Information and Communication Technologies (ICT) Programme

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D2.1: CERBERO Scenarios Description

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Abstract:

This report is meant to provide a description of the CERBERO scenarios: Smart Travelling, Self-Healing for Planetary Exploration and Ocean Monitoring.

Disclaimer

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Table of contents

1. Executive Summary

This document provides an overview of all the application scenarios that are used to assess the CERBERO framework and methodologies. It highlights the challenges and goals for each scenario, along with the solutions featured by CERBERO to address them and provides a description of their basic characteristics. Moreover, an overview of the use-cases and demonstrators implemented within each scenario is tackled [USECASES], indicating the different parts composing the cyber-physical environment are presented, to clarify where CERBERO technologies/tools intervene to facilitate and improve design, integration, deployment and verification phases. Finally, an update on the initial requirements for each use case is presented if necessary.

This is the final document of its kind. In previous iterations (M9 and M13) the description, requirements and technical specifications were presented for each use case.

1.1. Structure of Document

This document is organized as follows:

- Section 1 presents an executive summary of the document, detailing its structure and presenting other documents related with it.
- Section 2, Section 3 and Section 4 explore the different Use Cases description. For each scenario, and overview of the use case and its goals will be provided; followed by the system-level description of the demonstration environment and its main constituting software and hardware components, and the preliminary list of evaluation scenarios with the expected outcomes for each of them.
    - Section 2 - Travelling for Electric Vehicle – describes the Smart Travelling scenario, along with a detailed description of its goals.
    - Section 3 - Healing for Planetary Exploration – describes the Planetary Exploration scenario, along with a detailed description of its goals.
    - Section 4 - Ocean Monitoring – describes the Ocean Monitoring scenario, along with a detailed description of its goals.
- Section 5 states the conclusions reached through this document.
- Finally, Section 6 lists the different references used along the document.

1.2. Related Documents

This document is related to the following deliverables [DELIVERABLES]:

- D2.3 (CERBERO Scenarios Description – Ver. 1), D2.4 (CERBERO Scenarios Description – Ver. 2), D2.6 (CERBERO Technical Requirements – Ver. 1) and D2.7 (CERBERO Technical Requirements – Ver. 2) that have been already approved by the commission. These deliverables describe the generalities and features of the three CERBERO use cases, the technical specifications we derived from them and the project scientific challenges to drive all the project activities. In particular, the present document is an evolution of D2.4 and represent the base for the evolution of D2.7.

- D6.7 (Demonstration Skeleton – Ver.1), already approved by the commission, has started to detail the use case to technology mapping for each demonstrator. In this deliverable, plans for M18-M36 are refined. D6.1, the evolution of D6.7, will receive the present document as a starting point.
- D6.8-10 have presented demonstrators achievements at M18. Those documents will be evolved in D6.2 (Space Demonstrator - Final Version), D6.3 (Ocean Monitoring Demonstrator - Final Version) and D6.4 (Smart Travelling Demonstrator - Final Version) and will receive the present deliverable and D6.1 as input to discuss the final results of the demonstration and to derive indications and guidelines for the next 18 months of the project based on achieved results.

2. Use Case description Smart Travelling for Electric Vehicles

2.1. Introduction

In this section we intend to describe the latest insights on the Smart Travelling for Electric Vehicles use case challenges, goals, architecture and incremental prototyping architecture/components. The generalities of this scenario have already been covered in D2.3 and D2.4.

Mapping among use case and CERBERO technologies and tools is provided in subsection 2.5 of the present document. This mapping was already presented in the previous version of this deliverable, but it is constantly evolving with the project and will be further refined in the final versions of the Demonstration Skeleton and Smart Travelling Demonstrator deliverables (D6.1 and D6.4).

The Smart Travelling Demonstrator will be integrated into the operational Driving Simulator of CRF in Turin, Italy. Integration will mean that processing capabilities are added to run the added motor and battery models and perform MECA and DynAA processing. Realistic HMI supporting adaptation scenarios will be added with additional hardware including interface with MECA for interaction with the driver.

2.2. Challenges and Goals

The Smart Travelling use case is meant to demonstrate how CERBERO will facilitate the design of heterogeneous system, along with their runtime management. Smart Travelling use case assesses self-adaptive runtime strategies for software adaptivity to system and environmental changes.

The general needs for this use case that have to be addressed using CERBERO technologies are summarized in Table 2-1.

Table 2-1 Smart Travelling general needs

ID	Need	High Level Requirement
ST1	Reduction of costs, increase of reuse in different simulation scenarios.	Development of parametric, modular and extendable cyber-physical co-simulation environment.
ST2	Reduce time of development, verification, integration, along with the related costs, exploiting a library of reusable components/metrics integrated by common framework in different levels of abstraction. Incremental prototyping.	Development of an integrated open-source or commercially available toolchain for design space exploration and co-simulation, with system-in-the-loop capabilities.
ST3	Efficient support of functional adaptivity, according to system, human and environment triggers.	Development of a (self-)adaptation methodology with supporting tools.

The key challenges of the Smart Travelling Demonstrator, as summarized also in Figure 2-1 below, are:

Verify the condition awareness capabilities of the CERBERO framework for real-time system-in-the-loop simulation:

- Integration of external electric motor and battery models (of TNO) into the SCANeR driving simulator for system-in-the-loop simulations. The integration should support extensive monitoring of the vehicle behaviour and its environment, to simulate behaviour of motor and battery in a realistic manner and adapt in case of relevant changes occur in the integrated models or the environment.
- Execution of itinerary simulation in DynAA as system-in-the-loop adaptation verification. In order to speed up required calculation, DynAA will be extended with parallel distributed processing capabilities to reduce calculation time and ensure the solution can still fulfil timing requirements given large solution spaces.
- Synchronise logging data from different distributed simulation modules, to obtain consistent and accurate overall logging data (to be used for detailed scenario analysis).

Continuous system monitoring/optimization for adaptiveness management:

- Integrate and provide basic mechanism in DynAA for vehicle simulations, which can be used to make predictions of the impact of specific routes. Integration should provide sufficient monitoring data in order to adapt based on changes in the environment.
- Integrate MECA with DynAA and SCANeR and provide the basic mechanism in MECA needed to support driver support.

Human machine interface which can support adaptation scenarios:

- Develop and integrate Human Machine Interface (HMI) which can support the driver in adaptation scenarios and where MECA will continuously monitor situation. MECA and DynAA can provide advice via the HMI on itineraries when adaptation is required.

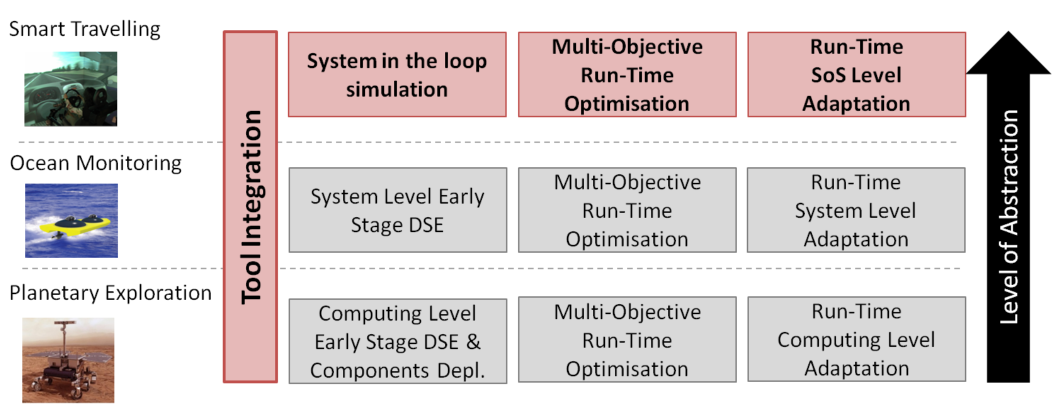


Figure 2-1 Problems to be solved by CERBERO for the ST use case.

Although some experiments will be executed on use AOW in the design phase to perform optimization of itineraries and interface with DynAA using CIF, this work will not be part of the Smart Travelling Demonstrator itself.

Given the available time, it was concluded that full integration of additional CERBERO tools like AOW, SAGE and CIF in the ST Demonstrator would be too time consuming and risk the foreseen implementation of the defined scenarios on the CRF Driving Simulator. Activities on AOW and CIF are therefore defined as separate activities, which could help in the development of CIF, but not directly contribute to the Demonstrator. SAGE is used to validate a subset of the requirements. This will also not impact the Demonstrator as this activity will only be completed after most of the development has already be done and thus merely show results of the validation.

As adaptation is not only relevant for the CERBERO tools themselves, but also for CRF to see how drivers are able to handle new adaptations (related to electric vehicles) and how drivers could be supported with functionalities to advice the driver, the goals of the use case cannot be described without defining the goals of CRF.

As CRF is the end user of the proposed technologies and wants to investigate human interaction related to smart travelling using electric vehicles, focus group interviews have organized in the Netherlands and Italy in the beginning of the project. As a result of these interviews was a list of experienced and expected difficulties driving an electric vehicle. Based on this list a number of use case scenarios were defined in which adaptations were included and should be handled by the car in cooperation with the driver.

The identified types of scenarios to include are:

- *Basic scenario* (driver wants to drive from A to B);
- *External trigger* (car receives trigger from the environment, which requires the route to be altered);
- *Car trigger* (internal trigger is generated, which requires the route to be altered);
- *Human trigger* (trigger from the user is received, which requires the route to be altered).

To implement these scenarios and make them clearly understandable, a story board was created in which a sample of all of them was included. The story is based on Paolo and his family. They live in Turin and use an electric vehicle for short trips around the city. When Paolo is performing a trip, multiple things happen, requiring Paolo to alter his trip. In the Demonstrator interactions between MECA, DynAA and the HMI support Paolo in performing the set tasks and confronted need for adaptation during the trip.

The story board is currently under adoption to develop the different CERBERO modules and interfaces and allow for the verification of the developed functionalities. By running the story in the simulator at CRF the different functionalities can be tested. After the project CRF will be able to use these functionalities to analyze the actual behavior of the driver using the CERBERO tools (which is out of scope of the CERBERO project), In Figure 2-2 a sample step in the story of Paolo is shown where Paolo realizes that his car will not have sufficient charge to reach the altered destination. In the annex of this document (Section 7.1) all other steps of the story boards are given.

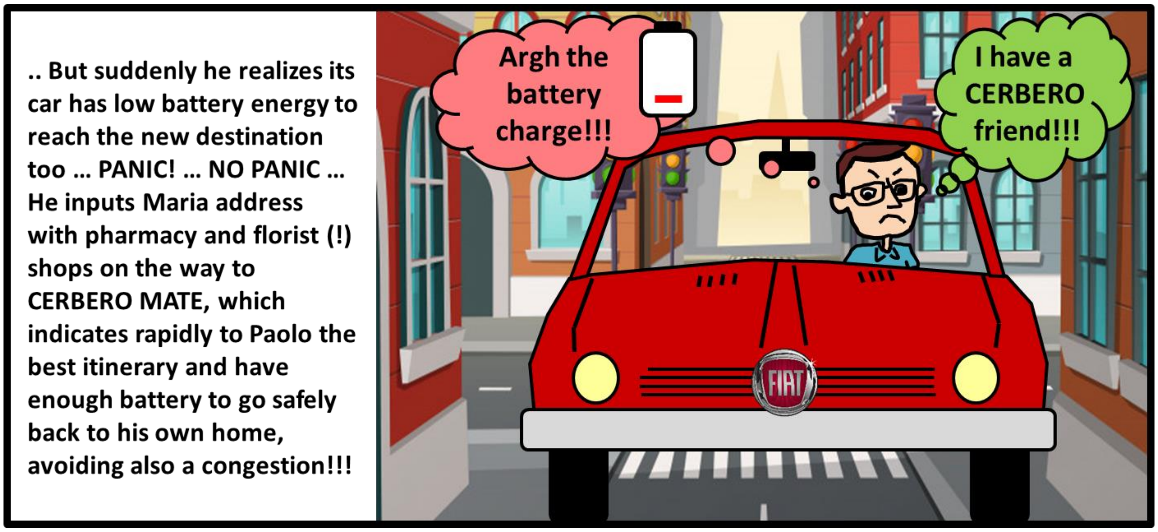


Figure 2-2 One of the steps in the story of Paolo.

The samples scenarios selected for the story board are in line with the selected scenarios as follow:

- *Basic scenario*: Paolo plans to drive home from his work;
- *External trigger 1:* Paolo receives a phone call from his wife Sandra to pick up medicine for his mother in law Maria;
- *External trigger 2*: the driver support system receives trigger from charging infrastructure that reserved charging pole is out of order and other route has to be taken in order to charge the car;
- *Human trigger*: the driver support system detects that Paolo is tired/distracted and system adapts route to charge car earlier so Paolo can get some rest or attentional support;
- *Car trigger*: the driver support system detects that battery is lower than expected (or predicted) at given location and system advices Paolo to perform additional charging at next charging station.

The plan is to build Demonstrator in such a way that the implemented scenarios can be activated during a test drive, so the test can be shortened or extended based on its focus or the available time.

2.3. Added value of the CERBERO approach

The added value of the CERBERO approach in the Smart Travelling use case is mainly extended flexibility of the simulation environment enabling new functionalities without modifying or developing the complete software stack. By using the CERBERO tools already available functionalities could be easily integrated and extended to provide the required functionalities. Specifically, the CERBERO tools are providing the following:

- Fast integration of new functionality once DynAA was connected (no need to ask vendor of current tools like SCANeR to make adaptions or extend the provided functionalities);
- Flexibility:
  - Ability to easily connect additional models in simulation;
  - Ability to easily add driver support and external control functionalities (using MECA);
  - Inclusion of different models in the vehicle to simulate difference in behaviour (without dependency on vendor of SCANeR vehicle simulation software);
  - Reuse of models for different purposes (real time simulation and predictions using DynAA);
- Less coding required for functionalities like predictions in a driver advice function, as tools already provided basic simulation framework. Coding was mostly limited to implementation of interfaces and addition of some domain specific functionalities;
- Easy and automatic fusion of logged data via the added data synchronisation tool (which involved multiple manual transition steps before CERBERO).

In the initial Demonstrator developed in M18 of the project was implemented on a test platform. In the test platform SCANeR software was used to perform integration. The SCANeR based driving simulator in Turing also includes physical elements for driving and monitoring functionalities to register and analyze the executed driving trips.

The main purpose of the driving simulator in CRF Turin is to perform analysis of human-car interactions, where physical interfaces are of utmost importance. This was one of the reasons for adding Human Machine Interface to the Demonstrator (also see Section 2.4).

The Smart Travelling Demonstrator developed for the operational environment of CRF in Turin will show the real benefits of introducing CERBERO tool chain. Additional advantaged can be gained once the CIF tooling is more mature and can be used in the design process to integrate tools and reuse defined models. In the current Demonstrator most of the design work for the use case had been already performed when the first version of the CIF tool became available.

2.4. System architecture and components

The architecture of the Smart Travelling Demonstrator is given in Figure 2-3 below. The architecture is a runtime architecture focused on the simulation of the driving experience, as CRF is mainly interested in the human interaction aspects. This is also the reason a specific HMI is added to the architecture which can more realistically support adaptation scenarios defined for the use case.

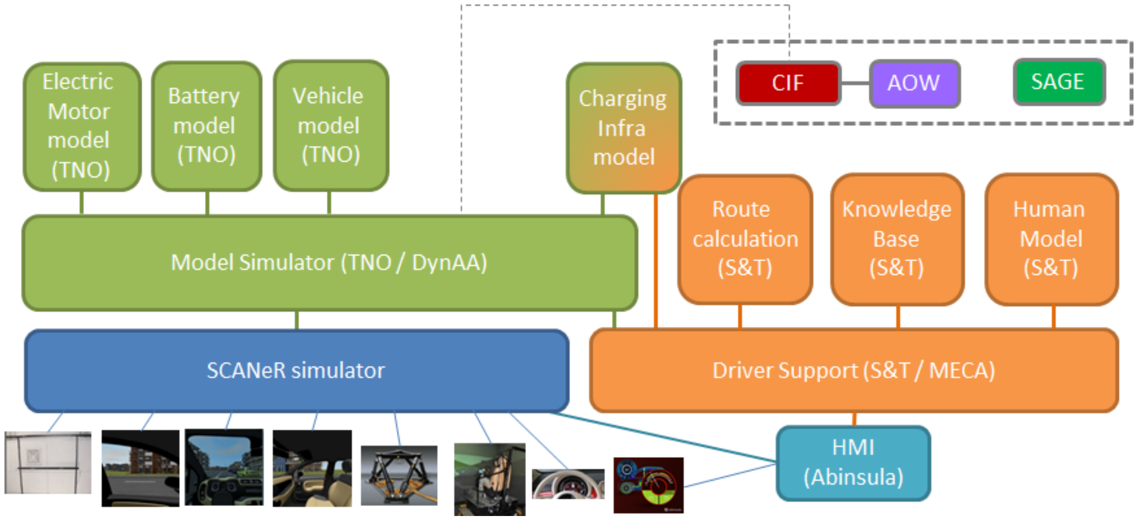


Figure 2-3 Architecture of the Smart Travelling Demonstrator.

To synchronize on the development activities between the involved partners, an integration session was held on the 27th and 28th of November 2018 in Turin were the partners CRF, TNO, S&T and Abinsula agreed on the planning, scope, design, interfaces and story board for the use case in the second phase of the CERBERO project.

Since different modules are developed by different partners of the project, a high level architecture was defined describing main modules and their interfaces. Each module is assigned to one of the partners with a minimum set of interfaced defined on which partners should agree before the start of the development process. Internal interfaces could be designed by the partners themselves during the development process. The high level architecture of the Smart Travelling Demonstrator used for integration of the components is depicted in Figure 2-4. This architecture does not include the simulation of battery and motor, but only the functionalities related to the driver support interactions.

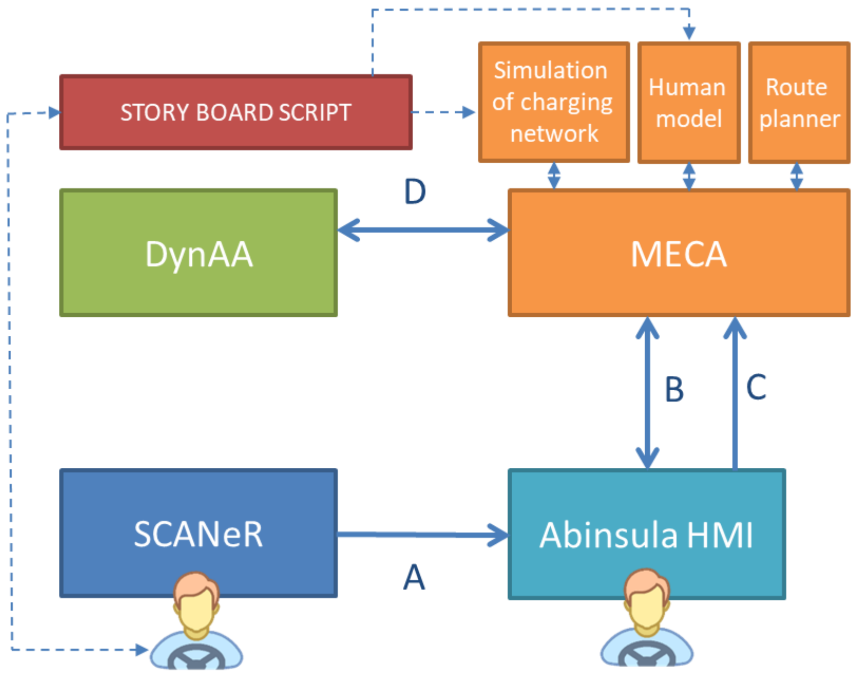


Figure 2-4 High level architecture of the Smart Travelling Demonstrator.

The defined modules are:

- SCANeR, a given simulation tool as used by CRF – CRF
- HMI, providing the interaction for adaptation – Abinsula
- DynAA, simulation tool – TNO
- MECA, driver support system – S&T
- Story board script which will be used to manage the overall scenario execution

In the high level architecture the following interfaces are defined between the modules (see capital letters in Figure 2-4):

A. CAR info: Battery load, GPS, speed, etc.
B. User advice interaction
    a. Propose and select itineraries
    b. Advice to driver, like how to reduce energy consumption
C. Provide Battery load and GPS data to MECA
D. Itinerary simulation request/response

Based in this high level architecture and interfaces and the agreed story board for the Smart Travelling used case, a number of state diagrams were generated. These diagrams will be used to develop and test the defined interfaces. A sequence diagram describing the information flow between the different components in the architecture is shown in Figure 2-5. In the appendix of this document (Section 7.2) the sequence diagrams for all the defined adaptation scenarios of the story board are given.

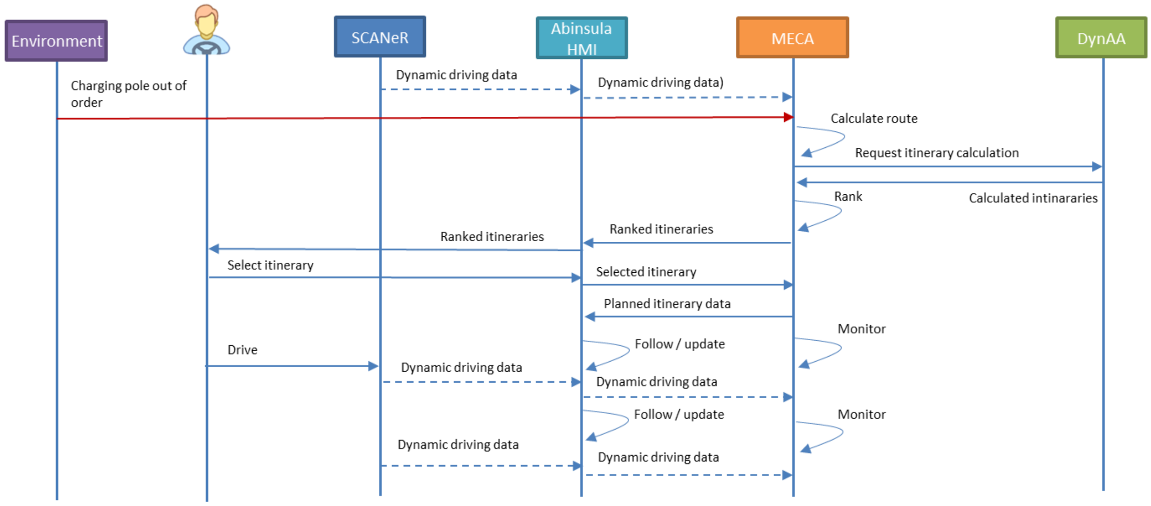


Figure 2-5 Sequence diagram for handling a "charging pole out of order" event.

For the driver the only visible thing is the HMI in the car. This will need to provide status of the electric vehicle (currently not available in the SCANeR interface) and the interaction with the driver support functionality provided by MECA and DynAA. The simulated car in SCANeR will perform behaviour of electric car based on motor and battery models of TNO.

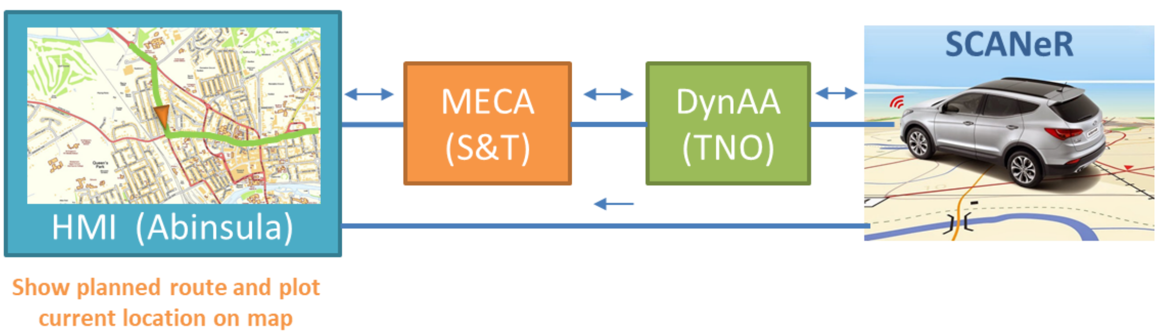


Figure 2-6 The data flow between SCANeR and the other modules.

The developed modules of the Smart Travelling Demonstrator will contain following functionalities:

SCANeR The already available simulation software of AV Simulation at CRF premises, which is extended with some new functionalities and improved physical implementation in 2018.
SCANeR in the CRF environment within CERBERO is extended with battery and motor models from TNO to simulate electric vehicles. For the collection and processing of data from the simulation environment, the data synchronisation tool of TNO will be used.

MECA The driver support function based on the S&T MECA tool for astronaut planning support. The functionality is extended to support all the scenarios as defined in the Smart Travelling story board. Functionality includes adaptation based environment, car and human triggers. For human triggers the signal driver tired will be used, which will be generated by new sensors in the CRF simulation environment. MECA will be equipped with monitoring functionality for detecting both human, car and external triggers and to monitor the car location and route. MECA will also integrate with a new HMI instead of usage of normal terminal for more realistic driver-car interaction.

DynAA The simulation tool DynAA from TNO is being updated extended with all functionalities needed for the defined scenarios (including models for battery, motor and vehicle for prediction simulation). To shorten response time even under increase of search space, DynAA will be extended with distributed processing functionalities which will allow the processing of multiple simulations in parallel on distributed hardware. This functionality is currently not available yet, but would help to use DynAA in time critical system-in-the-loop simulations.

HMI For interaction with the driver Abinsula will develop HMI system, based on already available car dashboard software. For the HMI new hardware screens will be added to the simulator environment which will partly replace the user interface provided by SCANeR. This will allow for new, more use case specific functionality to be developed for the driver simulator. The HMI will include functionalities like visualisation of the car status (e.g. battery load), the geographic map and planned and followed route. The HMI will also support interaction on itinerary selection and other relevant advice to the driver.

Script To manage the overall use case scenarios a specific story board execution script will be developed which will control and synchronise actions during the execution of the use case scenarios.

Part of this components were already available in M18 demonstrator with a reduced set of functionalities. For example, in the M18 demonstrator, there were no HMI, battery integration and no story board scripts.

2.5. Use-case vs. technology mapping

In the use case Smart Travelling the tools used were all focused in the runtime support. The focus was on integrating DynAA and MECA tools into the SCANeR based runtime environment. Tools for design support, like AOW and SAGE, were not used during the development of the use case, but as a separate exercise. In the table below the tools already mentioned in D2.4 are greyed out.

Table 2-2 Smart travelling Use case vs Technology mapping.

Component (model / tool)	**Functionality**	**Purpose**	**(Generic) KPIs addressed**
DynAA system-in-the-loop adapter	System-in-the-loop simulation	Synchronised simulation to run multiple simulation modules which interact with the SCANeR simulation.	• Response time to trigger • Latency
Battery model	Simulation of battery behaviour (to be executed in DynAA)	Equip vehicle with parametric simulation model of battery and use it in the loop for predicting impact of possible future routes.	• Energy • Response time to trigger
Electric motor model	Simulation of electric motor behaviour (to be executed in DynAA)	Equip vehicle with parametric simulation model of battery and use it in the loop for predicting impact of possible future routes.	• Energy • Response time to trigger
Charging infra model	Model of charging infrastructure, including current availability (to be executed in DynAA)	Used to optimize charging of the vehicle and to optimize the charging infrastructure itself	• Energy • Cost • Response time to trigger
MECA Driver support	(Self-)adaptation manager, handling functional adaptivity.	Provide user with advice on route and charging. Generate on request and pro-active advice on optimal route (based on predicted impact calculation)	• Cost • Energy • Response time to trigger • Fault recovery time
HMI	Provide Human Machine Interface for supporting adaptation	Help driver to detect and be informed of needed adaptations and support in decisions on the required adaptations via a friendly graphical interface	• Cost • Energy • Response time to trigger • Fault recovery time
AOW optimizer	Find optimal solution in solution space	Determine optimal solution for charging charging car of driver and possibly create functionality that could provide overall optimal solution for overall charging pole network (given that multiple drivers would issue requests)	• Cost • Response time to trigger
SAGE verification tool	Requirements and properties verification	Formal methods for (i) requirement consistency verification; and (ii) property verification on formal models.	• Cost • Energy • Response time to trigger

Component (model / tool)	**Functionality**	**Purpose**	**(Generic) KPIs addressed**
CIF	Model database using CERBERO intermediate format	DynAA and modules will use CIF to store model data as much as possible	

3. Use Case Self-Healing System for Planetary Exploration

3.1. Introduction

In this section we intend to describe the latest insights on the Self-Healing System for Planetary Exploration use case challenges, goals, architecture and incremental prototyping architecture/components. The generalities of this scenario have already been covered in D2.3 and D2.4.

Mapping among use case and CERBERO technologies and tools is also provided in subsection 3.5 of the present document. This mapping was already presented in the previous version of this deliverable, but it is constantly evolving with the project and will be refined in the final versions of the Demonstration Skeleton and Planetary Exploration Demonstrator deliverables (D6.1 and D6.2).

During the course of the project it was discovered that the adaptivity loop for the robotic arm has the highest potential benefit for the space industry. Therefore, it has been decided to focus on this scenario to access all the technologies and tools related to the FPGA based processing. Thus, from now on the Planetary Exploration use case tackles exclusively the robotic arm scenario, in charge of the generation of arm movement trajectories and validation of collision-free motion paths. Its demonstrator is being developed and validated in WP6 and using the CERBERO toolchain developed in WP3, WP4 and WP5.

The main controller device of the robotic units is designed adopting the CERBERO design environment, and it is based on a flexible, heterogeneous MPSoC architecture with self-reconfigurable FPGA COTS technology.

The scenario should present fault-tolerant and self-healing capabilities. In addition, the platform should be able to adapt to the changing environmental conditions of the planetary exploration cyber-physical system. In this regard, radiation-induced faults will be emulated using functional fault injection in those areas that are actively protected (e.g. ARTICo^3 slots in the FPGA fabric). The results will be equivalent to those obtained using bit-level fault injection (as originally proposed for this Use Case) but in a more efficient and less time-consuming way.

3.2. Challenges and goals

The Planetary Exploration use case is meant to demonstrate how CERBERO will facilitate the design of heterogeneous systems for space applications, along with their runtime management. Runtime strategies for hardware and software adaptivity will be assessed, to answer to system and environmental changes in a self-adaptive manner.

The general needs for this use case that have to be addressed using CERBERO technologies are summarized in Table 3-1.

Table 3-1 Planetary Exploration general needs.

ID	Need	High Level Requirements
PE1	Minimization of energy consumption and costs, while keeping/improving resiliency.	Enable Dependable Hardware / Software (HW/SW) co-design.
PE2	Provide multi-objective design space exploration and multi-view analysis. Reduce development time of complex heterogeneous systems by increasing the level of abstraction. Increase quality and verification level to ensure proper operation of the system.	Develop integrated open-source or commercially available toolchain environment for the design and assessment of heterogeneous cyber-physical systems.
PE3	Efficient support of architectural adaptivity, according to radiation effects and harsh environmental conditions.	Development of a HW/SW (self-)adaptation methodology and supporting tools.

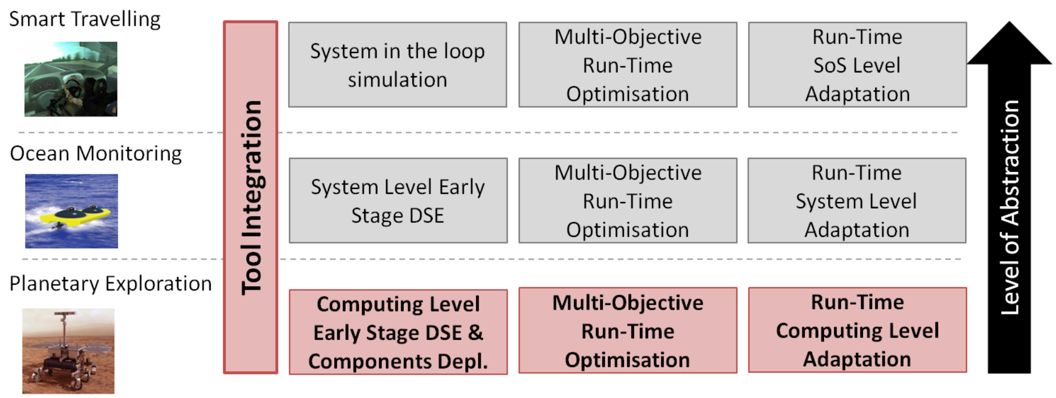


Figure 3-1 Problems to be solved by CERBERO for the PE use case.

Consequently, the Planetary Exploration key challenges and goals, related to CERBERO technologies summarized in Figure 3-1, can be summarized as follow:

- **Failure detection and correction**: in space applications, subatomic radiation particles can produce a variety of integrated circuits malfunctions. These effects are frequently referred as "single event effects" and they can cause flip-flops and memory cells to change state, affecting the functionality of the electronic component. Thus, a dynamic hardware-software reconfiguration strategy, referred in Figure 3-1 as Run-Time Computing Level adaptation, is adopted. Fault tolerance improvements and redundant execution are foreseen for critical task execution. Also, software and hardware runtime monitors will be defined and implemented in the system in order to autonomously provide this kind of support in combination with proper healing techniques.
- **Environment adaptation and self-learning**: the different cyber-physical systems involved in a planetary exploration mission experience very harsh environmental conditions. Adaptability to the dynamic physical environment and self-awareness (through run-time monitoring of multiple KPIs and multi-objective optimization) become crucial to cope with such extreme situations. The system will combine continuous KPI monitoring with functional, reconfigurable and real-time

descriptions of the application and self-learning strategies to ensure reactiveness and resiliency.

- **Power measurement and optimization**: usually, robotics aimed to investigate planetary surfaces are solar-powered. Optimal deployment, as well as run-time adjustments are needed. Future missions will require high efficiency and very low power consumption to ensure an adequate level of autonomy. The system features performance monitors that provide energy measurements to the adaption manager, which make decisions on how and when trigger reconfiguration to optimize the system power consumption while guarantee the requested performance level.

A storyboard was created in order to make the robotic arm scenario more clearly understandable. The story is based on Robert, the ROVER in charge of the Mars Sample Return mission. Robert must be able to retrieve different kind of materials from the martian surface, at the same time that it adapts to the unexpected events that may occur in this uncertain environment. In the Demonstrator, the ARTICo³ architecture will be able to handle the reconfiguration of the accelerators, under the different situations that trigger adaptation.

In Figure 3-2 a sample step in the story of Robert, the martian ROVER is shown where a solar storm takes place and suddenly a lot of radiation failures are induced into the FPGA fabric. Thanks to CERBERO tools, Robert is capable of detecting this phenomenon and reconfiguring its hardware to implement Triple Mode Redundancy (TMR), achieving a fault-tolerant behaviour. In the annex of this document (Section 8.1) all other steps of the storyboard are given.

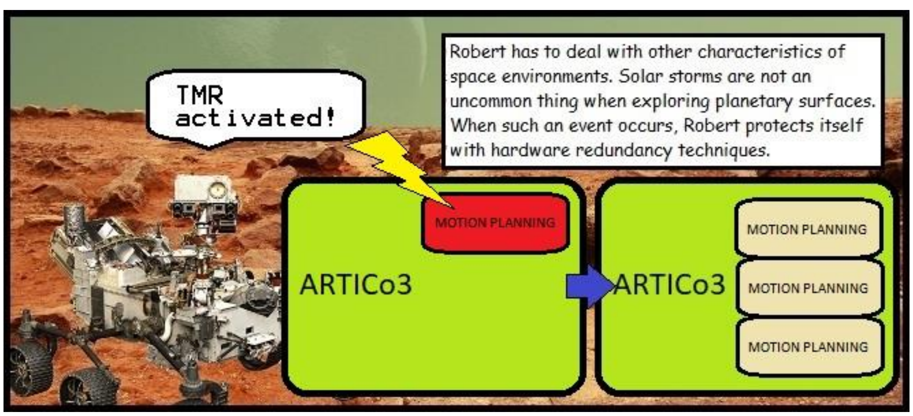


Figure 3-2 One of the steps in the story of Robert

The idea for the M36 demonstrator is to implement a single scenario which tackles some of the adaption mechanisms highlighted in the use-case storyboard.

3.3. Added value of the CERBERO approach

In the Planetary Exploration use case, the added value of the CERBERO approach is focused on the novel heterogeneous design workflow provided by ARTICo3 and MDC, the automatic instrumentation of the code, and the KPI oriented, user transparent reconfiguration.

The main advantages found so far when working with the CERBERO toolchain are:

- The architecture and algorithm definition are presented in a very straightforward manner in the PREESM framework.
- The code instrumentation, which otherwise is a complex and laborious task, is made simple thanks to PAPIFY. This way, software KPIs are measured by performance monitors automatically provided to the system.

Among all new functions to be implemented in the near future for this scenario, the following are expected to be the more important features:

- The SAGE verification tool, where ReqV is capable of translating requirements from natural language to a mathematical specification through a property specification pattern.
- A groundbreaking heterogeneous design flow, capable of generating HW/SW threads with low effort using ARTICo^3+MDC.
- A powerful, fault tolerant and reconfigurable architecture provided by ARTICo^3 and MDC, in charge of providing different levels of parallelization and multi-grain adaptivity support.
- The SPiDER runtime scheduler that provides adaptive scheduling in order to support external, non-predictable events in runtime management.

In the M18 demonstrator a very early stage of the scenario was deployed. PREESM was used to describe the architecture and a simplified version of the algorithm and corresponding code were automatically instrumented by the PAPIFY component of the CERBERO toolchain. PAPIFY Viewer was assessed too in this scenario, obtaining diagrams for the total number of instructions and execution time for each actor of the algorithm. At the time this deliverable is submitted, ARTICo^3 and MDC are integrated and assessed standalone. Their potentials within the PE scenario is meant to be accessed in this second phase of the project. The M36 PE demonstrator will show the benefits of working with the computing-level components of the CERBERO toolchain, as depicted in Figure 3-3.

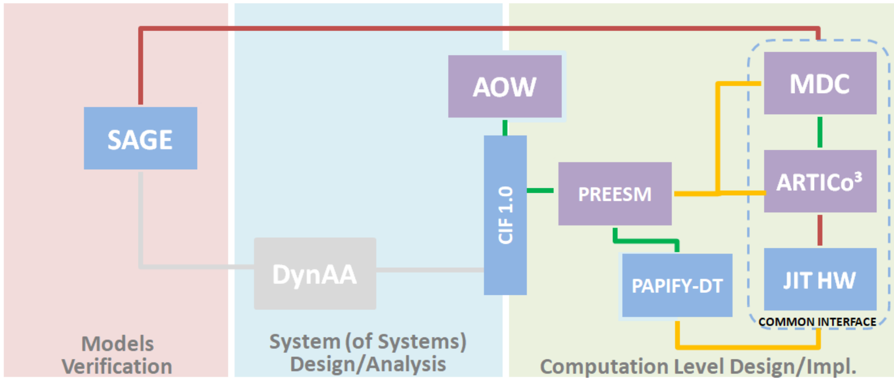


Figure 3-3 CERBERO Design Time Technologies used within the PE use case.

3.4. System architecture and component

An overall view of the Self-Healing System for Planetary Exploration system components is presented in Figure 3-4. The physical system is a robotic arm composed of two main parts: the Robot Control Unit (RCU) and the Servo Control Unit (SCU). The Robotic arm scenario focuses on the RCU to provide Adaptive Motion Planning and Self-Healing functionalities to the robotic arm.

On one hand, the Adaptive Motion Planning feature enables the movement of the robotic arm in harsh, uncertain environments. The system will perform all necessary calculations, including interpolation, inverse kinematic solution or optimization, in order to find a feasible, smooth trajectory to achieve the required displacement. On the other hand, the proper operation of the system is ensured by the Self-Healing capabilities – RCU components must be able to detect and correct errors caused by the impact of radioactive particles.

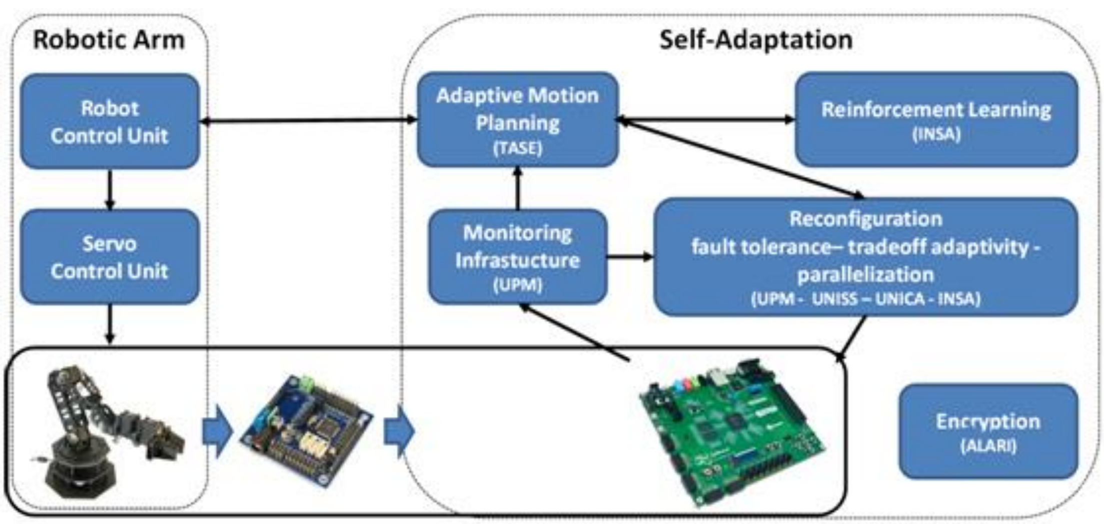


Figure 3-4 Architecture of the Planetary Exploration demonstrator

In order to meet these demands, CERBERO tool will be used ranging from design-time formal verification to runtime monitoring and reconfiguration capabilities for advanced model-based trade-off management.

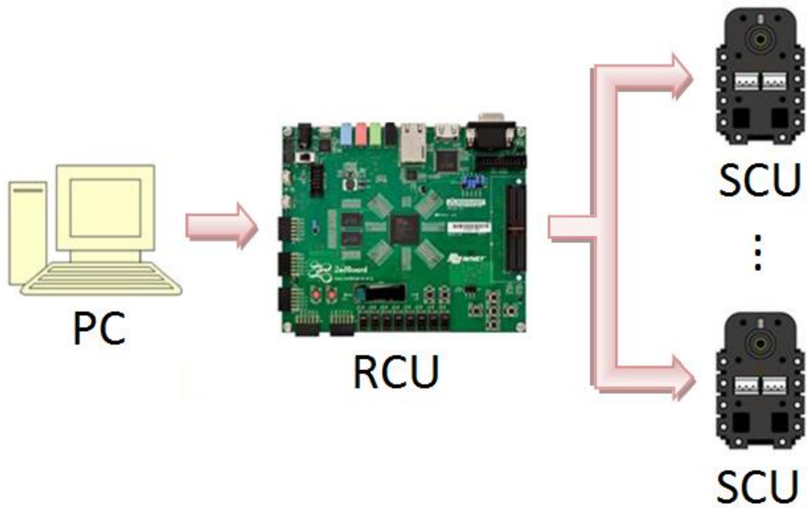


Figure 3-5 Hardware elements for the PE Robotic Arm scenario

Figure 3-5 shows the solution used to address the challenges and goals described in Section 3.2. The main hardware elements in this solution are:

- RCU: performs high level computing like motion planning or interpolation, and maintains communication with the robotic arm. It is provisionally implemented in the Zynq FPGA present in a ZedBoard but for the final version it will be migrated to Zynq UltraScale+ technology.
- SCU: drives each one of the six Dynamixel actuator joints of the WidowX Robot Arm. The SCU included in these actuators implements functions of torque limit, PID regulation, status table, etc. These actuators serve for demonstration purposes only since they are not representative of space use case applications.
- PC: its purpose is to provide serial communication with the RCU in order to send and provide debug options. This communication will be encrypted using CCSDS cryptographic algorithms, which are standards for Space Data System, in order to guarantee the confidentiality and integrity of the data in critical applications.

The self-adaptation and self-healing solution are achieved through high level components shown in Figure 3-6.

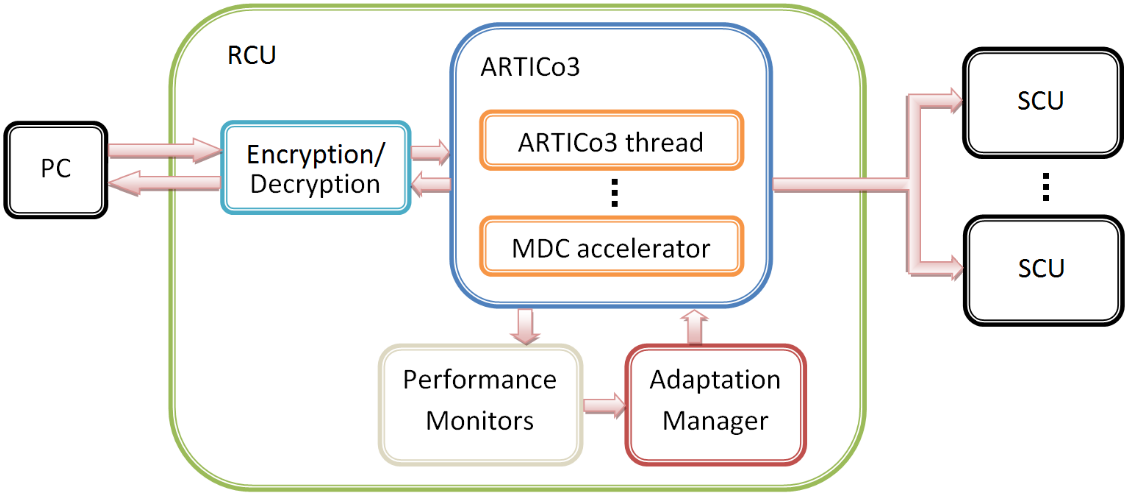


Figure 3-6 High level architecture of the Planetary Exploration demonstrator.

The following techniques, as depicted also in Figure 3-3, will be used at design time:

- **Formal verification**: the SAGE verification tool by UNISS provides a way to prove the correct construction of the system. It is based on formal methods of mathematics.
- **Heterogeneous system design**: PREESM will decide upon the preliminary core mapping, while the integrated ARTICo³ and MDC toolchain wraps a Coarse-Grained Reconfigurable (CGR) HDL computational kernel with the logic necessary to serve as an ARTICo³ Dynamic Partial Reconfigurable (DPR) partition. It also generates the static and reconfigurable bitstreams, and the software application that manages operation execution and offloads computation from the hardware accelerators [RECONFIG]. AOW will potentially provide backend optimization engine (for PREESM and MDC) using CIF for tools interconnection.
- **Performance monitors:** the automatic code instrumentation provided by PAPIFY is focused on reading the different KPIs, software and hardware performance monitors that then will be provided at runtime to the models on the (self-)adaptation manager.
- **Motion simulator**: the robotic arm trajectory will be simulated with Python SPYDER so it can be validated prior to execution.

At runtime, the following CERBERO components and third party tools are used:

- **Hardware accelerators:** the processing power of the platform is held by the ARTICo³ and MDC cores. Thanks to the aforementioned multi-grain reconfigurable architecture, scalable parallelism and fast functional reconfiguration will be provided through DPR and CGR, respectively, along with self-healing capabilities.
- **Heterogeneous Adaptation Loop:** the PE demonstrator will benefit from WP4 main outcome. It will access both functional and architectural runtime adaptivity management according to functional and non-functional trade-off categories derived by the different system monitors and sensors. Different types of **reconfiguration** will be assessed exploiting distributed hardware/software engines.

It will also make use of reinforcement learning techniques in order to support external, non-predictable events in runtime management and helping decide upon optimal (trade-off and situation aware) heterogeneous system configuration

- **Encryption/Decryption**: the communication between the PC and the RCU must be encrypted in order to ensure the security and authenticity of the data. The implemented solution will a space industry standard based on AES cryptographic algorithm.
- **Functional fault injection**: each hardware accelerator will have two different operation modes: normal and faulty. A multiplexed output will be controlled by means of configuration registers. During the fault injection test the accelerators logic will behave correctly until the mode is changed, so invalid output values are generated instead.

3.5. Use-case vs. technology mapping

In the Planetary Exploration use case there are different models and tools that will be used to address needs and challenges identified in this context (see Table 3-1). Models, methodologies, architecture and tools are summarized in **Error! Reference source not found.** of D2.4, describing their functionality, purpose in the use case and KPIs addressed and/or optimized. The details on how the technologies listed in the table are implemented in the demonstrator are presented on Figure 3.2 of D6.8 (which is an extension of Figure 3-4 in this document) and will be further explained in D6.2.

3.6. Update on requirements

The following modifications on the use case are considered:

- As explained in Section 3.4 the brushless motor control demonstrator has been eliminated, therefore requirements from TASE-011 to TASE-019 are removed from the project.
- The SEM IP is no longer envisioned to be included in the system: functional fault injection will be used instead. Consequently, the following requirements change:
    - TASE-004 verification is modified to “Fault injection will be used by implementing fault emulation techniques in order to test the robustness.”
    - TASE-010 description is modified to “The MPSoC/FPGA design must make use of fault emulation techniques in order to test the RCU behaviour under fault injection conditions.”

The rest of the requirements are in line with those defined in D2.3 and updated in D2.4.

4. Use Case Ocean Monitoring

4.1. Introduction

The following subsections present an update and refinement of the Ocean Monitoring use case description and requirements based on D2.3 and D2.4. It consists of descriptions of the use case challenges, goals, architecture and incremental prototyping of the architecture/components.

In the document the mapping between the use case and CERBERO technologies and tools is provided. It will be refined and finalized in the last version of the Demonstration Skeleton and the Ocean Monitoring Demonstrator deliverables (D6.1 and D6.3).

The Ocean Monitoring Demonstrator uses CERBERO technologies to enable and facilitate the development, prototyping, and operation processes.

4.2. Challenges and goals

The Ocean Monitoring use case demonstrates the benefits and advantages of system-level CERBERO technologies and shows how the aforementioned can facilitate both the design and the runtime of a heterogeneous system.

The Ocean Monitoring use case is going to assess the runtime strategies for software adaptivity to environmental changes and user preferences. Table 4-1**Error! Reference source not found.** presents the general needs to be addressed using CERBERO technologies.

Table 4-1 Ocean Monitoring general needs.

ID	Need	High Level Requirement
OM1	Reduction of energy consumption and costs, increase reuse in other projects, while keeping or improving safety and security level and maintenance costs.	Provide complete design cycle from system level design to HW/SW co-design and implementation of Ocean Monitoring robot using adaptable COTS.
OM2	Facilitate development cycles, reduce time to market, and increase reuse, quality and verification level by incremental prototyping from high level of abstraction directly to working real time applications.	Develop integrated "open" toolchain environment for development of Ocean Monitoring robots with focus on incremental prototyping.
OM3	Efficient support of functional adaptivity, according to system, human and environment triggers.	Development of a (self-)adaptation methodology with supporting tools.

So far, the needs have been addressed by the following CERBERO technologies as follows:

- Data Storage System for efficient storage and retrieval of information which uses the adaptive hybrid image fusion CERBERO technology.

- Development of data fusion models for information retrieval and for image enhancement purposes.
- Development of the initial version of the multi-lens physical prototype of Adaptive Camera System.
- Incremental prototyping of the OM robot based on the DynAA simulation models and the KPIs such as video processing throughput, java performance, battery performance, and storage performance.
- Components such as the camera system can also be reused in a different context, outside of the OM use case.
- The adaptation of the camera system can be triggered by human and environment. The adaptation will result in different subsets of lenses being selected for different contexts and functionalities, and different levels of image enhancement plus automatic brightness correction.

The main challenges and goals of the OM are:

- Current approaches to ocean monitoring would benefit from enhanced vision and sensing capabilities.
- Current approaches would benefit from reduced development and deployment cost.
- Environment, wireless communication, availability of technologies.

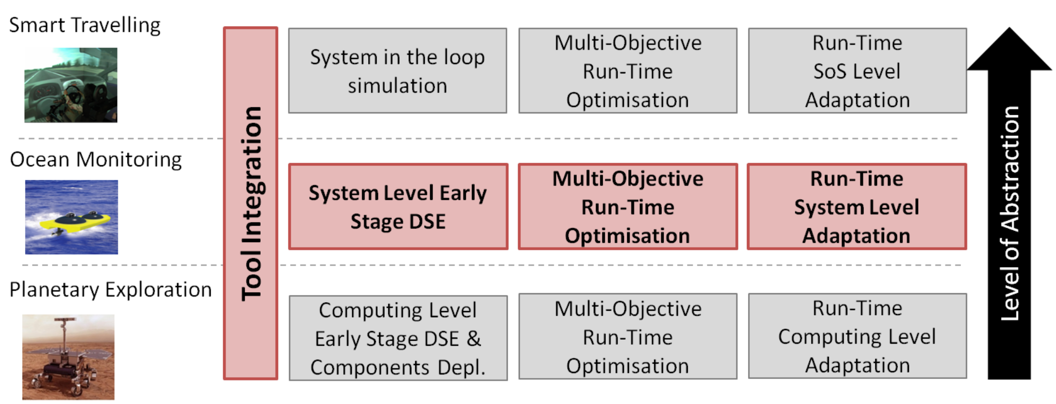


Figure 4-1 Problems to be solved by CERBERO for the OM use case.

CERBERO technologies, as summarized in Table 4-2, would help realizing the current challenges and goals of the OM use case by:

- Use of SAGE and CIF for verifying and modelling OM platform.
- Final physical prototype for the Ocean Monitoring demonstrator, including:
  - Final adaptive camera for OM.
  - Implementation of the frame-difference based object detection and fusion with colour-based approach.
  - DynAA-based runtime adaptation models.
  - Runtime optimization for the adaptation manager.

Evaluation through underwater trials and test collections are planned and feedback into CERBERO technology work-packages is provided (see Section 4.3 of Deliverable D6.9, where a detailed feedback on DynAA is provided).

We have been also investigating the potential use of the AOW for solving optimisation problems related to OM use case, and the use of ARTICo^3/MDC to offload processing. It is difficult to imagine at the moment the implementation of these latter in M36 demonstrator of the OM use case, but stand-alone accessing on the reference processing seems to be feasible to plan future migration to heterogeneous platforms beyond the project timeframe.

We have verified with the oil and gas off-shore companies in order to gather additional detailed up-to-date environmental and monitoring requirements. The off-shore industry is in need of environment monitoring solutions that could work deep underwater. For example, the solution should overcome the challenges of poor visibility conditions, and fish that are attracted to light and can obscure vision. The industry needs enhanced visibility. There is an interest in combining imagery from a sonar and camera sensors for enhanced environmental awareness. Current limitations also relate to low resolution imagery, inspection and classification of visual data. Hyper and multispectral cameras are used to gather relevant information. The cost of hiring and operating a supply boat and a ROV or an AUV is also very high.

We have been considering the following scenarios:

- Ocean Monitoring System for subsea environmental monitoring by oil and gas / energy company.
- Adaptive camera for ocean surface monitoring.
- Ocean Monitoring System for obstacle avoidance.

Scenario 1: Ocean Monitoring System for subsea environmental monitoring by oil and gas / energy company.

Sam is Senior Risk Manager working for Aquatic Oil, and is working on a new contract to track the deep sea ecosystem and monitor for changes using a range of multispectral cameras. Multi-spectral cameras use different light spectra including non-visible light. The oil company wants to monitor the health of the deep sea wildlife to ensure it is not harming the environment. Sam is experienced with their current deep sea monitoring solution, which involves mapping the undersea area around their major installations. Collecting the data, however, is a slow and expensive process due to the limited water visibility at the depths involved. Moreover, the resolution of images is low which reduces their usefulness for human operators and computer vision algorithms.

Sam decides to assess the CERBERO Ocean Monitoring System with its Adaptive Camera, and attaches it to their AUV (Autonomous Underwater Vehicle) sensor systems, alongside their existing multispectral camera system. Later, Sam compares the data from the two systems, and notes that there is a clear improvement in the image clarity at distance, one which could significantly reduce mapping time - and therefore the cost.

On their next mapping run, weather conditions are worse, and lead to increased turbidity, so the visible range of their existing camera setup is reduced from to about 5m. Sam reconfigures the Ocean Monitoring System to combine two different infrared wavelengths with visible light, to improve imaging range. However, the system encounters an area close to a tidal flow where turbidity is particularly high, so the system adapts to pre-process the raw imaging data, building a fused video stream that provides optimum clarity, while notifying the operator of the inferred range, so the mapping plan can be updated to the new conditions. The use of cameras at different spectra of light including the infrared, and the ability to change the synchronicity of individual cameras allows seeing through the rain for enhanced situational awareness purposes.

- External trigger 1: as the depth changes, the adaptive camera detects changes in the red light proportion, and uses that to adapt its processing algorithm.
- Human trigger 1: Sam gets a weather alert of an incoming storm with expected swell, and re-configures the Ocean Monitoring System for an expected increase in turbidity.
- Power trigger: after a data collection session that extends beyond planned duration, the Ocean Monitoring System reconfigures to reduce power consumption, switching to a more economical compression algorithm and reducing lighting power.

Scenario 2: Adaptive camera for ocean surface monitoring.

Sam is also responsible for updating the surface camera contract, responsible for tracking surface waters and detecting early warning signs of oil. This is due for renewal, and Sam wonders whether the CERBERO Adaptive Camera might be a good solution for that, too. Currently, they use both radar and visible light cameras, but due to the changes in ambient light between day and night, even the combination is struggling to adapt to the low visibility at night, and is generating frequent false positives as it misclassifies dark regions, especially at night. Again, Sam sets up the Adaptive Camera alongside the current solution, and compares the data, and notes that the processed video substantially improves the detail in the dark patches. After training with prior data, the improved detector reduces the risk of false positives, and Sam decides to maintain the system for a longer-term evaluation alongside their current systems as a

- External trigger 1: as the sun sets, the adaptive camera detects the reduced light and enables additional lenses and configures for noise reduction by fusing the images
- Human trigger 1: Sam gets weather alert of increased winds, re-configures the Adaptive Camera water surface analysis algorithm for increased waves.

Scenario 3. Ocean Monitoring System for obstacle avoidance.

Sam attaches the multi-purpose multi-lens adaptive camera system to his AUV. He wants to use it for distance measurement and disparity maps calculation in order to avoid obstacles. During the operation of AUV the weather changes rapidly and the turbulent conditions cause the lenses to slightly change position. The fused images are now misaligned which would normally render the camera rather useless for distance measurement purposes. Because the camera checks the quality of the image alignment from time to time, detection of rectification error triggers the self-healing process. The camera system uses automatic learning image rectification method based on detection of progressively better corresponding image patches. Over time better matches between images are detected, the representation of images in the common plane gets continuously assessed, and the rectification improves.

- External trigger 1: The occasional automatic assessment of the image alignment process leads to the camera rectification self-healing process.
- Human trigger 1: Sam uses the automatic image rectification functionality that can be also triggered remotely to correct the image misalignment errors.

4.3. Added value of the CERBERO approach

Added value of CERBERO approach to address the challenges described in the previous section includes the following:

- OM adopts CERBERO new development methodology for complete CPS design cycle – with principles of reduced cost and development time, reuse, KPIs, incremental prototyping.
- OM uses CERBERO toolchain for fast, incremental prototyping and reduced cost.
- OM adopts CERBERO adaptivity framework.
- OM uses CERBERO fusion technology for image enhancement and image retrieval purposes.

Using DynAA at design time allowed for better risk assessment on the performance bounds of the alternative hardware platform designs. This was because of the more effective predictions of the data throughput capacity under different conditions, avoiding the challenges of different supplier specification structures.

Using the CERBERO adaptation framework is helping separate the components systematically, so that a hierarchical approach to the overall architecture can be used. This is significantly reducing complexity due to the separation of different aspects of adaptation in a structured way. For example, power adaptation, lighting adaptation, and image quality adaptation can be organized as distinct components without a single central manager, enabling new adaptation structures to be added and maintained over time.

CERBERO's ARTICo^3/MDC offers an effective way to offload processing, when the video pipelines needed by the adaptive camera system are more fully specified. At this stage, Ocean Monitoring has not yet adopted these technologies, because algorithmic prototyping is more cost effective with standard GPU systems in place on standard platforms, but as said in the previous section the project results seem to be promising to explore in future that direction.

4.4. System Architecture and Components

Figure 4-2 presents the architecture of the Ocean Monitoring Demonstrator. It is both runtime and design time architecture focused on Information Storage and Information

Fusion models, Video Enhancement strategies, and physical prototypes of the Camera System.

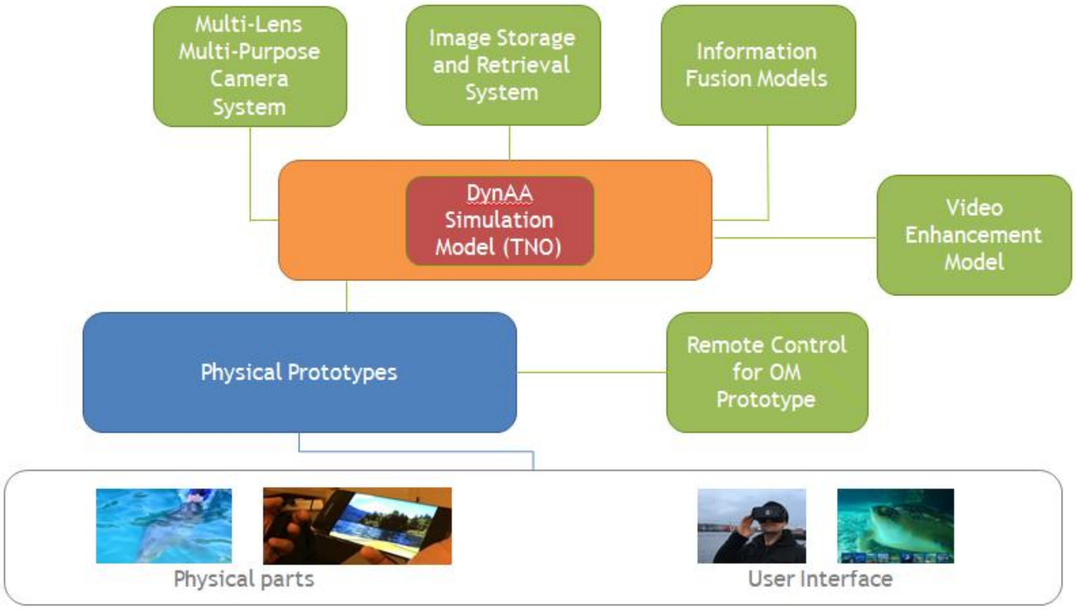


Figure 4-2 Architecture of the Ocean Monitoring Demonstrator.

The OM architecture consists of the following modules:

- **Multi-Lens Multi-Purpose Camera System:** the camera model will be extended by addition of wi-fi and infrared sensors. The updates are related to the exploitation plan and aim at meeting and exceeding the potential buyers' needs.
- **Information Storage and Retrieval System:** the image storage and retrieval system will be extended by the database of underwater and surface image collections, and content based retrieval methods to (for example) detect oil spills.
- **Information Fusion Models:** New information fusion models will be developed and implemented in order to combine data from additional sensors.
- **Video Enhancement Model:** The model will be extended by addition of frame-difference based object detection, and combined/fused with existing colour-based detection and tracking technique. This should utilize the advantages of both thus reducing the drawbacks of the colour based and frame-difference based frameworks.
- **Remote Control for OM Prototype:** The camera system will be remotely controlled using wi-fi. The operator will have remote access to all the functionalities of the camera and will see the footage in real time.
- **DynAA Simulation Model:** DynAA tool will be used for the runtime adaptation of the OM demonstrator to achieve optimal performance with respect to defined KPIs.
- **Physical Prototypes:** New physical prototypes will be developed and validated. The prototypes are going to implement the aforementioned updates.

We have removed the propulsion, battery, and the engine modules from the OM architecture diagram. This is due to lowering of their priorities and focusing on novelty.
The chosen hardware platform is multicore, Snapdragon based, with Intel i7 reference architecture with hyper threading, and the Nvidia Jetson TX1/TX2. The firmware is based on Linux operating system with a Java Virtual machine running on top.

4.5. Use-case vs technology mapping

Ocean Monitoring use case adopts CERBERO development methodology for complete CPS design cycle – with its principles of reduced cost and development time, reuse of components, different KPIs, and incremental prototyping. It uses CERBERO DynAA tool for fast, incremental prototyping and reduction of cost. In addition, OM adopts CERBERO adaptivity framework.

More integration of CERBERO technologies and tools are planned, e.g. potential use of ARTICo^3/MDC to offload processing, use of SAGE and CIF for verifying and modelling OM platform, and AOW for solving optimisation problems related to OM use case. Table 4-2**Error! Reference source not found.** presents the Ocean Monitoring versus the CERBERO technology mapping. Tools with minor changes versus the previous version in D2.4 are greyed out.

Table 4-2 Ocean monitoring components, tools, their purpose in the use case and the specific KPI they address and/or optimize.

Component (model / tool)	Functionality	Purpose in use case	(Generic) KPIs addressed.
DynAA, Camera System Model	System simulation	A model of a system of cameras/lenses providing images of the same environmental area from different perspectives. This Model is for design time. The Camera Model uses DynAA.	• Response time • Image quality (Ranked feature) • Throughput
Object detection & Image Enhancement Model	Automatic object detection techniques and image enhancement	Enhance the underwater image to alleviate the poor visibility conditions and detect and track moving objects for the enhanced situational awareness of the user.	• Image quality (Ranked feature)

Component (model / tool)	Functionality	Purpose in use case	(Generic) KPIs addressed.
Information fusion Models	Combining different types of information for different purposes	Needed to enhance images and videos – image fusion, make decisions based on different information types – e.g. fusion of text and visual content for data storage and retrieval system.	• Image quality (Ranked feature)
Reference architecture implementation	Implement / instantiate the reference architecture	To provide a well defined framework for integrating data-flow black-box components (networked black-box) within the overall architecture.	• Response time • Cost
SAGE verification tool	Requirements and properties verification	Formal methods for (i) requirement consistency verification; and (ii) property verification on formal models.	• Cost • Energy • Response time
AOW optimizer	Find optimal solution in solution space	Determine an optimal solution for the OM path recovery problem	• Cost • Response time
ARTICo^3/MDC tool	Offload processing	Offers an effective way to offload processing	• Cost • Response time

4.6. Update on requirements

The OM is in line with the requirements defined in D2.3 and D2.4 according to the priorities. There is an update / refinement to the “Marine robot propulsion and transport” scenario and related requirements R2.1, R1.3, R2.3, none of which were priority 1. These have now been lowered to priority 3. This is aligned with update on the priorities and focus in the OM architecture. The current OM architecture diagram thus excludes the propulsion module.

5. Conclusions

In this document we have described all the CERBERO assessment scenarios, their challenges and goals, architecture and components, testing environments planned within them, technology mapping for each use case and update on requirements with previous deliverables.

This deliverable provides a high level description based on previous iterations of the document. The CERBERO framework has been updated and adjusted in order to serve evolving scenario requirements, also guaranteeing an effective industry-driven deployment.

This document serves as a basis for the final versions of the Technical Requirements Elicitation, contained in D2.2, and the definition of the Demonstrators skeletons, which will be part of D6.1.

6. References

[DELIVERABLES] http://www.cerbero-h2020.eu/deliverables/

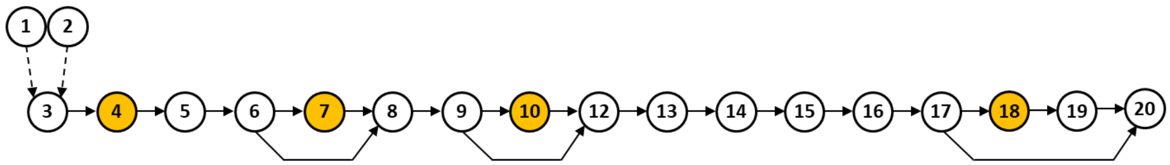
[USECASES] http://www.cerbero-h2020.eu/use-cases/

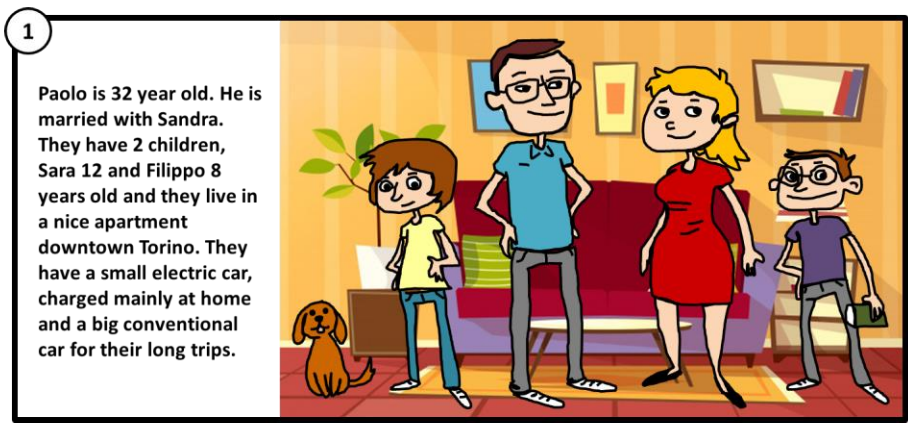
[RECONFIG] T. Fanni, A. Rodríguez, "Multi-Grain Reconfiguration for Advanced Adaptivity in Cyber-Physical Systems," ReConFig'18

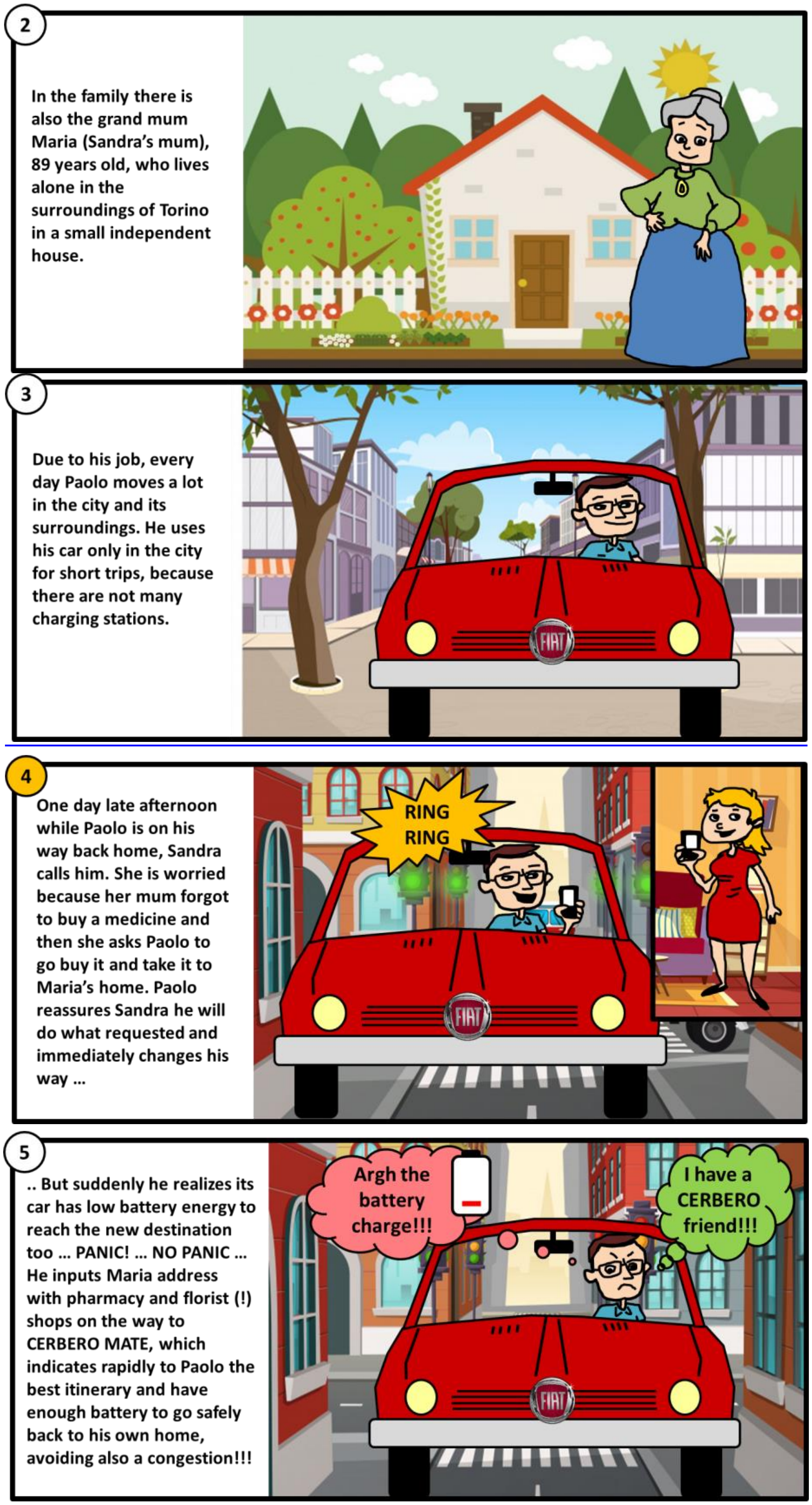
7. Annex – Smart Travelling use case details

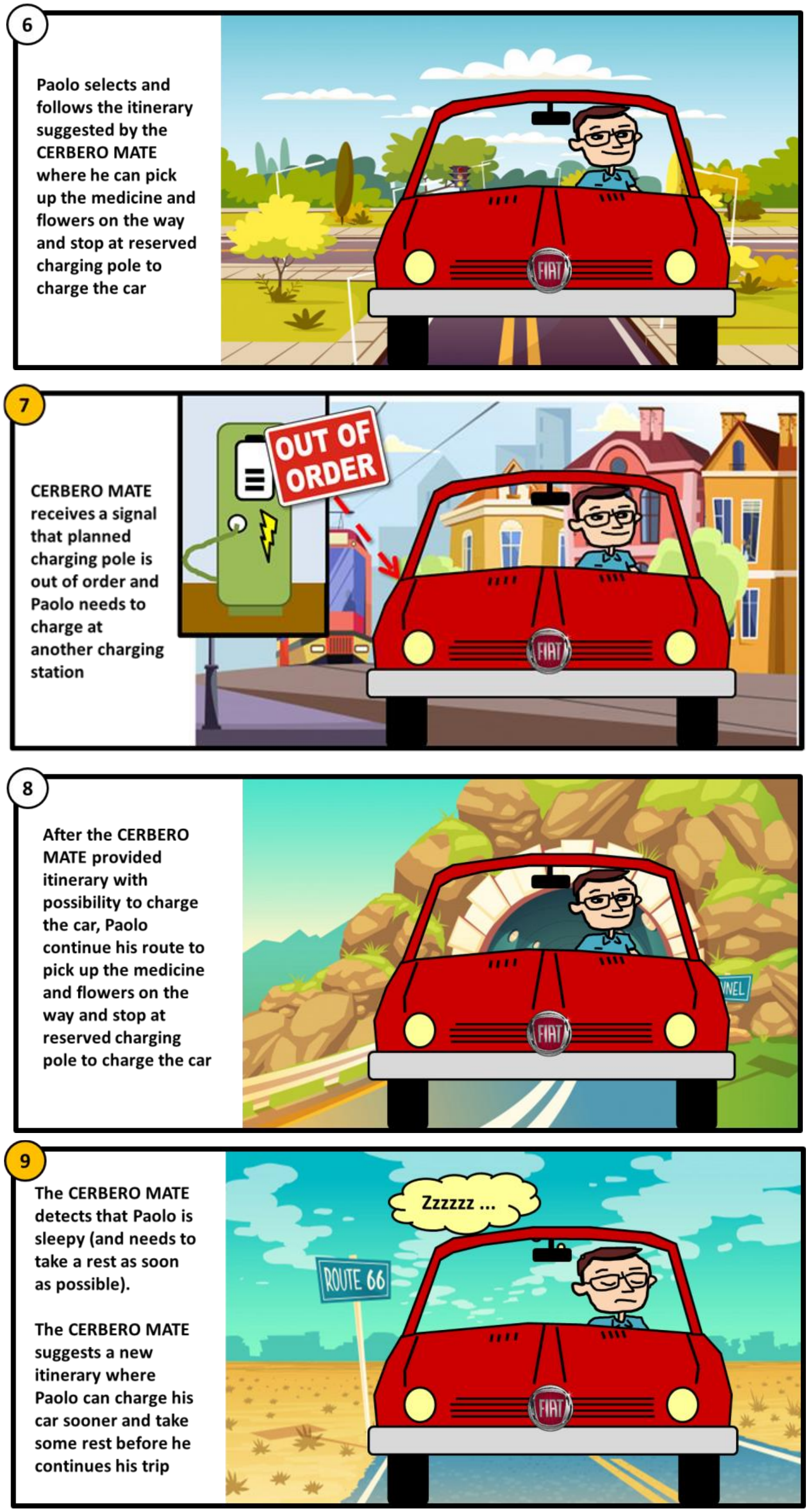
7.1. Story board

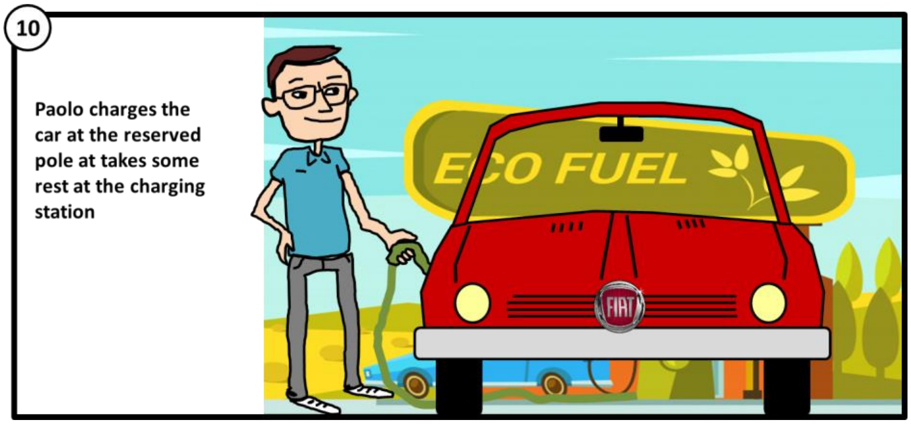
In this section the steps of the story board for the Smart Travelling use case are sketched. The story is constructed of a number of steps, where adaptation steps are indicated with orange colored numbers and where adaptation steps can be skipped to create different reduced versions of the story.

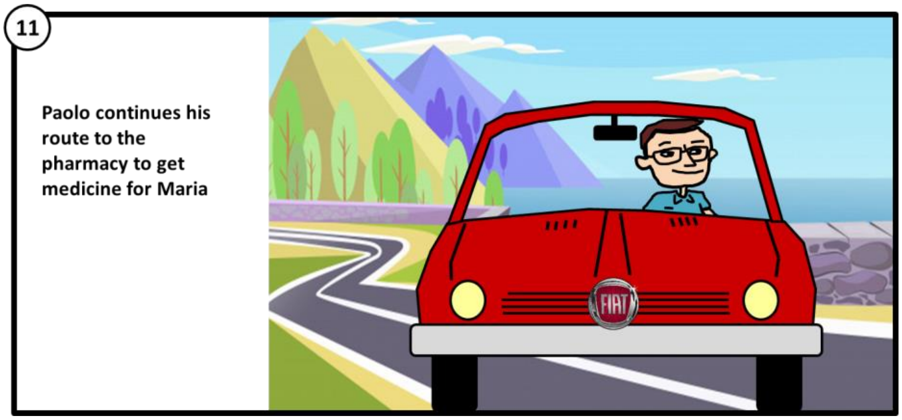




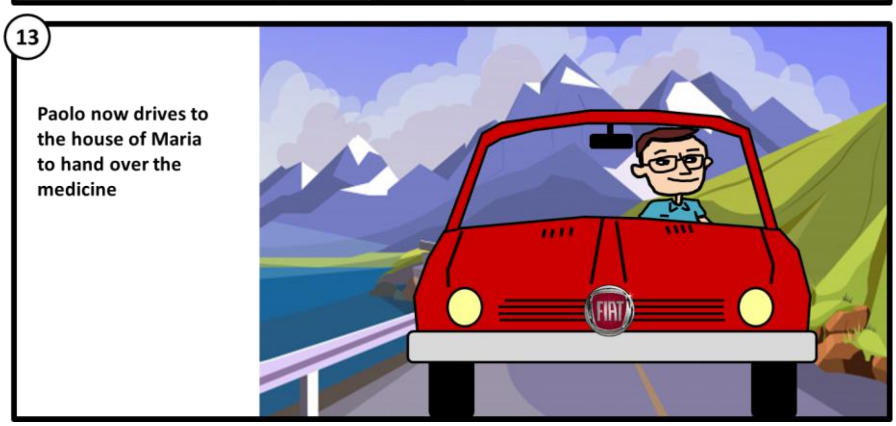

2
In the family there is also the grand mum Maria (Sandra's mum), 89 years old, who lives alone in the surroundings of Torino in a small independent house.
3
Due to his job, every day Paolo moves a lot in the city and its surroundings. He uses his car only in the city for short trips, because there are not many charging stations.
FIAT
4
One day late afternoon while Paolo is on his way back home, Sandra calls him. She is worried because her mum forgot to buy a medicine and then she asks Paolo to go buy it and take it to Maria's home. Paolo reassures Sandra he will do what requested and immediately changes his way …
RING RING
FIAT
5
.. But suddenly he realizes its car has low battery energy to reach the new destination too … PANIC! … NO PANIC … He inputs Maria address with pharmacy and florist (!) shops on the way to CERBERO MATE, which indicates rapidly to Paolo the best itinerary and have enough battery to go safely back to his own home, avoiding also a congestion!!!
Argh the battery charge!!!
I have a CERBERO friend!!!
FIAT


6
Paolo selects and follows the itinerary suggested by the CERBERO MATE where he can pick up the medicine and flowers on the way and stop at reserved charging pole to charge the car
FIAT
7
CERBERO MATE receives a signal that planned charging pole is out of order and Paolo needs to charge at another charging station
OUT OF ORDER
FIAT
8
After the CERBERO MATE provided itinerary with possibility to charge the car, Paolo continue his route to pick up the medicine and flowers on the way and stop at reserved charging pole to charge the car
FIAT
9
The CERBERO MATE detects that Paolo is sleepy (and needs to take a rest as soon as possible).
The CERBERO MATE suggests a new itinerary where Paolo can charge his car sooner and take some rest before he continues his trip
Zzzzzz ...
ROUTE 66
FIAT


10
Paolo charges the car at the reserved pole at takes some rest at the charging station
ECO FUEL

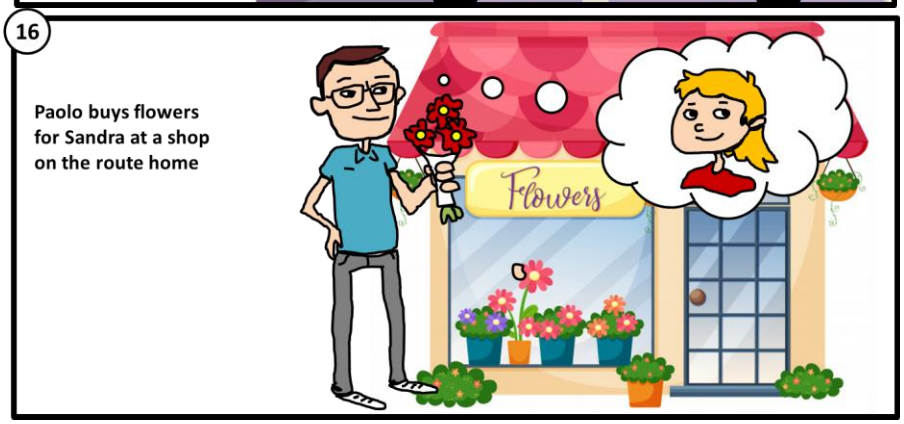

11
Paolo continues his route to the pharmacy to get medicine for Maria

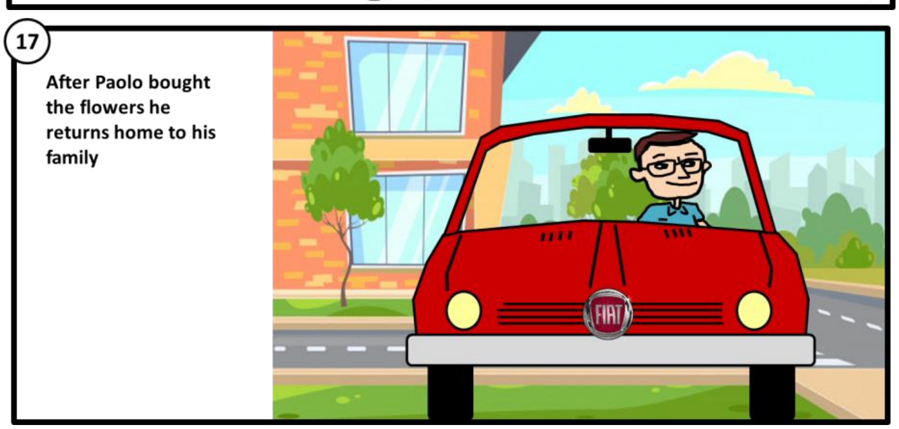

12
Paolo collects the medicine for Maria when he arrives at the pharmacy

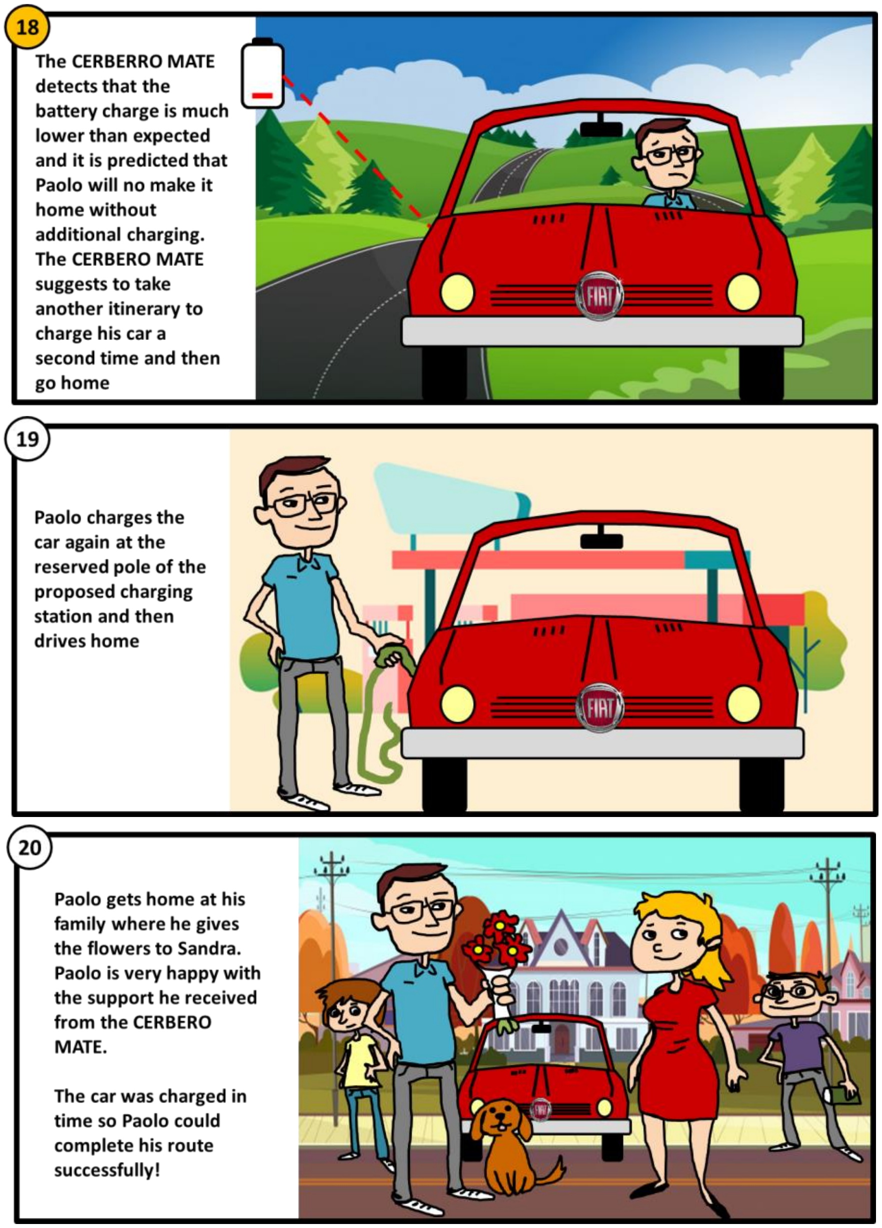

13
Paolo now drives to the house of Maria to hand over the medicine


14
Paolo hands over the medicine to Maria


15
Paolo now drives back home and will stop on the way to pick up the flowers for Sandra as planned


16
Paolo buys flowers for Sandra at a shop on the route home
Flowers


17
After Paolo bought the flowers he returns home to his family


18
The CERBERRO MATE detects that the battery charge is much lower than expected and it is predicted that Paolo will no make it home without additional charging. The CERBERO MATE suggests to take another itinerary to charge his car a second time and then go home
FIAT
19
Paolo charges the car again at the reserved pole of the proposed charging station and then drives home
FIAT
20
Paolo gets home at his family where he gives the flowers to Sandra. Paolo is very happy with the support he received from the CERBERO MATE.
The car was charged in time so Paolo could complete his route successfully!

7.2. Sequence diagrams

Based on the scenarios in the story board a number of sequence diagram are sketched in this section, based on which the interfaces will be developed.

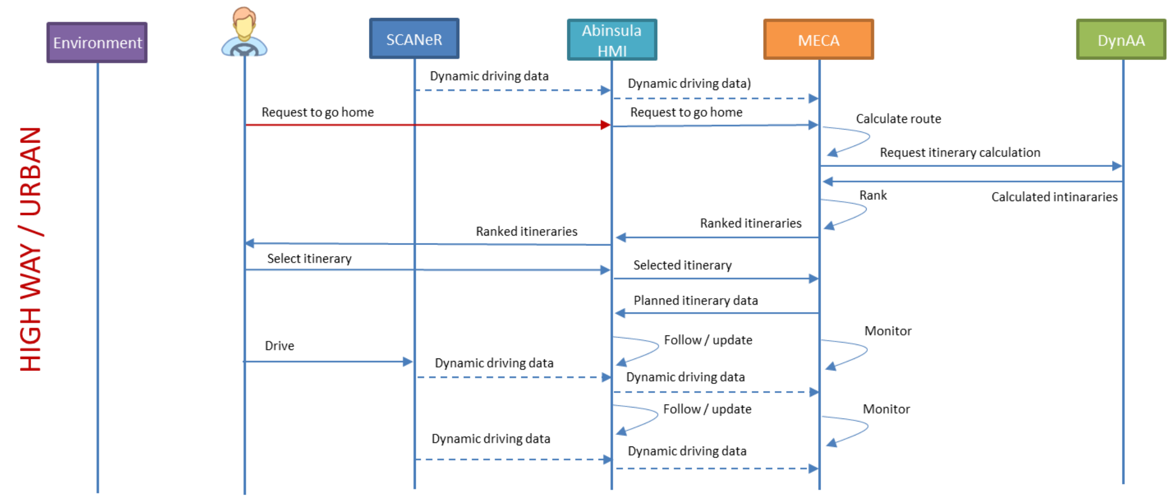


Figure 7-1 Basis scenario.

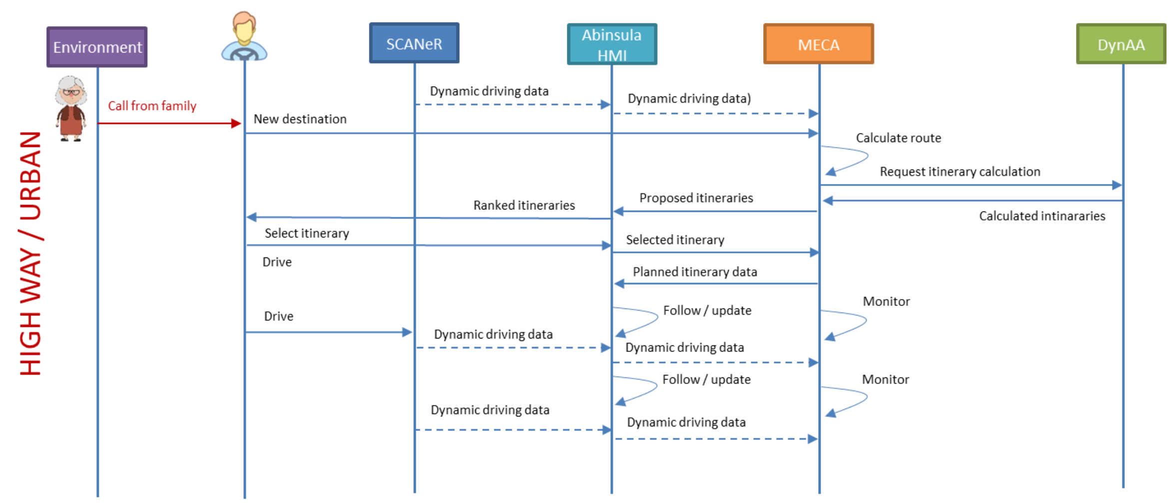


Figure 7-2 Family call scenario.

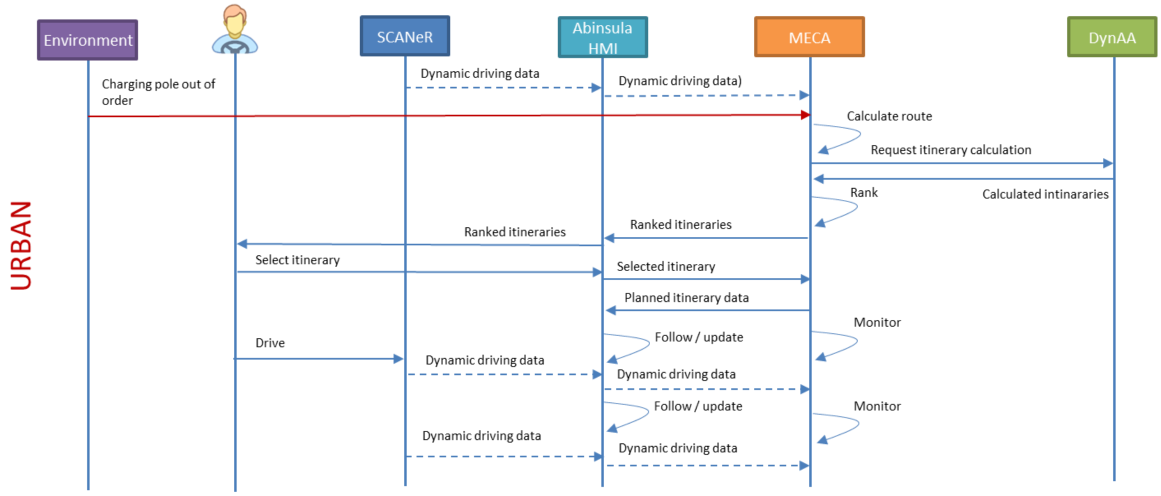


Figure 7-3 Charging pole out of order scenario.

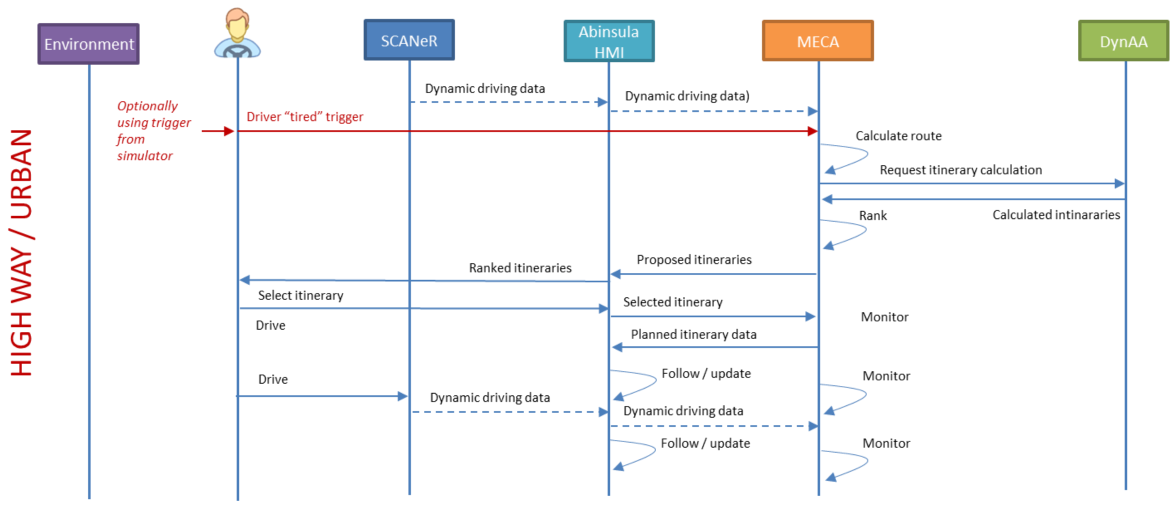


Figure 7-4 Driver tired scenario.

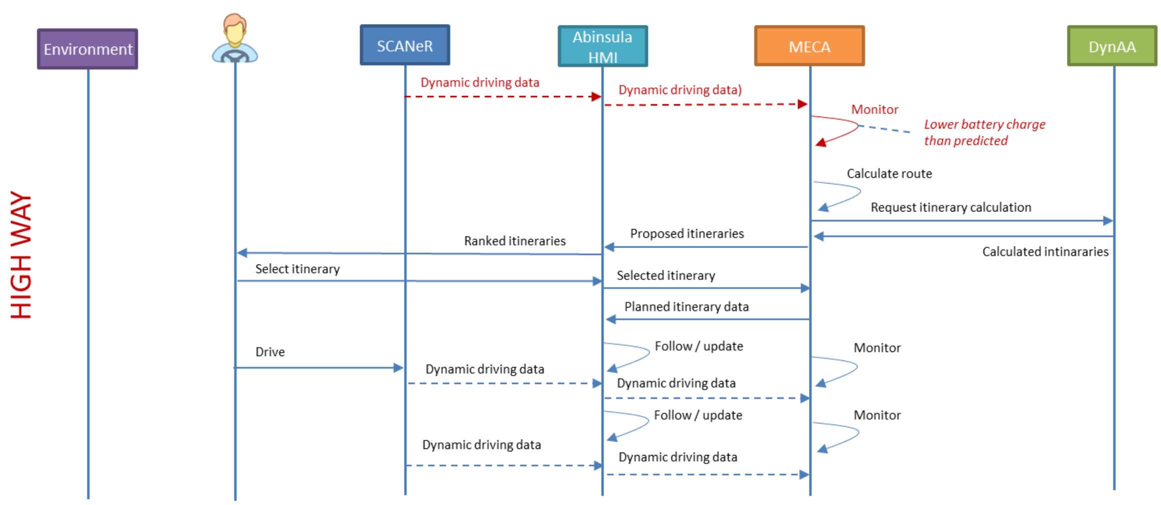
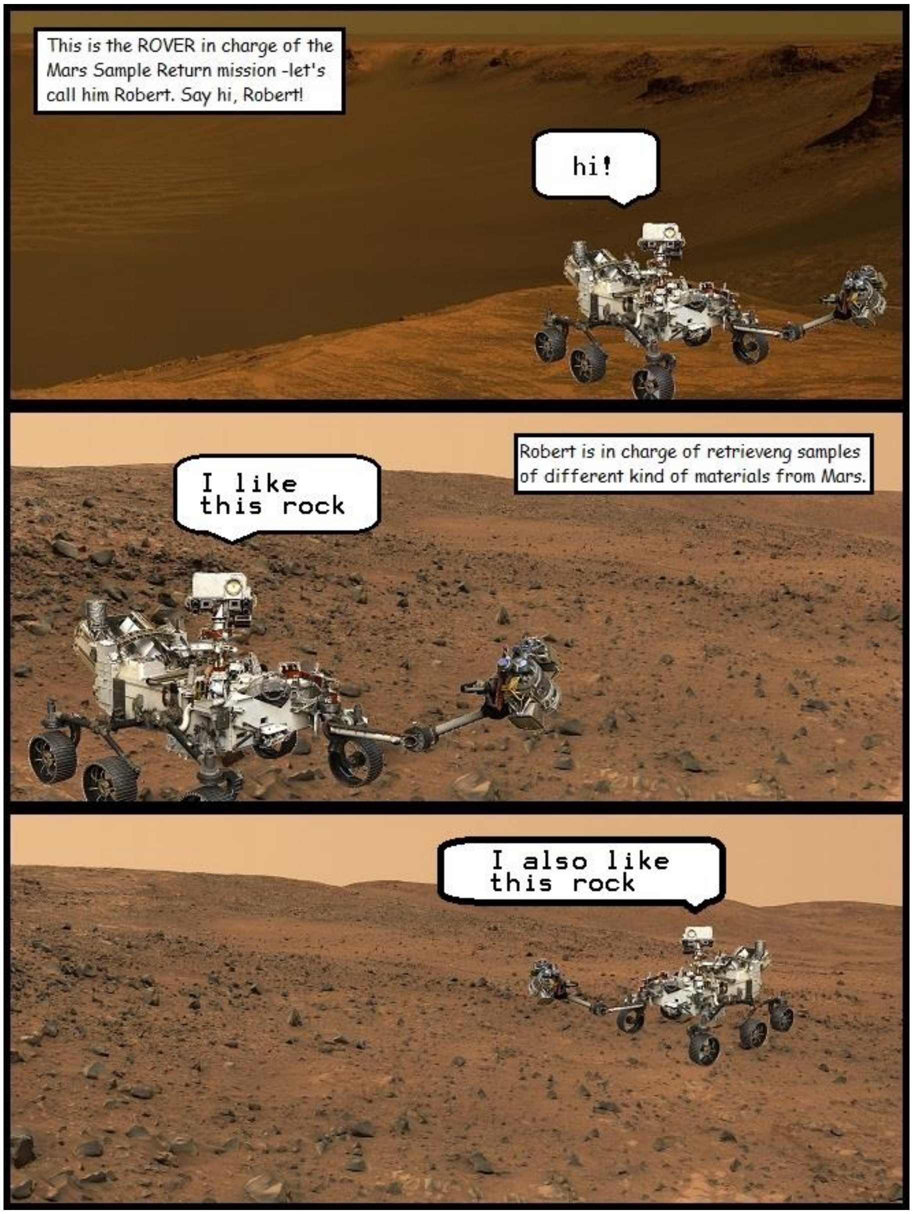


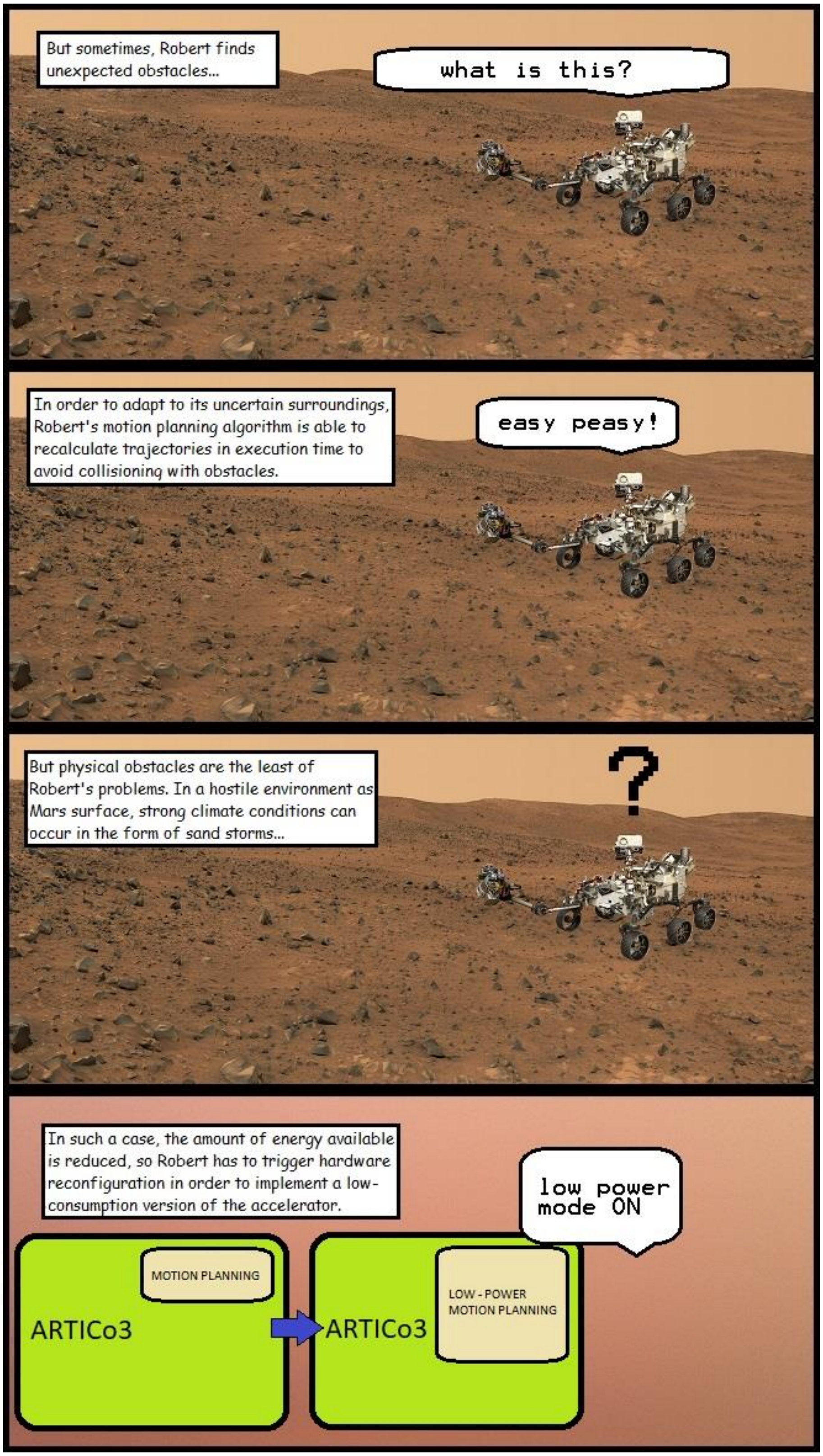
Figure 7-5 Low battery scenario.

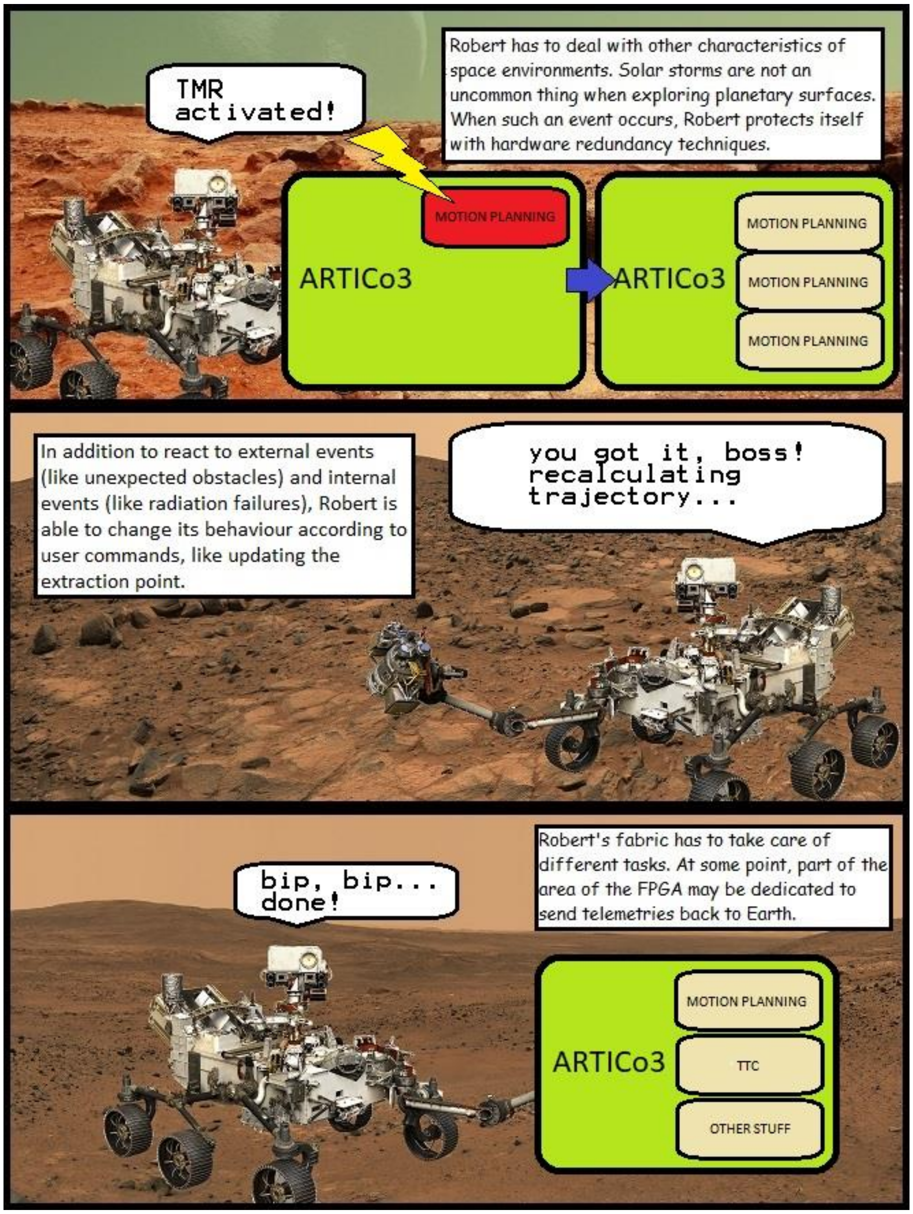
8. Annex – Planetary Exploration use case details

8.1. Story board

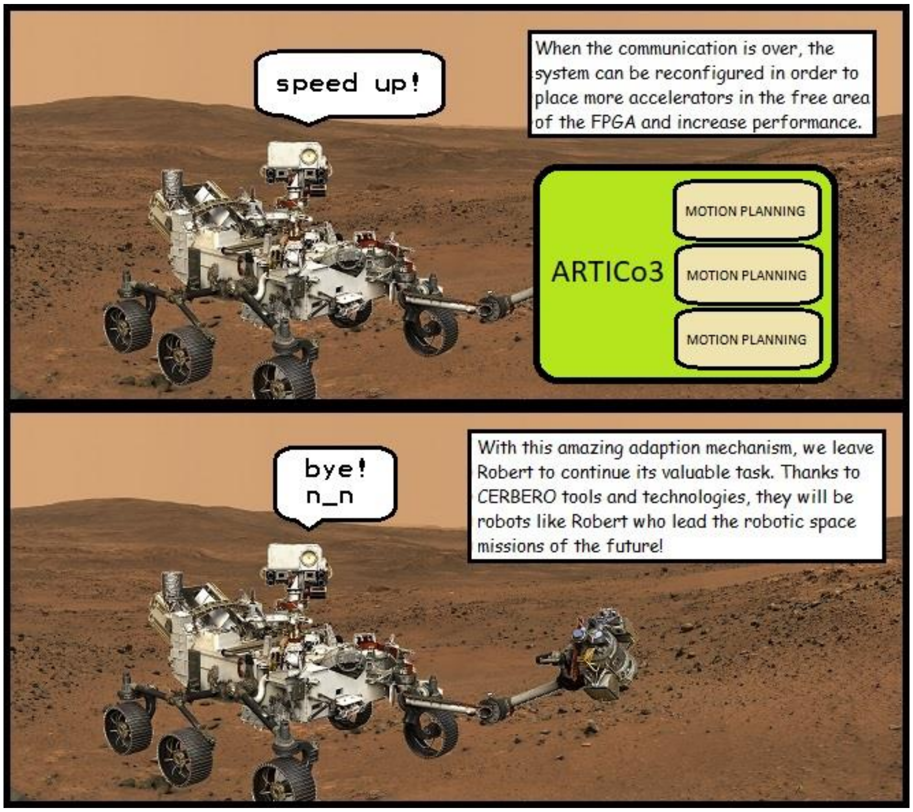
In this section the steps of the story board for the Planetary Exploration use case are sketched.




But sometimes, Robert finds unexpected obstacles...
what is this?
In order to adapt to its uncertain surroundings, Robert's motion planning algorithm is able to recalculate trajectories in execution time to avoid collisioning with obstacles.
easy peasy!
But physical obstacles are the least of Robert's problems. In a hostile environment as Mars surface, strong climate conditions can occur in the form of sand storms...
?
In such a case, the amount of energy available is reduced, so Robert has to trigger hardware reconfiguration in order to implement a low-consumption version of the accelerator.
low power mode ON
MOTION PLANNING
ARTICo3
ARTICo3
LOW - POWER MOTION PLANNING



Robert has to deal with other characteristics of space environments. Solar storms are not an uncommon thing when exploring planetary surfaces. When such an event occurs, Robert protects itself with hardware redundancy techniques.
TMR activated!
ARTICo3
MOTION PLANNING
ARTICo3
MOTION PLANNING
MOTION PLANNING
MOTION PLANNING
In addition to react to external events (like unexpected obstacles) and internal events (like radiation failures), Robert is able to change its behaviour according to user commands, like updating the extraction point.
you got it, boss! recalculating trajectory...
Robert's fabric has to take care of different tasks. At some point, part of the area of the FPGA may be dedicated to send telemetries back to Earth.
bip, bip... done!
ARTICo3
MOTION PLANNING
TTC
OTHER STUFF


speed up!
When the communication is over, the system can be reconfigured in order to place more accelerators in the free area of the FPGA and increase performance.
ARTICo3
MOTION PLANNING
MOTION PLANNING
MOTION PLANNING
bye! n_n
With this amazing adaption mechanism, we leave Robert to continue its valuable task. Thanks to CERBERO tools and technologies, they will be robots like Robert who lead the robotic space missions of the future!