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A Data System for the European Relay Coordination Office - the Mars Relay and expansion to the Moon

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Abstract

The European Relay Coordination Office (ERCO), part of the European Space Agency (ESA) and the European Space Control Centre (ESOC), manages communication relay services between ESA orbiters and landed assets from various space agencies. Currently, it oversees the relay between ESA orbiters around Mars and the National Aeronautics and Space Administration (NASA) landed assets on Mars. The system is being expanded to cover the landed asset of ESA's Rosalind Franklin Mission and is under consideration for upcoming Lunar orbiters and Moon landed assets.

ERCO's tasks include coordinating relay services between ESA orbiters—such as Mars Express, ExoMars Trace Gas Orbiter, and the future Earth Return Orbiter—and Mars landed assets from different space agencies. Coordination is based on orbiter-lander and orbiter-Ground Station visibilities and tracking schedules, highlighting potential conflicts among lander relay requests. The relay services execution features unprecedented automation, both for routine and emergency situations, independence from the lander or orbiter control centre, tracking progress, performance summaries for the lander teams, and full support by a dedicated Data System, the European Relay Coordination Office Data System. The European Relay Coordination Office Data System (ERCO-DS) is a complex software supporting various relay services activities: from planning, through execution, dissemination and evaluation.

This paper presents the structure of ESA's Relay Coordination Office Data System and highlights its interaction with NASA's Mars relay coordination infrastructure. It provides lessons learned from several years of relay experience between ESA's ExoMars Trace Gas Orbiter and various NASA landed assets. Additionally, it details the main capabilities of the European Relay Coordination Office Data System, including its interfaces with multiple Mission Operations Centres and Rover Operation Centres. Finally, the paper offers an overview of the future of the European Relay Coordination Office and its Data System amidst their expansion to Lunar relay services.

Keywords: Data System, Mars, Relay, Orbiter, Inter-Agency, Lunar

Acronyms/Abbreviations

CCSDS .... Consultative Committee for Space Data Systems
CRF .... Command Request File
DSOC .... Deep Space Optical Communications
EDDS .... EGOS Data Dissemination System
EGOS-MPS .... Mission Planning System
ERCO .... European Relay Coordination Office
ERCO-DS .... European Relay Coordination Office Data System
ESA .... European Space Agency
ESOC .... European Space Operations Center
ExoMars .... Exobiology on Mars
ExoMars TGO .... ExoMars Trace Gas Orbiter
LCNS .... Lunar Communication and Navigation System
FLB .... Forward Link Binary file
FLT .... Forward Link Trigger file
GFTS .... Generic File Transfer System
JPL .... Jet Propulsion Laboratory

LCC .... Lander Control Centre
MaROS........ Mars Relay Operations Service
MMI........ Man Machine Interface
MO .... Mission Operations
MOC .... Mission Operations Centre
NASA .... National Aeronautics and Space Administration
OCC........ Orbiter Control Centre
OOF .... Overflight Opportunity File
OPAF........ Overflight Performance Assessment File
TGO .... Trace Gas Orbiter
MEX .... Mars Express
RFM .... Rosalind Franklin Mission

1. Introduction

If we take as an example the landers and rovers on Mars, we can understand why data relay is a fundamental part of Mars exploration. The landed assets on Mars must first transmit the data they have collected on the Red Planet, to a spacecraft in orbit around Mars. These orbiters then use their much larger, more powerful transmitters to 'relay' the data across space to the deep-space antennas on Earth. Data is then processed and decoded at the Orbiter's Mission Control Centre and finally made available to the Landed Assets Control Centre and respective team. In the below figure (Fig. 1) is depicted the whole communication chain to receive data from a Mars Landed Asset:

1. The Landed asset Control Centre (LCC) prepares the request for the Landed Asset to transmit data back to Earth. It sends the request to the Orbiter Mission Operations Centre (MOC) in the format that the Lander can understand.
2. The Orbiter MOC encapsulates the request from the LCC into Orbiter Telecommands and sends them to the Orbiter.
3. The Orbiter sends the request from the LCC to the Landed Asset.
4. The Landed Asset replies with data and sends it to the Orbiter.
5. The Orbiter "relays" the data from the Landed Asset, encapsulated into Orbiter Tele back to Earth, to the Orbiter MOC.
6. The Orbiter MOC strips out the encapsulation headers and sends the Landed Asset data back to LCC.

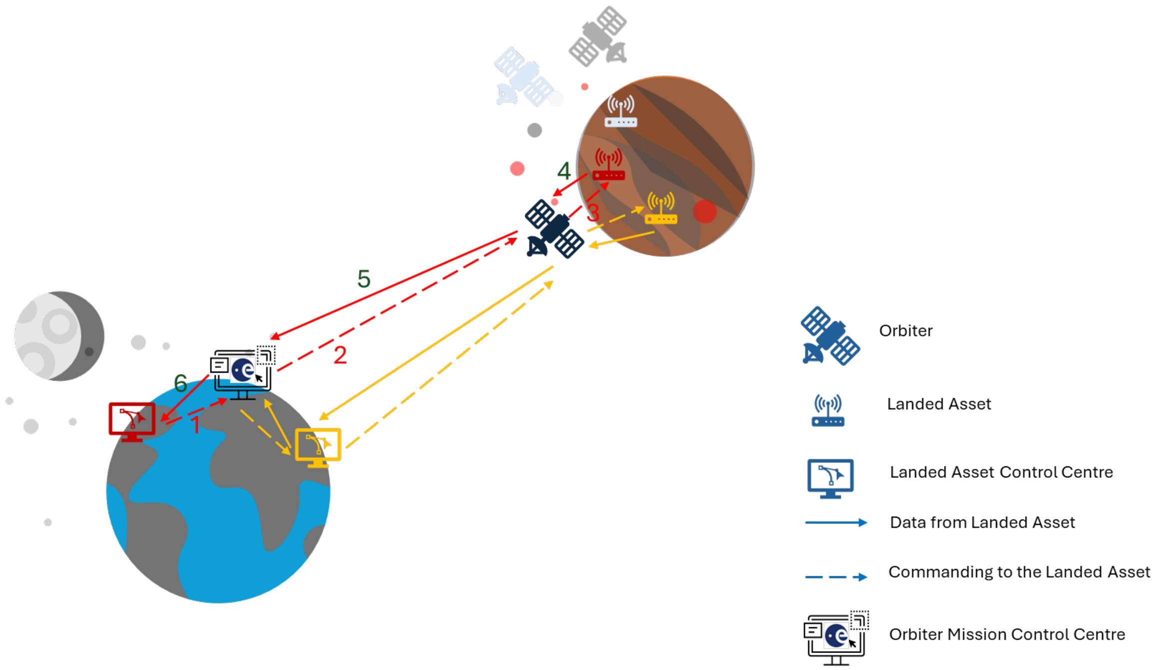

Fig. 1: Point to Point Data Relay steps for a Mars Landed asset

The scenario depicted above is clearly very simple and does not offer any service guarantees to the LCC nor does it optimise the data transfer to and from the Landed Asset. For a routine interplanetary data relay support between agencies, it is necessary to implement a protocol to request, acknowledge, accept, implement, deliver and measure the efficiency of a service or set of services. Having this protocol in place for the communication of one Landed asset via an Orbiter is extremely useful, and having it applicable to any pair of landed assets and orbiters is fundamental for the standardization and broadening of the relay service, in an automated way.

2. The European Relay Coordination Office

The European Relay Coordination Office main function (referred to as the Relay Office) currently is to coordinate Mars landed assets communication with Mars relay orbiters via a single interface. The landed assets and orbiters can belong to any Space Agency that wants to be part of the service. Currently, ERCO works with ESA's orbiters around Mars (ExoMars TGO and MEX), and NASA's landed assets. The Rosalind Franklin Mission which is scheduled to launch in 2028 will also benefit from ERCO's relay service once landed on Mars. The same will be the case for the upcoming Earth Return Orbiter, part of the Mars Sample Return, a cooperation mission between ESA and NASA.

ERCO offers a single interface for any Lander Operations Control centre, regardless of which Orbiter it wants to use for the relay, and independently from which agency either of them belongs to. The translation between formats of requests and replies is the responsibility of ERCO and the service requesters do not need to implement format or interfaces changes. They do not even need to know the LCC or MOC specific formats. This makes the service flexible to all parties. It also has the advantage of keeping the proprietary formats of the landed assets hidden from the orbiters service providers, and vice – versa.

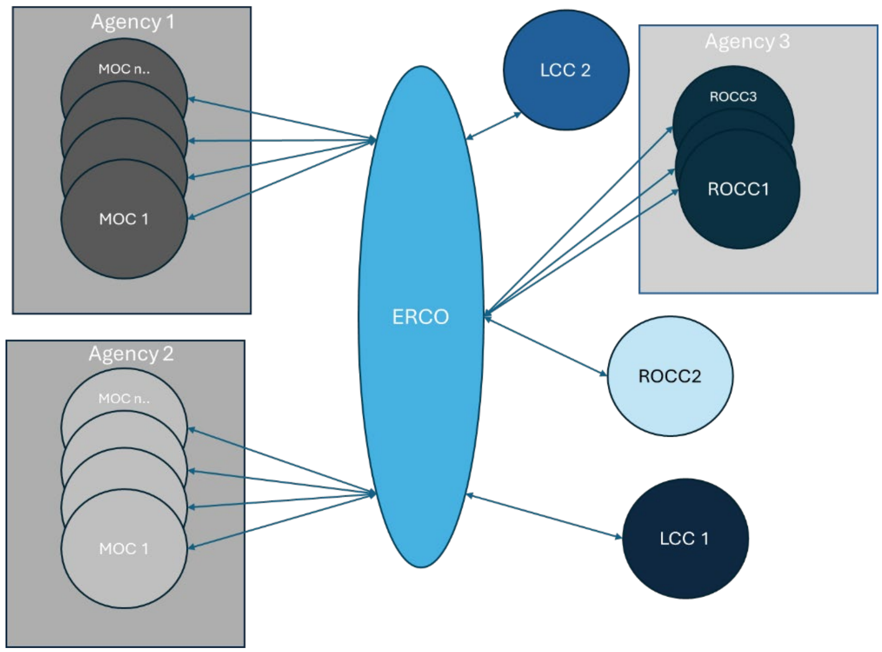

Fig. 2. ERCO as Single Point Interface for all Agencies and Control Centres for Landers and Orbiters.

ERCO offers, in addition, a protocol that provides to the LCC: 1) acknowledgement of reception of relay requests; 2) confirmation of the overflight for implementation of relay requests at various planning stages; 3) confirmation of transmission of Forward Link requests to the Orbiter's MOC; 4) confirmation of uplink of the Forward Link data to the orbiter; 5) confirmation of implementation of the relay; 5) return of the relay product; 6) summary information of the overflight including the actual timing of the link connection and dropout ; 7) overflight performance information [4] and 8) autonomous implementation of the Emergency and unplanned Relay Sessions with very short latencies between their request and their subsequent execution. The nominal Relay Session status indicators used by ERCO are illustrated in Fig. 3 below.

Relay sessions start with geographical overflight information from the event file. For relays based on ESA's Orbiters, ERCO performs an automated process that provides suggestions for the relay session allocations to the LCC (Assigned status). If accepted, the LCC includes it in planning cycles, marking the request as proposed. NASA relay requests directly enter this state. The Orbiter MOCs can either report that they can support the relay session request or that they cannot support it, marking it as Unavailable.

An Unavailable relay session request is considered a final state in the process and the session will not be offered again. A supported request enters the next stage of the planning cycle, whereby LCC and Orbiter MOC exchange information about the actual configuration of the relay communication in terms of data rate, modulation scheme, etc., until eventually the commands to perform the relay activities are implemented onboard the orbiter.

In advance of the overflight execution the LCC can provide to the Orbiter MOC the instructions that must be delivered to the landed asset, if any. After the overflight, any data received by the Orbiter from the landed asset is downlinked to ground and finally delivered to the LCC.

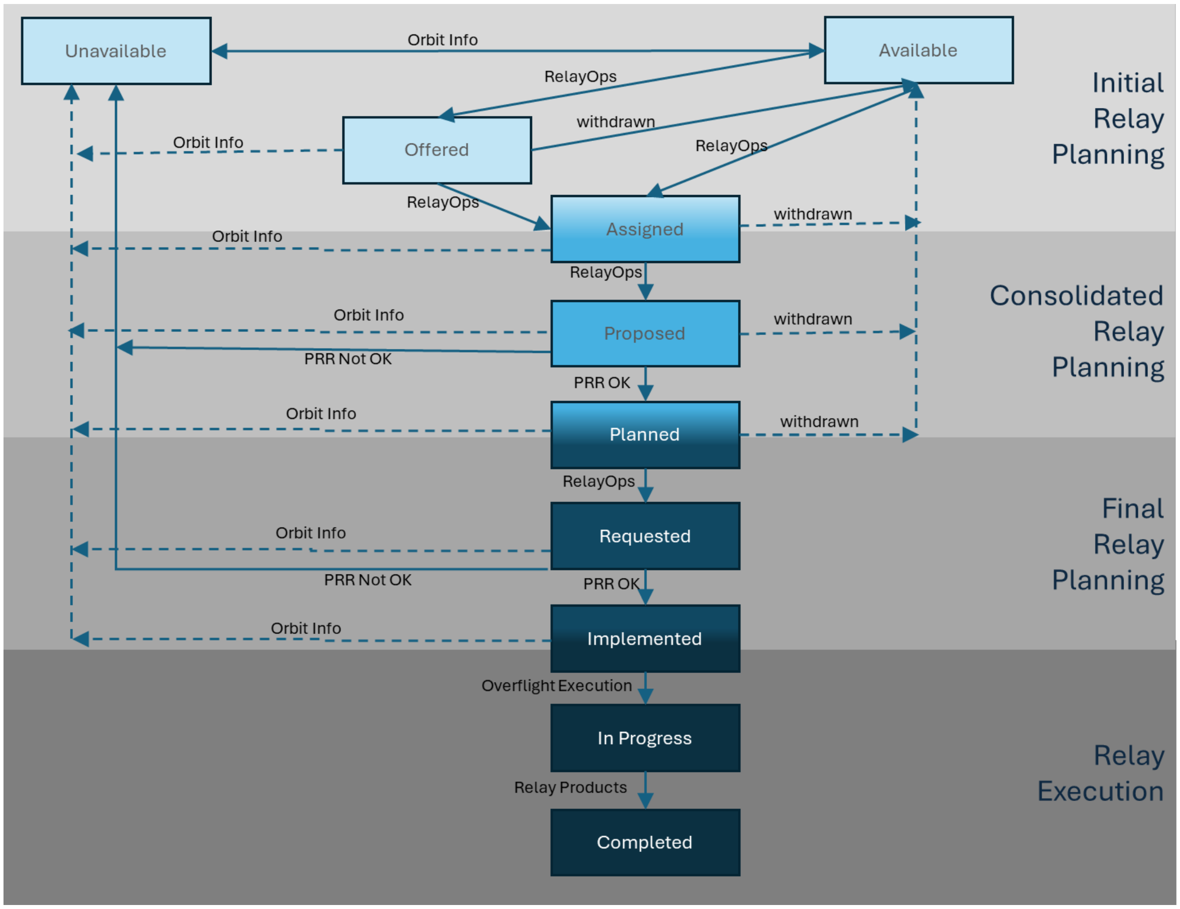

Fig. 3. Relay Session status indicators provided by ERCO

As depicted above there is a lot of autonomous stepwise information made available to the service consumers of ERCO, providing the adequate level of transparency and disclosure needed, without compromising security or functionality.

3. The European Relay Coordination Office Data System

The European Relay Coordination Office Data System (ERCO-DS) supports the Relay Office by providing an automated and standardized relay service among a set of Relay providers (Orbiters) and Relay requesters (Landed Assets). The services provided by ERCO-DS include:

- Planning of relay sessions between landed assets and orbiters;
- Transfer of files required for the planning and execution of relay sessions between the relevant stakeholders (Commanding files, protocol handshake files, etc);
- Conversion of files between formats supported in the Orbiters relay network (TGO MOC, MEX MOC, RFM MOC, etc) and formats supported in the Landers relay network (MaROS, LCCs);
- Tracking of the progress of each supported relay session from planning to execution;
- Archiving of data received during the relay session and dissemination to relevant stakeholders;
- Production of reporting products for the relay session;
- Display of reporting products for the relay session;
- Implementation of Emergency and unplanned Relay Requests as well as tactical change requests;
- Distribution of Relay products through the EGOS Data Distribution System (EDDS), delivered as files;
- Delivery (point-to-point) of Relay products directly to the LCC.

The ERCO-DS is a system separate from the MEX, RFM and TGO MOC systems dedicated to flight operations. The starting point for the ERCO-DS was the existing ERCO TGO File Manager application, which was described in [4] and which evolved to support the needs of an extended Relay Network.

3.1. Interfaces

The main ERCO-DS system interfaces are depicted in Fig. 4, below. Most data transfer, depicted as blue arrows below, is done through the exchange of files between ERCO-DS and the ESA Orbiters' MOC, the European Landed Asset Control Centre, and the Relay Planning Tool at JPL (MaROS). The exceptions to this are the telemetry data requests to the Orbiters' MOC used by ERCO-DS to create the Scorecards and the overflight performance information Reports. This interface is done via the EGOS Data Distribution System (EDDS) API available for all missions controlled from ESOC.
The figure below is a simplification of the deployment as it hides the usage of the Generic File Transfer System (GFTS) for all file transfers and the usage of intermediate machines, that hide the actual network topology of ERCO-DS and its redundancies.

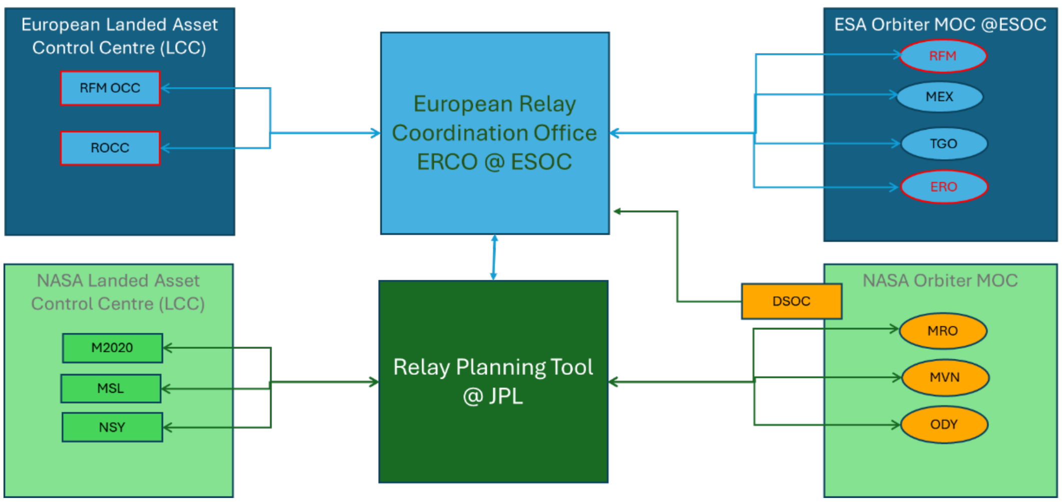

Fig. 4: ERCODS high level Interfaces

3.1. Architecture

The overall ERCODS architectural design is driven by the reuse of the EGOS MPS and its precursor ERCO TGO, described in [4]. The EGOS MPS provides the overall baseline infrastructure for the system.

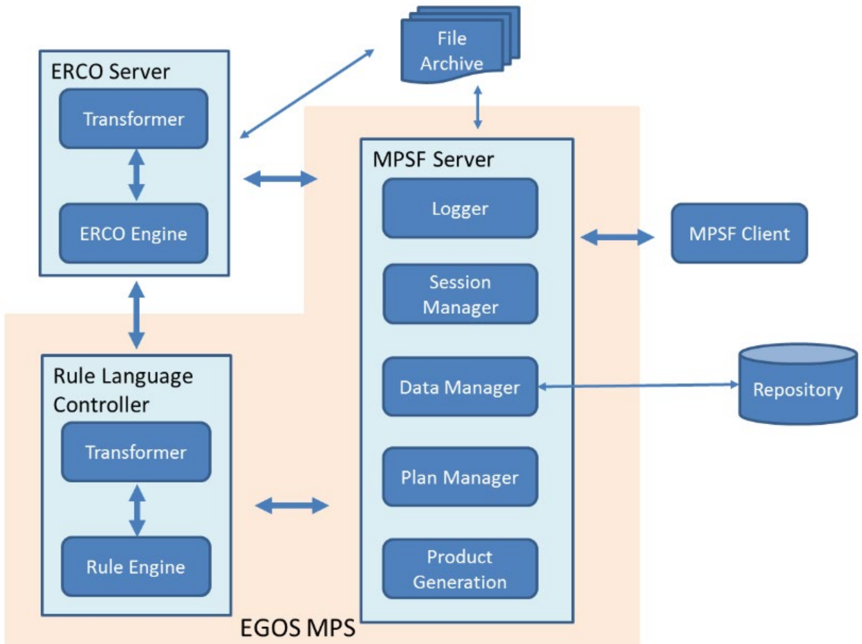

Fig. 5. Overall ERCODS design with components reused from EGOS MPS

Within Fig.5 we illustrate how the re-use of the EGOS MPS and the ERCO TGO components work together. As can be seen from the diagram, the EGOS MPS is composed of several components that support the requirements of the ERCO-DS. The ERCO-DS server component is made up of two main parts: 1) a transformer, which handles the communication with the components of the EGOS MPS, and 2) an engine. The engine contains the core features taken over from the original ERCO TGO system [4] and additional functionality to support the extended requirements.

ERCO-DS is therefore a collection of several independent modules that can interact with each other. Below we explain the main functionality of the following ones, as depicted in Fig.5.:

- the ERCO Server Engine (based on the ERCO TGO File Manager);
- the Repository;
- the Man-Machine Interface (MMI) including the ERCO View plug-in;
- the File Archive.

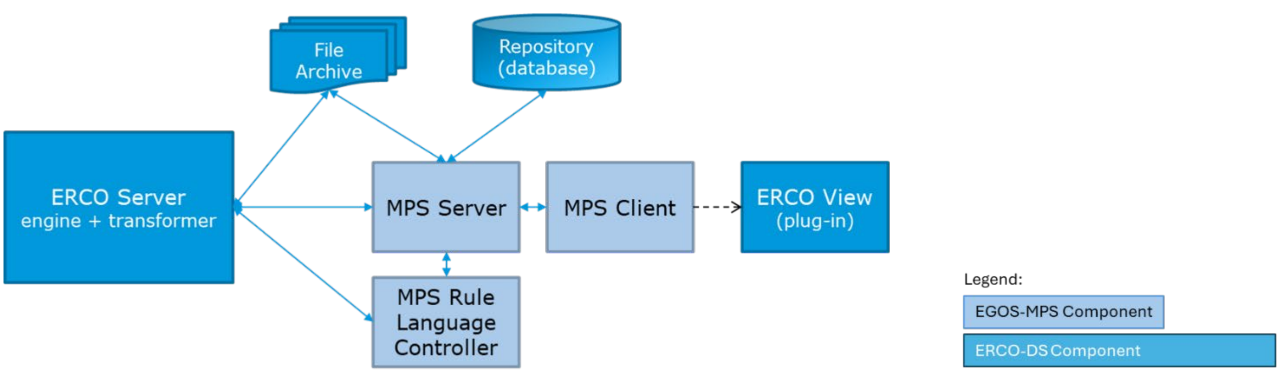

Fig. 6. ERCO-DS Architecture.

3.1.1 ERCO Server Engine – the File Manager

The ERCO-DS File Manager application, inherited from the ERCO TGO system, serves as a simple interface and file conversion software. During the NASA lander relay phase, and well in advance of the RFM arrival, the functionality of the ERCO File Manager application has been extended to include file transfer and processing capabilities. This allows the TGO, Mars Express, and NASA relay orbiters to support the ESA and NASA landed assets. This File Manager is built around the Generic File Transfer System (GFTS) configured to support file transfer between the Lander Control Centres, Orbiter Mission Control Centres (OCCs/MOCs), ERCO-DS, and MaROS, including all necessary file format conversions to ensure a generic, orbiter-independent interface for the LCCs.

The File Manager also supports the execution of scheduled tasks and the production of performance assessment files about the TGO relay performance, based on telemetry parameters obtained from the TGO MOC. The same applies to the MEX mission and MEX MOC. Additionally, it includes a Command Request File (CRF) Checker application.

ERCO-DS also supports the fully autonomous implementation of Emergency and unplanned Relay Sessions as well as tactical changes with very short latencies between request and execution on board the spacecraft. The latency for the implementation of these Emergency Relay Sessions are mainly driven by the availability of suitable uplink windows to the Orbiter.

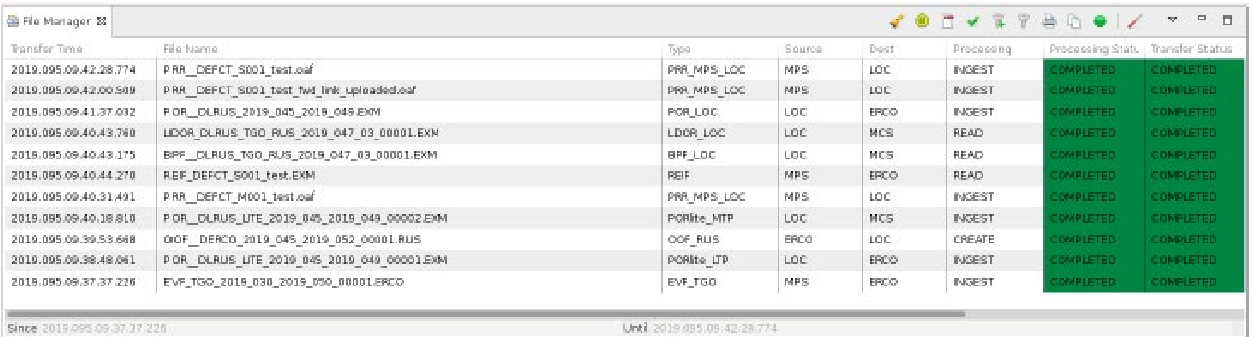

Fig. 7. ERCO-DS File Manager MMI

The automatic file handling tasks such as polling external entities for new files or archiving incoming files, can be scheduled in three ways:

- Run at specific times. This will be done using the 'cron' Linux utility.
- Triggered by file reception. This is triggered by GFTS procedures.
- Based on the relay planning in the ERCO-DS repository. In this case a configurable planning rule executed within one of the steps above will create a scheduled job to be run at the desired time.

3.1.1.1 ERCO-DS Relay Planning and Execution

The main steps in the ERCO-DS relay planning follow the basic planning scenario steps:

- Overflight planning: Here ERCO-DS ingests event files and creates planning facts representing the overflights. These are then used to generate opportunity files.
- Initial request handling (see Fig. 8). ERCO-DS ingests requests for relay sessions and creates planning facts for them. Configurable planning rules verify that the requests are feasible and update the state of the corresponding overflights. The files needed to book the resources needed for the sessions are generated.

Fig. 8. Information exchanged for Relay Planning

The main steps in the ERCO-DS relay execution follow the steps:

- Relay session execution (see Fig. 9): ERCO-DS ingests booking confirmation files, updates the state of the sessions and generates the needed commanding files to execute the relay session.

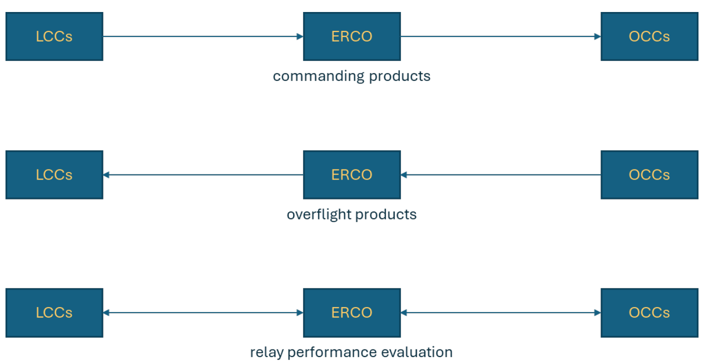

Fig. 9. Information exchanged for Relay Execution

3.1.2 Repository

The ERCO-DS Repository contains all the relevant information about the overflights of the various Mars landed assets serviced by the Relay Office.

The data included in the Repository are:

- overflight geometric information supplied from ESOC Flight Dynamics;
- relay orbiter operational information supplied from the relay service providers, i.e. the OCCs/MOCs;
- relay session requests and acknowledgements, supplied respectively from the relay service consumers, i.e. LCCs, and the relay service providers, i.e. the OCCs/MOCs;
- the list of files associated with each relay session (requests, acknowledgements, forward link data products, return link data products).

The information is ingested as a result of jobs performed by the File Manager and edited using the ERCO-DS MMI.

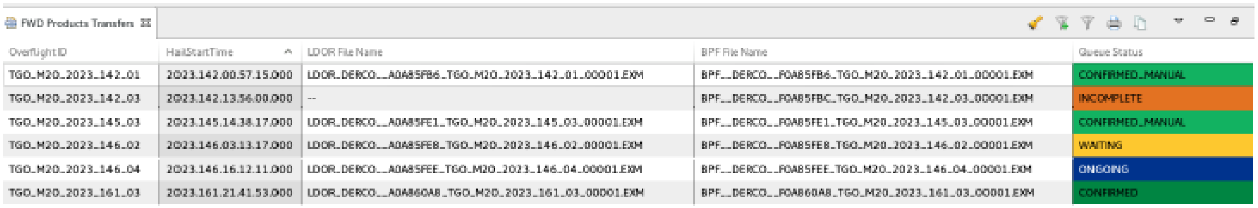

Fig. 10. Forward Product View

3.1.3 MMI

The ERCO-DS MMI provides an interface to visualize the overflights, their status, and all file exchanges associated with them, as depicted above. This interface is available within ESOC and only for authorized Relay Office personnel.

Additionally, the MMI is used by the Relay Office personnel to perform planning activities such as:

- triggering the ingestion in the Repository of overflight geometric and operational information;
- triggering the generation and distribution of Overflight Opportunity Files;
- highlighting planning conflicts. The prime conflict resolution foreseen at the time of writing ensures an assignment of overflights in accordance with the agreed Overflight Sharing Policy . Potential planning conflicts are resolved between orbiter and lander operators during relay coordination meetings.
- inspecting the overflight performance (see Fig. below).

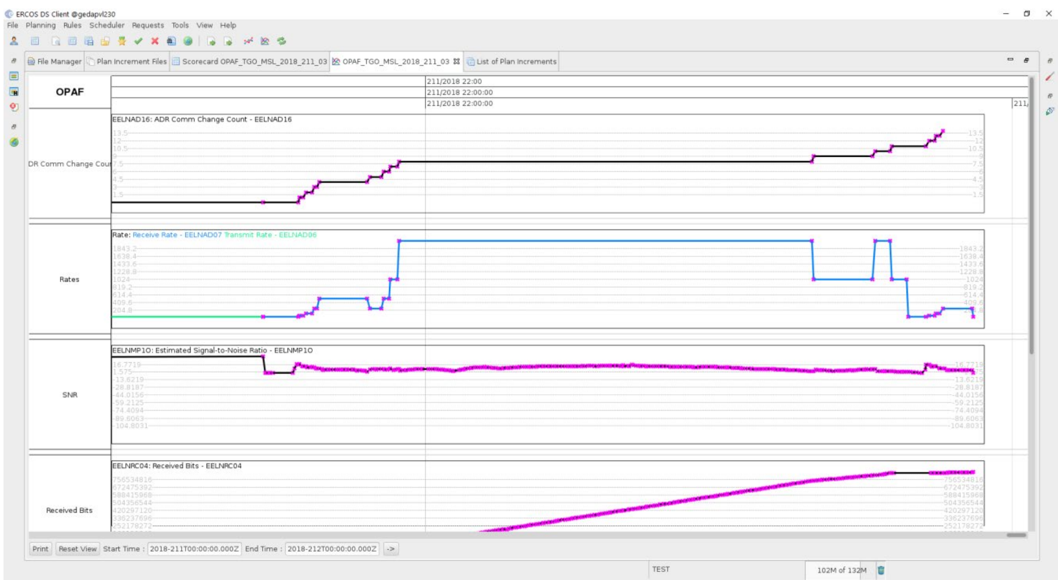

Fig. 11. MMI overflight performance profiles shown in the Gantt View.

3.1.3 File Archive

The ERCO-DS File Archive is responsible for archiving and retrieving all files transferred via the ERCO-DS File Manager, as well as all data related to the overflights coordinated by the Relay Office.

The design of the ERCO-DS maximizes the reuse of generic ESOC infrastructure (such as user management, redundancy, deployment, file distribution, etc.) and functionalities developed for the ERCO TGO [4].

4. Expansion of the ERCO-DS to perform data Relay of Landed Assets in the Moon

The concept of relay planning and execution activities presented for the Mars scenario are going to be applicable in the upcoming future also to the Moon exploration. The European Space Agency is currently developing the Argonaut programme, that will feature three robotic Moon landings in the next decade, and the Moonlight Lunar Communication and Navigation System (LCNS), that will setup the first network of orbiters providing telecommunications, position, navigation and timing services to institutional as well as private missions on and around the Moon. In turn, LCNS will be but one of the elements that will constitute the LunaNet network [8] .

The European Relay Coordination Office will enable the Argonaut end users to exploit the data relay capabilities of LCNS, and potentially of any other LunaNet service provider.

While the relay concept is unchanged, the setup of ERCO-DS will be expanded to:

- Interface with the various Argonaut Lander Control Centres. ESOC will be hosting the MOC for the Argonaut Lunar Descent Element (LDE), which is the "platform" component common to all Argonaut flights, while the payloads of the individual Argonaut missions will be operated by dedicated facilities outside ESOC.
- Interface with the LCNS service front-end and implement any needed conversion between the file formats used in the LCNS environment and those used in the Argonaut environment.
- Interface with other LunaNet service providers, again with format conversion as needed.
- Handle what is new for the Moon operational scenario with respect to the Mars one, namely:
    - The planning of relay activities between two Moon orbiters. Argonaut will need to use the LCNS relay service also for a period of time (from a minimum of one week to well above one month) while orbiting the Moon, in preparation for its descent and landing phase.
- The LCNS capability of servicing multiple (up to eight) landers concurrently, and to accommodate more than one relay session within one geometric overflight.
- Real-time communication via the relay network. Rather than only exchanging forward and return link data in the form of files, LCNS enables the Argonaut ground segment to downlink telemetry and uplink telecommands "á-la SLE", routing the data units via the LCNS ground and space segments. The experience from the perspective of the Argonaut operator becomes therefore the same as having a direct-to-earth link, albeit with longer transmission delay w.r.t. the one-way light time.

Depending on the chosen implementation strategy, the "lunar expansion" of ERCO-DS may result in a single central network point that governs both Mars and Moon relay, or two twin systems, one dedicated to the Mars missions and the other dedicated to the Moon ones.

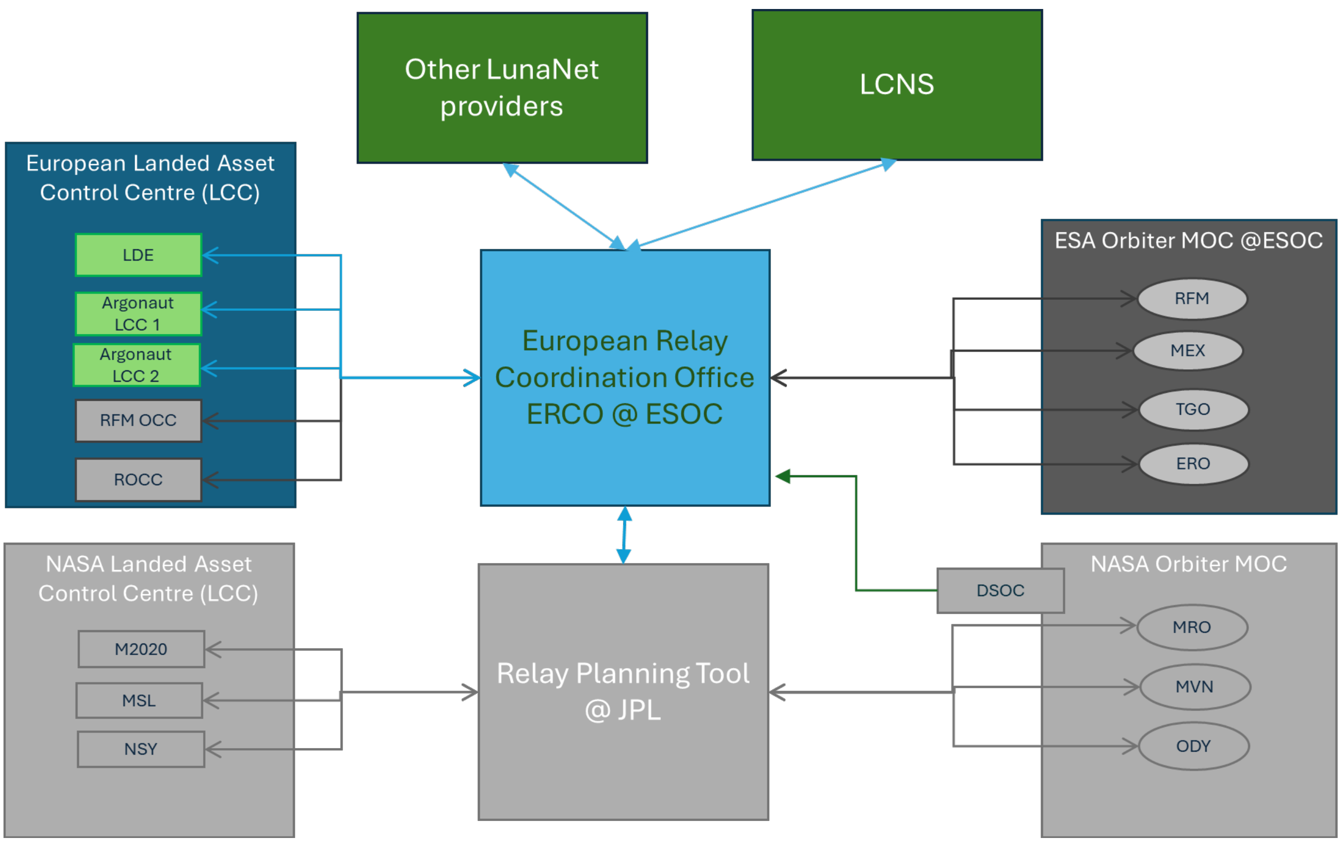

Fig. 8. ERCO-DS planned interface expansions to support the Relay of Landed Assets on the Moon

6. Conclusions

ERCO, and ERCO-DS have become an essential part of Data Relay services for Mars Landed Assets provided by the European Space Agency, and therefore a fundamental component of the international Mars Relay Network and the Mars Exploration Program.

ERCO has evolved from the early years of ExoMars TGO mission, from a single Orbiter service to a multi-mission, system. As the cooperation between new partners evolves, so does the Relay service concept. With the addition of new interfaces, new Orbiters and new Landed Assets, the system grows, and protocols and concepts are expanded.

The extension of the Relay services from ERCO to the Landed Assets on the Moon, will require yet the implementation of a different protocol that optimises the service considering the short propagation delay between Earth and the Moon Orbiters, the frequency of contacts and the variable duration of the overflights over different Moon regions.

Another area for exploration in ERCO's service is the method to transfer Relay requests, protocol handshakes and products. Currently ERCO-DS is purely file based, in the sense that it receives Relay requests in files and provides the Relay products and Relay performance evaluations as files.

In order to increase the reuse and standardize the service provided by ERCO, a project to implement the provision of the Relay outputs (Relay products, Relay performance assessment, Overflight performance assessment) using CCSDS Mission Operations (MO) services [6][7] will start soon. This parallel service will allow for a real-time retrieval (poll) method from consumers (typical LCCs), instead of waiting for the files to become available (push).

Acknowledgements

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