Early-IVV with SmartCube

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Lionel Guibellini, Iris Avila Martinez, Franco Bergomi, Jonathan Blanchard

Thales Alenia Space
5 allée des Gabians 06150 Cannes-La-Bocca, France

Email: lionel.guibellini@thalesaleniaspace.com, iris.avila-martinez@thalesaleniaspace.com, franco.bergomi@thalesaleniaspace.com, jonathan.blanchard@thalesaleniaspace.com

INTRODUCTION

For **complex and critical systems** (e.g. a satellite), integration is a **critical phase**, especially when **integrating** interconnected components from different providers such as platform and payload computers.

At Thales Alenia Space, traditional approach of testing components integration with the whole system is performed in the enterprise premises and involves heavy and expensive test means. This activity is performed only when all hardware equipment is available, i.e. almost at the end of the validation process which can be ~18 months after the completion of on-board software (OBSW) development.

On every project, an average of 10 system/software/hardware **anomalies are** discovered **too late**. If an anomaly is detected at this point, this induces equipment shipment back to the manufacturer, architecture and development rework, significant delay on product delivery and high cost impact. Furthermore, the software often has to adapt to the hardware and this causes software workarounds and sophistication. This constitutes both a non-negligible technical debt and a brake to scalability.

Besides the financial aspect, collaboration and communication between teams in different companies especially in different countries working on a same space program is not optimal. Many problems appear in this context such as the physical distance between the teams, or differences between technical practices which lead to synchronization and ultimately integration issues.

Thales Alenia Space has then developed an alternative solution for this **software/hardware integration** step: **SmartCube**. This solution provides the capability of replacing late software/hardware integration with a progressive and **agile** integration, built over a closer **collaboration** between Thales Alenia Space and its suppliers.

Fig. 1. SmartCube

SMARTCUBE

SmartCube is a **light** (~4kg) and portable (20cm x 20cm x 20cm) **early IVV** (Integration Verification and Validation) solution, which connects agile team all together and can be easily carried as plane cabin luggage.

SmartCube, a small-format computer built with **COTS** (Commercial Off-The-Shelf), is an **all-in-one** mean which:

- embeds **simulation models** of all system/software components except the one to be tested:

    - embeds the actual execution platform which allows to execute the actual **on-board (or mission) software** and an abstraction layers to **emulate** the OBPE (On-Board Processing Electronics) in **real-time**,
    - includes all **functional model of avionics equipment**,
- is connected to the component to be tested with the real interface (1553, CLTU, SpaceWire, etc..),
- runs the **integration tests** and generates reports as it includes the validation environment (called **Vertigo**),
- includes a shared **model-based engineering** environment for all users, and software build/integration to correct anomalies on the fly.

Accurate modeling of actual hardware is a key point for SmartCube success. **Representativeness** of emulated and functional models is elaborated thanks to:

- A design of models to **fulfill the needs of different test activities** (assumed by different teams: on-board software validation, functional validation, operation procedure validation). Most models are shared with the DSS (Dynamic Satellite Simulator).
- An **incremental development of models** to extend their abilities for each projects needs milestones.
- **Important use of emulation models** during software and functional validation. During this activity, models behavior is compared to EM (Engineering Model) behavior.

The high **representativeness** of these simulated and emulated elements, make SmartCube an actual **digital twin** of the satellite. Indeed, this high representativeness guarantees the reliability of the performed integration tests.

Thales Alenia Space has been using SmartCube for several years now. First to test **satellite platforms interconnections**, and lately for **satellite payloads**. SmartCube originally was a backup solution to de-risk the integration phase when traditional means were not yet available; It has now become a **standard practice** for all space programs.

Furthermore, since **payloads** are becoming more and more **digital**, mission software becomes more complex so it is distributed over several interconnected processors. Testing such an architecture will be eased by the usage of SmartCubes shared between providers. Each SmartCube allows providers to use a simulation mean of the missing interconnected computer (processor and electronic).

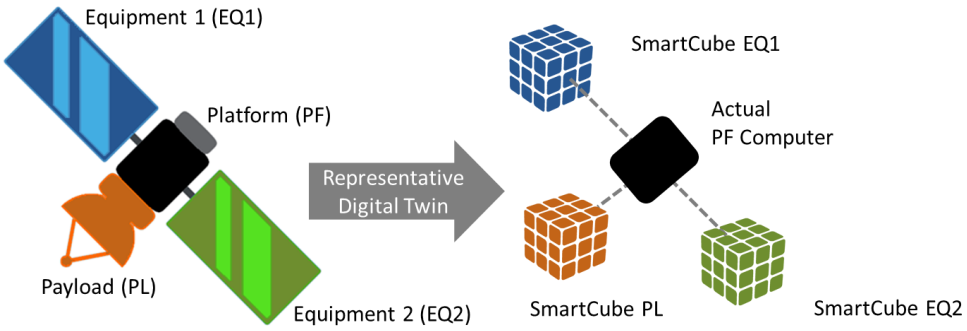

Fig. 2. SmartCube as a digital twin of the satellite

Up to now, there are three main categories of SmartCube:

- *SmartCube Satellite **Digital Twin***, for satellite platforms or payloads (see Fig. 3 and Fig. 3)
- *SmartCube **Test Bench***, or *Incremental Test Bench* composed of various SmartCubes (see Fig. 4). The goal is to replace little by little **monolithic** and **expensive** single-purpose tests means by **modular** and **low-cost** SmartCube-based networks.
- ***Equipment** SmartCube*

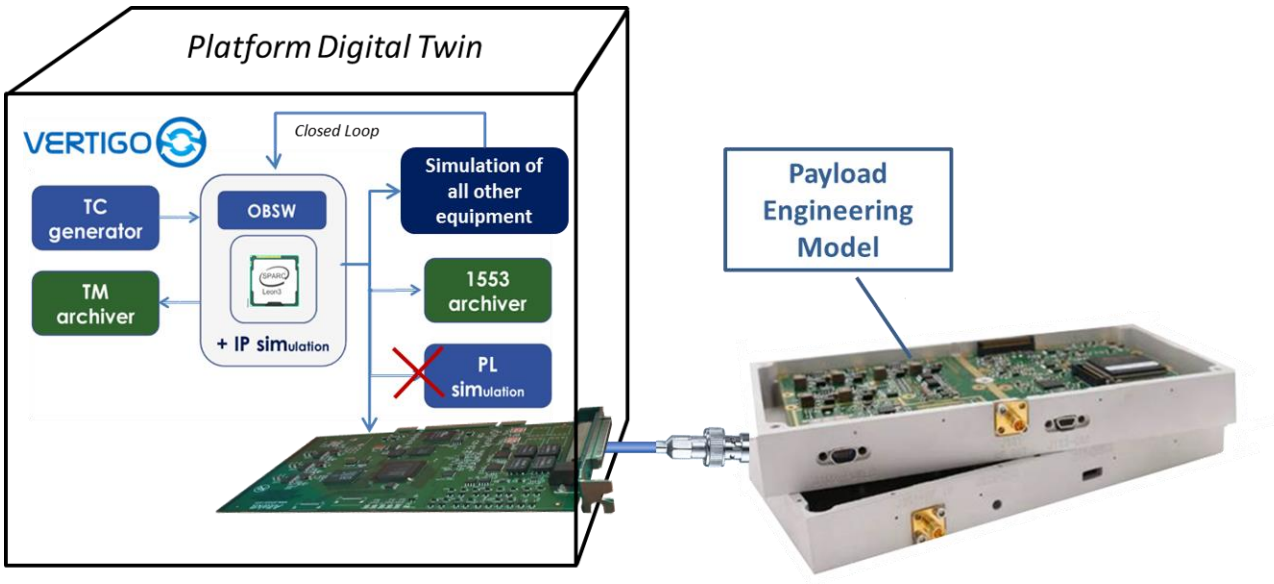

Fig. 3. Architecture of SmartCube as a satellite platform digital twin

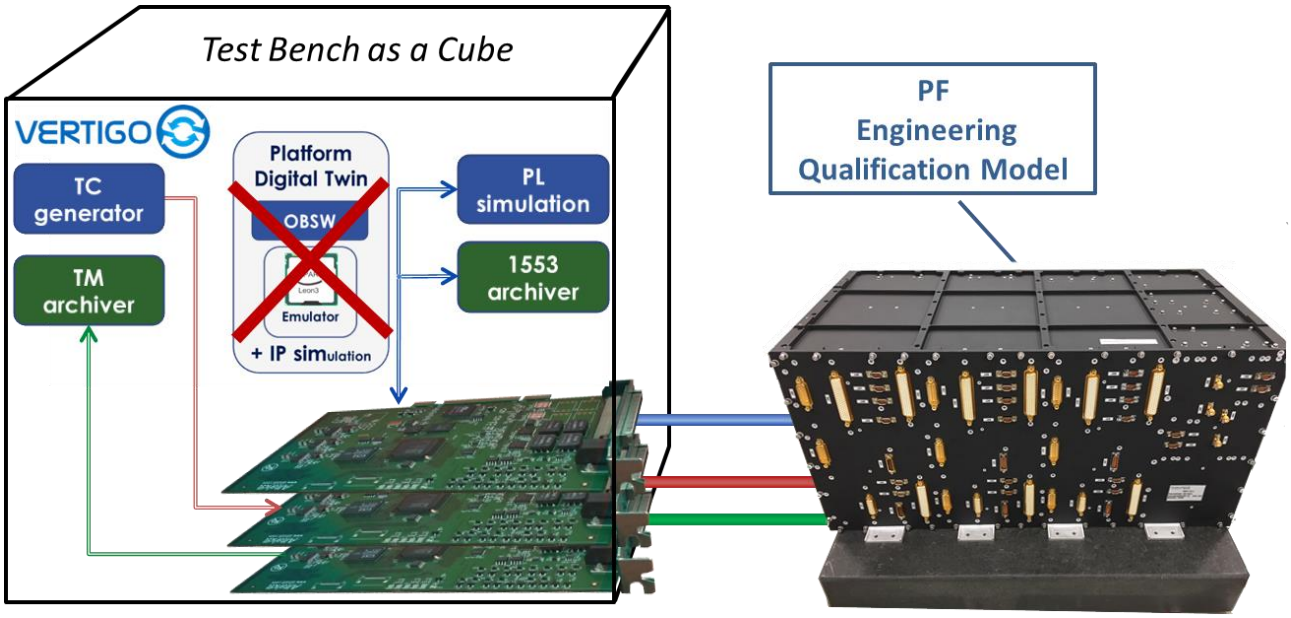

Fig. 4. Architecture of SmartCube as an incremental test bench

Fig. 5 shows all space programs that have already used SmartCube and the different application cases. As it can be observed, SmartCube has been used in Thales Alenia Space as well as in its subsidiaries and subcontractors premises.

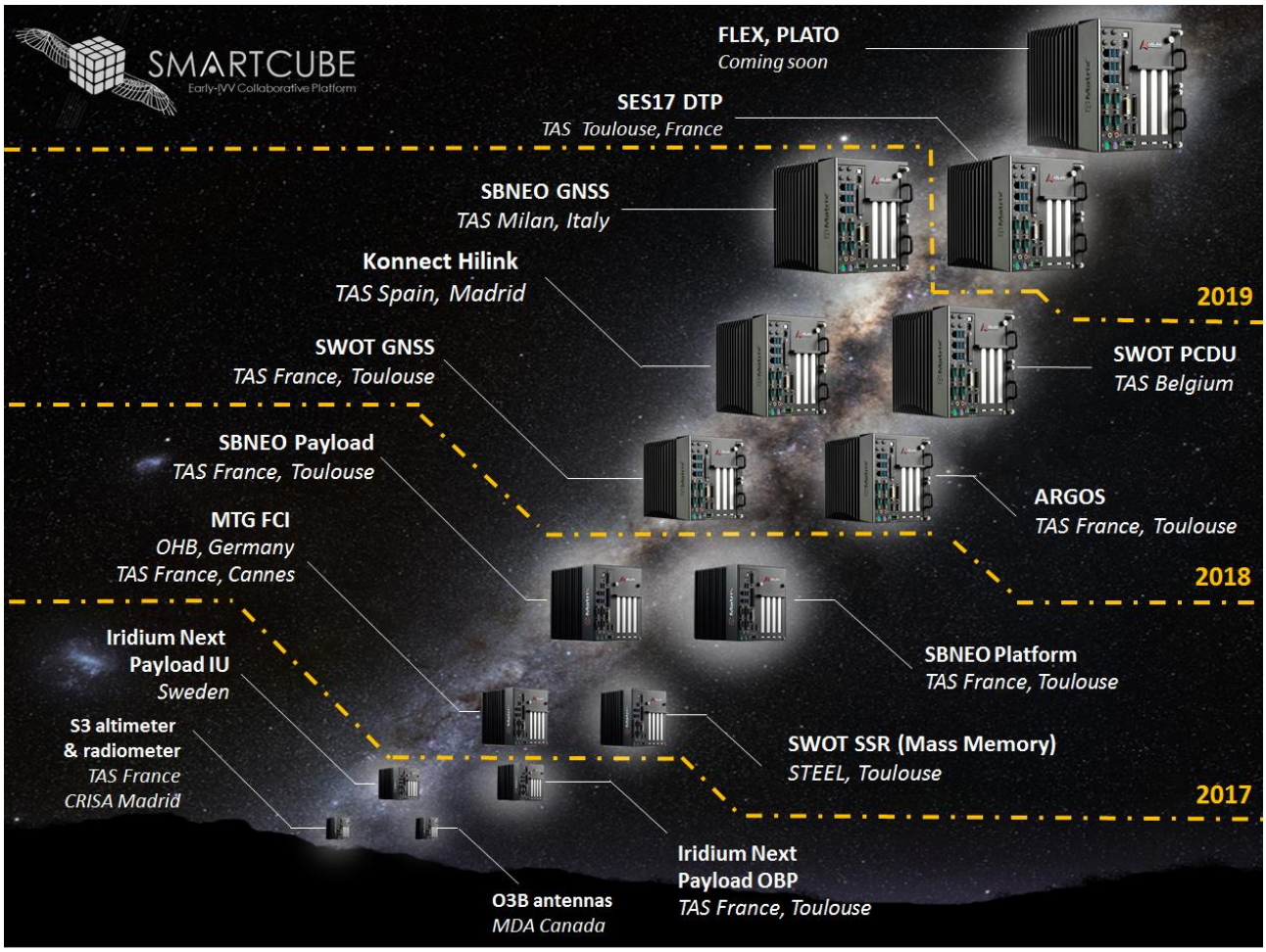

Fig. 5. SmartCube history

EARLY IVV WITH SMARTCUBE

In **2018**, the use of SmartCube exponentially increased, to help **de-risking** Telecommunication, Earth Observation and Navigation programs.

Changes on technical aspects
SmartCube main usage is to provide a solution for the preeminent software / hardware integration issues:

- *Issue* : Equipment design delay: delays in one equipment mean delays in the whole final integration since all equipment have to be available.
- *Solution* : SmartCube equipment type can help de-risking this integration while the real equipment arrives.

- *Issue :* Test bench complexity: since traditional hardware tests benches are monolithic, they are not operational until all the functionalities are developed. Delays in test bench delivery impact and shift the integration phase.
- *Solution :* Incremental test benches based on SmartCube(s) are a solution to this problem.

- *Issue :* Need for fast intervention/correction: sometimes an equipment or a mockup are just available for testing during a short period of time. In case of anomalies, debug and corrections have to be performed fast.
- *Solution :* SmartCube has already been very useful in these kind of situations.

Low cost risk reduction: the low cost of a SmartCube compared to all its benefits is largely worth it.

Thanks to a **test-and-learn** practice, SmartCube usage keeps maturing with the feedback of each application case. The **remote** capability of SmartCube has been recently developed. This **disruptive** solution allows to install SmartCube in the supplier's facilities and then control it remotely by Thales Alenia Space employees from Thales Alenia Space premises.

This new capability enables **remote** and **progressive** integration and testing, instead of (too) late integration testing. Also, a dedicated and user friendly interface, currently in development, will be offered to share data and tests results, update software and equipment models, and standardize exchanges and processes.

Changes on practices

The traditional development and IVV V-cycle is not fully compatible with an agile process, especially for the Integration phase. SmartCube allows to change this V-cycle to an **early** and **agile IVV** process (Fig. 6) by introducing the hardware in the loop. This means that equipment design and integration with the on-board software can be iteratively tested at the supplier's facility, with the representative avionics digital twin (including real on-board software itself).

With this approach, development/IVV cycle time is reduced, system maturity is improved, risks and non-quality **costs are reduced**.

Fig. 6. Early IVV Process

SmartCube practices build an interconnection between Thales Alenia Space, its subsidiaries and its suppliers:

- For Thales Alenia Space, it provides the opportunity to remotely perform integration activities with the software being connected to the real equipment
- For the supplier, it provides the opportunity to integrate Thales Alenia Space agile engineering process, with a modern access to the whole engineering data pack (models, requirements), but also benefit from an immediate feedback from integration tests results.

Cultural Changes

SmartCube practices as presented above represent a **cultural change** in the manner Thales Alenia Space **co-develops** systems with its partners. From now on, SmartCube is established by Thales Alenia Space Business Lines, Competence Centers, subsidiaries and industrial partners, as the new **early IVV collaborative standard solution**.

SmartCube is a vector to encourage inter-site collaboration and **agile squad teaming**. Every worker on a project is able to communicate and understand the others, thanks to this common layer-breaking solution. The **strength** of SmartCube resides in its ability to adapt the level of abstraction to the tricks of the trade it is used on.

RETURN ON INVESTMENT

Taking into account all Thales Alenia Space satellite programs that have already used SmartCube to de-risk their hardware/software integration phase, the return of investment of this solution can be clearly defined. Thanks to this previous de-risking phase with SmartCube, **the number of late anomalies** detected per avionics during final software/hardware integration tests, has **decreased by 70%** . As the late anomalies are reduced, equipment do not have to be shipped back to their supplier's facilities, which allows **up to 3 months planning reduction** for satellite tests duration.

Consequently, all of this implies **significant costs reduction:**

- Satellite avionics cost → **~20 M€**
- Average number of late anomalies found per satellite avionics → **10 anomalies/avionics**
- Correction cost per anomaly detected late during AIT (Assembly and Integration Test) or FCV (Functional Chain Validation) validation phases → **200 k€**
- Correction cost per anomaly early detected thanks to SmartCube → **60 k€**
- Cash saved per anomaly thanks to SmartCube → **140 k€**
- Cash saved per satellite avionics thanks to SmartCube → **1.4 M€**

Taking into account the number of space programs that have already used SmartCube, it is estimated that Thales Alenia Space saved about **10M€** thanks to this innovative, early IVV solution.

AXES OF EVOLUTION

The first axis of evolution is the miniaturization of SmartCube, the mini SmartCube. This reduced version weighs only 1 kg, measures 20 cm x 20 cm x 5 cm, and provides the same capabilities as SmartCube when it comes to 1553 or spacewire interfaces. Transport becomes even easier, which will facilitate SmartCube cluster deployment.

Fig. 7. Traditional SmartCube use

The second axis of evolution for SmartCube is to store in the cloud the data lake plus all possible configurations so the remote capability could be used even when SmartCube is outside Thales Group premises. This way, users would be able to easily configure their SmartCube In order to be able to put SmartCube in the cloud, three features have to be developed first.

The first feature is the **IoT (Internet of Things)** dimension. Deploying SmartCube into Thales Alenia Space's suppliers environment and having it connected to **Thales Digital Platform** is a real enabler.

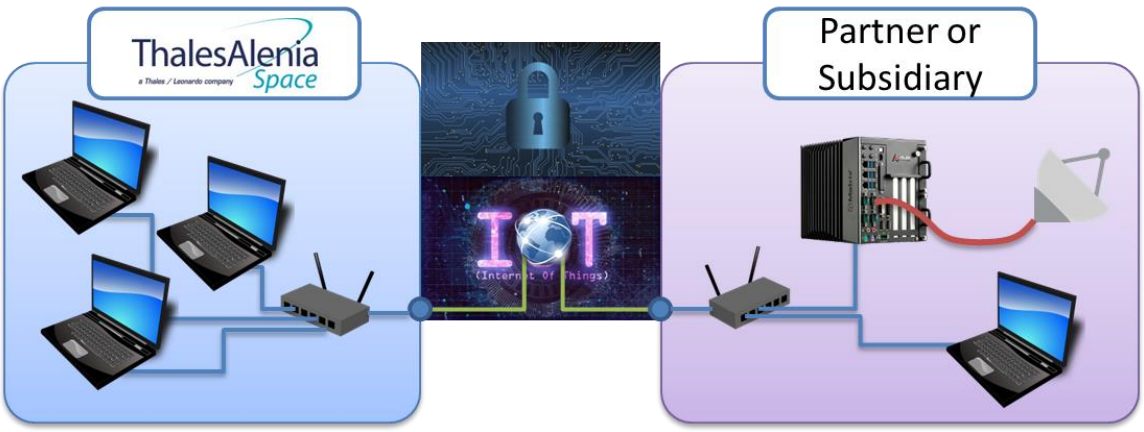

Fig. 8. SmartCube IoT

For this IOT paradigm, and also for following "Cloud" use case, C**yber Security** is a must have; SmartCube must provide proven secure links between Thales Alenia Space and partners in order to protect all exchanged artifacts (software binaries, test procedures, requirements, test results, documents, test evidences, etc..). Malicious tentative from both sides shall also be prevented. Armoring SmartCube with the appropriate **Cyber Security** defense and countermeasure is mandatory for the mutual trust between Thales and its partners.

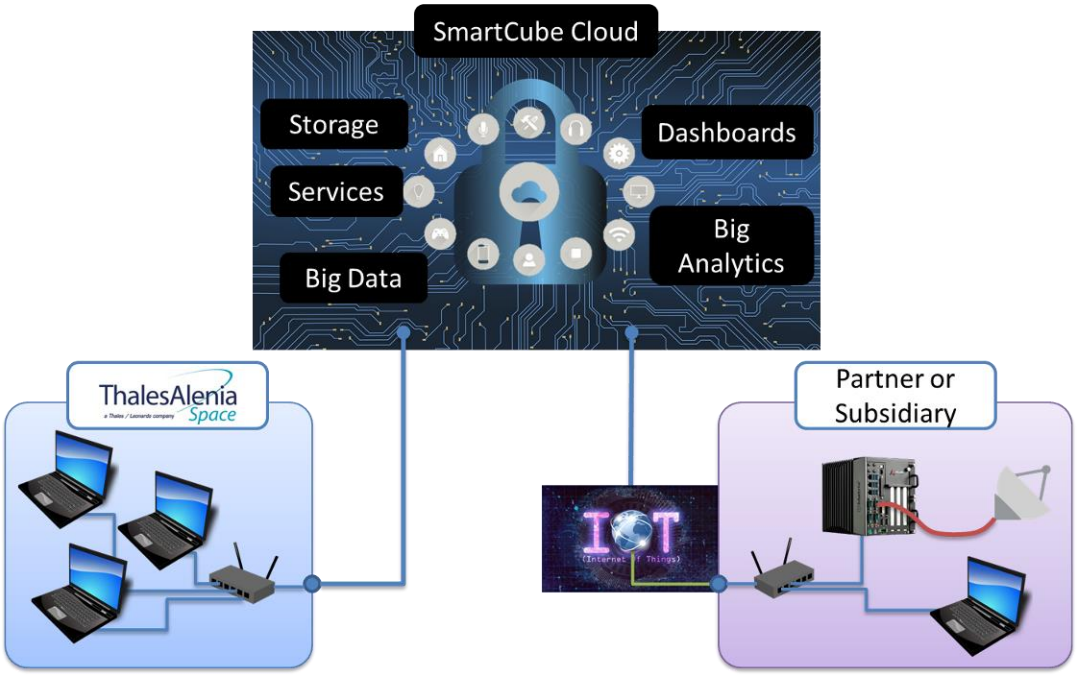

Fig. 9. SmartCube in the cloud

The second feature is **big-data** collection and **data science**. Current practices for software/hardware IVV are neither sufficient nor efficient enough in term of generalization, and completeness. Using **big-data** solutions to collect all available measures, inputs, data, results, creates the opportunity to easily share this information, and then execute all sorts of analysis with the help of **data science** solutions such as **Complex Event Processing** and **Deep Learning**, in order to build immediate results, monitor the status off SmartCube cluster, but also have more hindsight and **control of the technical dept**.

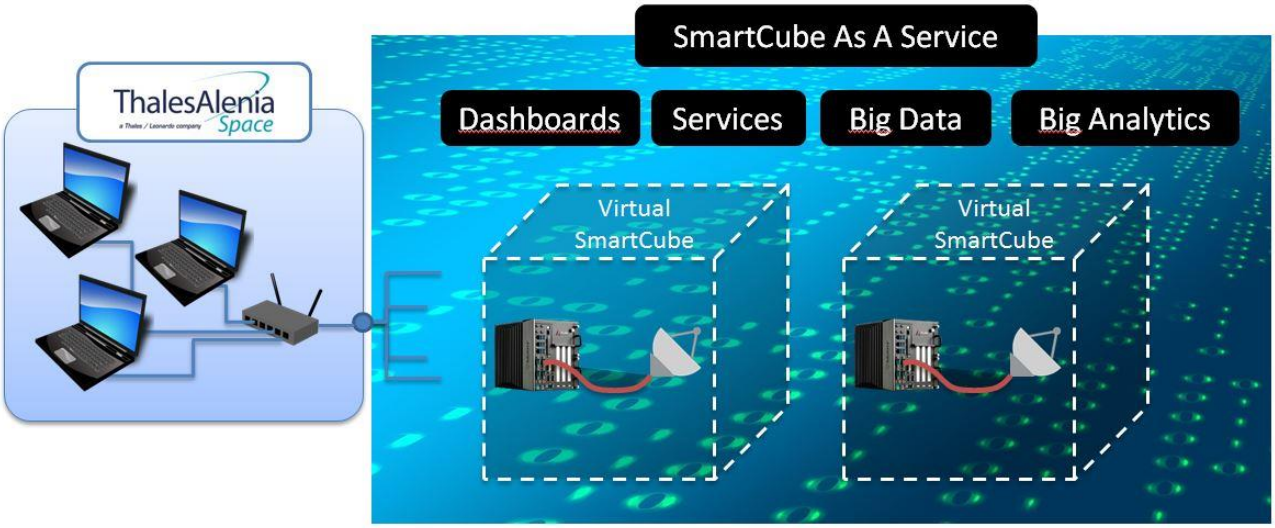

Fig. 10. SmartCube as-a-service

Finally, the third axis of evolution will be the **platformization**; This means to provide SmartCube **as a service** (SAAS). The as-a-service SmartCube is then intended to be used as a Virtual Test Bench, that is a Digital Twin of both the Satellite Platform, and its environment.

Thanks to the platformization, SmartCube users will be able to execute tests remotely in a computer cluster which is located in the premises of Thales Alenia Space Cannes. This computer cluster provides the capability to execute 150 parallel tests; Users and Program will simply "rent" some platform capability in order to run their tests when needed.

CONCLUSION

SmartCube contributes to early IVV practices, which increase efficiency and competiveness in the execution of software and hardware integration phases. This **hardware in the loop** approach provides the capability to early develop and test at the same time in an iterative way.

Thanks to this agile development and IVV process, critical phases are secured, time and cost impacts are reduced and thus risks are better managed. Besides, SmartCube is fully based on COTS, which makes it a low-cost, adaptable and reusable solution. Finally, SmartCube Building Blocks are capitalized for the final operation simulator with a high confidence level thanks to the preliminary maturation.

SmartCube is a key player in the **digital transformation** of the collaboration between Thales Alenia Space, its subsidiaries and its suppliers. SmartCube leverages collective efficiency by involving diverse teams in a shared, collaborative and agile process.