8th European Mission Operations Data System Architecture Workshop (ESAW)

Programme & Abstracts

	Tuesday					
	2 November 2021					
8:00	On-site Registration					
9:00	Safety Briefing & General Logistics					
9:15	Welcome Address by Nicolas Bobrinsky (Head of OPS-G)					
	Plenary Session 1	**OPS Data Systems**				**Mario Merri**
9:30		Innovation in Data Systems & Distributed Operation				M. Merri (ESA/ESOC)
9:55		Challenges of the Next Generation Mission Operations Infrastructure Data System				M. Pecchioli (ESA/ESOC)
10:20		The OPS-SAT Series: building a fleet of ESA Labs in space				D. Evans (ESA/ESOC)
10:45	Coffee break					
	Plenary Session 2	**Data Systems for New Space**				**Mario Merri**
11:15		M2020 EDL Support A Perspective by The Ground Data System Anomaly Team Lead				N. Dehghani (NASA/JPL/Caltech
11:40		ALTEC perspective on data systems evolution to serve future missions				A. Villa (ALTEC)
12:05		Design Patters for Scaling AI				J. Corbo (QuantumBlack)
12:30		Toward the Solar System Internet				Y. Kaneko (IPNSIG)
13:00	Lunch					
	Parallel Session A1	**Innovative Technologies for Mission Operations Data Systems (Operational adoption of modern technologies)**	**James Eggleston**	**Parallel Session B1**	**Innovative Technologies for Mission Operations Data Systems (Virtual and Augmented reality in Operations)**	**Holger Dreihahn**
14:15	Galileo GCS: development of a satellite telemetry analysis subsystem based on open source tools		G. Ramos	Virtually Supporting CubeSat Operations using SMILE infrastructure		C. Kneusel
14:40	SAMMBA's standard and modular services: smart use of 4.0 technologies to fit ground operations for NewSpace challenges		E. Diez	On the New SATCOM Paradigm: Managing Customer-Oriented Payloads-as-a-Service		L. Alonso-Gonzalez
15:05	Towards a Space Operations Web Application Ecosystem		M. Tykal	Augmented and Virtual Reality for Supporting Mission Operations at ESOC		R. Gad
15:30	Open MCT and Yamcs		N. Mihalache	End-to-End Concept for Offline Mission Operations		T. Nogueira
15:55	Coffee break					
	Parallel Session A2	**Innovative Technologies for Mission Operations Data Systems (Emerging new disruptive and game-changing technologies)**	**Alessandro Ercolani**	**Parallel Session B2**	**Multi-Mission Architectural Concepts (Architecture of mission operations data systems)**	**Vemund Reggestad**
16:15	Using Kubernetes and micro services in the Flight Dynamic Systems		G. Jolly	Peeling an operational monolithic mission chain into a cloud-native micro-services architecture (without breaking anything!)		D. Lemaresquier
16:40	There and back again: ground software for large constellations of small satellites		E. Fraga	SIMULUS based Simulations of Human-Robotic Operations		K. Kapellos
17:05	ProPML: Logfile analysis for anomaly prediction in ESOC ground systems		H. Petreski & P. Veskos	One Operation Data Systems Infrastructure for all ESA space assets		M. Prokopczyk & A. Rumbero
17:30	Telespazio's new Products Strategy for Ground Segment Control Systems		G. Montroni	An architecture for planetary robotic exploration control, the ExoMars 2022: Rover Operations Control System (ROCS)		A. Ortiz
18:00	1-Hour Tour of ESOC					
19:30	Social Dinner at Braustub'l					

	Wednesday 3 November 2021					
9:00	**Panel Discussion: Innovations in Mission Operations Data Systems - being a Spacecraft Operator in 2030**					**James Eggleston**
10:25	Coffee break					
	Parallel Session A3	**European Ground System Common Core (EGS-CC)**	**Daniel Fisher**	**Parallel Session B3**	**Interoperability and standards**	**Holger Dreihahn**
10:55	EGS-CC@GSOC		M. Hobsch	High Data Rate Ground Segment Architectures		F. Flentge
11:20	EGOS-CC Adoption by ESA Missions		M. Koller	High Performance Ground Segment Software		H. Dreihahn
11:45	Orbitcon MCS - Mission Control System for Nanosatellites		M. Sedlacek	Analysing Future Earth Observation Protocol Stacks via Simulation and Systems Engineering		J. Pierce Mayer
12:10	At the crossroads: The future of the Columbus Monitoring- and Control System		N. Trebbin	SIMULUS Next Generation: Impacts and benefits of adopting ECSS SMP		A. Ingenito
12:35	Challenges of using EGS-CC for low cost missions: The OPS-SAT case-study		M. Rey	Data Expression Standards: A Different Look at Data Using Satellite Mission Planning & Scheduling (MP&S) as a Test		D. Sather
13:00	Lunch					
	Parallel Session A4	**Multi-Mission Architectural Concepts (Model Based System Engineering, Agility and Digital Twin)**	**Alessandro Ercolani**	**Parallel Session B4**	**Innovative Technologies for Mission Operations Data Systems (Artificial Intelligence in Operations)**	**Vemud Reggestad**
14:15	Model-based Astronautical Systems Development: A project and call for support		R. Rovetto	Bringing AI for Telemetry Analysis into Production		M. Dauth
14:40	Digital Transformation of Ground Infrastructure		J. Klepper	Towards MLOps for ESA Mission Operations Data Systems		O. Kekisev
15:05	Towards a Digital Twin for robotic exploration mission operations		K. Kapellos & E. Ntagiou	Empowering SATCOM ground operations through artificial intelligence		L. Alonso-Gonzalez
15:30	Digital Twin for mission planification of Space Inspire, the software defined satellite by Thales Alenia Space		F. Vidal	A PLATFORM TO SUPPORT GROUND SEGMENT AI APPLICATION DEVELOPMENT		P. Beltrami Karlezi
15:55	Coffee break					
	Parallel Session A5	**Cybersecurity and Development Aspects**	**Mauro Pecchioli**	**Parallel Session B5**	**Design and validation of mission operations**	**James Eggleston**
16:15	ESA Developments in the Security Cyber Centre of Excellence (SCCoE) and Cyber Safety and Security Operations Centre		J. Irving	Aurora: a multi-mission programming simulator and visualization tool		S. Goulet & N. Bataille
16:40	Addressing Cybersecurity for a Multi Mission Ground Segment Infrastructure		M. Wallum	PME – A New Lightweight Procedure Management Environment for future Ground Segments		W. Heinen
17:05	EGOS-MG DevOps Solution Design		D. Serrano Torres & P. Iglesias	Building an OPEN Community Based on GitLab		A. Langs

Table of Contents

Session A1

Galileo GCS: development of a satellite telemetry analysis subsystem based on open source tools

Ramos G[1], Jimenez M[2], Pozo V[3]
[1]GMV, [2]GMV, [3]GMV

Parallel Session A1: Innovative Technologies for Mission Operations Data Systems (Operational adoption of modern technologies), November 2, 2021, 2:15 PM - 3:55 PM

Satellite ground segment subsystems development has been traditionally linked to the use of consolidated products and technologies, usually developed ad-hoc for these specific purposes and then maintained for many years to avoid costly revalidation campaigns. This approach provides a safe and reliable basis for operations, but imposes some limits and delays on the subsystem evolutions and prevents the use of state-of-art technologies that could radically improve their efficiency.

A promising alternative is the transition from monolithic subsystems (usually implementing many different functions) towards a collection of services covering a more reduced set of functions (or even a single one); this process can be associated to the introduction of open source software components in a modular and expandable architecture, which allows keeping legacy and reliable core system functions working on the background while some others are replaced by more modern solutions.

This solution allows reduced development times and eases a fast incorporation of improvements in the future, focusing the efforts on the customization for the operator specific purposes. In order to put this concept into practice, Galileo is a good target mission, being a long and stable project with increasing demands from the operator and a huge need to have a modern GCS architecture capable to cope with the latest needs in terms of obsolescence and security. In this case, the requirements for constellation performance and telemetry analysis drive the definition of flexible and scalable dashboards and processes in a highly demanding environment, with a huge amount of data to be managed. By using common APIs and standard data structures, the incorporation of additional tools (e.g. advanced data analysis ones) to the subsystem can be done in a straightforward way without requiring costly adaptations. Along the paper it will be shown the processes followed during the integration and the results obtained, in particular, the value added in terms of Routine Operations, Performance Analysis, LEOP support or KPI monitoring.

SAMMBA's standard and modular services: smart use of 4.0 technologies to fit ground operations for NewSpace challenges

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Parallel Session A1: Innovative Technologies for Mission Operations Data Systems (Operational adoption of modern technologies), November 2, 2021, 2:15 PM - 3:55 PM

Small NewSpace launcher initiatives across the globe are emerging with the aim to provide more responsive, flexible and affordable orbiting services to new generations of satellites. Due to the prevalent miniaturisation of components and the trend towards using resilient constellations comprised of numerous small satellites, access to space is shifting towards higher launch cadences, flexibility and low cost, which cannot be fulfilled by existing launch services. To apply these requirements to global operators and spaceports, which need to be able to flexibly manage a variety of NewSpace needs, SAMMBA is designing modular services that lead decidedly towards standardisation.

SAMMBA — Standard And Modular Micro launcher BAse services — is a European collaborative project that aims to design standardised ground services. Launch base systems and mission operations solutions are based on technological building blocks that will be initially validated by enabling a variety of spaceports to handle the diverse needs of the coming decades. SAMMBA relies on state-of-the-art and innovative technologies, and both modular architecture and standard interfaces to successfully provide new and unique modular services for the developing NewSpace market.

A crucial component of SAMMBA's offer is the targeted and effective application of emerging and innovative approaches to campaign operations, including the use of technologies such as virtualisation, cloud computing, containerisation, augmented and virtual reality, big data and digital twins, cybersecurity, vehicle automation, artificial intelligence, machine learning and predictive maintenance. The services designed and demonstrators achieved within the project will act to set up future industrial organisation efforts for NewSpace challenges, providing affordable, reliable, flexible and frequent access to space for small satellites in Europe and beyond.

To adequately respond to the evolving needs of small satellites, launch service providers and launch bases, the SAMMBA consortium utilises system engineering and modelling tools to centralise and trace system requirements, as well as applies innovation and value analysis methodologies to perform detailed techno-economical assessments of possible concepts. SAMMBA also benefits from feedback from potential customers, which help to efficiently adapt the designed solutions to customers' priorities — from the definition of needs to the deployment of demonstrators, including operational and cost models.

This contribution will present the technological accomplishments of the SAMMBA consortium as they apply to NewSpace challenges. While the project focuses on spaceport operations as the SAMMBA partners' core business, the technological concepts evaluated and assessed through demonstration in SAMMBA are applicable to not only spaceport operations but also mission operations, remaining under the same requirements of cost, responsiveness, operations RAMS, flexibility, standardisation, modularity and decentralisation.

SAMMBA is being implemented by a consortium of six European partners: Air Liquide Advanced Technologies (France), CT Ingénierie Paris (France), EURECAT (Technology Center of Catalonia, Spain), GTD Sistemas de Información (Spain), MT Aerospace (Germany) and SpaceTec Partners (Belgium). The project has commenced in January 2020 and will last for a total of three years.
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 870451.

Towards a Space Operations Web Application Ecosystem

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Parallel Session A1: Innovative Technologies for Mission Operations Data Systems (Operational adoption of modern technologies), November 2, 2021, 2:15 PM - 3:55 PM

During mission operations, requirements can arise that cannot be fully met by tools available to the mission team at ESOC. Consequently, new tools, frequently web-based, are created within the missions. These developments are usually mission-specific and their usage is limited to the members of the mission team. However, the problems that missions face are often similar and the tools developed by one mission could be useful for others.
Currently, there is no straightforward way to find out what tools and solutions are available in other missions. Furthermore, there is no common way to access these solutions or receive support for them. Therefore, it happens that tools with similar purposes are developed in different places, reinventing the wheel. Synergy between these applications is lacking as each application uses their own approach for security, data storage, data display and other typical functionality.
The Web4MIT study and the subsequent prototype is tackling exactly these challenges by offering a non-restrictive open platform that serves as a base for an ecosystem of web-based applications. The platform can be compared to a mobile operating system. It manages apps and provides shared functionality that all applications can use such as user authentication and preferences, application settings, data access and permissions, etc.
The platform is extensible and provides support for various web applications with common features accelerating their development without the need to reimplement standard functionality for each application. The effort required for developing new applications and maintaining existing ones can be reduced, shortening the time to operational use and reducing the maintenance effort. The advantages of the platform are taken even a step further by supporting and fostering interoperability and exchange of data between applications. This data exchange is organised in discoverable services, which can be leveraged to build new dedicated end-to-end solutions. Some of these advantages are not entirely new and were already drivers in the development of the EUD framework. They are here brought into the Web paradigm and multiplied by the intrinsic benefits of Web technologies in terms of interoperability and rapid development.
Moreover, the platform offers an integrated “App Store” allowing users to explore and discover new applications that are connected to the platform. End users can easily integrate new applications into their virtual work environment by enabling them through the store and configuring them notably for their data sources. Thus, the platform acts as the single entry-point through which users can access their applications.
This concept has the potential to engage both developer and end-user communities who may contribute together to a harmonized and interoperable environment while creating new applications as needed. This potential goes beyond the developments done by missions as this concept also facilitates the deployment and integration of third-party web-based tools, i.e. developed and sold by industry. As such, it is well qualified to become a prime example of the advantages of ESOC’s new software community approach, which will allow communities inside and outside of ESA to contribute to and benefit from solutions like the platform developed in Web4MIT.

Open MCT and Yamcs

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Parallel Session A1: Innovative Technologies for Mission Operations Data Systems (Operational adoption of modern technologies), November 2, 2021, 2:15 PM - 3:55 PM

This paper shares with the Open MCT and Yamcs communities recent improvements to these two tools to provide an integrated open source mission control system ready to support exploration missions.

Open MCT is an open source mission operations data visualization framework developed by NASA Ames Research Center in Silicon Valley, in collaboration with NASA AMMOS. It provides state of the art web-based interfaces for desktop and mobile devices. Open MCT is currently in use at multiple NASA centers supporting various missions including Earth orbiters such as JASON-3 and IceSat 2; interplanetary missions such as the Mars Cube One cubesats that accompanied the Insight Mars mission; and future missions such as the VIPER lunar rover and Europa Clipper.

Yamcs was originally designed to complement the standard Mission Control System at the Belgian User Support and Operations Center (B.USOC) for ISS operations. Remaining loyal to its core values of being lightweight, scalable, reliable and open source, Yamcs has evolved throughout the years to a complete end-to-end Mission Control System framework. Yamcs is now being deployed as the ESA MCS for some ISS subsystems and payloads and, outside the ISS world, it is being deployed to support exploration missions such as commercial Lunar landers and rovers.

The two tools are very complementary; Open MCT provides a state of the art mission operation visualisation framework, while Yamcs brings a reliable/CCSDS compatible/comprehensive backend for the control of a spacecrafts and payloads.

Thanks to the open source nature of both Open MCT and Yamcs, various mission operators have performed their own integrations of the tools and deployed it to support their mission. From those integrations a generalizable open source plugin to integrate Open MCT and YAMCS has been developed and is in the process of being released.

Both teams developing Open MCT and developing Yamcs support the integration described in this paper. Having an official Yamcs plugin integration with Open MCT will bring value for future missions to ensure the integration is maintained over time. While Open MCT and Yamcs continue to evolve, a state of the art open source solution will be readily available to new missions building their ground systems.

The initial deployment of the integrated system Open MCT and Yamcs for the VIPER mission has been conducted in early 2020 and the VIPER mission is scheduled for launch in late 2023.

Session B1

Virtually Supporting CubeSat Operations using SMILE infrastructure

Jain V[1], Kneusel C[1]
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Parallel Session B1: Innovative Technologies for Mission Operations Data Systems (Virtual and Augmented reality in Operations), November 2, 2021, 2:15 PM - 3:55 PM

SMILE – Special Mission Infrastructure Lab Environment is a team of individuals working from ESA's operations centre ESOC in Germany. The purpose of the SMILE lab is to provide services to small satellite teams, majority of which consists of CubeSat developers in ESA member states. In todays 'age ground station access is limited and small satellite developers mostly consist of university students lacking funds to invest into ground station development while budgeting for their satellite infrastructure. SMILE provides a complete end-to end ground station service where users can log in remotely, perform an end to end test with their spacecraft and further communicate with it. Data obtained from the satellite can be made available in real time or accessed later.

SMILE uses an unique service oriented - mission operations architecture in order to schedule passes allowing multiple users to access the ground station facilities. All of these operations are done using a virtual/remote setup, available to users from ESA member states. Such set-up enabled the team to support the launch and commissioning phase of two satellites from OpenCosmos, LacunaSat-2 and 3B5GSAT, during the COVID-19 pandemic. Details on the open API interface used for scheduling passes and TT&C support over the MQTT protocol will be highlighted in the presentation at the conference.

SMILE currently consists of a 3.7 m dish which support S band uplink and downlink along with X band downlink. A UHF antenna for uplink and downlink in the amateur band, a dish antenna supporting downlink in the S-band amateur frequencies and the team is currently testing a new antenna called Reindeer in Kiruna, Sweden which will support UHF uplink and downlink along with S-band Downlink. In addition to using the above antennas mentioned, SMILE team also provides its users access to all available Hardware and Software Interfaces, like SDR, SLE & MQTT, remotely. Ground hardware can be expensive to obtain and the SMILE lab allows its users to validate their mission operations concept remotely using the available ground station equipment.

In future, SMILE wants to explore potential customers and support the small satellite industry in ground station infrastructure, operational validation as well as satellite operations. The presentation at ESAW will enable users to understand SMILE and its potential benefits to the small satellite industry. Building a small satellite community will prevent re-invention of the wheel and allow universities benefit from lessons learned. SMILE is a small contribution to the future of such a community.

On the New SATCOM Paradigm: Managing Customer-Oriented Payloads-as-a-Service

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Parallel Session B1: Innovative Technologies for Mission Operations Data Systems (Virtual and Augmented reality in Operations), November 2, 2021, 2:15 PM - 3:55 PM

An unstoppable revolution in the SATCOM market is leading to the development of increasingly flexible satellites, capable of providing solutions to services and necessities never imagined before. The more capabilities these satellites provide, the more demanding services are being requested by the customers, and vice versa. To do this, these satellites are provided with telecommunication payloads which are no longer considered as custom hardware solutions, but customizable softwarized ones.

The development of such complex satellites is transforming the SATCOM market from different points of view. Nevertheless, the purpose of this presentation is focused on highlighting the fact that the final user is gaining prominence, as is being capable of managing these SATCOM payloads as mere services. This means a complete disruption in the SATCOM services paradigm, as with traditional payloads, these services were traditionally managed by satellite operators.

The Eutelsat Quantum is the pioneering commercial satellite in terms of providing the customer with the control of a software-defined payload-as-a-service. As a result, the customer is able to redefine the service coverage areas, and the rest of the radiofrequency resources allocation, in order to meet in real-time their dynamic business requirements, such as communications-on-the-move, guaranteeing 24/7 resilience.

This flexibility is a reality mainly thanks to electronically splittable, shapeable and steerable beams, or its flexible payload whose core is based on several Single-Channel Agile-Converter Equipment (SCACE), providing configurability to the spectrum resources allocation. Additionally, this payload supports the capability of interference geolocation and mitigation. In order to manage such a complex payload, a ground software tool such as the Communication Mission Reconfiguration Software (CMRS), developed by GMV, is indispensable. This tool shall manage numerous safety-checks to not only ensure the quality and security of its own operations, but also the compatibility with other missions, by the implementation of, for example, coordination agreements or power, limits and payload checks.

Although being a disruptive commercial satellite in the SATCOM market, the Eutelsat Quantum has a limited number of resources. Due to this, the most convenient management of those resources is through contracts, which exclusively delimit their use, facilitating the prevention of, for example, interferences. Nevertheless, newest software-defined satellites are foreseen to have the capability to generate thousands of beams and channels, which may lead to a different approach to explode the satellite resources, considering non-exclusive contracts and taking benefits of non-continuous use of the resources.

In this presentation, the authors propose and explain a potential advanced high-level version of the current CMRS, although capable of giving an answer to the optimum management of the upcoming satellites. While continuing putting the final user as the one able to control the payload, this system shall be based on a new paradigm: instead of delimiting operation areas and exclusivity of the resources, it shall contemplate the concept of guaranteeing the average-service providence. This new idea implies the necessity of managing potential resources overbooking, instead of their exclusivity and services-level-agreements, distinguishing between essential and non-essential services, so that the system is able to optimally manage the shared resources.

Augmented and Virtual Reality for Supporting Mission Operations at ESOC

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Parallel Session B1: Innovative Technologies for Mission Operations Data Systems (Virtual and Augmented reality in Operations), November 2, 2021, 2:15 PM - 3:55 PM

In this presentation, we present the ongoing work of a study on supporting mission operations at ESOC with means of Augmented and Virtual Reality (AR/VR). The study is the successor of two precursors activities that analyzed the applicability of AR/VR at ESA in a broader scope, e.g., including the European Astronaut Centre (EAC) and robotics.

The aim of the present activity is to identify and implement AR/VR tools which provide real value for operational use cases at ESOC. We consider this step as a significant challenge. It requires overcoming the "novelty barrier" from conceptual demonstrators towards real-world applications that add value to day-to-day tasks. We consider that experiences gained from previous activities, such as practical usage and feedback especially in terms of ergonomics, user interaction and data back-ends, and recent developments in the area of AR/VR hard- and software provide a good basis for taking this next step.

For increasing the applicability of the results, we foresee a "building block" concept. We envisage that building blocks can be applied in multiple use cases. Examples of building blocks are, e.g.:

- 3D/AR/VR content generation,
  We consider 3D scanning as a promising candidate for a user-friendly and cost-efficient way for producing 3D models. We also consider further steps of the content generation pipeline like annotating 3D models with supplemental information.
- 3D/AR/VR displays and interaction,
  We assess options for cross-platform 3D display solutions considering needs like, spacecraft and components display, planetary data and orbit display, interplanetary trajectory display, or collision analysis.
- connectors for integrating ESOC systems,
  We consider offline, e.g., static metadata and archived data, and online, e.g., live or re-played data, integration.
- and 3D/AR/VR workflow support and integration.
  We analyze the processes along the 3D/AR/VR asset lifecycle and aim for providing an integrated solution that eases steps along the entire pipeline.

We aim towards delivering real value for day-to-day application scenarios. We involve designated end-users and their feedback, which is augmented by the knowledge gained during the precursor activities. For easing the adoption of 3D/AR/VR, we aim on making 3D/AR/VR assets an inexpensively and quickly deployable and usable tool.

From our past activities, we learnt, e.g., that 3D/AR/VR content generation can be challenging. Creating 3D/AR/VR content can be very demanding, e.g., regarding the required expert knowledge in 3D authoring solutions.

With the 3D/AR/VR content creation building block, e.g., we aim on lowering this entry barrier. We intend to leverage recent advancements in AR/VR off-the shelf solutions such as easier 3D scanning of real-world objects or improvements in hand-interaction via AR/VR devices for easing the 3D content creation.

We also see advancement of commercially available solutions in the area of AR video conferencing. While these use cases are not the focus of the present activity, we consider the functionality offered by recently released solutions as enough for simple use cases out-of-the-box.

The presentation will give a quick summary of the previous activities, the use cases, the state, and give an outlook on the applications to be developed.

End-to-End Concept for Offline Mission Operations

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Parallel Session B1: Innovative Technologies for Mission Operations Data Systems (Virtual and Augmented reality in Operations), November 2, 2021, 2:15 PM - 3:55 PM

The End-to-End Concept for Offline Mission Operations, OFFOPS for short, is a study being conducted by VisionSpace and Solenix under a contract with ESA/ESOC. The OFFOPS study is looking for new approaches for satellite mission operations that defy traditional concepts.

This contribution reviews the motivation and objectives of the project, the proposed ConOps and design, and the current status of the prototype.

The OFFOPS ConOps is grounded on model-based, goal-oriented, explainable, hierarchical and service-oriented operations. The ConOps models the problem of mission operation as a multi-agent, concurrent, collaborative planning and scheduling system, where each agent aims at achieving its own optimisation criteria, and altogether the agents collaborate to support a global optimisation.

The proposed ConOps brings various operational benefits by providing increased autonomy and standardisation through reducing the need for online, synchronous access to the spacecraft. Routine and repetitive tasks are delegated to software agents, thus allowing spacecraft operators to play a supervisory role in the nominal mission phase and focus on critical and exceptional tasks instead. Automated planning and re-planning capabilities reduce human workload by processing planning requests without human intervention. Moreover, such automated planning capabilities offer an automatic and timely conflict resolution strategy, further reducing human intervention.

Based on the ConOps, the design and prototype are constructed around the Janus mission and a set of demonstration cases that seek to show particular concepts and capabilities. Janus is a hypothetical Mars mission inspired by the ongoing ESA's ExoMars Trace Gas Orbiter and the planned Sample Fetch Rover and composed of the Janus Surface Rover (JSR) and the Janus eXperimental Orbiter (JXO).

The demonstration cases build on a multi-agent framework to explore new capabilities and concepts in the areas of planning and scheduling, fault prevention, detection and management, data management, onboard software and security.

The prototype, running on a Kubernetes cluster, is currently being finalised by the team. The prototype showcases the different capabilities and how they come together to implement end-to-end mission scenarios.

Session A2

Using Kubernetes and micro services in the Flight Dynamic Systems

Jolly G[1]
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Parallel Session A2: Innovative Technologies for Mission Operations Data Systems (Emerging new disruptive and game-changing technologies), November 2, 2021, 4:15 PM - 5:55 PM

The Flight Dynamic Systems (FDS) are softwares used by ground segment operators for mandatory computations. The results help in taking decision for satellite activities.
The FDS are used for many computations, some of them can be time consuming or require a lot of resources. The needs for the computations vary in time and may punctually increase. The FDS core are usually installed on a single hardware so changing the whole computation infrastructure to support such increase is not trivial and implies a service interruption or a transition phase that may trouble the user experience.
Kubernetes is an open-source platform for containered application management allowing dynamic increase for resources and workload balancing. It is possible to add resources without interrupting the service or to update the application to keep the user service continuity, leaving the external configuration untouched.
Oreflids is a Flight Dynamic System product, based on Orekit for algorithm computation, using Kubernetes offering a micro-services architecture with needs adaptability. Using the possibilities offered by Kubernetes, it is possible to increase the available workload for heavy duty phases. When the workload is lessening, the freed resources can be used for other applications. More resources can be added for the workload balancing while keeping the already available resources. Furthermore, the product can be updated without shutting down the application. Oreflids offers a user interface for the Flight Dynamic System data and activity management, but as these functions are available through a REST API it is possible for other clients to use them as well, be it a command lines or automated procedures.
The micro-services architecture to propose a set of algorithms beside the base services. Each algorithm is a micro-service defined by a containerable image and a parameter file. During the launch of an algorithm, the image is deployed on a new container and the parameter file helps to know which data is required as input. In order to work, the container get in touch with the base services to know which files should be retrieved through the data service. The execution environment is then isolated which allows to prevent any computation problem from troubling another computation. At the end of the execution, the outputs are stored through the base services and the container can then shutdown to free up resources for another execution. This mechanism allows for an easy increase of available algorithm. It only requires sharing a new containerable image and the description of the parameters in the database to be added to the list of available algorithms.
This presentation is focused on the advantage of a distributed environment with micro-services for a Flight Dynamic System. It will show how to set an algorithm computation as a service to have an isolated environment and to allow better workload balancing. The micro-service architecture can also be used to add application specific services. It will discuss how Kubernetes helps managing resource increase or software updates without user service interruption for critical phases.

There and back again: ground software for large constellations of small satellites

Garzón H[1], Gil J
[1]*Gmv*

Parallel Session A2: Innovative Technologies for Mission Operations Data Systems (Emerging new disruptive and game-changing technologies), November 2, 2021, 4:15 PM - 5:55 PM

A new paradigm in terms of communication satellites has arisen in recent years. From a model based on fleets with several 'big' GEO satellites to a new approach with many (100+) LEO satellite constellations. Some actors such as OneWeb or SpaceX have already started to deploy such large constellations while Amazon and others are also in the way.

This new concept introduces however new huge challenges not only in the space vehicles but also in the ground segment. The solutions in terms of control software historically in place for ground control centers of GEO satellites are no longer applicable to LEO large constellations.

The key driver here is scalability. Both the ground antennas and the control software needs to be able to seamlessly scale to hundreds or even thousands of satellites as the constellation grows, while ensuring the cost effectiveness as a major driver for producing feasible solutions.

In that sense, in 2019 GMV launched a disruptive initiative in the form of an internal project with a twofold objective:

- Develop a new ground software solution suitable for large constellations of small satellites.
- Align GMV ground software portfolio with modern software technologies.

The project relies on a roadmap of features to be supported by a system being built from scratch ensuring the flexibility to introduce iteratively new concepts depending on the feedback provided by GMV customers and ground segment experts focused on constellations.

In this paper we describe the most relevant features of the system currently being developed and also the methodology in place. The way in which the project is being carried out relies on introducing state of the art technologies in the form of modern software components that enable quick experimentation turnaround and allows the team members to evaluate the most appropriate solutions for each relevant use case.

The architecture of the system introduces standard components whenever possible with the goal of configuring software elements instead of developing ad-hoc code. The range of such existing technologies being used range from awareness frameworks such as Grafana, Docker for containerization of micro-services or modern time data series databases such as InfluxDB.

The resulting system, which enlarge the GMV portfolio of ground system products, is already providing a large range of features including the management of satellite contacts, telemetry download, telecommand uplink, aggregation of monitoring data, logging and alarms and scheduling of activities. Further, the system supports labelling and filtering of system components and APIs for external users' access with the objective to provide a unified access to large satellite constellations in a homogeneous way.

Special care has been devoted to the deployment mechanisms so as to not depend on any operating system version nor particular physical hardware architecture. This eliminates constraints regarding horizontal scalability to support any constellation size with maintaining the resources usage footprint under control.

ProPML: Logfile analysis for anomaly prediction in ESOC ground systems

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Parallel Session A2: Innovative Technologies for Mission Operations Data Systems (Emerging new disruptive and game-changing technologies), November 2, 2021, 4:15 PM - 5:55 PM

The ever-increasing complexity of Ground Systems used in space missions has made the efficient debugging of software failures an important priority for ground operations. Previous ESOC activities have created tools assisting developers diagnose system performance issues using machine learning methods. While work was performed to accelerate the diagnosis process and enable it to process big-data scale volumes of data, these activities fundamentally aimed at post-hoc root cause analysis of problems that had already occurred.
Extending this work, ESOC systems could also benefit from notification of impending anomalies or failures. This would enable operators better plan actions to avoid problems before they occur and help reduce maintainability costs if early warning of problems could be automated. The aim of ProPML was to create a software prototype to predict failures from system logfiles and to deliver a standardised relevant dataset that can be used to learn such predictive models. Use cases were collected from ESOC stakeholders, including missions, ground station, the ESOC Advanced Operations Technology group, and GSRF testing facilities. To provide non-space data for the study for comparison purposes, a partnership was established with an avionics company.
Logfiles were retrieved from ESOC archives, spanning a 9-month period. Significant effort was spent to overcome formatting inconsistencies across systems, even within individual files, as ESOC logfiles do not adhere to a common format. The data preparation & dataset assembly process utilized the ELK stack. Storing logs in the ELK database enabled execution of complex queries to cross-correlate logged events with other data sources such as Uberlog (mission operators log) and spacecraft pass schedules, reconstruct timelines using visualisations, and testing of different hypotheses as to the causes of system failures.
Unsupervised ML clustering was used to discover similar messages based on statistical techniques, without requiring user input. Natural Language Processing (NLP) methods were used to extract text from logs and capture semantic information. Red Hat Log Anomaly Detector (LAD) was adapted to be used with ELK for this purpose. This correctly labelled some log messages as anomalous, as confirmed by the operators, but with some false positives.
As supervised methods depend on the existence of labels indicating which logs correspond to anomalous events, Uberlog was used as a starting point as it included information from system experts (operators) about problems encountered. Timeframes containing unusual patterns and potential problems were correlated with logs and the output of the unsupervised approach to detect all instances of each anomaly. This way the unsupervised method was used to 'bootstrap' the labelling process. The results verified the importance of the quality of data labels: If done correctly, it could reach a success rate up to 99% for anomaly prediction in certain use cases.
Using the prototype with the non-space dataset showed that its policy of logging everything as ERROR biased the results, marking rarely present messages relating to normal system functioning as anomalous. This again highlighted the importance of experts with knowledge of both the system and the logs to correctly provide initial feedback (labelling) to the algorithms.

Telespazio's new Products Strategy for Ground Segment Control Systems

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Parallel Session A2: Innovative Technologies for Mission Operations Data Systems (Emerging new disruptive and game-changing technologies), November 2, 2021, 4:15 PM - 5:55 PM

The global space industry is evolving at an unprecedented pace of change, affecting the business models of market operators. This evolution is happening in Europe as well, where international and national organisations are increasing their support and funding of ambitious new programs.

The transformation of the space industry is so dynamic that has seen the introduction of new terminology; NewSpace describes activities not fully mapping to the activities of major institutional programs that represents the Classical Space domain. As documented through a market analysis, the space sector is segmenting into different parts, each with a unique set of drivers. Factors such as willingness to accept (non-catastrophic) failures, time to market, different operations models, lead to very different system requirements that are not optimally satisfied by a single product. Central in all markets is the Operations as a Service (OaaS) concept, which is becoming increasingly important in operations management, with key examples already present in Europe.

Telespazio has developed or contributed to the development of new systems, mapped to the identified market segments, namely EGS-CC, EASE-M, and ENABLE.

Classical Space and EGS-CC: ESA, national agencies and industry primes have been working since 2010 on developing EGS-CC, a truly common ground segment infrastructure system to be used as the basis for the development of the majority of the systems used in the ground segment and operations. Telespazio has invested in this activity since the beginning and has led the European consortium that ultimately developed EGS-CC. We consider EGS-CC to be the most complete and functionally capable system on the market. Therefore, it is the key element of our offering, as we plan to use EGS-CC based products in the European market; specifically for cases where the complexity of the mission requires the use of a fully standardized system.

OaaS and EASE-M: EASE-M is a product developed by Telespazio Italy, mainly to be used for the Operations Services offered at its Fucino operations control centre. With EASE-M, Telespazio can propose the management of mission operations, owning the full stack of systems and infrastructure, and at the same time is in the position to address the needs of both civil and defence markets. EASE-M is an in-house product solution, web-based, able to support multi-mission configurations.

NewSpace and ENABLE: the market is witnessing the entrance of new players, mainly start-ups, and the introduction of a product like ENABLE fits well in this sector.
With ENABLE Telespazio addresses the needs of companies that are normally operating constellations of small satellites with simple mission objectives and short timelines. ENABLE is a cloud native end-to-end solution that provides the main functionalities such missions require. This offering is adapted to the financial constraints of small ventures with simplified licensing schemes, and low cost solutions. The ownership of the IPR allows us to promptly respond to new customers' requests, and operate flexibly outside the European market.

In this presentation, we will outline the rationale for Telespazio's multi-pronged strategy and the latest developments in our activities.

Session B2

Peeling an operational monolithic mission chain into a cloud-native micro-services architecture (without breaking anything!)

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Parallel Session B2: Multi-Mission Architectural Concepts (Architecture of mission operations data systems), November 2, 2021, 4:15 PM - 5:55 PM

In a ground segment for earth observation satellites, the mission chain is the sub-system in charge of the deposit and follow-up of programming requests by the operators, and the computation of an optimized mission plan that will be send to the control ground segment based on these programming requests.

Until 2019, earth observation mission chains were based on the MISEO3 software, developed by Airbus Defence & Space. This software was based on a client / server architecture, which grew over the time into a complex monolithic software.

As new programs came (Pleiades NEO, CO3D), with new concepts of operations (CONOPS), more automation and an increased volume of acquisitions, an interrogation came out: should we continue to invest on the MISEO3 software, based on outdated technologies and on a complex architecture, or should we construct a brand new software, able to respond to all the future CONOPS?

R&D studies and trade-offs led to the conclusion that the existing solution was unable to respond to all the technical and business needs:
- Scalability,
- Developments outsourcing,
- Testability,
- Modularity,
- Cloud deployment
- Costs reduction
- Product strategy

The microservices architectural pattern is based on the definition of small software units, independently deployable and centered on business capabilities. This kind of architecture is perfectly suited to the mission chain needs and answers to the aforementioned criteria. As such, the microservices architecture was chosen to build the next-generation of mission chains (MISEO4).

The MISEO4 architecture is a fully event-driven microservices architecture, constituted of microservices communicating together either synchronously (for data querying) or asynchronously (for events or commands). Each of these microservices is centered on a single mission chain functionality and is delivery as an Helm chart, deployable in a Kubernetes cluster.

This presentation tells the story of this (r)evolution of our mission chain product, describes the benefit of the selected microservices architecture and details the questions raised for such a transition:

- What can be reused from the previous version and how?
While most of these microservices were rewritten from scratch, some existing MISEO3 components were kept as-is. How to integrate legacy components in a microservices architecture?

- How to benefit from the existing tests base?
MISEO3 was the results of many years of developments and was thus extensively validated. How to take opportunity of the existing tests to validate the new MISEO4 architecture?

- How to cope with data migration?
The MISEO3 software is already used in production, and will have to be replaced by MISEO4 in 2022. How to ensure a seamless migration of the mission chain, with all its operational data, with the lowest downtime possible?

- How to monitor an event-driven microservices architecture?

- How to ensure the robustness of a microservices architecture?

- What is the impact of a distributed architecture on the software performance?

- What organizational changes were implemented to deal with this new architecture? What are the impacts of this new architecture on development, engineering and validation teams?

SIMULUS based Simulations of Human-Robotic Operations

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Parallel Session B2: Multi-Mission Architectural Concepts (Architecture of mission operations data systems), November 2, 2021, 4:15 PM - 5:55 PM

This paper presents the SIMROB system that is under development at TRASYS in collaboration with EMTECH and ALTEC in the framework of the 'Simulations of Human-Robotic Operations' ESOC TDE Study.
The objective of this study is to design and implement a harmonized architecture for new capabilities of operational simulators based on the ESA SIMULUS framework to support system wide simulation and assessment of multi-asset mission scenarios. In overview the study aims to demonstrate the following:

1. Possible extensions on SIMULUS to accommodate Human-Robotic missions
2. Multi-asset simulations, suitable for planetary exploration missions
3. Suitability of the approach from earlier phases of the spacecraft development lifecycle
4. Integration with 3DROCS for extending commanding and visualization capabilities

The work is divided in three tasks. It commences with a requirements analysis, followed by the requirements mapping to SIMULUS architecture and concludes with a Proof of Concept that demonstrates the applicability of the proposed extensions.

- Initially, the requirements and the functionality that are needed for multi-asset human-robotic operations simulations including orbiters, robotic systems, crew on the surface and the ground infrastructure are presented. These are the results from the analysis of a set of mission scenarios such as ExoMars and European Large Logistic Lander and the analysis of simulators already developed including 3DROV/3DROCS. We focused on:
  - The targeted simulators' support of all mission phases,
  - The requirements' and functionality's classificasion as generic, as specific per type of asset and specific per mission phase,
  - At what extend the requirements and functionality are already covered by SIMULUS, what can be covered by extending the existing infrastructure and what should not be part of SIMULUS.
- Afterwards, we present the design and the implementation of the main SIMULUS extensions the concept:
  - Atmosphere model: while for an orbiter the measures of interest are the density of atmosphere, air drags and solar fluxes, for an asset operating on the surface of a planet additional elements shall be considered. For example, for Mars surface operations, elements such as air/surface temperature, air specific heat capacity, wind velocity, dust optical depth and the radiation flux at ground level are important for the simulation.
  - Environment Mechanical Dynamics model (SIMDYN extension): represents the topological, morphological and mechanical dynamics aspects of the environment in which the assets evolve. It concerns exclusively the assets which operate in close loop with their environment: a rover moving on a terrain, a robotic arm grasping an object, a robotic system using exteroceptive sensors to perceive its environment.
  - The extended SIMSAT MMI allows to monitor elements of the simulation that are specific to robotic missions such as the 3D representation of the operations environment, images/DEMs/PCLs generated by specific sensors, etc.
- In addition, we present the proof-of-concept simulator demonstrator of a robotic moon surface mission in a multi-asset setup (including a rover, a lander, an orbiter and crew members) focusing on areas that are not covered by SIMULUS. The demonstration mission scenario covers all aspects that need investigation and proof of their feasibility.

One Operation Data Systems Infrastructure for all ESA space assets

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Parallel Session B2: Multi-Mission Architectural Concepts (Architecture of mission operations data systems), November 2, 2021, 4:15 PM - 5:55 PM

A number of European Ground Operational Software Common Core (EGOS-CC) systems have been developed by ESA to establish the new generation of ESOC's ground data systems M&C infrastructure for supporting all applications related to mission and network operations, preparation and execution. It is desired that the new generation will be used for distributed multi asset operations in favor of a wide spectrum of mission scenarios, including robotic or human habitat space cases in addition to the traditional M&C use cases of unmanned space probes. Recent studies analyze the new EGOS-CC infrastructure to check its applicability for these scenarios, and specify extensions, which address the shortages in the functionality.

The "Prototype of an EGS-CC based MCS for Robotic Exploration Missions" (MCSREM) study has just finished and addressed the Surface Planetary Robotic Exploration Mission (REM) needs. The starting point was the analysis of the functionality provided by the ExoMars MCS and the METERON experiment M&C system. Considering functional blocks of both solutions, a specification of MCS for a Robotic Exploration Mission was created. It was compared with EG(O)S-CC to identify gaps. As a result, a gap requirements specification and a gap architecture of MCS for REM were synthetized. The most important areas not covered by current ground segment infrastructure were: assessment, situational awareness (with 3D visualization), planning and plans validation.

"One Operation Data Systems Infrastructure for all ESA space assets" (ONEOPS) is currently in an ongoing state. The study analyzed additional scenarios based on the experience from GMV, Trasys and Airbus. It reused analysis from MCSREM and extended it by a more detailed inspection of robotic and human habitat needs. Thanks to large synergies available in the project, a refined and more accurate specification of requirements for a Robotic Exploration and Human Habitat missions MCS was defined. Support of multi asset missions operated in a distributed manner was emphasized. The development process aiming at further integration of robotic features in areas of assessment and planning into EG(O)S-CC, updating EGS-CC tailoring for robotic needs and defining a new mission for the Columbus Module (for prototyping) has recently started. A significant input for development is the prototype created in the frame of MCSREM.

As part of the output of both studies, a common architecture is being specified based on the next generation of ground data systems. Among new features are:
--Multi-asset operations;
--Distributed monitoring and control;
--Parallel usage of different communication and application protocols than ECSS PUS;
--New elements on top the EGOS-CC infrastructure to cover robotic, human habitat or orbital station use cases, like assessment and planning functionality enriched by 3D asset, environment visualizations;

In addition to the specification, a representative proof of concept prototype is being developed to validate and trade-off feasibility of migrating core functionality of a robotic monitoring system into a common M&C system based on EGS-CC. Some of the functionalities to demonstrate include:
--Robotic mission operational modes for online and interactive autonomy;
--Integration of new MMIs providing 2D and 3D visualizations;
--Demonstration of multi-asset operations;
--Robotic activities planner tools;

An architecture for planetary robotic exploration control, the ExoMars 2022: Rover Operations Control System (ROCS)

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Parallel Session B2: Multi-Mission Architectural Concepts (Architecture of mission operations data systems), November 2, 2021, 4:15 PM - 5:55 PM

ExoMars-2022 is the first Mission to deliver an European Rover to the Martian planet and represented a challenge and an opportunity to GMV for enlarging its Ground Segment development knowledge to cover also the particularities of the operation robotic exploration needs.

This paper provides and updated overview of the GMV developed ESA EXomMars-2022 Rover Operations Control System (ROCS) SW architecture which is a fundamental part of the Rover Operations Control Centre (ROCC) deployed in Italy, Turin.

Currently in its latest stages of development, the ROCS provides to the Rover Operations and Science teams all the necessary tools in direct support to both the Rover cruise to Mars and further surface operations until EOL. This coves all the operational concept implementation including TM/TC reception and generation, science and vehicle planning and simulations, on-board software management, Science and HKTM data archiving and exploitation, etc. via more than 20 integrated subsystems based on ad-hock development but also on COTS, deployed in two main platforms whose major functions are with major architectural divers:

- Reuse of the in-house existing products to maximise benefits from parallel roadmaps, flight proven interfaces, user interfaces and tools integrations to minimise impacts from a variable design in such a company pioneering context.

- Achieve a distributed and collaborative activities planning process between Science and Operations teams in two main “layers”: Strategical (long- term) and Tactical (short term) considering the variable surface conditions and Rover status via several simulation levels implied the reuse of tools between these two operational layers with different degrees of detail in the inputs and outputs.

- Provide the quickest feedback of the science processed and archived products coming from the Rover environmental assessment payload (E.g.: Science, navigational and localisation Cameras, Radar, etc.) back to the planning cycle and in particular for the navigation and mobility aspects. Such loops closure is improved by maximising the re-use of the same interfaces, services and tools used in the previous planning process analysis and verification, allowing for effective data comparison between predicted and effectively downloaded data.

Such architecture is being delivered to our customer ALTEC SpA (Italy) and the ESA in charge of the operations as an integrated suite and turnkey solution ready for the upcoming ExoMars-2022 launch next year.

Session A3

EGS-CC@GSOC

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Parallel Session A3: European Ground System Common Core (EGS-CC), November 3, 2021, 10:55 AM - 1:00 PM

In the 2020s, the European Ground System Common Core (EGS-CC) will be the basis for commercial and institutional check-out systems as well as for monitoring and control systems. As one of the stakeholders, the German Space Operations Center (GSOC) with its Mission Control and Data Systems group (MCS group) is involved in the Steering Board and System Engineering Team. In the presentation the role of GSOC in the EGS-CC project will be illustrated and the measures the MCS group intends to take to promote EGS-CC at GSOC will be described.
At the moment GECCOS (GSOC in-house development based on SCOS 3.1) is the Monitoring Control System used by all Lower Earth Orbit (LEO) and Geostationary Orbit (GEO) satellites operated by GSOC. Through years of improvement and operational experience, GECCOS has become a very stable and well accepted MCS. Nevertheless, systems based on EGS-CC in Europe in the future will offer new technologies (i.e. new Spacecraft database system, new archiving concepts, data bus based on CCSDS MO, new software techniques, improved support for PUS). GSOC as stakeholder can now catch up at an early stage to them. The advantages of using a common code base both in assembly & integration and in operation predestine coordination with the manufacturer of the space segment. This intention failed with SCOS. Even if the question about the obsolescence of systems based on GECCOS has not yet been answered at GSOC, the core of the MCS will in future be oriented towards what the manufacturer prefers for his AIT campaign.
The Mission Control and Data Systems group within their role as „integrator“ continue to test and provide feedback for new releases - as an example serves the support of the EGS-CC consortium in the course of the performance tests. The MCS group participate in reviews and are part of all EGS-CC boards. An ESOC-GSOC Memorandum of Cooperation has been brought to life end 2018. One objective is to promote EGS-CC and EGS-CC development at ESOC and GSOC. Synergies should be identified and used. As a first short-term application goal of the EGS-CC at GSOC the DLR satellite Eu:CROPIS has been commanded with an EGS-CC based system for one contact as a proof of concept. A longer-term goal will be to implement a command system for the DLR satellite EnMAP based on EGS-CC. EnMAP will be launched with a GECCOS based MCS. Part of the project will be to design a system based on the EGS-CC and to identify new software or adaptations of existing software. With the help of a migration plan, the EnMAP MCS shall then be replaced by the new European MCS in routine operation. The Columbus Monitoring and Control System at GSOC will also be migrated to EGS-CC (MCS-R). At the end a review what has been achieved so far and what still needs to be done to successfully deploy EGS-CC at GSOC will be presented.

EGOS-CC Adoption by ESA Missions

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Parallel Session A3: European Ground System Common Core (EGS-CC), November 3, 2021, 10:55 AM - 1:00 PM

As the EGOS-CC project is reaching its end, it is of high importance to ensure rapid rollout of its products for operational usage at ESOC. In order to speed up this process within the EO missions and increase the user acceptance of the EGOS-CC based systems at ESOC, a dedicated activity is on-going to prepare the roll-out of an EGOS-CC based control system for EO missions.
The roll-out follows a path of three consecutive stages for each mission: demo, shadow and operations. During the demo phase, the system is deployed into the development environment and used with an operations mission simulator. During shadowing, the system gets deployed into the operations environment and is used in parallel to the existing S2K system for operations. Finally, the systems is used as the prime control system. In the scope of the on-going activity, there are two missions being used: SWARM (a three spacecraft mission) which will be taken up to the shadowing phase and Sentinel-6 up to demo.
The selection of those two missions as initial pilot candidates has the following advantages:

- Two missions can be done with minimal extra effort for double the output, hence better value for money;
- Doing two missions demonstrates the Multi-mission capabilities of the system, hence added promotion value and accelerates the move towards EGOS-MG.
- Doing one after the other the progress would be slower; Choosing Sentinel-6 and SWARM covers single spacecraft and multi-spacecraft missions in one go. Potential compromises can be validated by both types of mission simultaneously.
- Sentinel-6 requires a functional scope that covers most key features required for EO, hence is a very good test missions for the majority of the features to be developed as part of this work, however since Sentinel-6 is not operated at ESOC, it does not offer a quick path to operational usage.
- SWARM is a mission with quite long expected lifetime and offers a good path towards quick operational adaption of EOGS-CC with added value for the mission.

The activity comprises two work packages: the development of missing features that are required on top of the currently existing MCS-CC system and the promotion campaign for the selected missions. The development is conducted in an agile fashion, and at the time of ESAW is in sprint 3. The user stories stem from four different sources: there is an existing backlog of missing features coming from an earlier study where a gap-analysis had been conducted between the Sentinel-3 S2K controls system and MCS-CC features. There are mission specific features required by SWARM and Sentinel-6 respectively and there are additional interface requirements, mostly towards the flight dynamics systems and the mission planning system.
The first system has been deployed at ESOC and is under initial validation, while the definition of the user scenarios that will be used for the demo and shadowing campaigns is on-going.
The presentation will show the approach of the roll-out, the current status, the key features that are to be developed and look at the scenarios under consideration.

Orbitcon MCS - Mission Control System for Nanosatellites

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Parallel Session A3: European Ground System Common Core (EGS-CC), November 3, 2021, 10:55 AM - 1:00 PM

OrbitconMCS is a full-fledged mission control system (MCS) customized for SmallSats category, mainly for CubeSats, using a European Ground Segment Common Core (EGS-CC) as a kernel component. The kernel component is customized to specific needs of CubeSats missions, given by the fact that heterogeneous protocols are used there and there is less standardization comparing to "big satellites" missions.
The newly created MCS offers standard interfaces (REST API, WebSockets) and easy mission instantiation. The service is hosted in a hybrid-cloud environment that allows both data protection, global accessibility, and redundancy. The MCS contains basic tools needed to cover a whole lifecycle of a mission. To enable quick expansion of the MCS service, we encourage the connection of existing Ground Stations (GS) via predefined interfaces specified according to the OpenAPI standard.
In parallel, we developed a modular reference design that can be used for a nascent Ground Stations (GS). The design covers VHF, UHF, and S-BANDs. The reference GS design guarantees seamless integration with our MCS.

At the crossroads: The future of the Columbus Monitoring- and Control System

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Parallel Session A3: European Ground System Common Core (EGS-CC), November 3, 2021, 10:55 AM - 1:00 PM

With the 2019 amendment to the Advancing Human Spaceflight Act, the National Aeronautics and Space Administration (NASA) is preparing to continue the International Space Station programme through 2030. International partners such as the European Space Agency (ESA) are therefore preparing to ensure a smooth and efficient continuation of current operations by upgrading the Columbus ground segment and the on-orbit segment. A key part of the Columbus ground segment modernization efforts includes the replacement of the current Monitoring and Control System, initially designed to last until 2020, by a new system called MCS-R. To counteract the threat of obsolescence, our industry partner conducted an initial Phase A study back in 2016, followed by a joint Phase B1 in March 2018 and a Phase B2 in January 2020, conducted by DLR's German Space Operations Centre in close cooperation with our main industry partner Airbus Defence and Space. The results of the design and study phase have consolidated the decision to base the new Monitoring and Control system on the emerging EGSCC - an initiative that aims to prepare and enable the operation of future and long-term space missions across Europe in the coming decades. Taking advantage of an emerging iterative product that is currently still in the pre-maintenance phase and constantly experiences updates and refactoring throughout the on-going development resulted in a follow-on study B3, which was used to prototype some of the major adaptations required for MCS-R and Columbus operations. This phase was successfully completed in July 2021, just in time for the release of the final Common Core product, currently scheduled for Q1/2022. This presentation will describe the actions and decisions taken, the obstacles overcome, solutions found, and the alliances forged to ensure the continuity and ongoing operation of Europe's laboratory in space. At the end of Phase B3, we are at a critical crossroad to the future of the Columbus MCS. Not only because the renewal of the Columbus MCS requires a large financial investment, but also because of all the development and parallel verification- and validation work required to implement the new system at the Columbus Control Centre (Col-CC). On the one hand, such a financial and time investment can be justified by postponing the end of ISS operations to at least 2030, also because the newly developed MCS could be reused as a proven and reliable basis for future ESA European exploration missions. On the other hand, any further delay, a yet unidentified obstacle or even a sudden shortening of the remaining ISS lifespan could jeopardise the current strategy. To mitigate the current uncertainties and potential risks, the newly formed Col-CC Integrated Team, composed of ESA staff, DLR staff and key subcontractors, jointly assesses and frequently judges the overall status of the project and its dependencies. Last but not least, the presentation gives an outlook on the planned Phase C/D activities, the collaborative project management approach and how the new system will be deployed to minimise the impact on the ongoing science- and real-time operations of Columbus.

Challenges of using EGS-CC for low cost missions: The OPS-SAT case-study

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Parallel Session A3: European Ground System Common Core (EGS-CC), November 3, 2021, 10:55 AM - 1:00 PM

OPS-SAT is ESOC's first CubeSat mission, and it is also the first satellite implementing and flying with the latest CCSDS MO Services standards. It's been in operation since December 2019. It's purpose is to serve as a flying laboratory to demonstrate improvements in Mission Control capabilities by providing separate experimenter boards available to operators.

The European Ground Systems – Common Core (EGS-CC) is a European initiative to develop a common infrastructure to support space systems monitoring and control during the whole lifecycle phases for all mission types. As EGS-CC has achieved its first major release, it is mature enough to be considered for operational scenarios.

C2LOCO, a GSTP project for ESA lead by VisionSpace together with Spacebel and GOMSpace, aims to provide a one-stop solution for a Monitor & Control System based on EGS-CC for CubeSats and SmallSats. It has enabled the first usage of EGS-CC during a live pass of a flying spacecraft.

In this presentation the key points developed by C2LOCO will be presented, including:
- Generation of EGS-CC compatible definitions of MO services.
- Implementation of EGS-CC extension components to handle TM/TC for MO services and operations.
- Streamlining of EGS-CC configuration and deployment.

OPS-SAT on-board software uses the Nanosat MO Framework (NMF) to implement MO services to monitor and control the spacecraft. The specification of the MO services are used to generate EGS-CC definitions automatically. These contain the activities and parameters to call MO operations on the spacecraft and to receive responses and verification information in the form of telemetry.

Telecommanding operation invocations, and receiving telemetry with information responses, is handled by C2LOCO extension components developed on top of EGS-CC's Reference Implementation and Adaptation layer.

C2LOCO offers a command line tool to streamline the configuration and deployment of an EGS-CC system. Using convention over configuration, most common aspects of the EGS-CC configuration are abstracted away so the deployment only has to deal with the customizations for the mission at hand. Using only a single configuration file, the whole system can be deployed and started.

Session B3

High Data Rate Ground Segment Architectures

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Parallel Session B3: Interoperability and standards, November 3, 2021, 10:55 AM - 1:00 PM

Future missions will feature very high downlink data rates, with up to 10 Gbit/s, over unreliable network links, which may require re-transmission of lost data. This does not only require ground systems supporting such high data rates but also an overall ground segment architecture, designed taking into account specific constraints, such as available terrestrial data rates, operational requirements and security. The large amount of data requires new concepts for the handling and management of this data. In some cases, a decoupling of a highly performant, near-real-time communication from slower data processing will be necessary.
One example of such an architecture with the related ground systems is the Distributed CFDP system, which has been designed and prototyped for the Copernicus Sentinel Expansion Missions. This concept will be implemented from next year on, with the aim of supporting downlink data rates between 3 Gbit/s in 2025 and 7 Gbit/s in 2027. A Ground Station DCFDP system will process incoming data at high rate and provide only the necessary information for CFDP protocol closure to a dedicated Control Centre DCFDP system. Based on this information, the Control Centre DCFDP system can run a CFDP protocol engine and generate the required protocol directives (e.g., requesting retransmission of lost data) to be uplinked via the mission control system. In order to support the use of external, commercial ground stations, the interface between the Ground Station DCFDP System and the Control Centre DCFDP system will be standardised based on the CCSDS Cross-Support Transfer Service framework. From a spacecraft perspective, the distributed CFDP system will behave exactly like a standard, non-distributed, single CFDP entity. The actual file data will be forwarded in the form of files at a lower data rate to a CFDP File Reconstruction system that will re-construct the files as they have been sent by the spacecraft. The system will also support the downlinking of files spanning multiple ground station passes over different ground stations (partial downlink of a file at one ground station with finalising the downlink including re-transmissions at another station) and filtering of the downlinked data according with Global Virtual Channel IDs or CFDP Entity IDs; for example, in order to distinguish between house-keeping and science data. For operations, this will shift the focus from the management of individual packets to the management of files.
The talk will introduce the ground segement challenges related to high downlink data rates and present the related Distributed CFDP architecture and systems to be implemented for the Copernicus Sentinel Expansion Missions. As an outlook, current ideas for potential future high rate ground segment architectures based on Disruption Tolerant Networking (DTN) technologies will be sketched. In a companion talk on 'High Rate Ground Segment Systems' we intend to present more information on individual system performance optimisation and early performance assessment and testing.

High Performance Ground Segment Software

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Parallel Session B3: Interoperability and standards, November 3, 2021, 10:55 AM - 1:00 PM

Future missions will use very high data downlink rates to cope with the increasing capabilities of on board instruments. The Copernicus Sentinel Expansion Missions foresee downlink bit rates of up to 7.5 Gbit/s, which have to be handled in ground systems. Such high data rates are not only challenging for the physical layer, which can be either RF or optical, but also for the higher layer protocols above the coding and synchronisation layer (space packets, CFDP, SLE and Cross-Support Transfer Services). To keep costs low and flexibility high, it is envisaged to realize the implementation of ground systems and higher layer protocols as far as possible in software running on commodity hardware or in virtualised environments.

In this talk, we will illustrate with the example of the Distributed CFDP system for the Copernicus Expansion Missions, how individual system performance optimization and initial performance testing is performed. Early and continuous testing of performance is seen as a crucial element to take an educated decision for the final system architecture. Furthermore it minimizes the risk, in case the target performance is not met.

The considered approach is based on the decomposition of the processing chain into individual functionalities, which are then iteratively prototyped, performance tested and performance tuned without altering the overall functionality. Examples of prototyped functions include, but are not limited to network interface performance, telemetry frame reception and space packet extraction and last but not least CFDP processing. The latter includes some special functions required to distribute the CFDP protocol machine on ground and the dedicated service to facilitate distribution of CFDP PDUs on ground.

We will introduce the methodology and technical foundation of the performance prototyping, which is based on the Java programming language. Additionally, we will include a dedicated performance comparison with an equivalent C++ implementation. Furthermore, general best practices for performance implementations will be highlighted along with design patterns allowing the exploitation of multi core architectures in the context of more or less serial data processing chains.

The companion talk ‘High Data Rate Ground Segment Architectures’ will introduce the overall system architecture.

Analysing Future Earth Observation Protocol Stacks via Simulation and Systems Engineering

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Parallel Session B3: Interoperability and standards, November 3, 2021, 10:55 AM - 1:00 PM

Future Earth Observation missions will produce large quantities of data, with varying communication requirements, priorities, and latencies. These requirements have wide-ranging impacts on many aspects of the relevant communication architectures. In order to satisfy these requirements, these missions shall utilise a range of new communication methodologies, such as File-Based Operations (FBO) and Delay Tolerant Networking (DTN). The space-to-ground link will be similarly enhanced, using new channels including X-Band, Ka, EDRS, and DTE optical downlinks. Taken in conjunction, these upgrades are poised to result in significant impacts across the protocol stacks utilized for mission communications.

The End-to-End Protocol Stacks for Earth Observation (ETEPS-EO) study analysed all aspects of future satellite architectures, including on-board interfaces, Space-to-Ground links, and terrestrial data dispatch methods with the goal to devise innovative protocol stack(s) which consolidated future communication requirements while simultaneously increasing functionality. A multi-pronged approach was utilized in order to accomplish these differing goals. First, future mission requirements were analysed, while present communication stacks were evaluated for their applicability to future missions. In parallel, an ns3-based simulator was developed. The simulator utilized existing and custom software components in order to simulate CCSDS protocols, RF & optical links, as well as CFDP, DTN, and LTP. While the use of mathematical simulation was studied, it was determined that such simulations could not produce the desired fidelity in light of the advanced retransmission mechanisms present in future protocols.

18 scenarios were developed to represent different mission types and protocol layering opportunities, all of which were run through the simulator. A Jupyter-based autonomous analysis framework was utilized to ensure that the study team did not suffer from “information overload”, and produced results which were immediately understandable to a systems engineer. These results were used to quickly study the end-to-end performance of a given protocol stack. This systems-oriented analysis methodology determined robust protocol stacks for future mission profiles.

This presentation shall outline the methodology, simulator design and development, and results, showing how event-driven simulation and systems-oriented engineering can be used in conjunction to gain meaningful insights.

SIMULUS Next Generation: Impacts and benefits of adopting ECSS SMP

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Parallel Session B3: Interoperability and standards, November 3, 2021, 10:55 AM - 1:00 PM

SIMULUS is the ESOC operational simulators infrastructure software, with SIMSAT being the implementation of the simulation services and GENM the implementation of the most common simulator functionalities, like orbit propagation and electrical distribution. During the finalisation of the ECSS-E-ST-40-07C (ECSS SMP) standard, ESOC and TPZG were already preparing a plan for the adoption of the new SMP standard. Immediately after the submission of the final draft of the standard, TPZG has completed the implementation of the core services and started the migration of the Generic Models (GENM) to ECSS SMP. At the end of 2020, TPZG has delivered the first SMP version of SIMULUS, and migrations of operational simulators are already ongoing.

The previous generation of SIMSAT was supporting the SMP2 Specification and other APIs through an adaptation layer. The internal communication between SIMSAT components was implemented using a proprietary component model based on the Common Object Request Broker Architecture (CORBA). The new SIMSAT drops support for the other simulation APIs and focuses solely on ECSS SMP, using its interfaces natively as the interfaces between components. This offers several advantages, especially in terms of speed and simplicity of the infrastructure, at the cost of the loss of some of the less used functionalities of SIMSAT. This paper will analyse the advantages and how they justify the features that have been left out of the new SIMSAT.

The previous generation of the Generic Models were natively based on customisation of the SMP2 specification and have migrated to the ECSS SMP standard. This paper will describe the activities involved in the migration of library of models and operational simulators, focusing on:

- New ECSS SMP mechanisms that allow replacing proprietary, SIMULUS specific functionality.
- Differences in SMP2 and ECSS SMP that require changes in code or design.
- Tool support added to SIMULUS to handle ECSS SMP, and migration from SMP2 to ECSS SMP.
- Extensions to ECSS SMP design to cover additional ESOC needs.

Finally, this paper will provide an outlook into the planned ECSS SMP Level 2, to be developed by an ECSS Working Group, where SIMULUS with its native support of ECSS SMP (Level 1) can play a fundamental role in developing and validating concepts beyond the portability of individual models, to further increase the portability of subsystems and even complete simulators between different simulation environments.

Data Expression Standards: A Different Look at Data Using Satellite Mission Planning & Scheduling (MP&S) as a Test Case

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Parallel Session B3: Interoperability and standards, November 3, 2021, 10:55 AM - 1:00 PM

Many organizations/agencies are evolving toward enterprise architectures from the traditional stovepipes to share data, provide enterprise situational awareness and reduce cost. Many of these enterprise architectures are, in some form, service-based. The concept behind the transition to common enterprise services is many functions involved with satellite ground are, at some level, common across programs and perhaps some software development/maintenance/sustainment cost savings can be achieved if a single suite of common, "one size fits all", services can be used across the enterprise as opposed to individual stovepipes developing & maintaining unique codebases redundantly performing essentially the same functions. To realize cost savings, the "common" set of services requires new programs coming into the enterprise to tailor their concept of operations (CONOPS) and/or mission requirements to conform to the operational paradigms embodied in the enterprise common services which can limit mission effectiveness especially for legacy programs. If the enterprise manager doesn't rigidly enforce the use of common services "as is", the services are often tailored by programs to meet unique mission requirements which results in the once "common" services morphing into sets of semi-custom or completely unique mission services. For organizations that fly many satellites, the cost to maintain the once common services is rapidly becoming just as cost prohibitive as sustaining individual stovepiped systems. This leads to the question: Other than the service/application codebase, is there any other place in the enterprise where mission "uniqueness" can be expressed to reduce costs while still enabling individual mission optimization? One place to look, other than the codebase, is in the data the code operates on. Leveraging advances in model-based engineering, standardized schemata using a high order modelling language (XML, for example) could be developed to describe the data and then the data presented in the standard schema could be operated upon by truly common, generic functional services. Examples of such an approach has been successfully demonstrated in the niche areas of telemetry & commanding (XML Telemetric & Command Exchange (XTCE) by the Object Management Group (OMG)) and satellite contact schedules (Simple Schedule Format (SSF) by the Consultive Committee for Space Data Systems (CCSDS)). This concept is currently being investigated using satellite mission planning and scheduling (MP&S) as a test case. MP&S is felt to by many to be the most unique of all areas in a typical mission; in other words, if success is possible in MP&S, it is likely this approach can be successfully applied to other mission areas. The presentation will offer details on the approach using MP&S as a test case as well as future plans to develop standard data description schemata.

Session A4

Model-based Astronautical Systems Development: A project and call for support

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Parallel Session A4: Multi-Mission Architectural Concepts (Model Based System Engineering, Agility and Digital Twin), November 3, 2021, 2:15 PM - 3:55 PM

This project is developing a suite of knowledge models for astronautics. It is relevant for model-based systems engineering (MBSE), related artificial intelligence (AI) approaches, and both terminology development and space policy. More specifically, ontologies being developed are for spacecraft, their systems; as well as space surveillance and tracking; and orbital knowledge.

Project will explore formalizing the ontology models--also called knowledge, semantic or conceptual models--in distinct MBSE and knowledge representation languages.

Most relevant to ESA projects, such as the OSMOSE MBSE project, is implementation using the fact-base modeling language Object Role Model (ORM) and associated tools or plugins. Other formalisms include semantic web languages such as Web ontology Language (OWL) and Common Logic Interchange Format (CLIF).

Website links describing the project include https://purl.org/space-ontology and https://ontospace.wordpress.com

Previous work includes approximately 10 articles, ESA grant proposals (such as https://tinyurl.com/3782n3mp), a NASA Technical Memorandum (see https://tinyurl.com/cne5z4rw), etc. An example publication is the 2015 journal paper "An Ontological Architecture for Orbital Debris Data" (in Earth Science Informatics), and "Preliminaries of a Space Situational Awareness Ontology" with (2016 with T.S.Kelso). The author is listed in the EU Commission as a expert in Data Modeling focusing on these aspects; and serves in international committees for aerospace topics as well as standards development, and MBSE/semantic/ontology related topics.

The models are relevant for MBSE, AI, knowledge representation and reasoning, and conceptual data modeling. The formal conceptual analysis and rigor that will go into the project tasks involves terminology work that can help with related issues in space policy, law and generic astronautics.

As unfunded work in the authors own time, the author welcomes invitations to formally collaborate, sponsors, or invitations to be a PhD student. This presentation thereby encouraging parties in and outside of ESA with interest to make contact to support the realization of this project vision.

The ontologies being developed, and the author's specailty in spaceflight knowledge modeling, can benefit projects such as ESA OSMOSE.

Digital Transformation of Ground Infrastructure

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Parallel Session A4: Multi-Mission Architectural Concepts (Model Based System Engineering, Agility and Digital Twin), November 3, 2021, 2:15 PM - 3:55 PM

Space is changing in both how it is used and how it is viewed by space-faring participants. Access to space as well as commoditization of space-industry components – i.e. spacecraft and their payloads, launch systems, and ground infrastructure – has opened the door for anyone to develop and deploy space-based systems. Despite rapid innovation in space-based platforms and adjacent terrestrial networks, satellite ground systems have remained firmly rooted in decades-old technologies and architectures. The technical paradigm is shifting from traditional proprietary boxes to something completely different. Kratos proposes an approach based on the ability to design systems for flexibility, agility, and extensibility, enabling users to seamlessly access the combination of multi-constellation and multi-orbit approaches through dynamic and much more.

The rapid adoption of new space systems, technologies, and architectures, coupled with additional access to space through new launch options, is forcing ground systems towards common standardization and automation, shifting to software-defined ground-based infrastructure without sacrificing security, reliability, and agility. The ground systems supporting these new trends in the space market will need to standardize mission interfaces on the ground and leverage commercial technology to the greatest extent possible.

To address these market trends, Kratos developed a service-oriented architecture for the ground infrastructure built on six key pillars: (1) digitize spectrum as close to the edge as possible, (2) assure data transport and delivery, (3) virtualize network functions to the fullest extent, (4) leverage cloud infrastructure (be it private or public), (5) orchestrate ground infrastructure at the service level, and (6) enable multi-domain operations via a unified, enterprise platform. While some customers tend to implement one or more of these, to truly address market changes all pillars must be implemented. The presented strategy and the components/products are available now, have been deployed into ground networks today, and have shown the ability to support tens of thousands of passes.

Kratos will discuss and demonstrate how software-defined ground entry points can be orchestrated as an integrated, synchronized, complex system-of-systems in a virtualized or cloud environment. Apertures, digitizers, software components, management, orchestration layers – all become part of an enterprise architecture that spans multiple-missions, tenants, sites, orbits, and more. The strategy and architecture proposed by Kratos enables true scaling of the ground infrastructure at the rate at which space is changing.

Towards a Digital Twin for robotic exploration mission operations

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Parallel Session A4: Multi-Mission Architectural Concepts (Model Based System Engineering, Agility and Digital Twin), November 3, 2021, 2:15 PM - 3:55 PM

Digital Twin for mission planification of Space Inspire, the software defined satellite by Thales Alenia Space

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Parallel Session A4: Multi-Mission Architectural Concepts (Model Based System Engineering, Agility and Digital Twin), November 3, 2021, 2:15 PM - 3:55 PM

Thales Alenia Space launched its new Space Inspire satellite product line (INstant SPace In-orbit REconfiguration) which allows seamless mission and services reconfiguration, instant in-orbit adjustment to the demand, transition from video broadcasting to broadband connectivity services while maximizing the efficiency & effective use of the satellite resources.
To leverage this flexibility, Space Inspire ground products delivers to its customer a full software suite covering mission planning, satellite resource management and flexible payload management.
Among these ground tools, Thales Alenia Space proposes a Digital Twin of the Space Inspire satellite. This digital replica of the satellite and its payload provides information on the satellite ability to fulfill its mission.
The satellite operator is able to plan a mission tailored to its needs and knowing it will be matched by the satellite capabilities.
This work was supported by CNES VASCO Project under the study “Modélisation satellite Space Inspire et définition des algorithmes associés pour application sol”.

Session B4

Bringing AI for Telemetry Analysis into Production

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Parallel Session B4: Innovative Technologies for Mission Operations Data Systems (Artificial Intelligence in Operations), November 3, 2021, 2:15 PM - 3:55 PM

As spacecraft are getting increasingly complex, the amount of data they produce has skyrocketed. A modern satellite easily generates, for example, thousands of data samples every second just for providing continuous information on its status and health condition. Handling and analyzing the vast amount of data on ground is one of the major challenges for space operations today.

Our aim is to provide engineers working with spacecraft a comprehensive, single framework which eases the monitoring and analysis of satellite telemetry. Part of the framework is the Automated Telemetry Health Monitoring Service (ATHMoS). It is based on semi-supervised machine learning techniques to automatically detect novel behavior or outliers in telemetry data. The results of the ATHMoS algorithms are visualized in the Data Analysis and Visualization (ViDA) framework. In addition to displaying ATHMoS results, ViDA allows engineers to plot telemetry in various ways and run custom analyses on the data. A central task, which our team has been working on during the last years, is to bring our vision into production to support multiple missions at the German Space Operation Center (GSOC).

Key to this enterprise is a reactive, i.e. robust, resilient, and scalable, design of all components involved.
The ViDA single page web application is the central user interface to interact with the ViDA framework. To provide a modern user experience, we based the frontend on the Angular framework.
Although only the web app is visible to the users, several micro services and a central backend server are deployed on our cluster infrastructure to do the heavy lifting under the hood.
For the server side, scalability and robustness were the drivers for choosing Scala and the Akka toolkit for the backend implementation. To keep the frontend as slim as possible, the backend shoulders all resource demanding processing and retrieves the actual mission data from our databases. A wide range of data can be requested from the backend via our GraphQL API that is accessible from a single http endpoint.

To host the data from various missions, we decided for a relational TimescaleDB database. TimescaleDB is an extension to PostgreSQL and has the benefit of being fully compatible with SQL while being optimized for time series data.
Since ViDA is required to display telemetry for entire mission life-times in one plot, we had to make use of data reduction techniques such as computing averages, minimum, and maximum values for representing large time ranges. For this purpose TimescaleDB offers continuous aggregates to do the computation directly on the database itself.
Other services such as the data-ingestion from GSOC's offline telemetry procession products and the ATHMoS services are also deployed as Docker containers on our infrastructure. To orchestrate all services, we have gained some experience with DC/OS, while we are currently planning to setup a Kubernetes cluster for managing our services.

Towards MLOps for ESA Mission Operations Data Systems

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Parallel Session B4: Innovative Technologies for Mission Operations Data Systems (Artificial Intelligence in Operations), November 3, 2021, 2:15 PM - 3:55 PM

ESA has a wide variety of data that is already being used for Artificial Intelligence (AI) projects and in particular for Machine Learning (ML). This results in various user needs ranging from easing the access to the data sources to being provided with the corresponding computational power. Satisfying those requirements would speed up and improve ML experimentation, allow for a rapid development of higher TRL products and maximise the code reusability. It has become evident that building an ML model out of an offline dataset is just the first step in developing a complete operational application; the real challenges arise when trying to build an integrated ML system and continuously operate it in production. Machine Learning Operations (MLOps) is a new field that tackles the problems of continuously delivering and creating automatic pipelines in machine learning. MLOps incorporates some of the ideas from DevOps like Continuous Integration (CI) and Continuous Development (CD), but also adds the ML specific Continuous Training (CT) to the mix. Ultimately, MLOps aims at making the model development cycle faster and more efficient, automating the steps as much as possible and reusing the code or modules in different parts. In ML model development projects, then there are 8 basic steps:

1. Data extraction
2. Data analysis
3. Data preparation
4. Model training
5. Model evaluation
6. Model validation
7. Model serving
8. Model monitoring

Some of the listed steps require a lot of computation power (e.g. training a model) while others less; this means there is a natural need for elastic resource management in the workflow. Kubernetes is built exactly for this kind of use case: scaling up a service, when more resources are needed and scaling down when there is no need. Kubeflow is an open-source ML toolkit developed specifically to work on a Kubernetes cluster. It has many components that help with different steps of ML projects like creating data pipelines and serving models easily on the cluster.

In the context of the Predictive Maintenance of Ground Assets project, we installed Kubeflow on an on-premise Kubernetes cluster at ESOC and tested how it would help in MLOps workflows. The pipelines module and automatic metadata and artefacts gathering greatly help in the development phase. By developing an orchestrated pipeline and not only a trained model, sharing pipeline elements is facilitated, resulting in maximised reusability.
The platform has already been employed in the development of a Machine Learning model aiding the maintenance of the Frequency and Timing System of a Ground Station. The developed ML model and resulting pipelines will be demonstrated in order for future OPS users to become familiar with the capabilities and current limitations of the platform, in view of upcoming projects which will aim at operationalising the output of the project.

Empowering SATCOM ground operations through artificial intelligence

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Parallel Session B4: Innovative Technologies for Mission Operations Data Systems (Artificial Intelligence in Operations), November 3, 2021, 2:15 PM - 3:55 PM

A new generation of flexible communication satellites is currently taking over the space segment, in order to address the increasing demand of dynamic services, hence providing solutions to the constantly changing users' requirements. To handle such necessities, SATCOM payloads are evolving from the traditional analogic ones, already defined and fixed for specific missions, to their state-of-the-art flexible and digital counterparts, capable of redefining their mission on demand.

This change of paradigm involves challenges such as the operation within 5G/6G networks, the management of software-defined networks, or even sharing frequency bands with terrestrial communication systems. In this context, current approaches based on the fragmentation of the ground segment into independent systems in charge of, i.e., the payload control or the resources allocation, are no longer feasible. Currently, it is more important than ever the implementation of automated and completely integrated systems, based on the duality Operations/Business Support Systems (OSS/BSS). The BSS interfaces the users allowing them to define, be provided and billed for the services. The OSS is in charge of the management of the operations required to provide and guarantee the quality of the requested services. Then, the OSS/BSS shall be understood as an orchestrated system-of-subsystems, interrelated and provided with a single source of globally accessible resources, known as the inventory.

The design of a SATCOM service is envisioned as divided into different steps, managed by different subsystems, which can be mapped within the responsibilities of the OSS/BSS. First, the definition of the service requested by the customer is managed by the Resources Management System (BSS). It mainly consists of obtaining the optimal ground and space assets capable of meeting the user service requirements, considering the overall information of current and future services. Then, the service shall be planned at a high-level from the BSS, and in a short-term, by the scheduler (OSS). Different subsystems such as the Payload Control System, Satellite Control Centre, Carrier Monitoring System and Network Management System will be involved in the required operations and monitoring to guarantee the service quality and continuity (OSS). Additionally, from the point of view of the user, the service will be monitored through business intelligence tools (BSS) which can provide aggregated and accounting information and help to optimize the resources providing feedback to the system.

In this presentation, an enhanced procedure to manage SATCOM services is proposed, based on empowering the explained BSS/OSS subsystems with artificial intelligence (AI) algorithms, capable of optimally automating these processes and reducing manual operations. To do this, different AI-blocks are proposed, either trained or fed by data from former operations, or from external systems. These blocks not only empower the subsystems individually, but also provide feedback within each other, enhancing the whole optimization process of the service definition. This AI-powered ground segment is to address two scenarios: the gateways diversity and routing, and the demand prediction and the gateways correlation analysis. For both of them, the authors explain the detailed description of the proposed solution, currently being developed within the context of the H2020-ATRIA project.

A PLATFORM TO SUPPORT GROUND SEGMENT AI APPLICATION DEVELOPMENT

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Parallel Session B4: Innovative Technologies for Mission Operations Data Systems (Artificial Intelligence in Operations), November 3, 2021, 2:15 PM - 3:55 PM

Artificial Intelligence/Machine Learning technologies have reached a state of maturity where they have the potential to help to substantially increase the level of automation in ground segment operations. The objective of the ESA GSTP project AI4OPS is to define and implement a platform for developing and supporting applications for AI for Operations Automation and demonstrating it with a set of novel proof of Concept AI Applications. The activity also includes the definition of an AI Strategy and an AI Information Architecture focused on the practical use of AI in ESOC missions.
The development of the platform will be based on a series of different use-cases identified, iterated and expanded together with ESA. These use cases are based on real world operational needs, covering different classes of problems such as anomaly detection, prediction, mission planning, spacecraft reconfiguration, sensor CCD checking and speech recognition.
A vital part of any AI activity is the access and preparation of the data for training and validating AI/ML applications. Ensuring that this data is of good quality, it is labelled and is sufficient for the training/validation can be an enormous task. The increasing use of MUST and ARES across ESA missions helps to provide access to the data and to provide it in a form that is more accessible to the AI, but further work is still required to prepare the data. These preparations aspects will also be investigated. Security is also a vital consideration in the ESA operational environment, where there is a separation between the operations LAN (OPSLAN) and the pre-operations LAN (PREOPS LAN) with strict controls on the data that can be exchanged between them and with external entities
The AI4OPS activity is developing a solution based on Lambda Architecture but refined through further work done in actual applications. It is a practical realisation of open-source AI, cloud, and big-data technologies, that can be applied to an operational environment, rather than an AI research lab, while supporting the prototyping and experimentation that will be necessary to develop the application. The architecture is designed to be open and cloud ready and to support the longer-term evolution of the platform to cover a wide range of missions and users, both internal and external. The platform is also intended to be building on top, complementing and/or taking on-board on the results of other ESA initiatives such as DataLabs; PMGA, MLOPS, etc..
Once the platform has been established, a series of novel AI applications will be implemented using the platform to demonstrate its validity and initial capabilities. These applications will be based practical use cases identified in mission operations and will be validated using real data available at ESOC.
This presentation will present the overall architecture of the AI4OPS platform, initial use cases and applications, summarising the initial results of the activity.

Session A5

ESA Developments in the Security Cyber Centre of Excellence (SCCoE) and Cyber Safety and Security Operations Centre (CSOC)

Irving J

Parallel Session A5: Cybersecurity and Development Aspects, November 3, 2021, 4:15 PM - 5:30 PM

Security is gaining significant prominence throughout the commercial and governmental domains in the Space Industry. With the declaration of Space as a warfighting domain, the increased industrialization and commercialization of production and supporting systems, the threats are increasing significantly. The European Space Agency (ESA) is not immune, and across the Agency there is greater awareness of the need to support the member states and industry by developing tools and capabilities to improve cyber resilience, whether for flight or on-ground. This is a relatively new initiative, and some aspects are still under the tender phase.
John Irving from the Security Office of the European Space Agency is part of a cross-directorate team leading the activities of the SCCoE & CSOC who will present the developments, their current status and planned roll-out.

Addressing Cybersecurity for a Multi Mission Ground Segment Infrastructure

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Parallel Session A5: Cybersecurity and Development Aspects, November 3, 2021, 4:15 PM - 5:30 PM

The ESA Ground Operations software System – Multimission Generation (EGOS-MG) project is an ambitious infrastructure development project with the objective to shift the overall management of ESOC's ground segment data systems from a mission centric to an infrastructure and service centric approach. This involves the 'multi-missionisation' of the existing infrastructure in several core areas including; extension of the existing re-usable software application layer to provide common products and services for missions, the establishment of common engineering and operational environments and of common processes including development, assembly, integration, testing, deployment and configuration. This encompasses also the provision of common stores for operational data and the sharing of IT resources.

With a rapidly evolving threat landscape and the recent increased focus of the global space and security communities on the topic of space system cybersecurity, it is clear that a robust and comprehensive approach to cybersecurity for EGOS-MG is required, not least to ensure an adequate protection of the future missions it will support. The project also represents the first major ESOC ground segment infrastructure development which will adhere to the recently updated ESA Security Directives and ESA Security Framework endorsed by ESA's Member States.

The major infrastructure revolution presents several cybersecurity challenges yet also opportunities. As a key objective, it is expected that EGOS-MG infrastructure will adequately respond to the vast majority of ground segment security needs of any typical unclassified mission, providing a reliable and trusted infrastructure and drastically reducing the cost associated with any mission-specific system security analysis or implementation within the EGOS-MG functional scope. From a security risk perspective this includes establishing a common security context relevant for operations of a target mission and deriving adequate security controls for the protection of systems and data Confidentiality, Integrity and Availability. It applies also to accounting for transversal effects of the multi-missionisation itself, for example that compromise of a shared/common resource could impact multiple missions. Multi-missionisation extends to the provision common security services which, whilst also implying some complexity to be managed, will lead to gains in both efficiency and efficacy. For example, through provision of a common Identity and Access Management (IAM) system, including Single Sign On (SSO) for EGOS-MG applications, common access control policies can be enforced and managed. Similarly, through enforcing a common development environment, security checks, approvals and release gates may be defined as part of the DevSecOps pipelines, ensuring a consistent approach to application security for both code-level (e.g. secure coding best practices) and configuration level (e.g. hardened container configuration checks, enforced security policies of orchestration tools) concerns.

The envisaged EGOS-MG Security concept therefore aims at achieving the following main objectives:

- Ensure that the EGOS-MG Infrastructure is designed, developed, deployed and operated in compliance with security requirements commensurate to its target applications and identified security assurance needs, in compliance with ESA Security Directives
- Identify a clear and effective split of responsibilities amongst the EGOS-MG services and layered architecture elements to implement identified security risk mitigation measures
- Promote a coherent adoption of security requirements and processes by all EGOS-MG target applications
- Enable a drastic reduction in the efforts involved to adequately manage ground segment security for future individual missions
- Enable a step change in overall security posture of the ESOC ground segment infrastructure, adhering to the key security principles suited to a modern system, including defense in depth, resiliency, segregation and least privilege

This presentation introduces the envisaged security concept of EGOS-MG, the current status of the security engineering work undertaken as part of a secure system development lifecycle, foreseen next steps and future work.

EGOS-MG DevOps Solution Design

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Parallel Session A5: Cybersecurity and Development Aspects, November 3, 2021, 4:15 PM - 5:30 PM

ESA Ground Operation System - Multi-Mission Generation (EGOS-MG) is an initiative to design and develop a common multi-mission infrastructure providing environments and services to on-going and future missions at ESOC. EGOS-MG DevOps is a sub-activity of EGOS-MG aimed at defining a DevOps solution for EGOS-MG needs, providing a common platform to design, develop, test, deploy and operate ESOC Ground Data Systems.
EGOS-MG DevOps has just reached the end of phase B. The phase B objective was to design a DevOps solution starting from the current DevOps standard and ESOC SDE and adapting them to the EGOS-MG needs. The solution designed has considered very important aspects of the multi-mission needs, including: long term solution design (10+ years), high availability, high scalability and very flexible configuration of the streamline process to build and deploy EGOS-MG applications.
The EGOS-MG DevOps solution has been designed to use very reliable software, largely adopted as standard tools for DevOps ecosystems, and based on container technologies which bring flexibility to maintain, evolve and scale the solution in real time with zero downtime. The DevOps solution covers the following features:

- Pipelines as automation workflow processes, to streamline the flow from “developing software” to “using software”. Generic templates are provided for all the projects to use, extend and adapt as required.
- Automated environments set-up, ensuring they are the same for everyone and providing environments for all the scenarios such as: development, AIV, shadow and operational.
- Automated tests, allowing extensive regression testing before releasing or deploying new software versions.
- Automated deployment, bringing a repeatable, reliable process for installing software and applying configuration and tailoring.
- Parallel testing of component testing and end-to-end testing in environments, thus increasing the confidence on changes introduced into the software and speeding up the validation process.
- Automated roll back to the previous working version, providing the capability to replace a component in runtime without affecting the whole system in case of malfunction.
- Centralised identity management and single sign-on, to increase the security of the solution, and to reduce the configuration and management time for support teams.
- Integration with management tools holding the status of the software production process.
- Secrets management, to increase the security of the solution centralising the credentials and sensitive data in one service, hence decreasing the management of multiple sensitive data sources.
- Static and dynamic security analyses as part of the pipelines workflow, including stages dedicated to analyse the code, binaries and software licenses, in order to find errors, miss-compliances, vulnerabilities, etc.
- Monitoring, to keep an eye on systems, application, containers, VMs and many other parts of the solution to provide a complete overview of the system status.

In conclusion, all these features bring high value to the whole continuous integration and deployment process for ESOC missions in the frame of EGOS-MG, in aspects such as automation, scalability, reliability, maintenance, system and application monitoring, communication, collaboration, trustiness in the process and automated deployment.

Session B5

Aurora: a multi-mission programming simulator and visualization tool

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Parallel Session B5: Design and validation of mission operations, November 3, 2021, 4:15 PM - 5:30 PM

Aurora is a fast and flexible satellite mission simulator used at CNES (the French Space Agency). This simulator was initially developed to assess the mission performances of competing configurations for the CO3D mission (an optical satellite constellation designed to produce a global digital elevation model of the Earth). The flexibility of this tool made it readily suitable to perform mission analyses in the early phases of a dozen other projects, and several additional studies.

Designed with a particular focus on performance optimization, Aurora is two orders of magnitude faster than the previously considered mission simulator for CO3D phase A studies. The time needed to run a 3 years long mission planning simulation was indeed reduced from typically one week to less than two hours on a laptop computer, which is very fast for the evaluation of a global coverage with a relatively small swath, taking into account 1h resolution weather forecasts to drive the closed loop, and considering the complexity of the models involved to be representative of the acquisition and satellite constraints. This efficiency allowed the completion of all simulations and parametric sensitivities necessary to meet the objectives of CO3D phase A.

Apart from statistics allowing the assessment of the performance of the system and its adequacy with the mission requirements, and from exports of detailed data on some chosen programming periods giving inputs to satellite design (energy, thermal, memory, etc.), Aurora also provides numerous 2D and 3D visualizations, which are essential for verification and mutual understanding, especially to illustrate the mission concepts and space segment capabilities and constraints to the scientific teams or foreseen users.

Easily configurable, the simulator enables the modelling of heterogeneous constellations and instruments (optical, radar, inter-satellite links, etc.), around the Earth, Mars, or for space-based observatories. In addition to the adaptable default behaviors available, an embedded scripting engine permits the dynamic customization required to more precisely meet the specific needs of each mission. Besides, being interactive and fully integrated within the simulator, this script engine allows quick prototyping with rapid visual feedback and accessible simulation results.

Aside from these upstream mission and design studies, Aurora might also be used as a support tool during the operational planning of some specific observations for MMX MIRS (an infra-red spectrometer mounted on the Martian Moons eXploration mission from JAXA), for which it already contributes through its use in the elaboration and evaluation of different observation strategies to map Mars and its moons, Phobos and Deimos.

The presentation will give an overview of the simulator, supported by a demonstration of its functionalities via illustrative applications on various missions.

PME – A New Lightweight Procedure Management Environment for future Ground Segments

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Parallel Session B5: Design and validation of mission operations, November 3, 2021, 4:15 PM - 5:30 PM

The Procedure-Management-Environment (PME) is a product of the FAVOUR study, conducted by RHEA for ESTEC. FAVOUR targets the preparation and execution processes for both AIT checkout campaigns and mission operations. A Mission-Model-Editor (MME) was also developed in the project.
The Mission-Model-Editor (MME) is an editor for EGS-CC Conceptual Data Model (CDM) data and is based on the OPEN framework developed by ESA. The CDM defines a hierarchy of Monitoring&Control Elements containing Aspects such as Parameters, Activities, Events and Calibrations. The MME adds a presentation layer on top of the CDM defining the items that a user would expect to manipulate such as packets, parameters and procedures. It also hides most CDM mechanisms, such as mappers and complicated class hierarchies, making the editing experience more intuitive and without requiring significant CDM knowledge.
The Procedure-Management-Environment (PME) is used to prepare both satellite test and operations procedures and is control system agnostic. It includes a test management capability with test sessions and logging. and supports the generation of the Verification- Control-Document for the mapped requirements or test cases. This process is optional; the PME can be used more straightforwardly to automate operations.
The PME has been developed for the EGS-CC while also supporting SCOS2000. Its editor provides different views of procedure data with a graphical overview and a custom script representation. Instead of adapting a multi-purpose scripting language it employs a Domain Specific Language (DSL) derived from a minimal UML model. It follows ECSS-E-ST-70-32 principles.
The procedure model defines an Abstract Syntax Tree for the human readable Xtext-based script DSL. Procedures can be executed directly in PME (e.g to help de-bugging) or can be used to generate Activity-Lists for the EGS-CC (or legacy MIB sequence tables for S2K). The user interface supports stepping and execution breakpoints in the DSL or the flowchart - via an Xtext-based tracing mechanism.
These procedures can also be scheduled and executed directly on the PME server without the UI while they can still be connected to and remotely debugged at the DSL level.
To maintain MCS independence, the PME server provides a REST-API based on a JSON data model which is independent of the MCS (i.e. it is not based on the CDM or the MIB) and provides procedure editing, validation & execution services. CDM and EGS-CC adapters have been implemented for it. The PME procedure editor and execution interfaces are therefore independent and can be used for another MCS - since the MCS adapters are isolated within the PME server.
A major advantage with this solution is that the complexity (and size) of the CDM data is managed in one application and the clients can be relatively “thin”.
Rhea has developed an Angular web-client for remote PME procedure execution and monitoring. Procedures can be started and controlled from a browser, and their execution status & session log viewed. The same webpages are available from the PME RCP application.
The presentation provides an overview of the PME architecture, its concepts, capabilities, technology choices and future developments.

Building an OPEN Community Based on GitLab

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Parallel Session B5: Design and validation of mission operations, November 3, 2021, 4:15 PM - 5:30 PM

The OPEN Preparation Environment (OPEN) is supporting the preparation of tailoring data for European Ground Systems Common Core (EGS-CC) based systems. In order to develop and distribute the OPEN software as well as other software within the space community, a collaboration platform called “Space Codev” has been established. Based on GitLab, it supports an extensive software development lifecycle and DevOps best practices. In order to cover the development of OPEN products for different user bases, a continuous methodology allowing to integrate and deliver the software on two platforms in parallel was adopted. The automated processes equally support exchange via Space Codev and an additional internal GitLab instance at ESA. These processes are underpinned by the Gitflow branching model supporting the development and maintenance of different releases as well as the use of merge requests for rapid developer feedback on every change.

Developing and maintaining the OPEN software on Space Codev for building these preparation systems enables the emergence of a strong community consisting of individuals, companies and organisations sharing common interests. Communities are widely known in the open source world where all actors benefit from increased collaboration, promotion of the software, simplified software distribution, increased transparency and new opportunities emerging from a wider audience. By building such a community for OPEN, and other systems foreseen to be hosted on the Space Codev platform in the future, ESA and its community partners are expected to benefit from enhanced innovation afforded by a wider user base which in turn leads to a greater exploitation potential for industry and potentially reduced lifetime costs through the sharing of some of the costs of ownership.

To achieve a prosperous community, a governance model, which describes the roles, processes and ground rules for participation, is vital. Existing Space Codev communities have already published their governance models.

In this paper, the OPEN community is used as an example to discuss these aspects. Furthermore, it also provides insights on the technical approach taken to implement the continuous development lifecycle including releasing and deploying the Eclipse RCP based OPEN framework with the help of Maven and Tycho in combination with GitLab package registries and p2 repositories for deployment of the artefacts. Additional features complement the realization of the community such as GitLab Pages documenting the governance as well as the technical specification of the software.

Finally, we share lessons learned from implementing a community with GitLab and the envisioned evolution of ESA communities in general and OPEN specifically. Thereby we hope to foster creation of additional domain communities following the path of a “more OPEN” environment and embracing DevOps principles