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Future ground segments with standardized interfaces: the DOMINO-X project

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Abstract

The DOMINO-X project was launched at the end of 2021 with 11 partners with a central aim of making main interfaces within EO ground systems public and standardized. The goal is for these interfaces to be adopted by industry and institutions, by primes and providers of ground segment building blocks. Key to the future success of this initiative is the involvement of the largest number of players in the domain. Stabilizing and agreeing interfaces of key building blocks increases competitiveness of the ecosystem, since the barrier to entry of build block providers is lowered, as the integration into end-to-end systems is facilitated.

The paper presents the motivation for this initiative, accelerated by the French Plan France Relance together with significant investment from industry. The concept of dominoes is explained, along with the breakdown of the ground segment architecture and key interfaces.

A domino is standalone, is monitored, produces KPIs on the delivered service, may serve more than one mission and relies on its own infrastructure. Regarding the latter, each domino and key interface are natively thought for virtual environment, up to cloud environment. Important to note, no common IT specification is worked on, but instead guidelines to simplify deployment of dominoes over the same IT infrastructure.

In addition, it is also key that a domino be of such nature and size that it presents an interest for a provider to develop or operate it. The system is then built by inter-connecting existing and/or new dominoes.

The dominoes are meant to answer to a wide array of use cases such as, to name a few, multi-mission federation, antenna as a service for reactivity or event based satellite acquisition programming. The DOMINO-X project addresses a wide array of axes of innovation feeding the definition of dominoes. The paper provides a broad overview of these axes, covering CONOPS, mission programming, command and control, the antennas, image chain, AI in EO ground systems and automated reprogramming.;

Keywords: ground segment architecture, Earth Observation, standardized interfaces, Domino

Acronyms/Abbreviations

EO: Earth Observation
GS: Ground segment
ITM: Image Telemetry
PDGS: Payload Data Ground Segment
RFoIP : Radio Frequency over IP

TT&C : Telemetry Telecommand Control

1. Introduction

Earth Observation space missions are increasing in number and will continue to do so. The ground segment is a key enabler to these missions. Although types of sensors, orbits, number of satellites and constellations, ground station topology, level of processing may vary a lot, the ground segments have been seeing always the same architecture broadly speaking. Indeed, from mission to mission we always find similar functions, be it within the command and control domain, the acquisition planning, product processing, advanced processing, supervision, etc. The implementation of each function changes of course due to mission specific performance or data, however the broad functions are always recurrent. It is therefore useful to standardise interfaces between certain groups of functions such that integration of the building blocks can be done more easily during production or the operational lifetime of the mission. This approach of setting invariant interfaces is applied successfully to Copernicus PDGS in particular.

Such decomposition of an EO ground segment architecture allows to leverage on an increasing trend enabled by virtualisation and Cloud. More services can be provided as a service via a public Cloud and the possibility to integrate such services in the overall ground segment can bring benefits.

It is therefore on these considerations, plus on the need to improve industrial competitiveness via further innovations in the EO ground segments, that the DOMINO-X project was retained by the France Relance recovery programme. DOMINO-X mobilises large investments by both the French State and industry. The project is led by Airbus and comprises a consortium specialised in various domains, its members are small, medium and large companies, with long heritage and newer ones. They are Capgemini, CS GROUP, Geotrend, Gisaia, Human design Group, Leanspace, Orange Business Services, Safran Data Systems, Stack Labs, Thales Alenia Space. CNES has an important role making sure that the Consortium does what it set itself up to do.

DOMINO-X has French roots, however the ambition of the architecture and standardisation activities is clearly international. The will is that over time agencies, other system integrators and ground product or service providers align with the breakdown. Hence the importance of industrial considerations when breaking down the ground segment architecture and not only technical considerations.

The paper explains the rationale for the breakdown, what a so-called “domino” is and what the current breakdown looks like. Important to note that the architecture is modelled in an open source tool and the model is free and accessible on demand.

Beyond the architecture work, DOMINO-X and the Consortium address a number of axes of innovation aimed at improving system attributes and lowering lifecycle costs. These are also briefly described in the paper.

2. The rationale for a standardised architecture breakdown

The aim is to define interfaces between the so called dominoes on which increasing number of actors agree. It is believed that this is possible because the main functions relative to ground segments have always been the same or very similar. The interfaces are public in order to foster adoption by the ecosystem of providers and integrators of dominoes.

The dominoes are coupled in a limited way, allowing to integrate and evolve different parts of the ground segment with limited impact on other parts of the ground segment. In this way, there is more flexibility to integrate new innovations or competitive products or services in the system, either during the production of the system or during its operational lifetime.

The technical and industrial philosophy is similar to the Copernicus PDGS architecture, whereby ESA defined interfaces and each vendor delivers its software or service with the agreed upon external interfaces.

It is expected that, once the domino interfaces are adopted by the domino suppliers for a given mission the integration, verification and validation activities would be simplified and accelerated. The ideal is to aim for minimal or zero software integration. A certain level of network integration will always be necessary.

3. What is a domino

A complete system is built by inter-connecting existing and/or new dominoes. They are the atomic elements for which the external interfaces are aimed for standardisation. What is inside a domino, including internal interfaces, is up to a domino provider to define. This approach leaves ample room for specialisation or innovations.

A domino provides a valuable service useful to any Earth Observation ground segment. It:

- Autonomously produces outputs from a set of inputs
- May serve several missions
- Can be deployed on a cloud
- Is independent from other dominoes infrastructure
- Is accountable for its performances
- Is interchangeable by another implementation respecting the same interfaces

For instance an image processing service able to transform ITM (provided by another DOMINO) into images delivered to its customers (or to a DOMINO archive).

A domino is therefore not a toolbox, is not a framework and is not a building block (not a library).

4. The scope of a domino

When defining the scope of a domino, the following checks can serve as guidelines.

Domino's scope checks:

- Domino scope shall have "ready to bid" offers by several trusted companies
- Domino scope shall represent a consistent and autonomous set of features which provide a solution to an E2E need
- Domino scope shall minimise communication interfaces with other dominoes
- Domino scope shall allow the reuse by several different missions without impact on its definition

Also keeping in mind additional checks:

- Avoid too big or too small dominoes / Keep a level of homogeneity between dominoes
- Keep a consistency in the business skills needed to implement the domino

5. Domino properties

In addition to properties induced by "What is a DOMINO", each domino must comply with a set of properties.

1. Domino technical definition shall not depend on technology choices and/or be impacted by short and long term technology evolution
2. Domino shall be able to run on its own infrastructure
3. Domino shall apply basic security guidelines and best practices to protect against outside threats
4. Domino shall comply with cloud computing standards in terms of deployment, monitoring & control, scalability and elasticity
5. Domino shall have well defined interfaces, based on recognised standards
6. Domino shall provide information, such as KPI and IT info, for high level supervision, on a configurable periodic basis

6. How a future domino based Earth Observation ground segment looks like

An Earth Observation ground segment will be composed of a number of dominoes. Each domino will be either deployed in a public Cloud, on premise or on a Hybrid Cloud. Furthermore, each domino will be supplied either as a software deliverable, an appliance i.e. an application plus the underlying hardware, or as a service. If a domino is provided as a service, it is operated by the domino provider. Fig. 1 illustrates schematically how dominoes would be combined to form a ground segment.

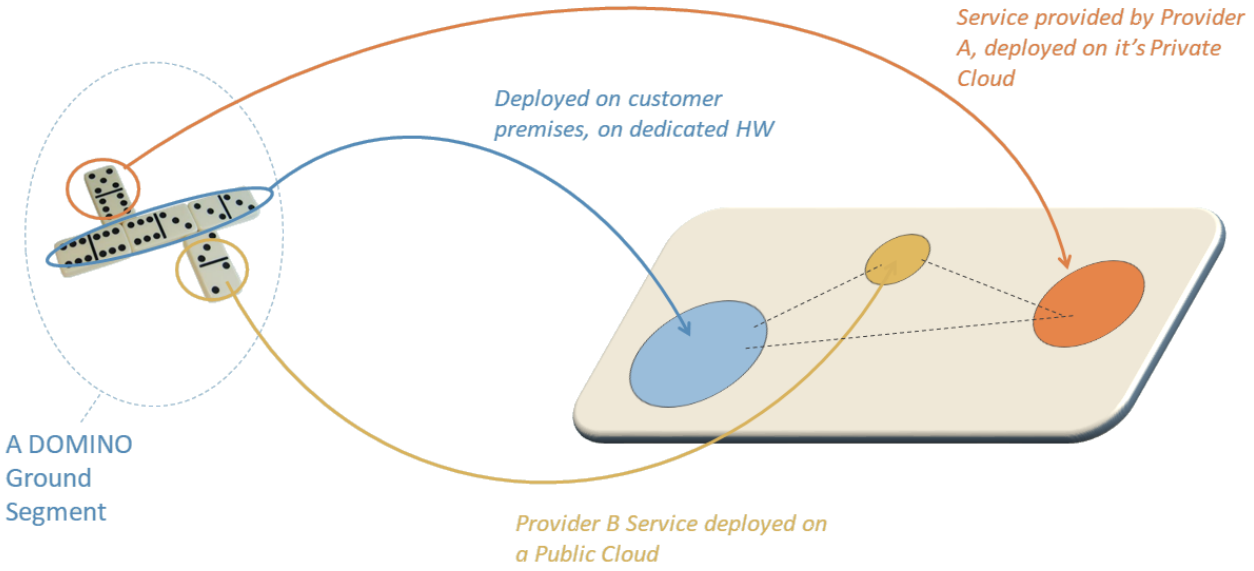

Fig. 1 Schematic view of possible deployment and delivery scheme of dominoes' services

7. Architecture breakdown

The engineering activities are still under way, however the number of dominoes is stabilised around 20 for the ground segment.

The results are capitalised in an open source system modelling software called Capella. Access to the latest version of the model is free to access.

The driving consideration behind the breakdown is defining dominoes with the right size: not too small so that the number of dominoes don't overwhelm integration costs and that they can be of interest to a vendor, not too large so that the domino can be provided by vendors who specialise in the corresponding business and who can focus their innovative effort on what they are specialised in.

Fig. 2 provides an overview of the set of dominoes that may comprise a ground segment. Note that not all dominoes are necessary for a given Earth Observation system.

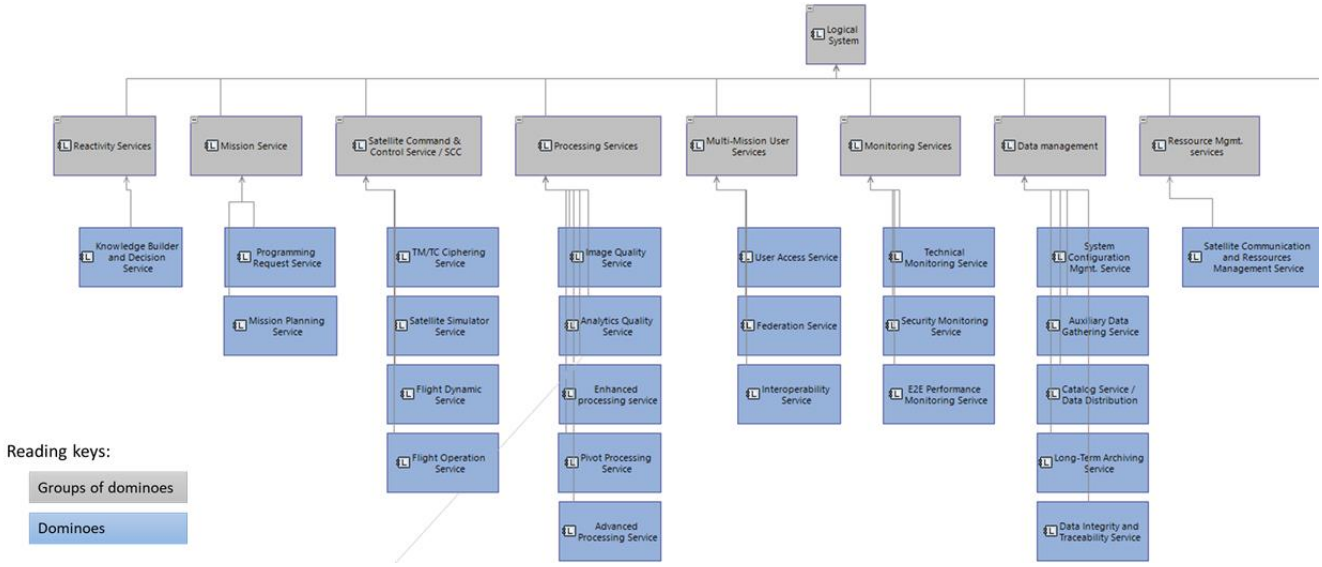

Fig. 2 List of the dominoes in each box, assembled into groups for better overview, as of June 2022. Note that this breakdown may evolve.

8. Other axes of innovation

Along with the architecture activities, a number of axes of innovation are being de-risked or industrialised within DOMINO-X through via prototypes or demonstrators. The purpose for these activities is to enhance the competitiveness of industry via new or improved features or improved costs over the lifecycle of the mission.

8.1 FINOPS

FinOps is a growing cloud computing financial management discipline that enables organizations to maximize business value by facilitating collaboration among engineering, finance, technology, and business teams on data-driven spending decisions. For DOMINO-X, we focus on the development of a cost model software to evaluate the cost of hosting a Ground Segment in the cloud.

8.2 Multi-mission federation

The aim of the multi-mission federation is to offer unified services to the User, whatever the missions, while optimizing the use of federated systems and performing orchestration of corresponding dominoes activities. It gathers as well basic functions for User Requests definition and status management, as advanced ones for feasibility studies or multi-mission programming, or for supervising and sequencing dominoes activities.

DOMINO-X prototypes focus on multi-mission programming (e.g. acquisition) with two use cases of interest: site monitoring and coverage of a large area at the soonest.

8.3 Augmented image production and automatic reprogramming

More and more EO satellites with distinct missions acquire more and more data. To allow the cloud-native multi-mission image production and make integration easier of new product generator based on EO satellites data, a set of standardized interfaces and generic EO product format are defined.

In front of so much data being produced from space segments and from other source origin (web, particular database …), a help must be provided to extract the right information from EO product, to correlate and to enrich EO product with external relevant sources, to make the right decision based on available heterogeneous information and, if possible, to automate decision-making. As for image production, a set of interfaces, an extension of generic EO product format and guidelines are defined to allow:

- the integration of thematic information extraction based on AI algorithm from training to operation deployment and monitoring by the use of a continuous improvement approach,
- the data fusion between EO product, information extracted with the help of AI algorithm and relevant data from external sources
- the automatic detection of event, based on heterogeneous available information and criteria of interest, allowing the simple user notification of the detected event, the implicated data highlight until the automatic reprogramming of a satellite for a future acquisition (site monitoring, event follow up …)
- The last point concerns the storage of these heterogeneous data, their cataloguing and their access. A set of standards are also defined to specify inputs and outputs of product storage and catalogue from data search request by the use of natural language until deeper analysis by the use of data cube concept.

8.4 Smart Image Quality Office

The Image Quality Office (IQO) is the set of tools and algorithms used to assess images quality and calibrate the image production chain. These operations mobilize many experts (especially on constellation systems) and their cost is high. The goal regarding IQO within DOMINO-X is to propose a new, smarter version such a tool to challenge the IQO operations costs.

The Smart IQO prototype will include automatization of basic repetitive tasks to enable a better surveillance of images quality with reduced human costs. The versatility of the software will ensure its use on several type of instruments and captors; the treatments will be rethinked to limitate the quantity of calibration dedicated data.

Through these upgrades, the main objective of the prototype will be to modernize the IQO procedures and to lower the operation cost. By optimising the team efficiency with smarter and more adapted tools, cutting their intervention to expert matters only; and by reworking algorithms to include latest scientific technics and reduce the data needs.

8.5 Cloud ready Control Ground Segment

The current control centre solutions are based on a strong legacy, mature and with many systems in flight. But the New Space creates challenges in terms of volume (constellations of several hundred satellites), scalability (heterogeneity of customer needs) and performance (TM/TC throughput, archiving, etc.). These constraints lead to numerous changes in operating methods (automation, constellation visualisation, screen customisation, notifications, instant updates).

It becomes necessary to upgrade existing solutions in order to maintain a competitive edge for the future. Within the framework of DOMINO-X, a new control centre is being developed on modern and cloud-compatible technologies suitable for a large number of satellites. This system is based on a modular architecture in order to offer an adaptable solution.

8.6 Ground Stations as a Service

The usage of a versatile ground station network based on GSaaS (Ground Station as a Service) is an attractive cost-effective mean to reach the performance, flexibility and scalability objectives of constellation systems. Similarly to the cloud computing services, the GSaaS model is allowing “on-demand” access to shared ground station network. Based on a “pay-per-use” model, the GSaaS is allowing a novel vision for dynamically managing the satellite communications.

While the GSaaS offer is quickly expanding, DOMINO-X is an opportunity to study how to seamlessly integrate a flexible satellite communication management within the EO systems, able to interact with GSaaS providers. A specific component (SCRMS) fully compliant with the DOMINO-X architecture is envisioned to support this new feature.

8.7 Advanced CONOPS and operations automation

Automate the ground segment and make it smart is one the biggest challenge for EO Ground segment for the coming years, along with standardized architecture. With new technologies coming from IT (big data processing, AI, Machine Learning, Cognitive Assistant…) we are now able to allocate only 10 operators to control a constellation of 10+ high performance EO satellites. The use of this technologies also addresses the need for an improved “data-access-time”. With advanced and centralized monitoring system, linked with AI, one operator can overview the health of the whole system, from spacecraft to ground system, from Mission part to external services. Automation and AI can perform routine operation autonomously. AI and cognitive Assistant can also suggest various actions and recoveries in case of contingencies or non-routine operation, when a final approval from an operator is needed.

Designing the new Concept Of Operations goes through all the details of the control: operators,

supervisions, User's Interfaces and room layout. New room layout to improve operators communication and better supervision is also part of DOMINO-X. The main centralized supervision is the heart of the new control room layout so everyone, from operator to technical manager, can monitor the end-to-end system at a glance. In a close-future, we can imagine the ground segment to be a "lights-off" center, where AI, Deep Learning technology and automated system can run without operator's intervention during routine operations.

Joining together the extended knowledge of various partners from Space Industry, Cognitive design and UI/UX allows the DOMINO-X project to cover all the aspects of the advanced CONOPS and operations automation.

8.8 Software Defined Antennas

As a satellite access interface, antennas play a key role in the performance of a satellite system. A domino based on the services provided by a network of antennas is being defined. Each antenna shall be usable on demand up to a simple time slot for communication with the satellite. The ground station must therefore be redesigned to allow such use.

Satellite Radio Frequency links will be digitized closer to the antenna. RFoIP links will be used to transport digitized data for real time processing. Digitized data format will used a recognized standard such as VITA49. Software modem for TT&C link and software receiver for EO ITM link are being developed. These software run on a standard on-premises server or are deployed in a cloud environment. They easily scale according to the characteristics of the satellite links such as the data rate.

The use of a versatile antenna system is one of the means envisaged to achieve the performance, responsiveness and flexibility objectives of a satellite constellation.

8.9 Image product integrity and traceability

The current progresses made in revisit and resolution capabilities of Earth Observation systems has multiplied the number of applications relying on the produced data to make decisive previsions and decisions. With these applications, the need has emerged for users to gain trust in the data manipulated, and in particular to be able to trace it and check its integrity.

DOMINO-X addresses this topic through the study and implementation of images digital signature solutions allowing the authentication of the source of the image as well as its integrity verification. The solution primarily foreseen is based on artificial intelligence and steganography techniques and ultimately allows the detection and localisation of potential degradations in an image initially issued from the ground segment.

9. Conclusions

The DOMINO-X project is ambitious and aims for increased competitiveness in the Earth Observation ground segment domain, hence a number of novelties being industrialised or derisked.

A central activity within the project is the breakdown of the architecture and work on the interfaces of the so-called dominoes. This activity is initiated within the project by actors based in France, however the ambition is to go have standard interfaces adopted across industry and agencies, system integrators and suppliers, irrespective of countries. Hence the effort made to open up the architecture, communicate on it and welcome interested parties to join the effort.

This approach of standardising interfaces will open the gates for injecting easily all the innovations that are burgeoning across the ground segment value chain, be it specific to the space domain or generally to IT, be it technical or in terms of business model.

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