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Satellites Constellation Simulator challenges

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INTRODUCTION

For many years, high-fidelity simulators are intensively used for validation, training and investigation during the whole life-cycle of a satellite. The mechanisms of fine modeling and the ease of models evolution have allowed capitalizing over years in order to achieve a high level of representativeness. This is how simulators can support many domains: from on-board software validation to spacecraft operations.
However, the arrival of the "new space" wave and its mass production leads us to revise the simulators needs and now better to consider the satellite fleet as a system rather than the systems as a set of single satellites units.
Service management must be considered at the fleet level rather than at the satellite level.
So the satellite's deorbiting constraint becomes essential. The loss of a single satellite could lead to the loss of a plan or a full fleet by domino effect.
Keeping this in mind, satellite operations should be planned in a safe and coherent way on a global system.

To achieve this safety goal, simulation tools are fundamental.
The classic simulation approach would be to multiply an already developed high-fidelity simulator in order to simulate all possible and imaginable cases: from any command processing, to any equipment failure.
This approach requires a powerful computer infrastructure that one’s could consider as low added value because from the ground segment's point of view, a satellite is ultimately a "simple" TC-TM answering machine among others. Moreover, and by the standardization of on-board services like PUS, a satellite can be considered as a service point.

Based on this analysis, we developed a satellite constellation simulator that makes the satellites appear as responders complying with the communication protocol. The objective is to simulate the response of a satellite as closely as we could to the real one.
In terms of data amount, from control center point of view, the model responds in the same way as the flight software.
This allows maintaining a representative load on the ground segment which must capture, archive and process the streams of all satellites.

CHALLENGES

Even for small satellite constellation (less than 50 satellites) a satellite constellation simulator cannot be limited to the aggregation of single satellite simulations (high-fidelity or not).
The fleet aspect is important and must be taken into consideration for the design, the management and the operation of such a simulator.
In fact, the management of a large fleet brings new questions. It is no longer possible to consider the satellite as single a standalone point as they all interact together: at least share the ground stations.
That is why the simulator must take into account this fleet aspect in order to prevent and assist the operator at fleet level.

Many constellation level indicators must be monitored. Here are short examples that raise a lot of new questions.
During the separation phase the relative speeds of the satellites between them are so small that it is difficult to discriminate the satellites from each other. Their distance must be quickly increased by causing a thrust on the propulsion system on the first of the queue and then on the following.
On such a case, the simulator will be in charge of checking the inter-satellite distances in order to alert the operator to a possible collision if the separation sequence has not been properly managed.

Likewise the sizing of the ground stations is difficult to anticipate. Indeed, it is easy to consider the nominal case, but this must be added to the new satellites and the deorbiting of the most defective ones.
In some worst cases, a ground station may not be able to track all visible satellites, which would require operators to choose between tracking a deorbiting satellite and fleet management for service continuity.

Let’s continue our thought on the concept “constellation as a service”. For an operator point of view the continuity of service is important. However, for a constellation of satellites, controlled deorbiting is essential.
The operator has therefore to manage transient phases during which it will be necessary to reshape a plane or constellation. This fleet management process can also be verified on simulator which provides and check the inter-satellite distances.

APPROACHES

We currently have at our disposal two types of simulators aiming complementary objectives.
For the development and validation of the satellite, we developed high-fidelity simulators.
These simulators are extremely fine grain in order to represent all the hardware mechanisms and up to a certain extent dynamical behavior. Indeed, most aspects are treated: flight processor mechanisms, electrical harness, thermal exchanges, environmental phenomena (gravity, solar wind, magnetic field …), equipment’s functional behavior or the spacecraft dynamic (attitude and orbit). Such simulator execute, unmodified, the central flight software to ensure a full representativeness of the satellite command / control aspects. It is a bit accurate and an usually an average cycle accurate (time fidelity > 75%) simulator.

The second type of simulators is similar to old simulators; used in early’s 90, where computer processing power was not sufficient enough for emulation, thus using functional or retarget part of the on-board software. Each satellite is represented by a simple model that ensures a sufficient representativeness at the level of the communication protocols.
It is representative on the data flow but partially on the content. Indeed, only a few important data are dynamically simulated: position, speed, time, attitude, state and modes of equipment, systems and AOCS modes. It should be mentioned that, it is easy to add simplified models/functional responders.
It is important to, again, mention that those two types of simulators are not competing each other. They are complementary.
Obviously, for the investigation of anomalies and deep investigations we would prefer the high-fidelity simulator.
Nevertheless, for a mass deployment at constellation scale and mission planning, the light-fidelity is easier to operate and provide success criteria of the maneuver at the constellation level.

COMPARISON

The following diagram shows the two types of simulators.

On the left side, the high-fidelity simulator (red circle) represents a single satellite and its ground stations.
The most important point is that it executes the flight software binary. As a consequence, most of the operations including memory patches can be tested and validated.

On the right side, a constellation simulator represents satellites in the form of a simple answering machine model. Like the high-fidelity simulator, it integrates ground stations models.

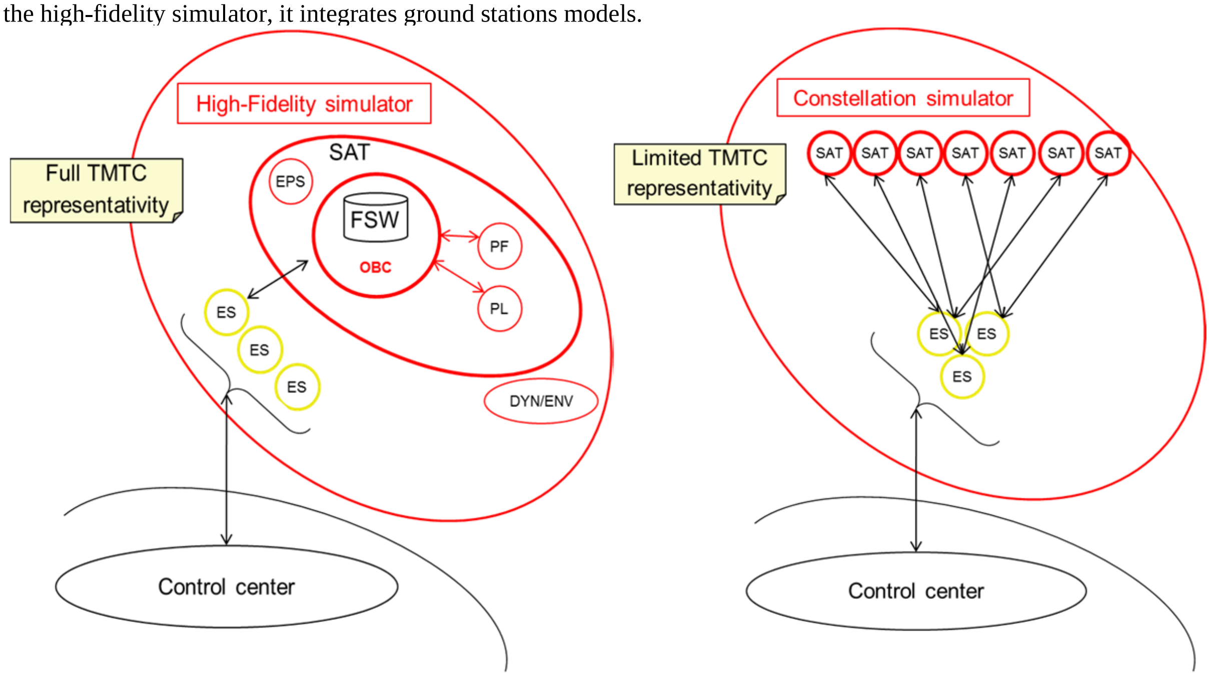

Figure 1: The two types on simulator

The difference between these two simulators is not only about representativeness.
It should be noticed that usually each high-fidelity simulator incorporates part of the ground segment (at least the ground stations). However, some use-cases experienced by AIRBUS allows execution of up to 10 high fidelity satellites in the same simulation sharing Ground stations. But in a large constellation, this solution can not be applied, mainly due to CPU resources and the ground stations still to be shared. How can we model this by multiplying high-fidelity simulators?
It would be necessary to synchronize the simulators and centralize the ground stations models.
To support such mechanisms, the computer infrastructure required to support 1000 satellites simulation was estimated to about 150k€ for one single simulation instance (recurring cost). This is not to mention the costs generated by the maintenance of such an infrastructure.
In comparison, a constellation simulator with a simplified satellite model is capable of simulating 1000 satellites for a limited recurrent infrastructure cost limited to a single computer (<10k€).

Other important aspects to consider are:

- Deploying and updating simulators
- Initial configuration: simulation date, position, attitude or initial temperature …
- Synchronized start of simulations
- Constellation-Level synthesis Model: inter-satellite distance, collision alert...
- Synchronized pause and stateset/breakpoint file restart

- Stop simulation and results processing (huge amount)

All these phases are paramount in order to facilitate the operability of the simulation system.

FOCUS ON CONSTELLATION SIMULATOR SATELLITE MODEL

As previously presented, in the constellation simulator the satellite is considered as a service provider. Thus, when a TC is received by one of the constellation satellite model, it is analyzed and routed to the corresponding service answering algorithms. The last model is in charge of generating all the dynamics of the associated service.
We have therefore developed the various modules: acknowledge, house-keeping, timeline, events, telemetry recording and retrieval...

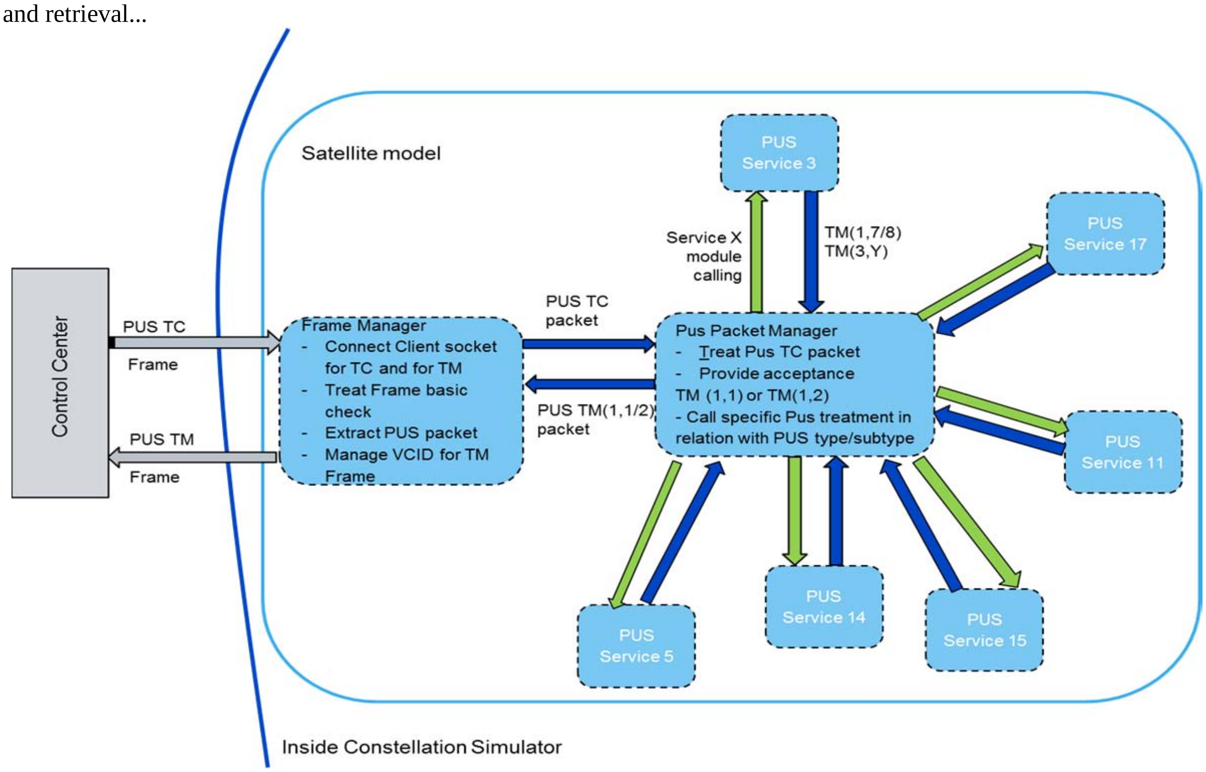

Figure 2: Satellite services responder model

WAY FORWARD ON CONSTELLATION SIMULATOR

Modelling a satellite as a service is a part of the solution. But to get a sufficient behavioral model, you have to add some dynamics models. A short and simple list here:

- Orbit and attitude restitution by ephemeris or propagator
- Computation of visibility towards ground stations
- Configuration and management of separation sequence

Nevertheless, in order to obtain representative behavioral models, it is necessary to know finely the dynamics of the flight software. This includes system mode switches, management of the payload and sometimes equipment specificities.
This can quickly leads to the development of heavy and poorly performing models with low added value. We will therefore be careful to respect the spirit of the simulator: Simple models, high scalability.

However, validation of behavioral patterns can be difficult. The specifications are often incomplete and it will be necessary to reproduce test cases on FlatSat or high-fidelity simulator and to dissect all the dynamics of communications.

In order to minimize the problems of representativeness, it would be interesting to integrate the application part of the flight software. This still poses technical problems because the flight software was not designed to be instantiated multiple times in the same environment.

CONCLUSION

In view of the complexity of the operation of a satellite fleet, Constellation Simulators have become indispensable.
There is not a single answer to solve the problems raised by the management of so many satellites.
Experience has shown us that the preparation of simulation cases is essential to the success of good operations.
Often we prefer a hybrid simulation combining several instances of high-fidelity simulators and several constellation simulators based on answering models.
This will limit the number of high-fidelity simulators to a plane or a separation sequence.
This is where we take the benefits of the high scalability of our simulators.

ACRONYMS

EPS: Electrical Power System
ES: Earth Station
PF: Platform
PL: Payload
OBC: On-Board Computer
SAT: Satellite