IRIDIUM NEXT Simulators & EGSE

Christophe Jacinto[(1)], Anthony Mollier[(2)]

Thales Alenia Space - France[(1)]
E-mail: christophe.jacinto@thalesaleniaspace.com

Thales Alenia Space - France[(2)]
E-mail: anthony.mollier@thalesaleniaspace.com

ABSTRACT

This paper presents simulators and EGSE developed for IRIDIUM-Next program. All this developments are based on THALES building blocks : simulation core K2 and check-out system OCOE-6.

The purpose of these simulators and EGSE, is to support the following activities:

- Platform software (PFSW) validation and debugging through Software Test Bench (STB),
- Avionics validation preparation through e-ATB,
- Avionics validation and debugging through Avionics Test Bench (ATB),
- AIT preparation through AIT simulator (SIM-AIT),
- Payload AIT through EMO AIT bench (SIM-EFM),
- Power AIT through Power Test bench (SIM-EFM),
- Satellite operations preparation through Dynamics Satellite Simulator (DSS).

Main objective of these developments is to explore synergies between simulators and EGSE :

- same hardware target : HP DL server,
- same operating system target : Linux Real-time Redhat 6 MRG 2.1,
- same software core : K2,
- same check-out system : OCOE-6,
- same satellite models.

These benches can be divided in 3 families :

- numerical bench : it is used to prepare real activities and exists in 3 versions : for avionics validation (e-ATB), for AIT (SIM-AIT), for operational team (DSS). In this case, PFSW is executed on a simulator of the on-board computer (OBC or PFC in IRIDIUM case). This OBC emulator is composed of a LEON 3 processor emulator, and the simulated OBC equipment model. The OBC emulator interfaces with the satellite models, which simulate satellite

equipments, EGSE, thermal, dynamics, and environment. All models, including the LEON 3 emulation, are embedded inside K2.

- hybrid bench with real OBC : it is used to perform avionics verification and validation activities and exists in 2 versions : STB (for software verification) and ATB (for avionics verification). In this case, PFSW is executed on the real OBC which interface, through the HW FEE with the satellite model. Furthermore, satellite equipment models can be replaced by real equipment.
- hybrid bench with simulated OBC : this generic bench (SIM-EFM) is used to perform AIT activities and exists in 2 versions : power test bench (PTB) and Payload test bench (EMO). In this case, PFSW is executed on a simulator of the on-board computer (OBC). This OBC emulator is also composed of a LEON 3 processor emulator and the simulated OBC equipment model. The OBC emulator interfaces with real equipments.

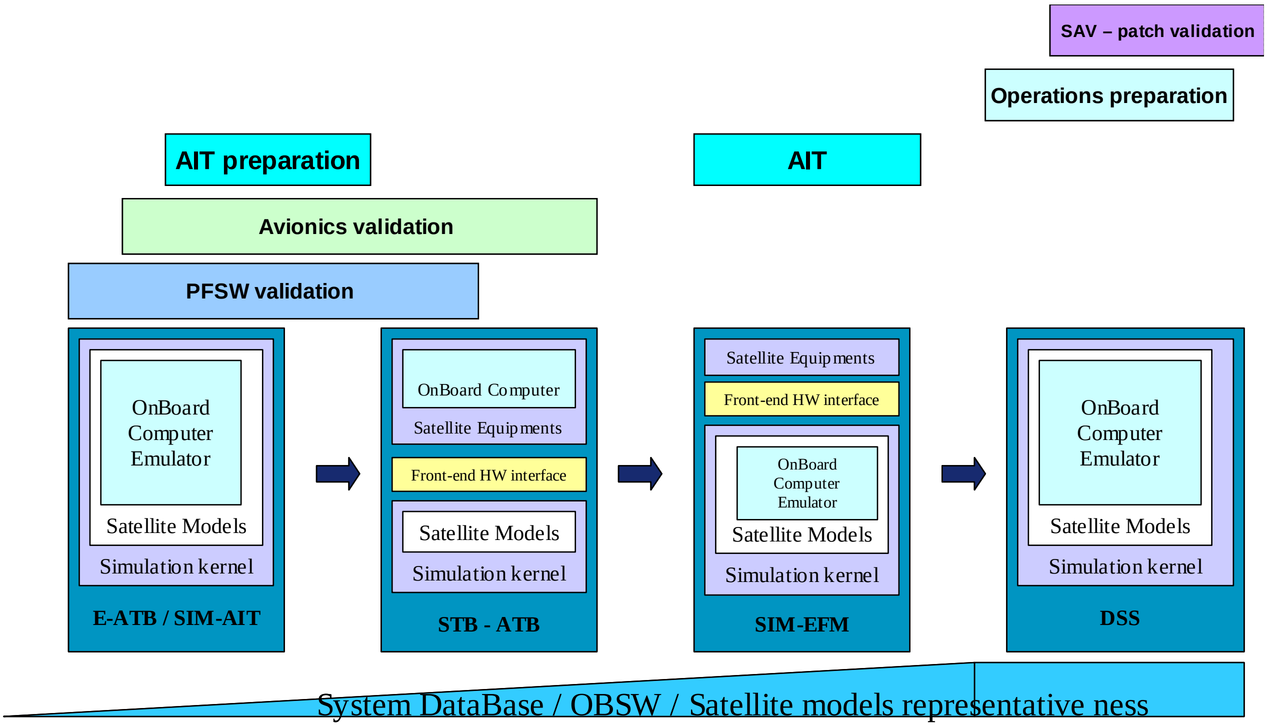

Fig. 1. IRIDIUM Next simulators and EGSE

A GENERIC APPROACH FOR SIMULATOR AND EGSE

First way to have a generic approach (called SCSIM) between simulators and EGSE is to share an unified software infrastructure which to allows portability, interoperability and re-used components (models, interfaces, process).

The unified software infrastructure SCSIM embeds following layers :

- a hardware target : HP DL server,
- a operating system target : Linux Real-time Redhat 6 MRG 2.1,
- a software core : K2,
- a check-out system : OCOE-6 .

About operating system, the choice has been driven by hybrid bench constraints. Usually, VxWorks was used to answer to real-time constraints but his use was not easy and hardware target was different of other bench like simulator. So, we have decided to analyse Linux capability to answer to all needs (simulators and EGSE).

We have benchmarked Real-time distribution with following results : the latency periods are considerably reduced with patched kernel, (approximately 90 microseconds max) for Xenomai and Preempt-RT, while in the domain Linux the latency periods reach the 12 seconds. This latency is once considerably reduced when the hyper-threading is deactivated. Linux with Preempt-RT patch becomes sharply more interesting because of the easy integration of numerous scrub software reused without must be optimized nor even modified by the whole to be compatible in Real-time.

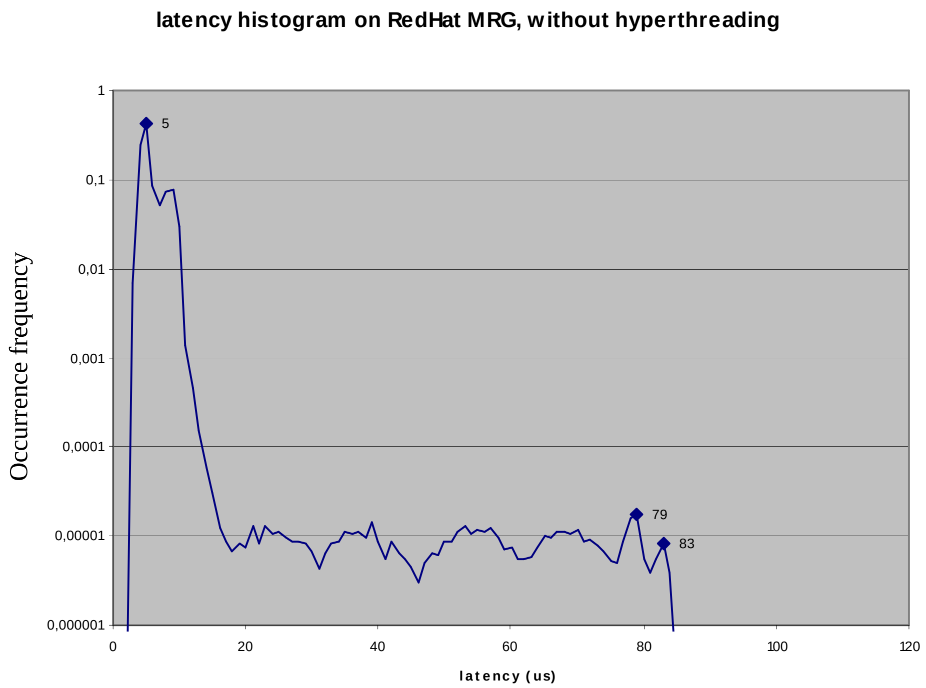

Fig. 2. MRG linux latency histogram

About software core, we have used an internal product K2.

The K2 core platform offers different kind of services :

- Data exchange : input / output, activation / routine, bus,
- Scheduler : is responsible for the co-ordination and processing of all events within the Simulation Kernel. An event on the schedule identifies an action that needs to be performed at a specified time in simulated time,
- Time Keeper : is responsible for maintaining and providing models and the MMI with the correct simulation-Time. It provides time in four formats, Simulation-Time, Epoch-Time, Zulu-Time and Correlated Zulu-Time,
- Data explorer : is responsible for making the values of both model and Kernel data items available for display in an MMI,
- Logger : supports the recording of model events that occur during a simulation. The log in which the current simulation messages are written is called the active log. The logger offers 6 levels (trace, debug, info, warn, error, fatal) and 100 debug sub-level. Logs can easily be turn on/off,
- Data tracer : periodically record the value of multiple data fields. Supports state, feature, input,
- Activation tracer : asynchronous record of the activation parameter and results on each call,
- Trace mode : record when entering/exiting models algorithms and routines. Useful for debugging,
- Profiler : record the time in every model. Useful for simulator performance optimization.

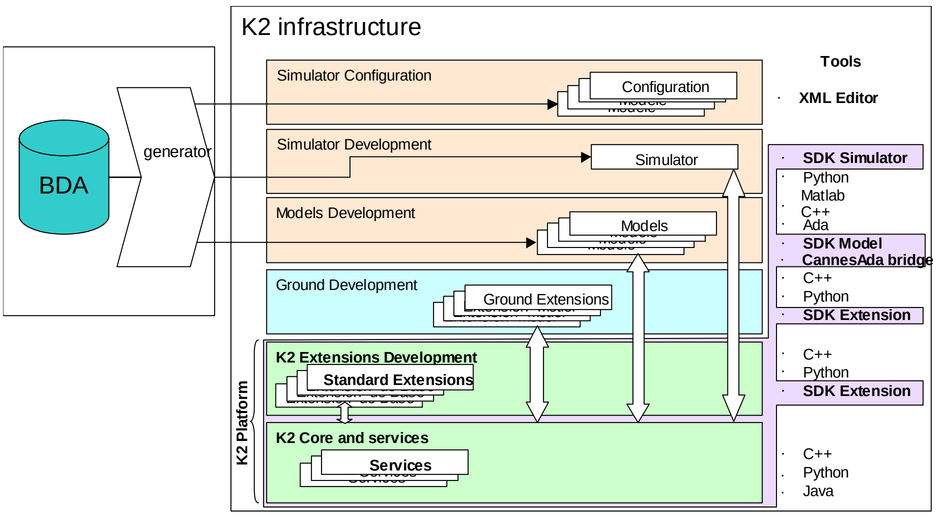

Fig. 3. K2 components overview

K2 has been modified to answer to hybrid bench constraints. We have added real-time scheduler and multi-threading capability.

About Check-out System, we have used an other internal product OCOE-6.

OCOE-6 components cover following functionalities :

- Test configuration management (e-tramm) : consists in test procedure configuration and test matrix definition,
- Test preparation (e-test labs) : consists in test procedure writing, checking and testing using the Satellite Database. It will also generate all necessaries data files needed for execution/report purposes,
- Test execution (e-scheduler) : consists in test procedure execution directly or by batch,
- Real-Time TM checks (monitoring kernel) : it will check TM parameter values during real-time test execution,
- Test monitoring (C&C MMI): consists in displaying the test execution to the end-user and bench errors/warning,
- Test execution analyze (e-tdhs) : it generates a report about execution and will make some off-line check about recorded data.

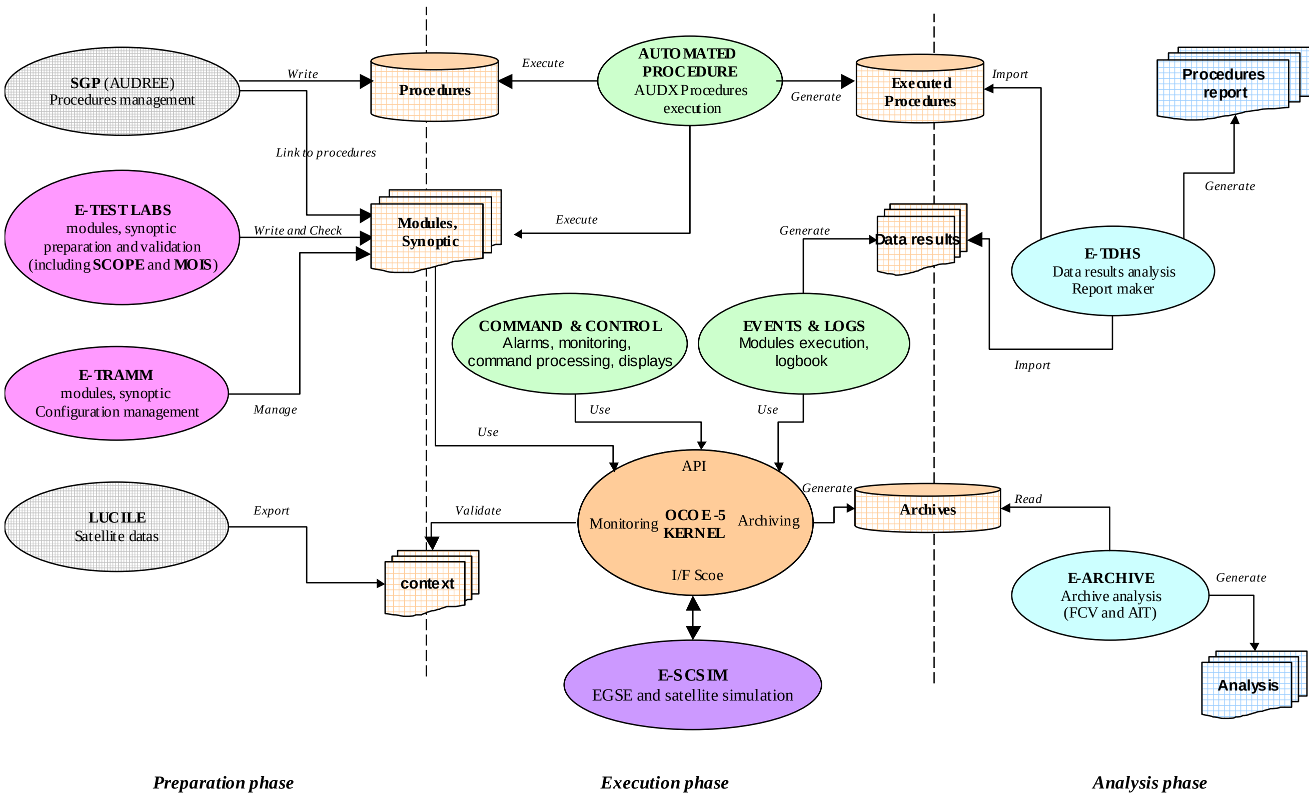

Fig. 4. OCOE-6 components overview

OCOE-6 has been modified to answer to hybrid bench constraints. We have added an new component based on SOA architecture with RCP frameworks to increase portability and interoperability between bench components and check-out system.

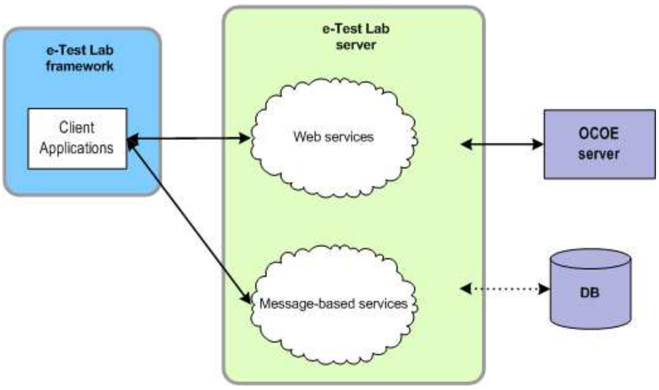

Fig. 5. OCOE-6 SOA architecture

Thanks to previous choices, the way is opened to share same satellite models between numerical and hybrid bench.

Figure below shows (in green colour) shared models between all benches on IRIDIUM-Next program.

Satellites models	Numerical bench	Hybrid bench with real OBC	Hybrid bench with simulated OBC
OBC		NA	
PAYLOAD Functional			NA
PAYLOAD coupler			
AOCS Functional			NA
AOCS Coupler			NA
Power Functional			NA
Power Coupler			
Thermal Functional			NA
Thermal Coupler			NA
ATB			NA
EGSE		NA	
SCC		NA	NA

Shared models

Specifc models

Fig. 6. shared models between IRIDIUM benches

NUMERICAL BENCH : FROM AVIONIC VALIDATION TO OPERATIONAL PREPARATION

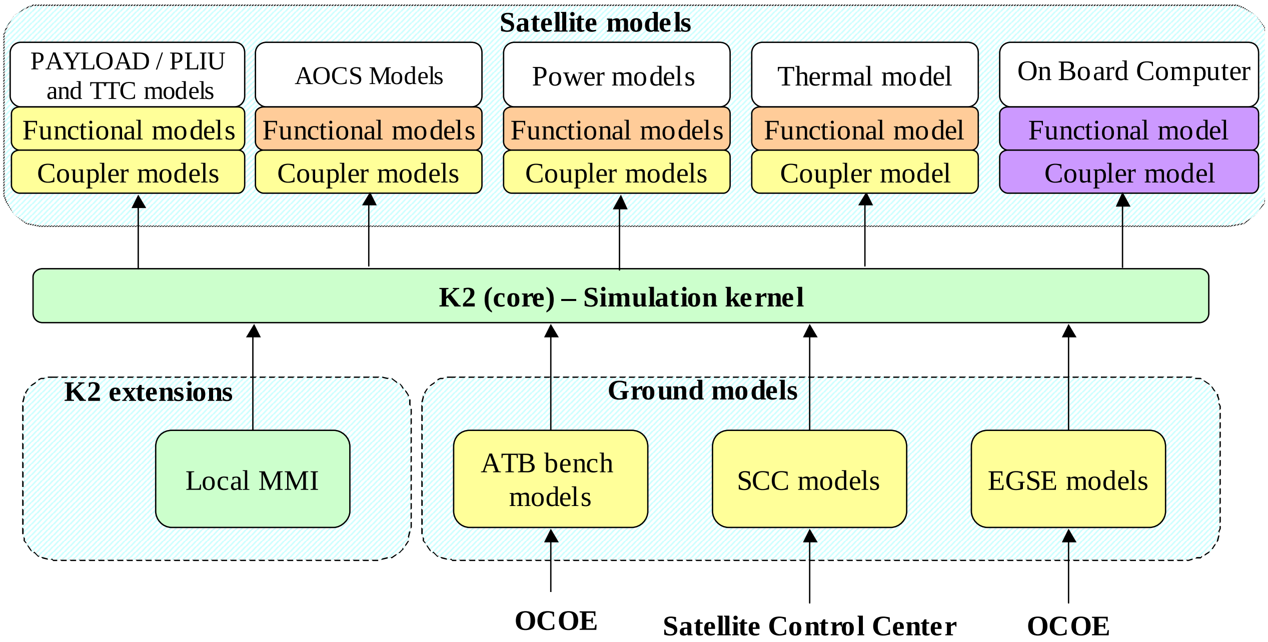

Fig. 7. numerical bench overview

These numerical benches support the following activities :

- Avionics validation preparation through e-ATB,
- AIT preparation through AIT simulator (SIM-AIT),
- Satellite operations preparation through Dynamics Satellite Simulator (DSS).

First, they are used to support avionics development. It is called e-ATB. It is delivered by increment to allow PFSW validation in open loop configuration up to closed loop configuration (AOCS, EPS and Thermal).

They simulate the data traffic between equipments and OBC on protocol level considering also data exchange times. The scheduling of the equipment models is managed by one master time because a processor emulator is used and each tick could raise an action which needs maybe answered immediately. Additionally, every equipment model is scheduled periodically in defined time slots in a highly deterministic.

Then, the numerical bench SIM-AIT support the preparation of test procedures before to be run on the AIT bench. Thanks to SIM-AIT, the test sequences are developed on a numerical bench one can run outside the AIT area and easily reproduced.

SIM-AIT is used the same check-out system than for the e-ATB. All the satellite equipments are simulated including the EGSE. The need to simulate the EGSE is only according to test sequence needs.

Finally, numerical bench is used to support the preparation of satellite operational procedures. It is a complete satellite simulator. All the satellite equipments are simulated including the SCC interface and link budget model.

The detailed architecture is composed of :

- **Satellite models :**
  - OBC (or PFC in IRIDIUM case) model with new LEON 3 emulator board,
  - Platform models : PLIU, PCDU, Star tracker, Wheels, MAG, MTB, CSS, batteries, SAPM, SAPT, environment & dynamics,
  - Power and Thermal model based on e-therm kernel,
  - Payload models : OBP, TTC, receivers, transmitters, docon, MFGU, MMA, link budget.
- **Ground models :**
  - Architecture & scheduling models : RTS, time manager,
  - EGSE models : UMBILICAL, SAS, BATSIM, AOCS,
  - ATB models : ML/DS – 1553 - Spw monitoring and simulation, archives.

The building blocks and interfaces are based on standard decomposition of a real equipment functions in two model categories : functional and coupler Models.

Functional models are responsible for the mathematical simulation of a spacecraft equipment (e.g. actuators and sensors) and for simulating the command and control functions of the spacecraft payload (scientific instruments) and platform (sensors/actuators) equipments. These models are primarily state machines, simulating the real equipment modes.

Coupler Models provide the interface between the Service models and the On Board Computer model. These models act as adapters between the functional models which handle command and control and the On Board Computer. Their primary task is the command and control protocol management.

Most of the models are re-used between the numerical bench :

Numerical bench models	e-ATB	SIM-AIT	DSS
OBC			
PAYLOAD Functional			
PAYLOAD coupler			
AOCS Functional			
AOCS Coupler			
Power Functional			
Power Coupler			
Thermal Functional			
Thermal Coupler			
ATB			
EGSE	NA		NA
SCC	NA	NA	

Fully shared models

Partially shared models

Fig. 8. shared models between numerical benches

HYBRID BENCH WITH REAL OBC : SOFTWARE AND AVIONIC TEST BENCHES

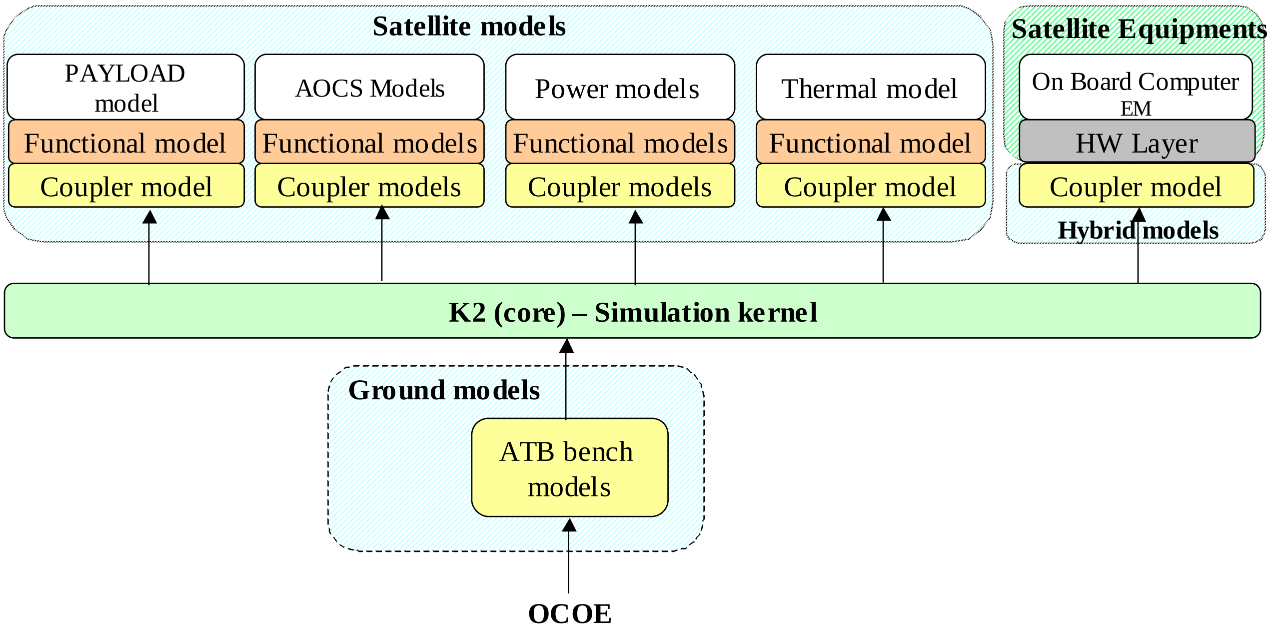

Fig. 9. hybrid bench with real OBC overview

The hybrid bench with real OBC performs PFSW integration tests (in STB configuration) and avionics equipment integration tests (in ATB configuration).

The major purposes of this bench are :

- to support the verification of the PFSW running on the real OBC,
- to support closed loop testing of the whole avionics,
- to support the integration of the satellite equipment tests,
- to cross validate simulation models,
- to support the PFSW and avionics maintenance.

For the ATB configuration, the real OBC and other real equipment are connected to the satellite simulation by front ends (FEE) which provide the corresponding electrical interfaces. So, the numerical coupler models of the numerical benches are replaced by the hybrid coupler models.

The satellite simulation uses the same functional models that have been already used in the numerical bench. These models are already validated in e-ATB. So, there is consistency between numerical and hybrid benches.

The ATB can gradually be extended by real hardware instead of simulation models.

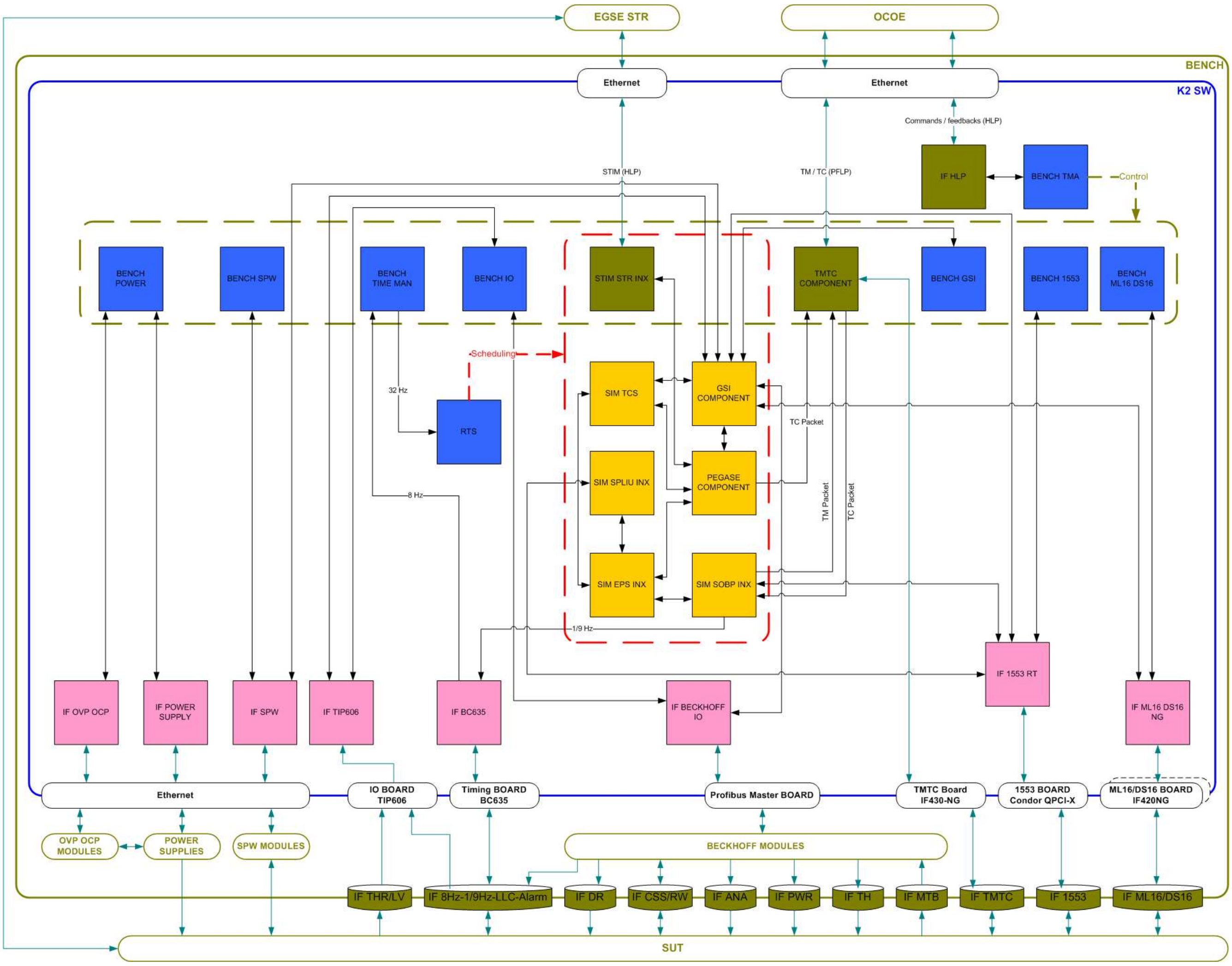

Fig. 10. hybrid bench with real OBC detailed architecture

The detailed architecture is composed of :

- **OBC Computer :**
  - o Real OBC. It is mandatory and the minimum hardware in the loop.
- **S/C equipments as hardware in the loop :**
  - o Additionally satellite equipments could be used as hardware in the loop, up to a configuration where all equipments are available as hardware in the loop and no simulation model is scheduled. In this configuration satellite equipment simulation is reduced to closing the loop by providing orbit and environment data of the satellite.
- **HW IF FEE :**
  - o Simulation FEE : Linux PC equipped with PCI cards responsible to transfer simulated IO data into electrical signals and vice versa. So, there are :

        - 1553 Bus IF cards,
        - Spw IF cards,
        - Serial IF cards : ML16/DS16, UART,
        - Analog, Digital, HPC IF cards,
        - Special IO cards.
    - Power FEE: Linux PC equipped with PCI cards responsible to provide power supply for HW IF FEE and additional equipments like hardware in the loop,
    - TM/TC FEE: Linux PC equipped with PCI cards responsible to provides satellite TC /TM IF for real OBC,
    - Star Tracker EGSE : To control and stimulate real STR equipments.
- **Satellite models :**
    - Platform models : PLIU, PCDU, Star tracker, Wheels, MAG, MTB, CSS, batteries, SAPM, SAPT, environment & dynamics,
    - Power and Thermal model based on e-therm kernel.
- **Ground models :**
    - Architecture & scheduling models : RTS, time manager,
    - ATB models : ML/DS – 1553 - Spw monitoring and simulation, archives.

The building blocks and reuse of elements are :

- the software core : K2,
- the check-out system : OCOE-6,
- the satellite equipment simulation (from numerical bench),
- the ground interface to check-out system.

HYBRID BENCH WITH SIMULATED OBC : PAYLOAD AND PCDU SIM-EFM

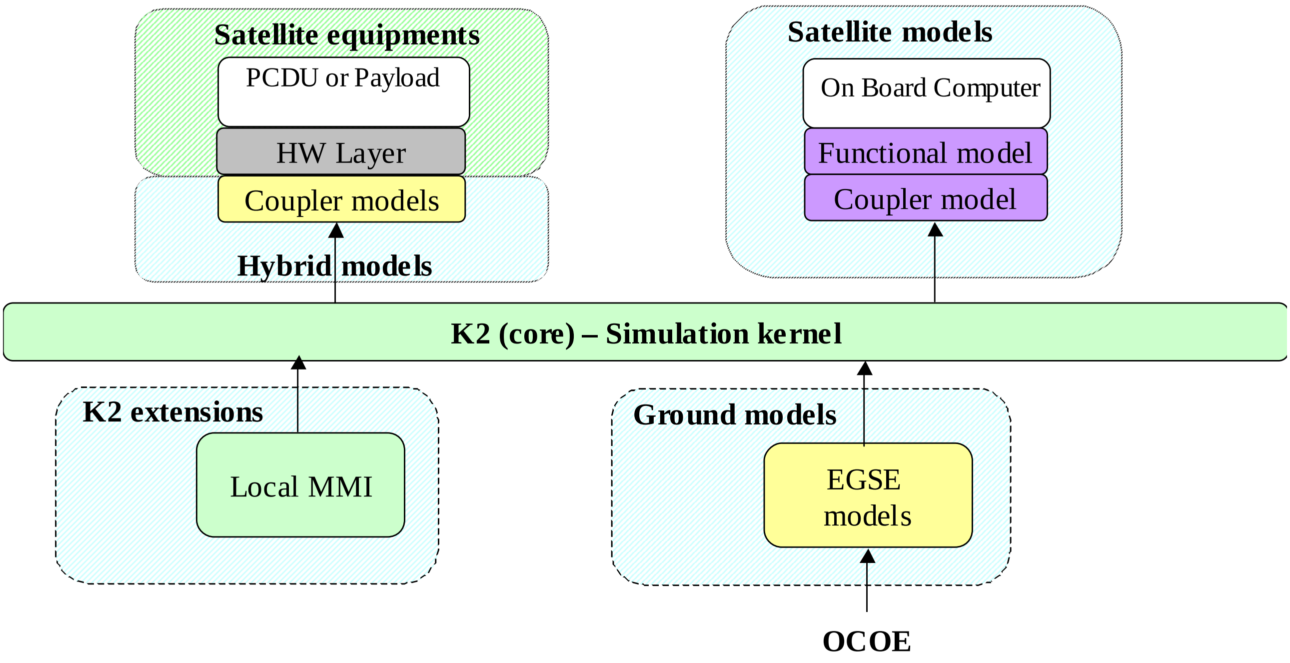

Fig. 11. hybrid bench with simulated OBC overview

The hybrid bench with simulated OBC (SIM-EFM) supports validation of functional chains without using a real OBC but only the real equipment related to the functional chain (power or payload for example). It is composed of an e-ATB running with real-time constraints and specific HW FEE to interface with the real equipment.

The major purpose of this bench is to reduce the cost of this configuration using a numerical model of the OBC instead of a real one. Thus, only one real equipment are required.

It is hardware in the loop configuration, with all the timing accuracy constraints as for the ATB.

It has to be representative in terms of data exchange timings on the data bus. The OBC model as defined for the e-ATB usage is accurate enough but this accuracy has to be kept with hardware in the loop constraints

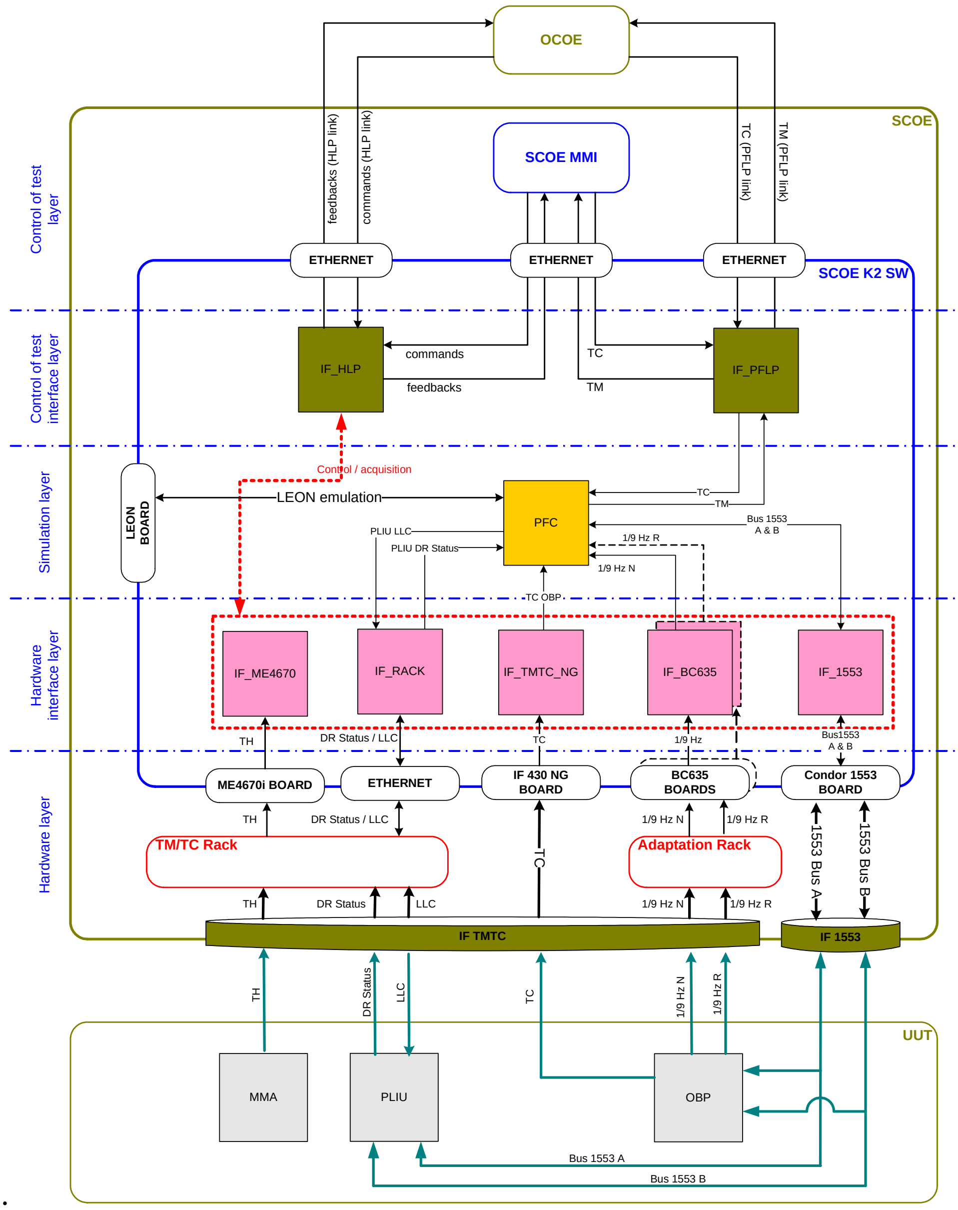

Fig. 12. hybrid bench with simulated OBC detailed architecture

The detailed architecture is composed of :

- **Satellite equipments as hardware in the loop :**
    - Payload or PCDU equipment
- **HW IF FEE :**
    - Simulation FEE : Linux PC equipped with PCI cards responsible to transfer simulated IO data into electrical signals and vice versa. So, there are :
        - 1553 Bus IF cards,

        - ANA, Digital, HPC, Pulse IF cards
    - Power FEE: Linux PC equipped with PCI cards responsible provides Power Supply for HW IF FEE and additional equipments like hardware in the loop.
- **Satellite models :**
    - OBC model (PFC in IRIDIUM case)
- **Ground models :**
    - Architecture & scheduling models : RTS, time manager

The building blocks and reuse of elements are :

- the software core : K2,
- the check-out system : OCOE-6,
- the OBC simulation (from numerical bench),
- the ground interface to check-out system,
- the HW IF FEE (from hybrid bench) :
    - 1553 Bus IF cards,
    - ANA, Digital, HPC IF cards.

The main challenge of this bench are the modelling of the 1553 bus controller with the hardware interface on one side and the reuse of the OBC model on the other side..

One of the major problem is the parallelisation of the OBC modelling and the bus modelling for the bus controller part. A reduced version of the bus model (immediate response) is not compatible with bench needs whereas for the numerical benches, it is enough.

The OBC model is a major cost in the bench development. So, it is very important to design it to be compliant with numerical and hybrid constraints , in order to re-use the previous validation of the model.