SAFE architecture for Robust distributed Application Integration in roLling Stock 2

CONtributing to Shift2Rail's NExt generation of high Capable and safe TCMS. Phase 2

Final Event – Introduction of Test Case 1 "Remote Hardware-In-the-Loop"

Imanol de Arriba (CAF) – idearriba@caf.net

30th June 2021

The projects CONNECTA-2 and Safe4RAIL-2 have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 826098 (CONNECTA-2) and No. 826073 (Safe4RAIL-2) respectively.

Outline

1. Urban Demonstrator
2. Technologies description
   2.1. Functional Distribution Framework (FDF)
   2.2. Application Profiles (AP)
   2.3. Simulation and Virtualization Framework (SVF)
3. Test Case 1 description
4. Expected results

Outline

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Urban Demonstrator - Timeline

TECHNOLOGIES SPECIFICATION

LABORATORY DEMONSTRATOR

TRAIN ENVIRONMENT

CONNECTA–1

CONNECTA–2

CONNECTA–3

Sep 2016

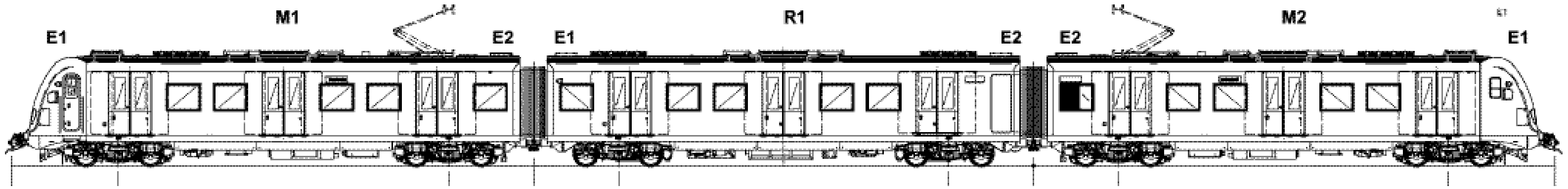
Oct 2018

Dec 2020

Jul 2021

NOW

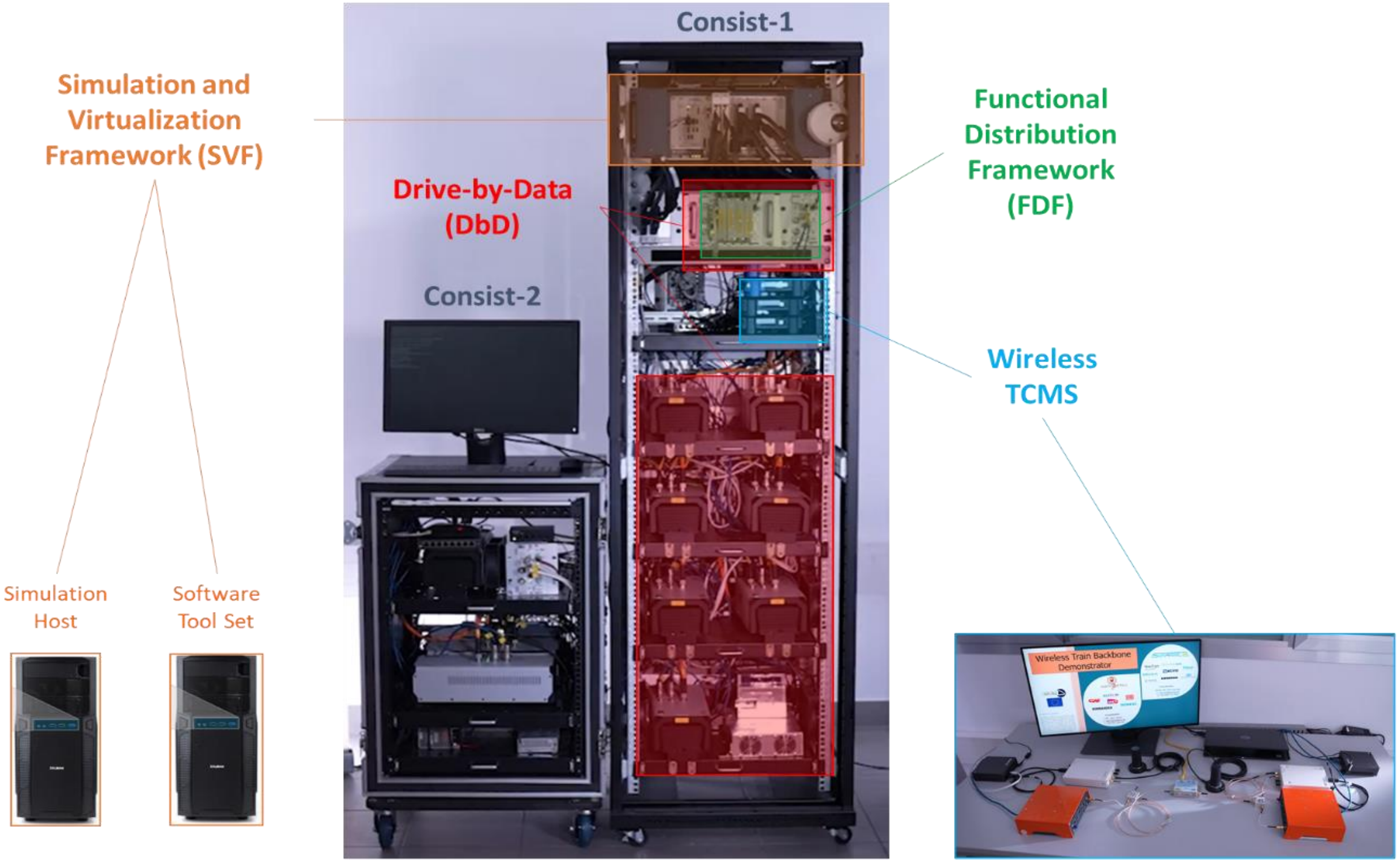
Jul 2023



Urban Demonstrator - Overview

- Laboratory demonstrator for the **proof-of-concept demonstration of innovative technologies:**
  - Drive-by-Data
  - Functional Distribution Framework and Application Profiles
  - Simulation and Virtualization Framework
  - Wireless TCMS (WLTB and T2G)
- Composed of two coupled consists

Urban Demonstrator - Overview



Urban Demonstrator - Functional Architecture

- **Physical architecture:**
  - Only the functional architecture related to **HVAC and BMS functionalities** shall run on top of **Functional Distribution Framework**:
    - Including TCMS logic and HVAC/BMS subsystem control logic
    - Functional interfaces between TCMS and HVAC/BMS subsystem: **Application Profiles**
  - This logical architecture will be allocated to physical end devices at consist level

- **Simulated architecture:**
  - The train control logic corresponding to the remaining subsystems will be simulated in the **Simulation and Virtualization Framework**

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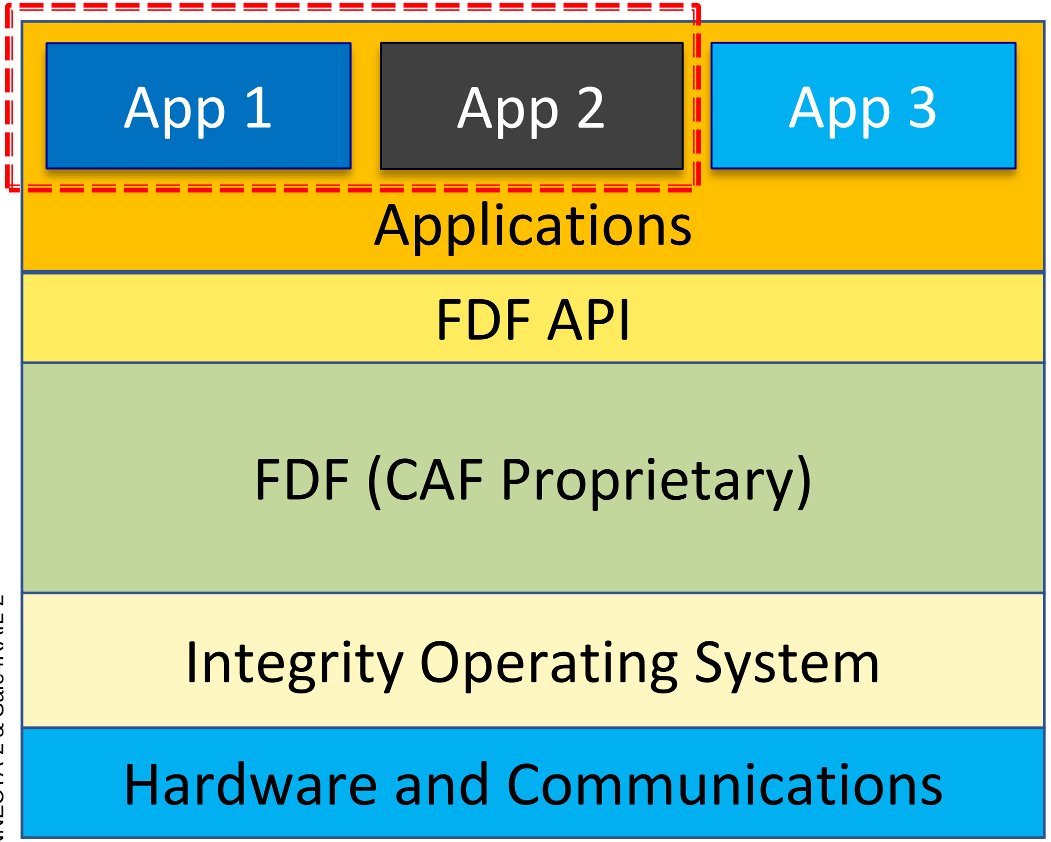
Functional Distribution Framework (FDF)

- Framework with a **standardized API** for the development of **distributed applications** (HVAC control, Doors control, etc.), allowing their communication and execution in different CPUs
- Middleware which **abstracts applications** running on top of it **from the underlying hardware and communications**
- **Mixed-criticality** embedded platform capable of executing **multiple safety and non-safety applications** (in different Virtual Address Spaces)
- Ensures portable applications between different FDF implementations
- Facilitates the development process, software reuse and maintainability

Urban demonstrator: Integrity FDF



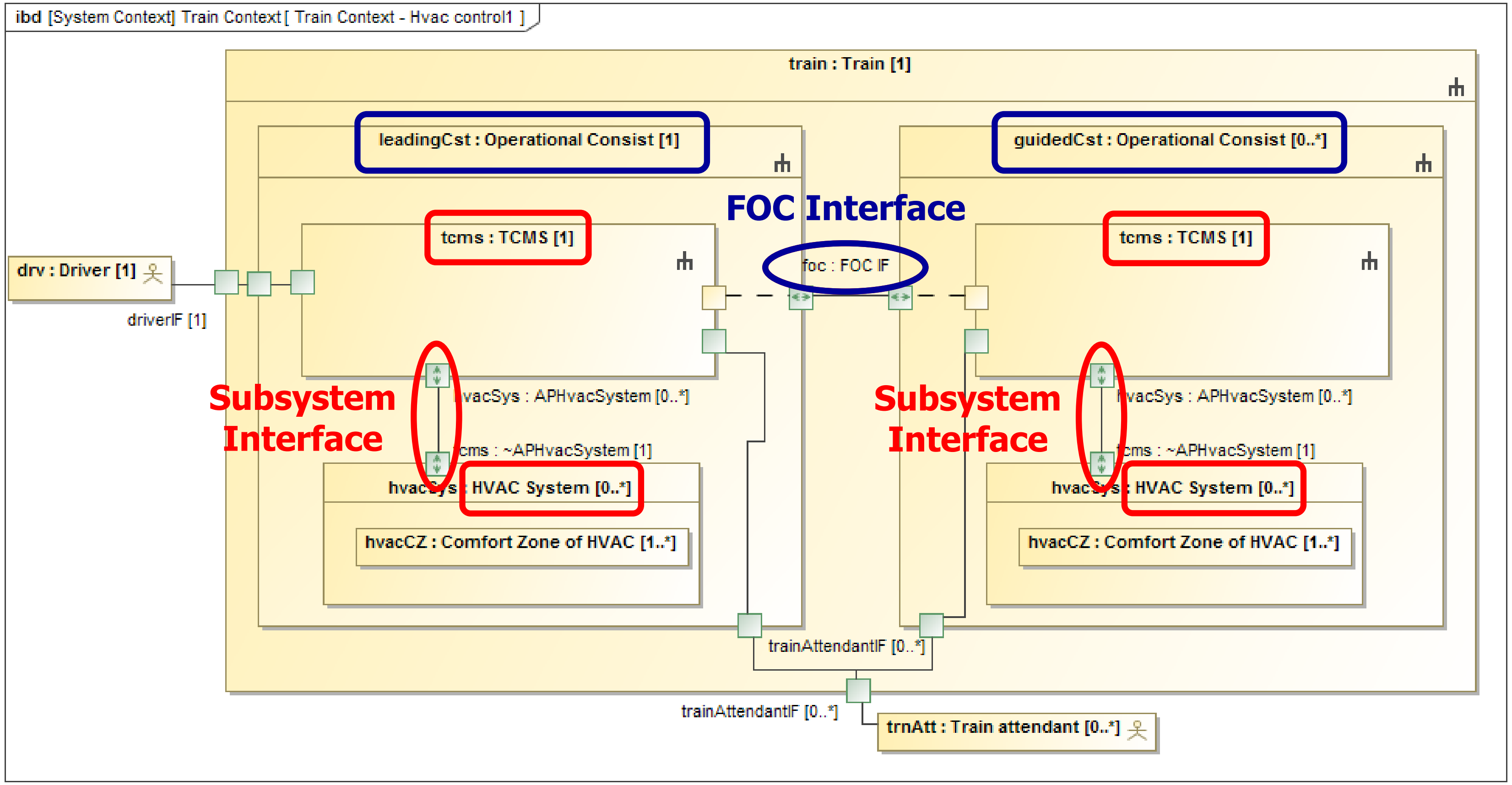
- GreenHills **Integrity** is a certified Real Time Operating System (RTOS) for critical applications
- **Signal-oriented communication** using **TRDP**
- Applications are independent from FDF implementation:
  - App 1 – Train control logic
  - App 2 – HVAC controller logic provided by third-parties (Liebherr supplier) as a static library
  - App 3 – Train-level (ETB) information exchange application

Outline

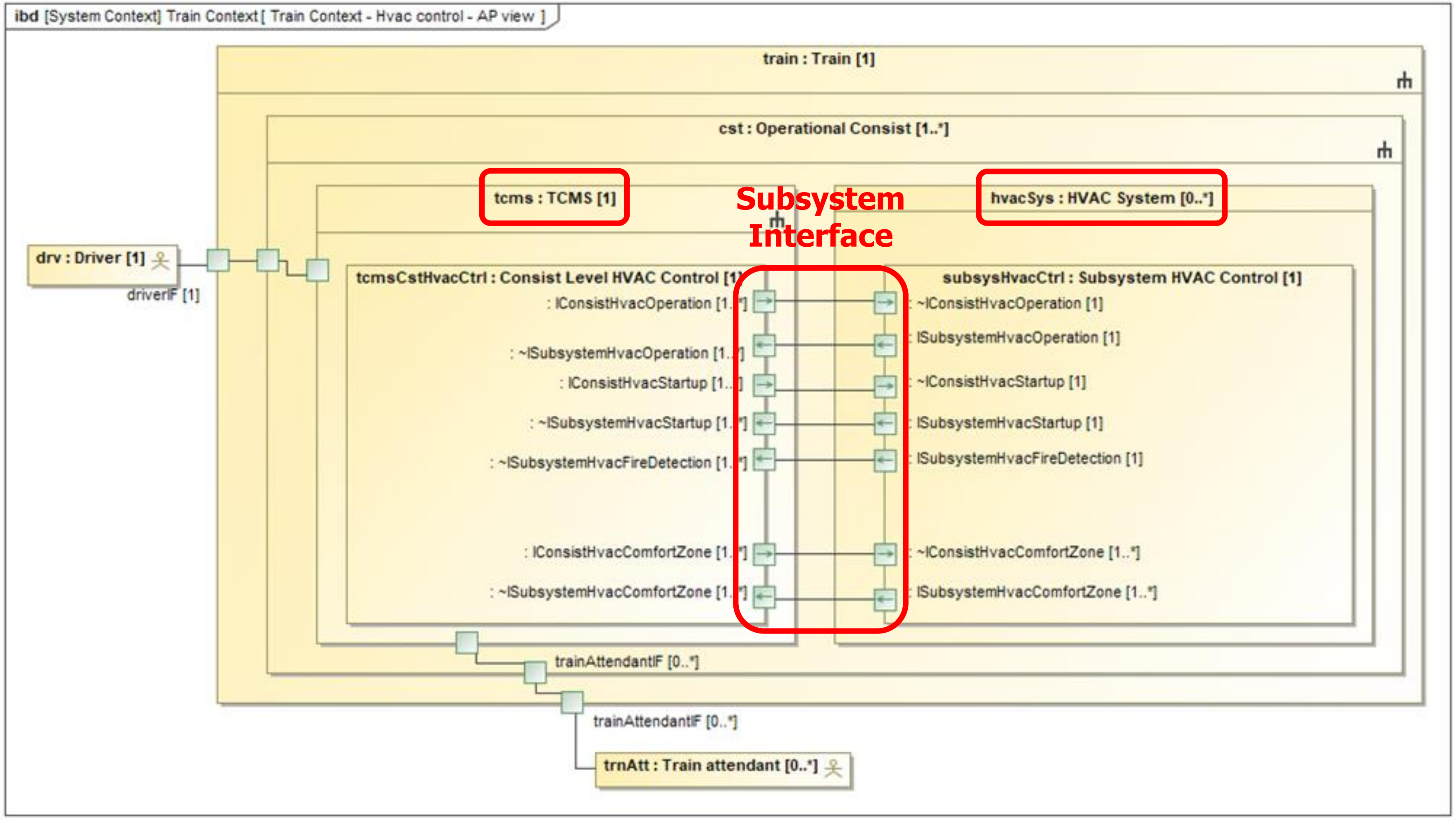
Application Profiles (AP)

- Specification of a **functional interface** between the TCMS and a subsystem:
  - Definition of **signals** to be exchanged between applications (**flow properties**)
  - TCMS can communicate with supplier subsystems in a **standardized** way
  - Founded on an analysis of which use cases have to be supported
  - Standardization process for the functionality of exemplary train subsystems (e.g. HVAC)
- Specification of **technical interface** of the functional interface:
  - Definition of data formats, cycle times, SIL level, etc.
- AP concept can be extended to describe information exchange at train level between consists (**FOC - Functional Open Coupling**)
- Due to standardization, less engineering is required for subsystems integration, leading to reduced costs, risks and integration time

Application Profile for HVAC



Application Profile for HVAC



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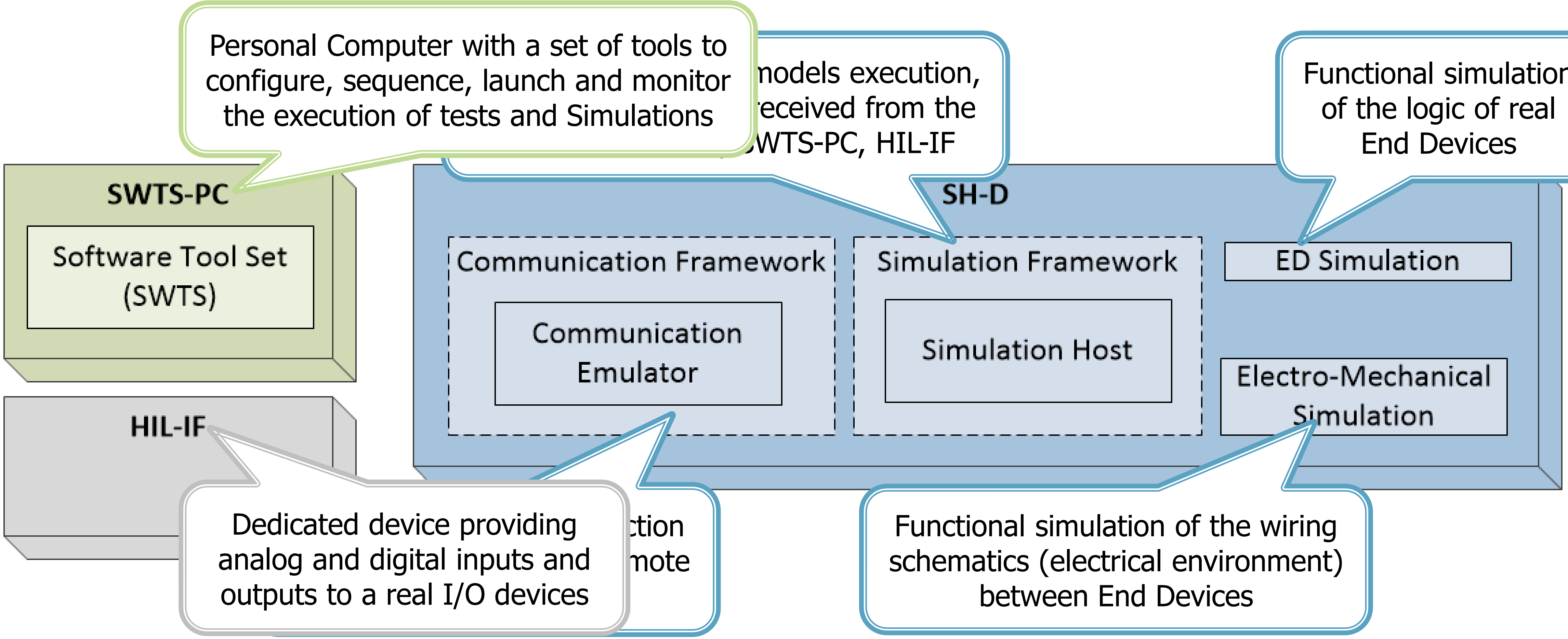
Simulation and Virtualization Framework (SVF)

- Set of tools for Train Virtualization, Simulation and Communications Emulation
- Ability to test train applications and technologies without the need for real subsystems → Mix of real hardware and simulated train subsystems in a virtualized environment
- Allows remote and distributed testing, including **remote Hardware in-the-Loop (HIL)**
- Allows the execution of a large number of **fully automated and simulated tests** before costly and time-consuming real environment testing (*zero on-site testing*):
  - Reduction and anticipation of risks
  - Speeding-up of verification and validation activities

Simulation and Virtualization Framework (SVF)



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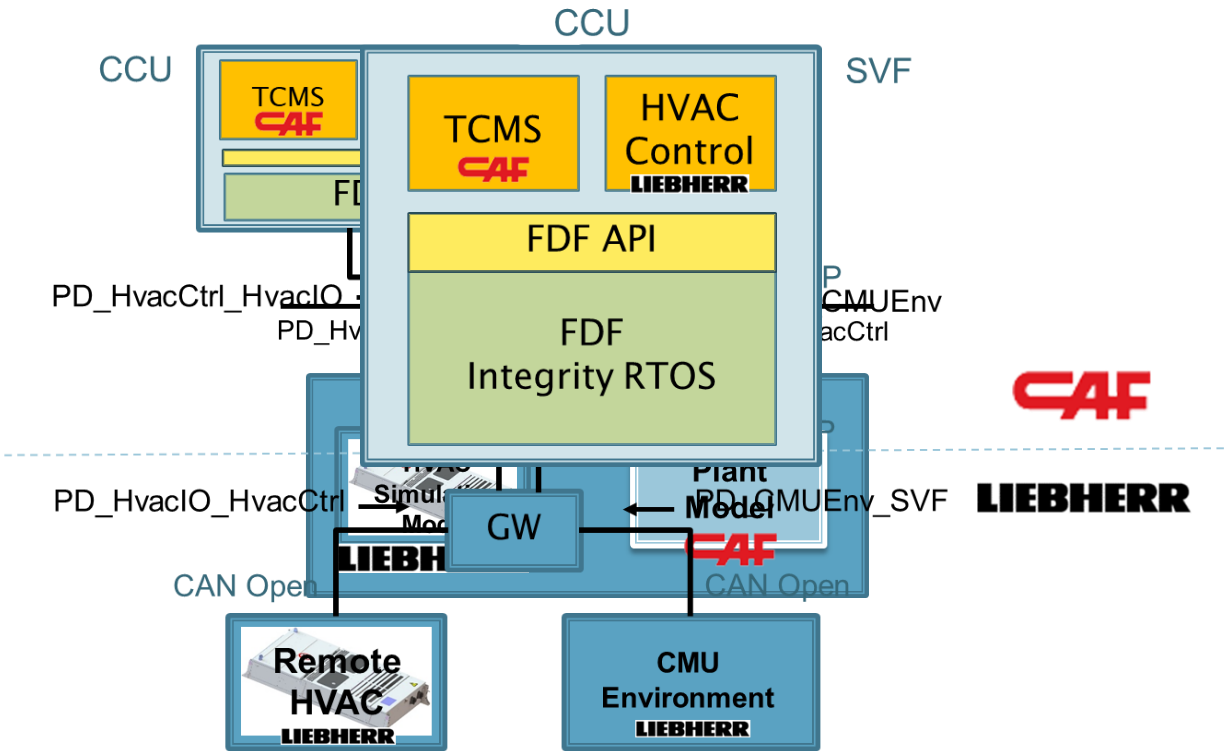
Test Case 1 description

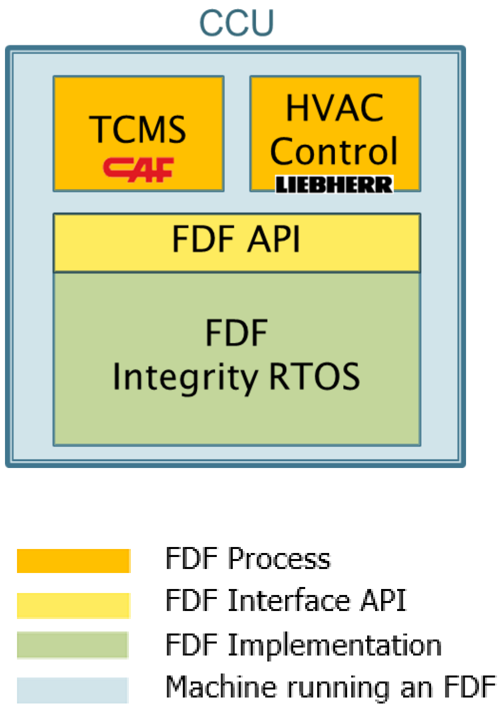
Remote Hardware-in-the-Loop (HIL) - incremental steps

- Integration of HVAC control application in Integrity FDF
- Communication between TCMS application and HVAC control application in CCU
- Remote HIL emulation in local ECN
- Remote HIL



Test Case 1 description

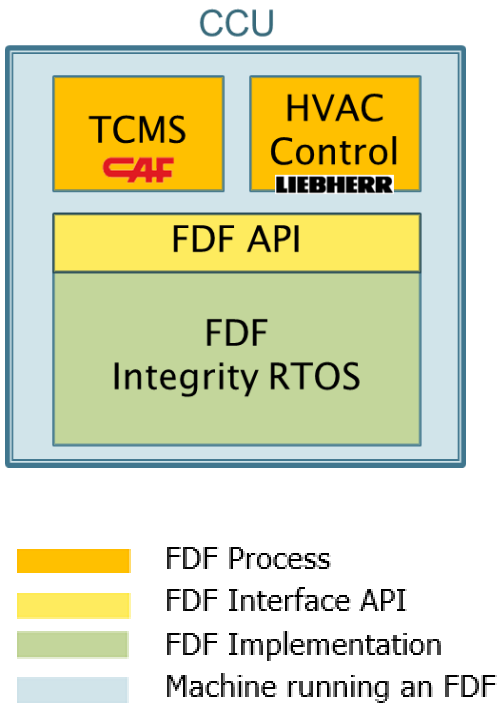
1) Integration of HVAC control application in Integrity FDF



- Development of application for controlling the remote physical HVAC unit (**HVAC control application**) by supplier:
  - Static library file provided by Liebherr
  - Application running on top of FDF, integrated by using standardized API
- Development of **TCMS application** by CAF for controlling this HVAC control application:
  - Application running on top of FDF, integrated by using standardized API
- Deployment of both applications on CAF's proprietary CCU:
  - A binary monolithic image is created

Test Case 1 description

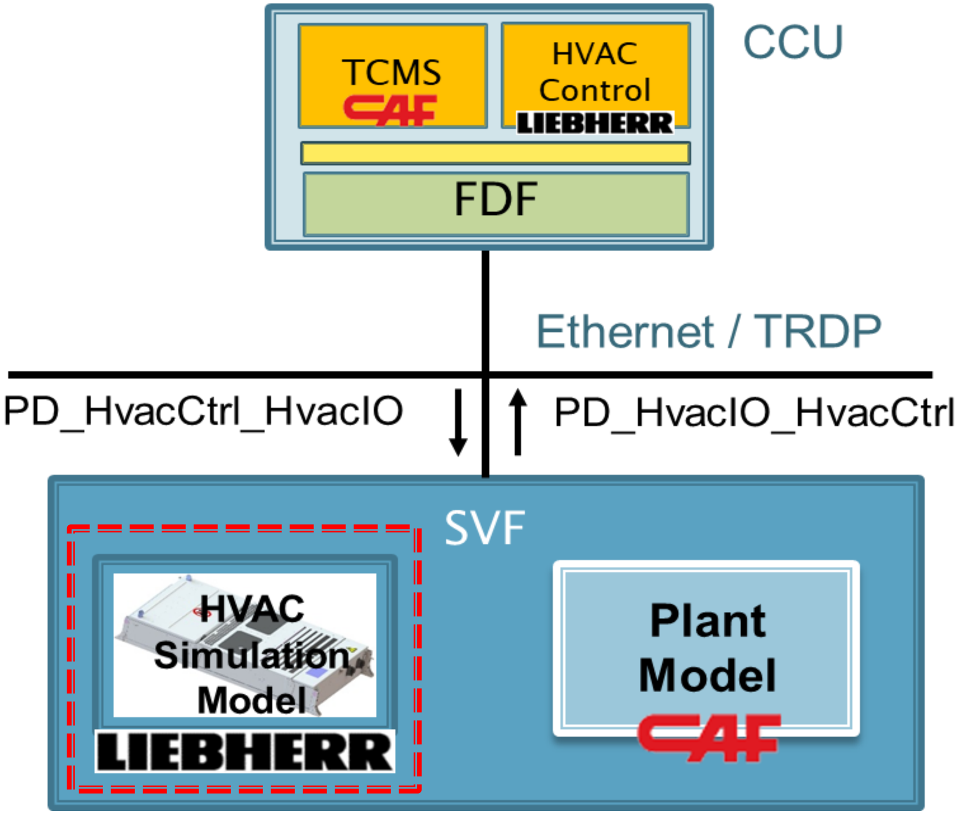
2) Communication between TCMS application and HVAC control application in CCU



- Both applications developed in compliance with the Application Profile for HVAC (functional and technical interfaces)
- Two main types of data:
  - Application Profile data structure to be exchanged between the TCMS application and the HVAC control application, through shared memory mechanisms offered by the FDF (using standardized API)
  - TRDP data structure to be exchanged between the HVAC control application and the remote physical HVAC unit, being the FDF responsible for packing (and unpacking) the data into TRDP messages

Test Case 1 description

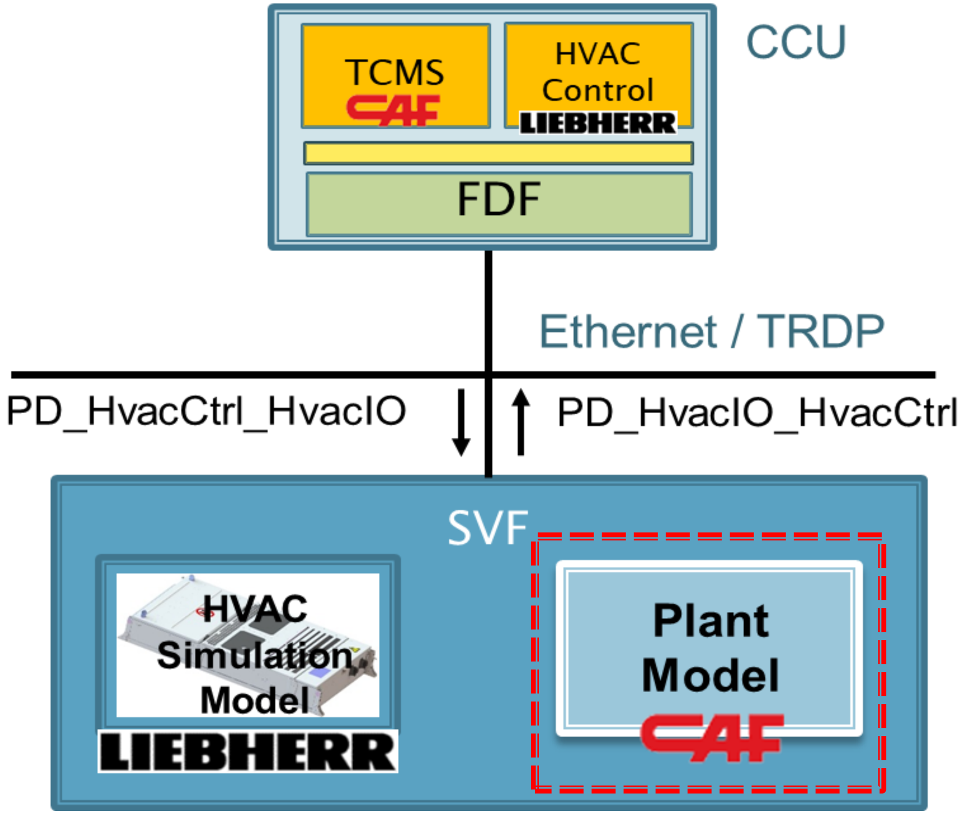
3) Remote HIL emulation in local ECN



- Preliminary stage to the remote HIL scenario
- Use of a **virtual/simulated HVAC** (**HVAC Simulation Model**) instead of the remote physical HVAC unit:
  - Provided by Liebherr as a **Functional Mock-up Unit (FMU)**, in accordance to the **Functional Mock-up Interface (FMI)**
  - Integrated in the SVF to validate HVAC function in a simulated environment before the remote physical HVAC device is connected
  - Useful to debug and test HVAC control application and its integration with TCMS

Test Case 1 description

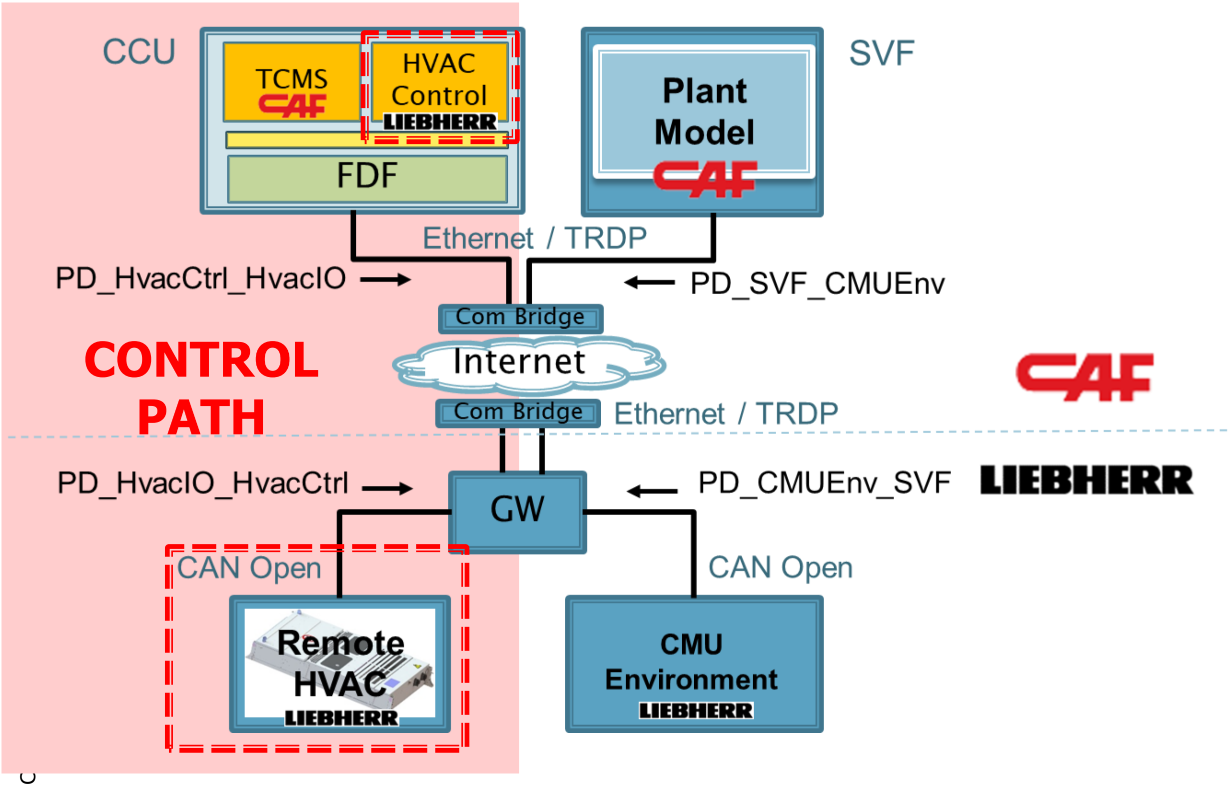
3) Remote HIL emulation in local ECN



- Development of a **Vehicle Thermal Loads Simulator (Plant Model)**:
  - Integrated in the SVF to **simulate the thermal loads of the vehicle (sensible and latent loads corresponding to passengers)**, and the **evolution of the internal temperature and humidity in the vehicle**
  - Based on the laws of thermodynamic and heat transfer
  - Interaction with the HVAC Simulation Model

Test Case 1 description

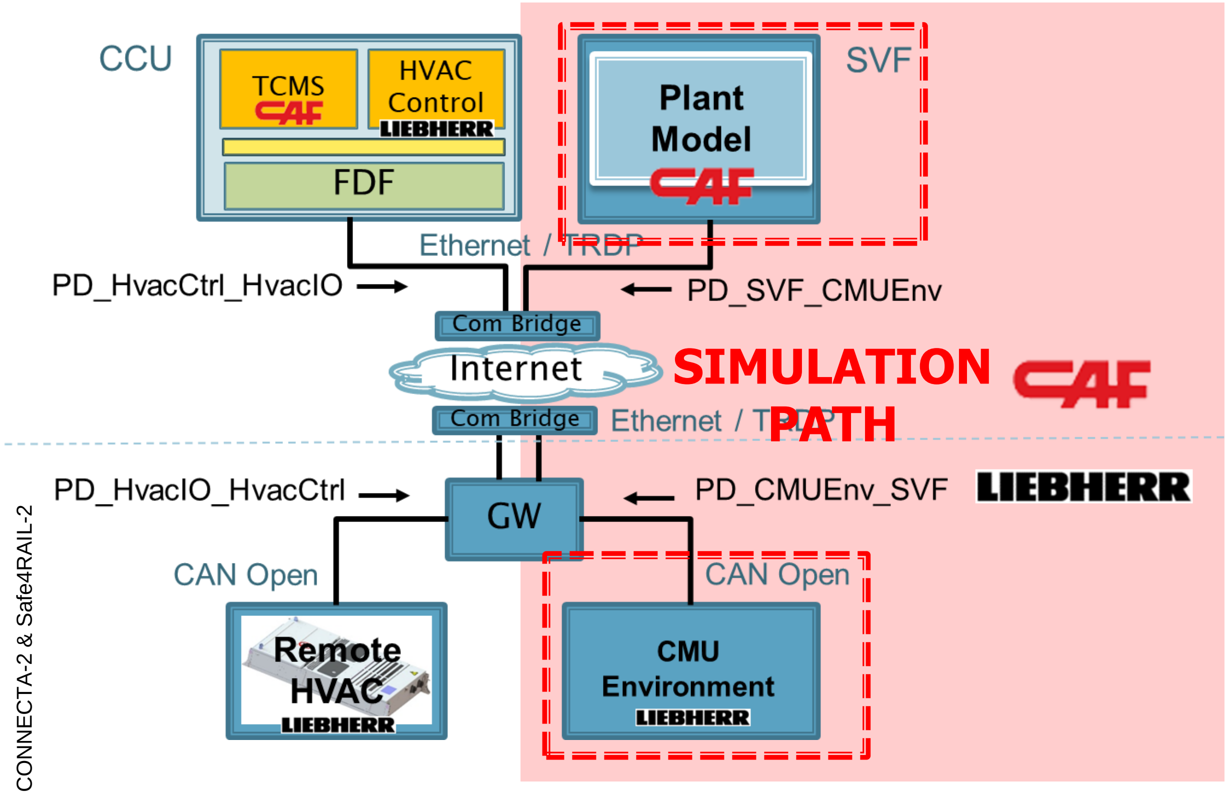
4) Remote HIL



- Use of the **remote physical HVAC unit** (Liebherr - Austria), which **is remotely monitored and commanded** by the HVAC control application (CAF - Spain):
  - Both physically connected through the Internet (by means of Communication Bridges)
  - Useful to test HVAC control application and its TCMS integration with the real HVAC equipment
  - HVAC system is located on top of a **Climate-Mock-Up (CMU)**

Test Case 1 description

4) Remote HIL



- Use of a **Climate-Mock-Up (CMU)** (Liebherr - Austria), whose environmental conditions are **remotely controlled and modified** by the SVF (Beasain - Spain):
  - Both physically connected through the Internet
  - The environmental parameters for the HVAC system located on top of the CMU are modified by means of a **Vehicle Thermal Loads Simulator (Plant Model)** running on the SVF, to simulate the thermal loads of the vehicle (sensible and latent loads corresponding to passengers)

Test Case 1 description

4) Remote HIL - Climate-Mock-Up (CMU)

- Climatic vehicle segment mock-up for **simulation of vehicle thermal loads:**
  - **Passenger sensible loads** for simulating occupation (heat)
  - **Passenger latent loads** for simulating humidity
- **Electrical heaters and humidifiers** remotely controlled by CAF's Plant Model (SVF)

Outline

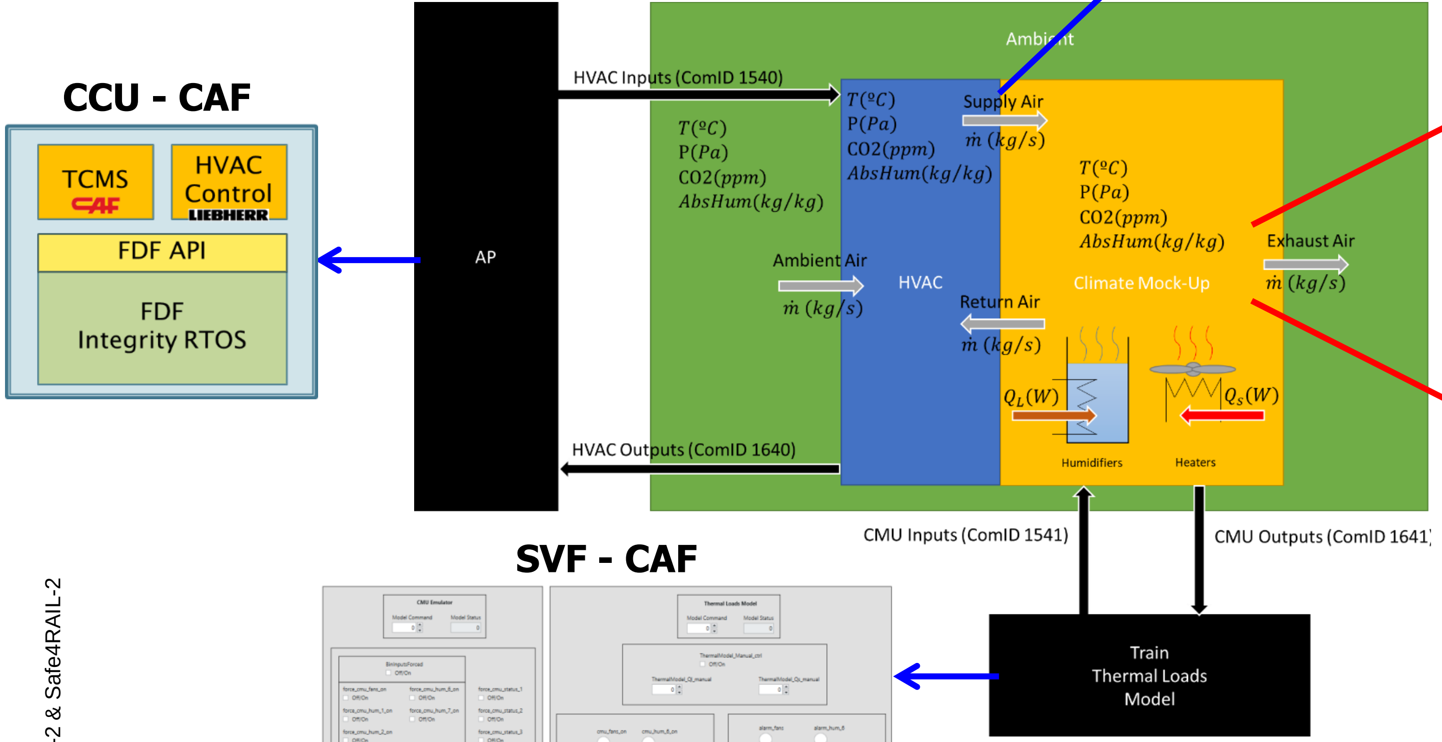
Test Case 1 Demo - Structure

Live execution of a Test Case for testing remote HIL scenario:

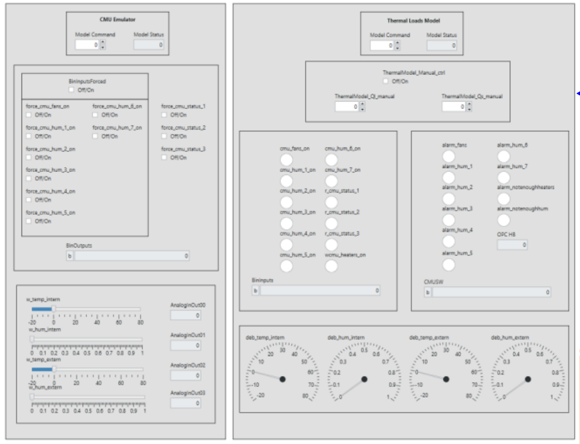
- Use of a graphical user interface to validate and monitor the interaction between the plant model and the CMU
- Consideration of a complete virtual scenario (plant model and virtual HVAC running on the SVF)
- Plant model running on the SVF and interacting with the real CMU
- Show interaction between HVAC control application (CAF) and remote physical HVAC unit (Liebherr)
- Show interaction between plant model (CAF) and remote CMU (Liebherr)
- Prove that the remote connection (sending and reception) is working properly
- Display of images received from CMU webcams

Expected results

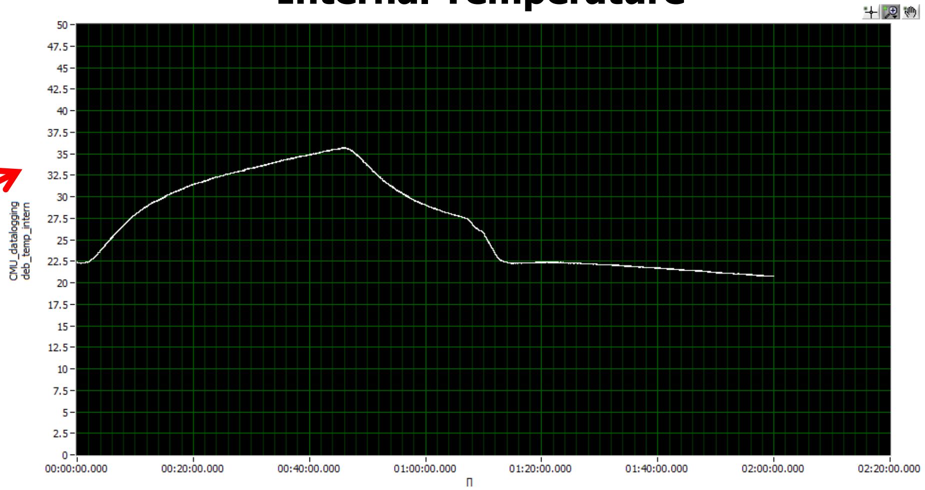
Remote CMU & HVAC - LIEB



SVF - CAF



Internal Temperature



Internal Humidity