

Ref.	Document Title	Issue, Date
[AD-1]	ESA-GSRF-USRF-SOW-0001 – Statement of Work	1.0, 2020/06/15
[AD-2]	VST-PM-AO10365-USRF-NM-MOM – USRF Negotiation Meeting	1.0, 2021/01/27
[AD-3]	VST-ESA-USRF-MIN-001 – USRF Project KO Minutes of Meeting	1.0, 2021/05/19
[AD-4]	ECSS-E-ST-10C – Space Engineering – System Engineering General Requirements	3.1, 2017/02/15
[AD-5]	ESA-OPS-QMS-GUID-CKL-9500 – OPS-QMS – ECSS-E-ST-40C Space Engineering - Software: Tailoring for Ground Segment Systems	1.0, 2016/10/19
[AD-6]	ECSS-E-ST-40C – Space Engineering – Software	3.0, 2009/03/06
[AD-7]	ECSS-E-ST-10-06C – Space Engineering – Technical Requirements Specification	3.0, 2009/03/06
[AD-8]	VST-ESA-USRF-GLO-001 - Glossary	1.2, 2021/10/04
[AD-9]	VST-ESA-USRF-RS-001 – Requirements Baseline	1.2, 2021/10/04
[AD-10]	VST-ESA-USRF-TN-001 – Space Mission Test Scenarios	1.2, 2021/10/04
[AD-11]	VST-ESA-USRF-DD-001 - USRF System Design Document	1.3 2022/21/03

Table 1 – Applicable documents

Ref.	Document Title	Issue, Date
[RD-1]	ESTEC-led CFDP study – *details missing – refer to open Action Items 001 and 002*	x.x, 2016/xx/xx
[RD-2]	ESA-GSRF-E2CS-MAN-0001 – E2CS – Software User Manual	0.1, 2020
[RD-3]	ESA-GSRF-E2CS-IF-0001 – E2CS – Interface Control Document	0.1, 2019
[RD-4]	ESA-GSRF-EEVAL-SUM-1001-i1r0 – E2EVAL – Software User Manual	1.0, 2021/03/08
[RD-5]	ESA-GSRF-EEVAL-ICD-1001-i1r0 – E2EVAL – Interface Control Document	1.0, 2021/03/08
[RD-6]	ESA-DOPS-STU-MAN-0003 – PenBox – Software User Manual (SUM)	1.0, 2020/05/11
[RD-7]	ESA-DOPS-STU-TN-0008 – PenBox – Software Design Document (SDD)	1.0, 2020/05/11
[RD-8]	NDIU Setup for Juice Connectivity to ESTEC	1.0, 2021/05/06

Ref.	Document Title	Issue, Date
[RD-9]	ESA-GSRF-GS-PR-0001 – Security Operating Procedures (SECOPS) for the Ground Segment Reference Facility (GSRF) – *excerpt*	2015/11/05
[RD-10]	E2EATB System Concept Detailed Design Document - E2EATB.SDD.002	24.04.2015
[RD-11]	The SPARTA Framework	-
[RD-12]	MITRE ATT&CK Framework	-
[RD-13]	SPACE-SHIELD	-
[RD-14]	EDA Captechs Presentation	03.2003
[RD-15]	TEMPPO Designer (IDATG) User's Guide – Part I & II	02/2018
[RD-16]	EGOS User Desktop Automated Regression Testing (EUDART) - Software User Manual	2015
[RD-17]	EKSE: A Command Line Interface for EGS-CC based Systems	28/05/2018
[RD-18]	Implementor's Guide for EGSERouter and MCS2BBE Application Protocol	11/08/2017
[RD-19]	Eagle-Eye ATB	
[RD-20]	Eagle-Eye OBSW	
[RD-21]	Scenario Validation developer training	18/11/2022

Table 2 – Reference documents

1.3 Terms, Definitions and Abbreviations

Refer to [AD-8]

2 FUNCTIONAL DESCRIPTION

The USRF project bridges the GSRF and the ATB test facilities by providing a common set of tools and capabilities for mission simulations. This project encompasses three key areas:

2.1 Test Design and Automation

The USRF offers a suite of tools that allow the design, configuration, conduction, and reporting of tests.

It supports the creation of "Test Assemblies" by connecting various hardware and software assets from these 2 ESA sites.

2.2 Interconnection of Facilities

The interconnection between the GSRF at ESOC and the ATB at ESTEC allows for seamless coordination between ground segment systems and spacecraft avionics.

The integration enables E2E scenarios, which include spacecraft avionics simulation, operational control systems, and mission-specific configuration testing environments.

2.3 Security and Scalability

The system architecture has been designed with security in mind, ensuring that all operations are securely contained within the ESA network.

The architecture is scalable, allowing for the potential future inclusion of additional facilities and mission components.

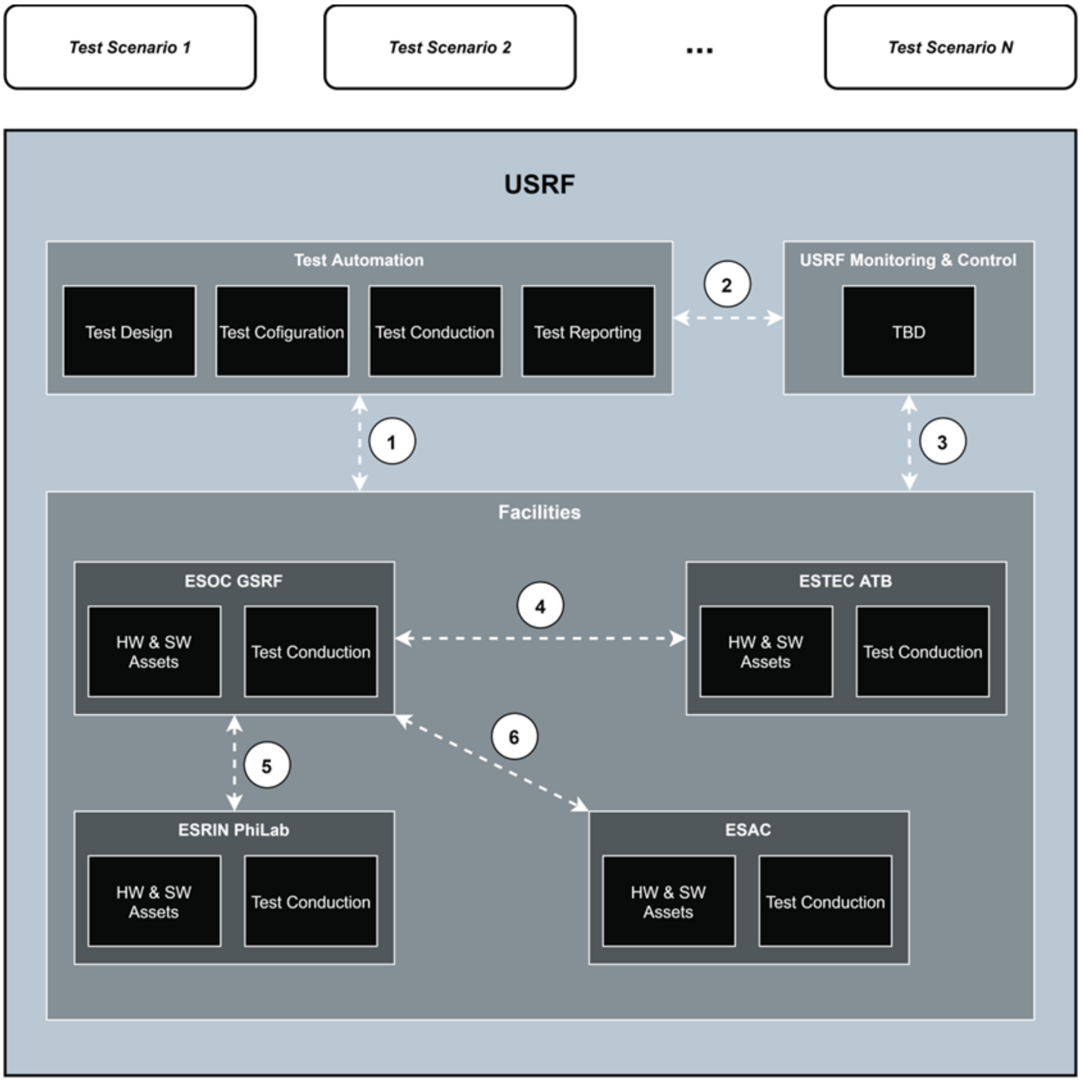

Figure 1 USRF High Level Functional Architecture

3 KEY COMPONENTS AND FUNCTIONALITIES

3.1 Test Automation

The Test Automation component is central to the USRF, providing functions for defining, designing, configuring, and conducting tests, as well as generating reports.

Two main options were considered for implementing this component:

Option I: Reuse existing tools e.g. TEMPPO and EUDART, already in place in the GSRF.

Option II: Use of MATIS and EGS-CC EKSE scripts from ESA mission operations.

After evaluation, Option I is selected due to its existing integration and reporting capabilities, despite some limitations in reusing operational schedules and procedures.

The selected automation tools effectively supported the design and execution of test scenarios, albeit with some challenges in reusability of operational schedules.

3.2 Test Environment

The test environment creates a realistic setting for executing the tests. It encompasses the necessary mission representative hardware, software, and infrastructure components. The test environment includes:

- A virtualised environment to deploy any mission operations software system, including spacecraft and ground station monitoring and control systems, multi-mission data systems and other mission-specific software systems;
- Ground station hardware and software systems representative of ESA ground stations;
- Hardware and software systems for the testing of the ground station equipment, including signal generators, attenuators, white noise generators, other

- FES (Functional Engineering Simulator)
- FVT (Functional Validation Test Bench)
- SVF (Software Validation Facility)
- RTB (Real-Time Test Bench)

  RTB (Real-time Bench) can be used to verify/validate the OBSW against its specifications and use-cases. In addition to that RTB can demonstrate the use of the HW stimulation, and migration process from processor to OBC.

  EagleEye OBSW

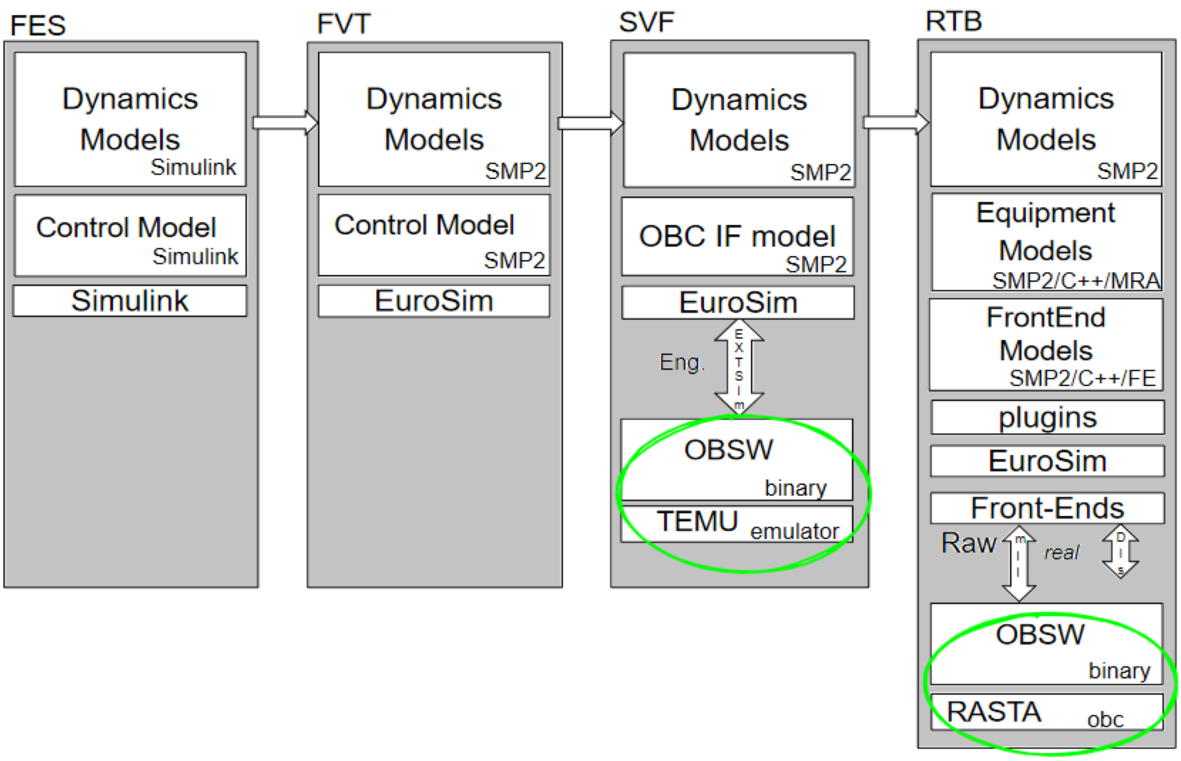

Figure 2: EagleEye OBSW

In the SVF (Software Validation Facility) simulator assembly, the On-Board Software (OBSW) is integrated as a binary running on either:

- an emulator (Terma Emulator) in the case of a SVF Simulator Assembly or
- a separated On-Board Computer (OBC) running on a processor (Leon 2, 3, 4, etc.) in the case of a RTB Simulator Assembly.

- **RouterX** and **TMTCFE** adapter.
- **atbqhawk**, configured to support the OBSW build process.

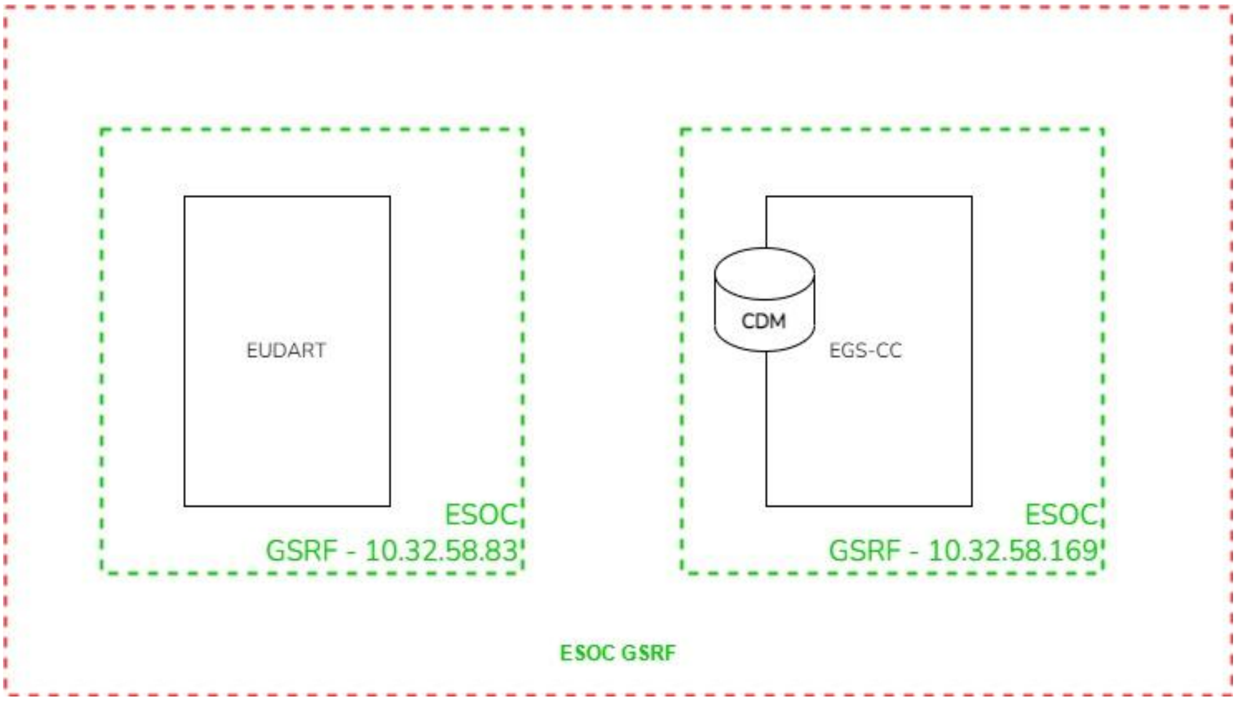

Figure 3 ESOC GSRF Components

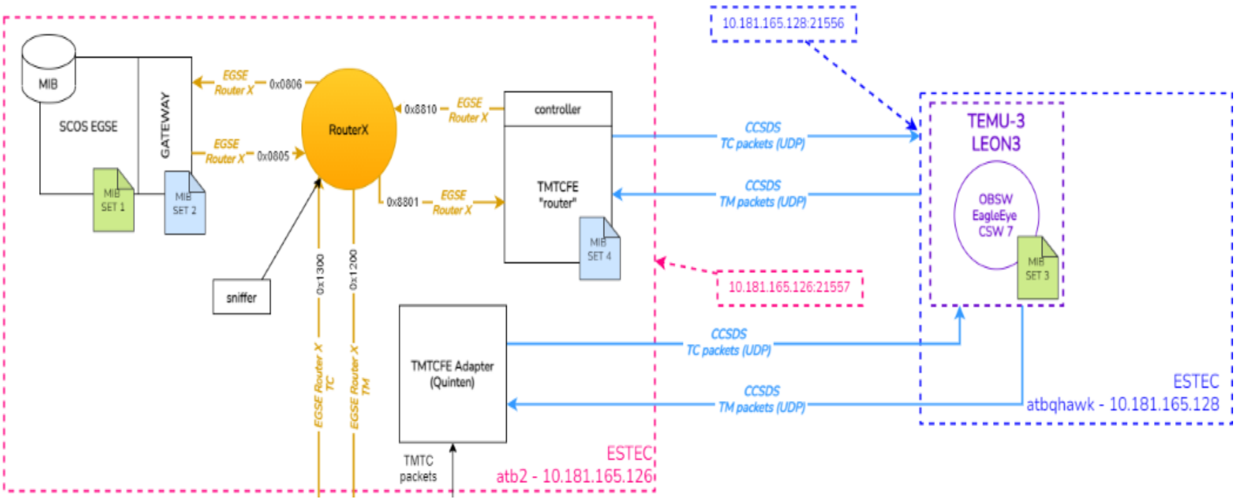

Figure 4 ESTEC ATB Components

3.3 Test Configuration: Eagle-Eye Reference Mission

The Eagle-Eye is a typical ESA Earth observation mission that provides images through the optical instrument named Golden-Eye. The Eagle-Eye mission simulation consists of simulation models and the Eagle-Eye On-Board Software (OBSW).

The simulation models cover the following parts:

- Environment
- AOCS (Sensors & Actuators)
- Power Subsystem
- Thermal Subsystem
- Payload

3.4 Communication Protocol: CFDP

An implementation of the CCSDS File Delivery Protocol (CFDP) and associated services as a C library is available for the mission OBSW, as well as a Java implementation for the EGS-CC MCS.

File Based Operations are tested running CFDP between EGS-CC and Eagle-Eye. CFDP payload is transported on top of PUS services.

3.5 Mission Control System

Over the USRF project duration, two different EGS-CC releases have been used: At the beginning of the project EGOS-CC R1 has been used (see section Option 1). At a later stage of the project, EGOS-CC R1 has been replaced by EGS-CC R1.6 as mentioned at option 2. The MCS has been deployed on a VM in the ESOC GSRF network.

In this approach the communication between EGS-CC (ESOC GSRF) and TMTCFE adapter (ESTEC ATB) is facilitated using CNC. The following features have been achieved:

- Receive TM flow from OBSW emulator.
- Send TC, perform file-based operations
- Access EGS-CC using the latest Web-UI

3.6 Security

Security testing in the USRF is guided by the Space Attack Research and Tactic Analysis (SPARTA) framework, which provides a structured approach to threat modelling and penetration testing for space systems. Given the diversity of space devices and their unique vulnerabilities, a generalized approach is necessary:

- **Threat Modelling**: SPARTA is used to model potential attack vectors by defining generic attack scenarios that map the tactics, techniques, and procedures (TTPs) a threat actor might use. These scenarios offer a roadmap for penetration testing, helping to identify vulnerabilities and evaluate the effectiveness of security measures.

- **Penetration Testing**: Given the challenges in creating specific penetration tests for each space device, generic attack scenarios based on SPARTA are used to simulate potential threats. These scenarios cover various phases of a space mission, particularly during the Launch and Early Orbit Phase (LEOP), where the systems are most vulnerable.

The security of the system was thoroughly assessed and found to be robust, as all operations were contained within the ESA network.

The chosen network design facilitated efficient communication between facilities, with potential for future expansion.

4 FACILITIES INTEGRATION

The USRF prototype connects the GSRF and ATB through a network designed to support complex test scenarios. This network ensures secure communication and coordination between different ESA facilities.

Several options for site interconnection were analysed, with a preference for a solution that balances security, scalability, and cost-efficiency.

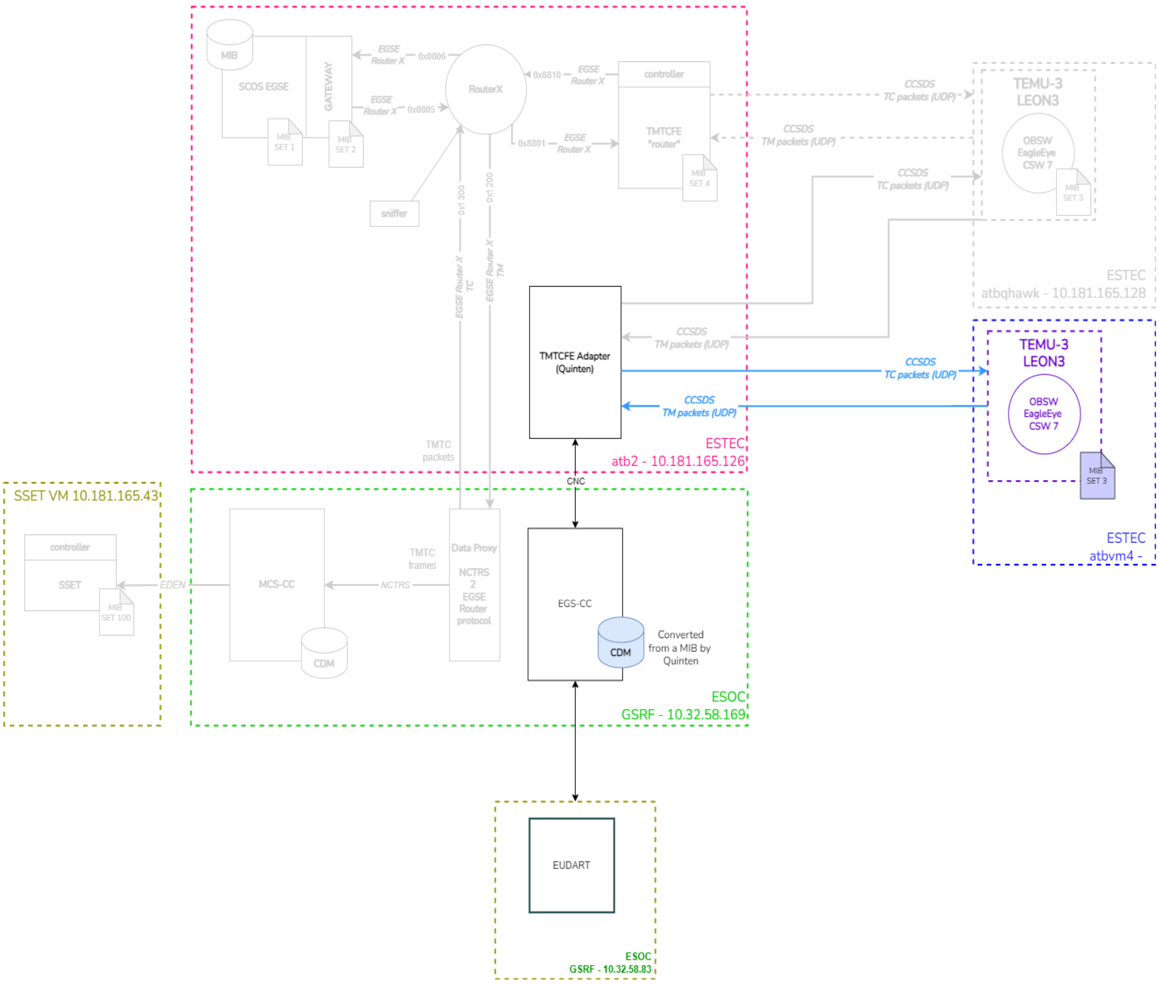

Figure 5 Final USRF Interconnection Architecture

FINDINGS

The USRF project successfully demonstrated the feasibility of integrating different ESA facilities into a cohesive mission simulation environment. The following key findings were highlighted:
The integration of the GSRF and ATB proved to be effective, enabling coordinated testing and validation across different mission components in a secured manner.

- Define test specifications to validate EGS-CC through EKSE using the TEMPPO designer and generate test scripts for execution in EUDART.
- Create test cases aimed at validating and executing UI-based tests on the EGS-CC WebUI using the Scenario Validation framework (Selenium).
- The following test cases have been identified and validated using the above listed approaches:
    - Open/Close TM/TC Links
    - Send TC
    - FBO operations (creating and downloading a file)