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The smart and open Earth Observation ground segment: towards an architecture with public standard interfaces

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Abstract

Eleven industrial actors in France decided in 2021 to invest massively in the transformation of EO ground segments, with co-funding from the French State via the Plan de Relance Recovery fund. The project is called DOMINO-X and groups together small, medium and large companies, namely Airbus, Capgemini, CS GROUP, Geotrend, Gisaia, Human design Group, Leanspace, Orange Business Services, Safran Data Systems, Stack Labs and Thales Alenia Space.

Multiple innovative topics are addressed within the project, covering a large scope of the ground segment: Cloud and FINOPS, multimission, AI on images, datacubes, web based alerting, automatic reprogramming, command and control in the Cloud, antennas as a service, automated operations, digitized RF and modems, image integrity and traceability. The presentation starts with a brief overview of these works.

The presentation then mainly focuses on the key driver of the project which is the breakdown of the ground segment architecture into building blocks, a.k.a. dominos. The objective is to define standard interfaces for the dominos, so that innovative and competitive providers of products and technologies can easily integrate their solutions into end-to-end systems, increasing the value provided by the latter to the end customers.

Key considerations when defining the dominos are of industrial nature and not only technical:

- the dominos are minimally coupled between each other in order to help each domino provider to develop and validate its solution independently from the other providers. This approach also eases integration, verification and validation of the end-to-end system. A key enabler to achieve such a low coupling is the data driven approach
- The dominos have the right size in terms of functional scope, so that they are large enough for them to be interesting for a supplier company, but small enough to ensure that suppliers can inject locally latest innovations and evolutions at a faster pace, independently of other parts of the ground segment.

The presentation gives an overview of the domino breakdown and provides insights in some of them.

It is an unhidden ambition that a thriving international ecosystem of players emerge, institutional and private, around the architecture and the interfaces. In order to enable that, wherever it makes sense, existing interfaces or standards,

e.g. ones of OGC, are reused. In addition, converging with interfaces adopted on large and long term EO programmes such as Copernicus, with many suppliers across the ground segment, make sense in this endeavor.

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

The DOMINO-X project brings together eleven industrial actors active in the domain of ground segments for Earth Observation and IT. The objective is to maintain competitiveness. These project is led by Airbus, the ten other partners, in alphabetical order, are Capgemini, CS GROUP, Geotrend, Gisaia, Human design Group, Leanspace, Orange Business Services, Safran Data Systems, Stack Labs, Thales Alenia Space. They all invest in innovative topics, and the Plan France Relance co-funds the activities.

The project is comprised of a certain number of axes of novelty and of an important ground segment architecture engineering activity whose aim is to standardise interfaces between functional modules that should have low coupling between each other.

The paper provides first an overview of the axes of novelty, grouped in four themes

- Virtualisation: Cloud ready Control Ground Segment, software defined antennas, FINOPS
- Reactivity and automation: augmented image production and automatic reprogramming, reactive CONOPS using Ground Stations as a Service, operations automation, smart image quality office
- Multiplicity of missions: multi-mission federation
- Security: image product integrity and traceability

These topics give an overview of the needs that future EO ground segments need to enable. The architecture of the GS is therefore important, so that it is sufficiently stable for best-in-class technology and subsystem providers to position themselves on it while allowing innovation to be injected in any part of the GS without impacting other parts of the system. This requirement goes equally to functional aspects and IT platform aspects.

The GS architecture should be broken down into a number of independent modules that are autonomous and as decoupled from each other as possible. Such modules could be called dominos. The project covers the full scope of the GS: antennas booking, command and control; acquisition planning, product processing, advanced processing, supervision. Each domino may run on its own hardware and may be integrated into the complete ground segment as a product or as a service. The key is to have sufficient stability and standardisation of the interfaces between the dominoes. The approach is inspired by the of the Copernicus PDGS.

The paper explains in more detail the rationale for such an approach, the definition of a domino and how they are meant to be integrated together.

2. Axes of novelty within the DOMINO-X project

A number of axes of novelty are addressed within the project, each one covered by one or more Consortium members. These axes are prototyped or industrialised, the target TRLs are 5 to 8 depending on the topic.

2.1 Virtualisation

2.1.1 Cloud ready Control Ground Segment

Existing control centre solutions are upgraded to meet the needs future systems in terms of volume, scalability and performance. Operating methods are therefore also upgraded. The new solution that is being developed has a modular architecture and leverages the benefits of Cloud technologies.

2.1.2 Software Defined Antennas

Within the project, Satellite RF will be digitized close to the antenna with known formats like VITA49. Regarding the modem for TT&C and EO Image TM, software solutions are developed, able to run on standard infrastructure, be-it on premise or in the Cloud for scalability. Antennas may be exploited on-demand and ground stations are therefore redesigned.

2.1.3 FINOPS

A cost model for Cloud resource usage is developed for sizing the next generation of EO systems for which part of the GS is running on public Cloud. The cost model is focusing on the parts of the GS that are particularly IT resource intensive, namely the image processing.

2.2 Reactivity and automation

2.2.1 Augmented image production and automatic reprogramming

Future EO systems will involve ever more analytics running on acquired images for easier image exploitation and for automatic reprogramming of the satellites. Within the project many facets of the topic are being developed: AI algorithm training, deployment, operations and monitoring, data fusion, event acquisition from the web for automatic reprogramming and powerful cataloguing technologies.

2.2.2 Reactive CONOPS with Ground Stations as a Service

Ground stations as a service allows high reactivity and reduced image delivery latency. Highly reactive CONOPS is being developed within DOMINO-X with a specific domino to enable that. The Ground stations as a service approach may also bring cost benefits in certain scenarios since payment is done proportionately to the usage of the antennas.

2.2.3 Operations automation

The objective of DOMINO-X is to address the needs of constellations. An important aspects being addressed is to limit the number of operators to 10 in order to control a full system of more than 10 high performance EO satellites. Operator roles and control room layout have been rethought, and modern ergonomic HMIs have been developed.

2.2.4 Smart Image Quality Office

High performance EO satellites require a number of advanced and specific calibration and validation activities along the satellites' lifetime. The project addresses the algorithms and framework for automating a number of the procedures, limiting the involvement of operators to expert matters alone.

2.3 Multiplicity of missions: multi-mission federation

Multi-mission federation will be ever more necessary as the number of EO systems will grow, as well as the complementarity between them. Within the project a unified user access is being developed as well as functions programming multiple missions for the use cases of site monitoring and for fast coverage of large areas.

2.4 Security: image product integrity and traceability

Image authentication and integration verification is becoming increasingly relevant. A solution based on AI is implemented, involving digital signature of the images and allowing the detection of degradations and their localisation within the image.

3. 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.

4. 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 image telemetry (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).

5. The scope of a domino

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

- 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 end-to-end 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

One must also keep in mind additional checks:

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

6. 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

7. 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. In particular, sovereign clouds seem to be a privileged solutions in the future in Europe. 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.

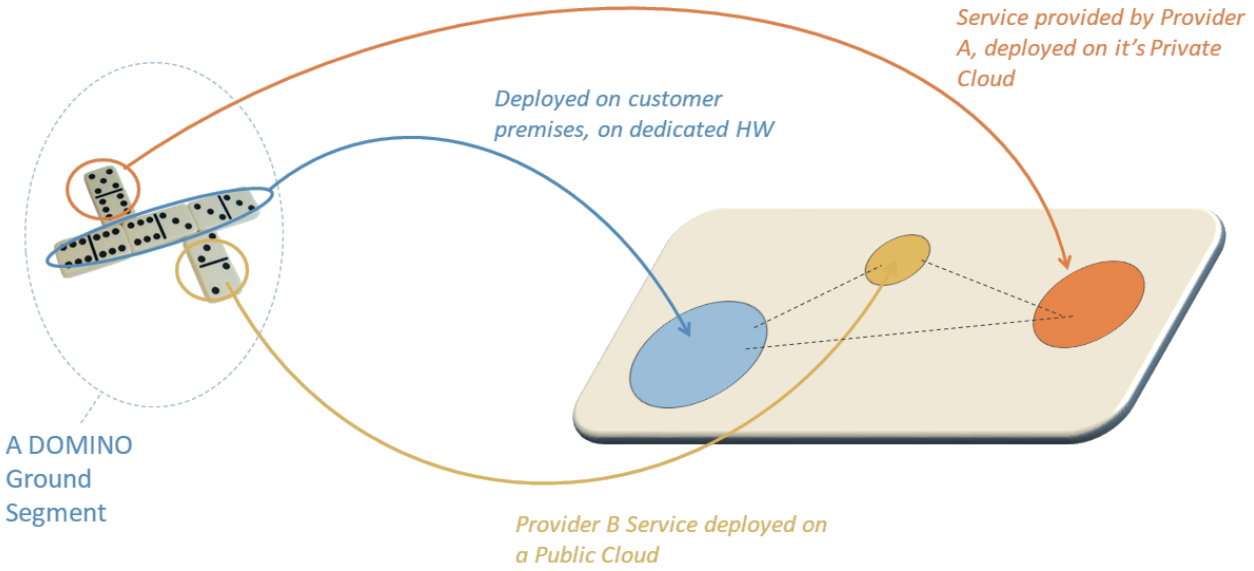

Fig. 1 Schematic view of possible deployment and delivery scheme of dominoes' services

8. Model Based System Engineering approach

DOMINO-X has large ambitions to push for standardised interfaces, therefore rigorous engineering methodology has been applied. Model Based System Engineering is adopted. Close to 30 ground segment level use cases have been defined, from which a functional breakdown of the full ground segment was derived. Fig. 2 illustrated how use cases are modelled.

Analysis of the functional breakdown led to 23 dominos identified, comprising a so called Domino Breakdown Structure for a full ground segment.

The Modelling tool is Arcadia/Capella which is free. The model of the GS itself has the vocation of being public and free.

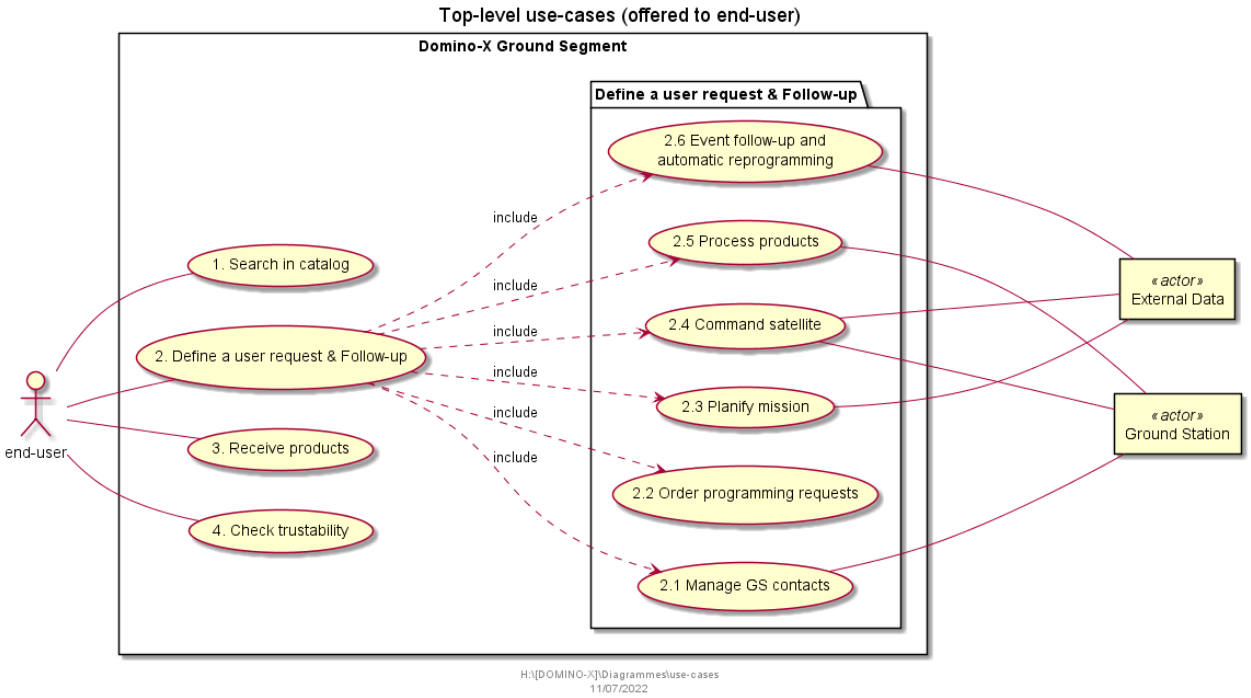

Fig. 2 Illustration of use case modeling, focusing here on "Define a user request & Follow-up" use case

9. Architecture breakdown

The engineering activities are still under way, however the number of dominoes is stabilised at around 23 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. 3 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.

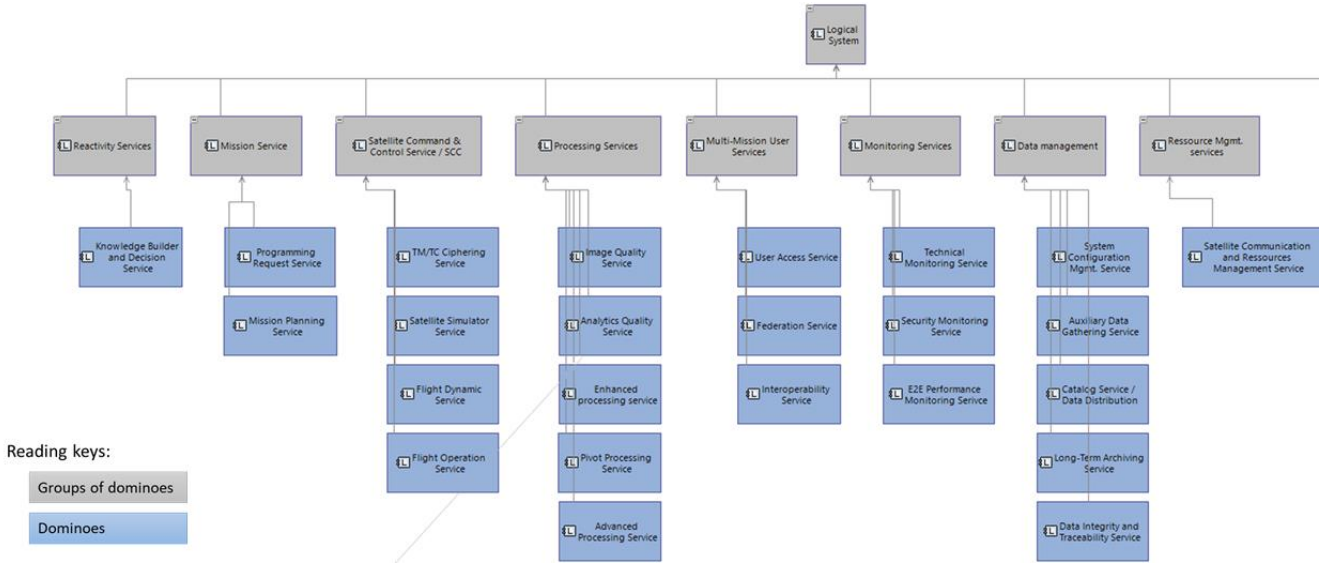

Fig. 3 List of the dominoes in each box, assembled into groups for better overview, as of June 2022. Note that this breakdown may evolve.

Fig. 4 provides an overview of the interface guidelines between dominos. The notion of pick-up points has been retained from the Copernicus PDGS approach, since it has proved that it works well operationally and it makes dominoes data driven. Two types of pickup points are applied in a domino-based architecture. One is the standard one adapted to the exchange of larger amounts of data, the other one is a light version more adapted to exchange of small volumes of data.

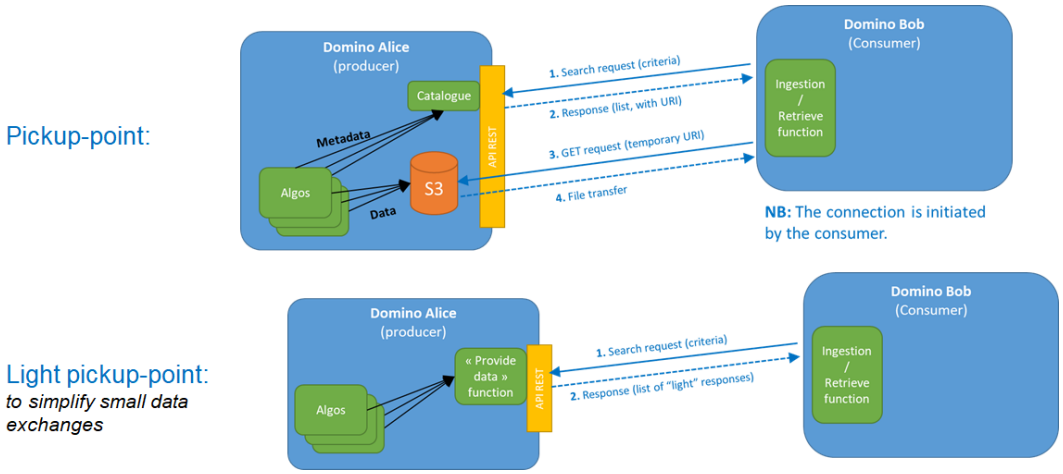

Fig. 4 Overview of interface guidelines between dominos

Fig. 5 illustrates the modelling between dominos, with a focus here on the Pivot Processing domino. The blue rectangles represent dominoes, the green boxes inside them represent functions present in the dominoes.

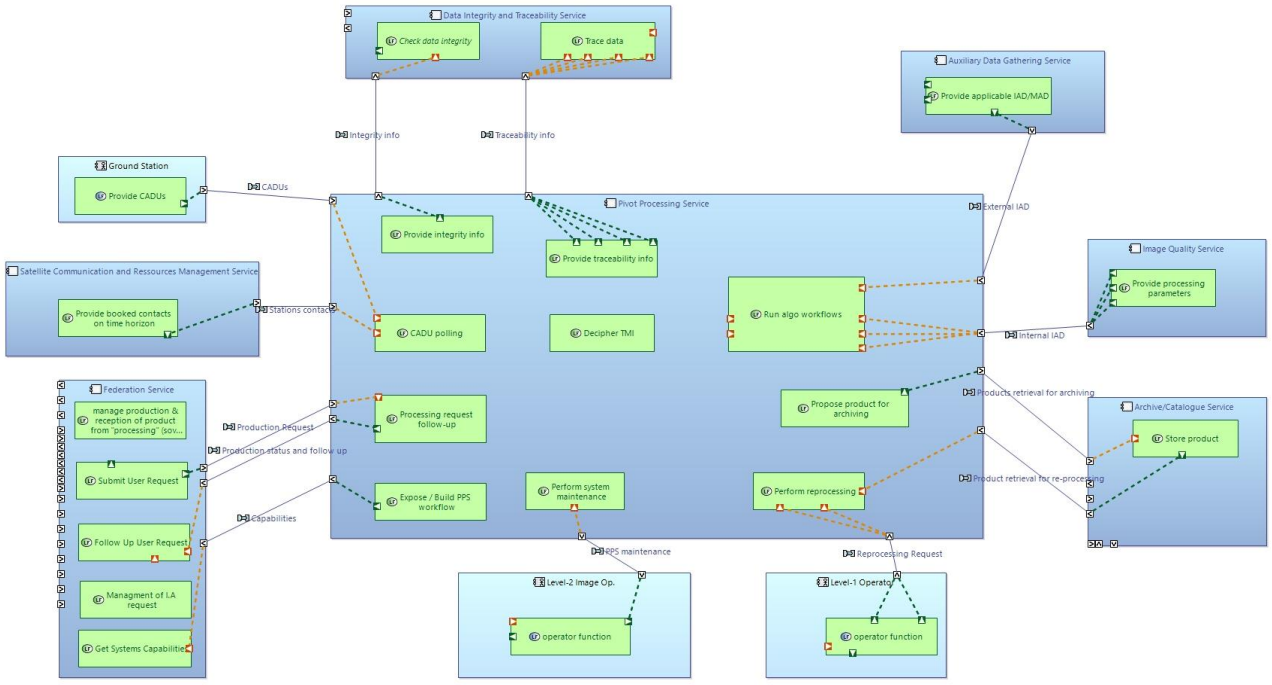

Fig. 5 Illustration of the modelling of the Pivot Processing Services domino

10. DOMINO-X Cloud guidelines

One of the key topics addressed in the project is virtualisation and Cloud. Indeed it is foreseen that more parts of the EO ground segments will be provided in a Cloud environment, in particular sovereign Cloud. Within DOMINO-X Cloud guidelines have been written aimed at domino providers. The guidelines cover hardware, software, architecture, security and human aspects. The document does not constitute a requirements list but generic guidelines.

11. Conclusions

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

A large part of the 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. In particular the engineering model is public and the modelling tool is free.

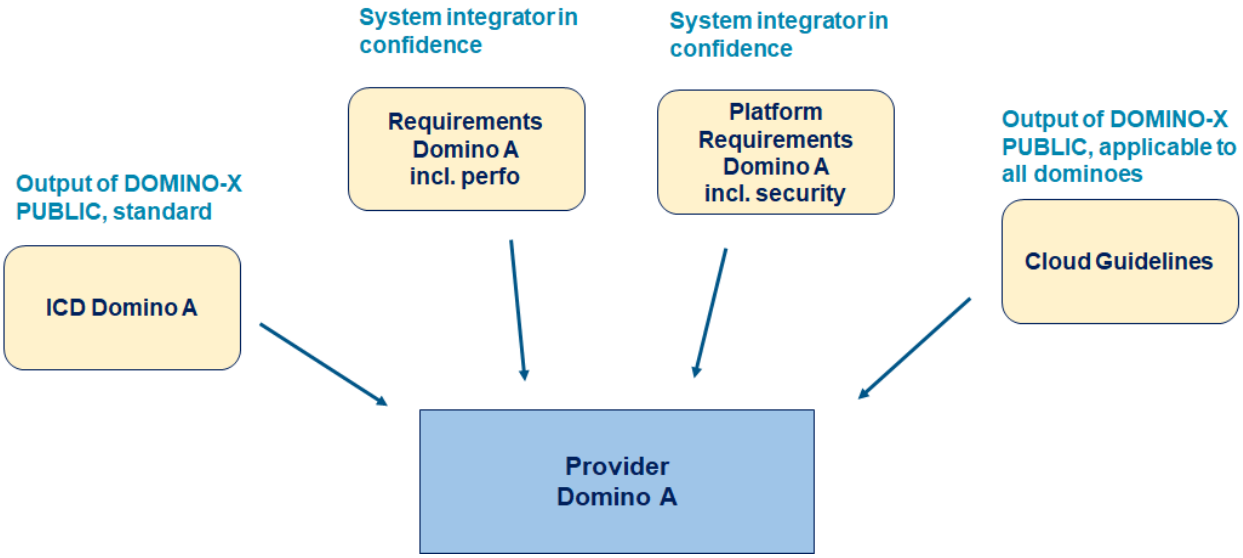

Fig. 6 Technical datapack provided to future domino providers

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. Fig. 6- illustrates the technical datapack that are typically provided to future domino providers.

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