The ECSEL FRACTAL Project: A Cognitive Fractal and Secure EDGE based on a unique Open-Safe-Reliable-Low Power Hardware Platform Node

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Abstract— **The objective of the FRACTAL project is to create a new approach to reliable edge computing. The computing node will be the building block of scalable Internet of Things (from Low Computing to High Computing Edge Nodes). The cognitive skill will be given by an internal and external architecture that allows forecasting its internal performance and the state of the surrounding world. The node will have the capability of learning how to improve its performance against the uncertainty of the environment. New industrial functions will flourish through the created space of the cognitive system. Cognitive advantages are brought to a resilient edge and a computing paradigm that lay down between the physical world and the cloud.**

Keywords- ***Edge computing, artificial intelligence, cognitive systems, Internet of Things***

I. INTRODUCTION

To achieve industrial edge computing, new devices are required to satisfy a new set of challenging requirements such as time-predictability, dependability, energy-efficiency, and security [1-5],[9]. In the next section, we introduce the concept of cognitivity.

A. Cognitivity

Cognitivity is provided by Artificial Intelligence methods, supported by internal and external architectures that allow the (platform) node to proactively adapt to changes in the surrounding world. Hence, this node will have the capability of learning in real-time how to improve its performance and dependability despite the uncertainty of the environment. However, while these features are critically important, focusing only on them leaves aside the enhancement opportunities brought by the continuous emergence of more powerful solutions in the area of Cyber-Physical Systems (CPS), Systems of Systems (SoS) and Internet of Things (IoT). For instance, opportunities coming from advanced microelectronics, high-performance computing, smart system integration, and improved cloud services have traditionally been mostly neglected. Missing those opportunities may easily make the node fail to meet the stringent requirements for increased autonomy coming from the new application domains. Making an edge system truly cognitive requires leveraging the following four main features: (i) application of AI methods to provide Smart Systems with learning, prediction and autonomy (artificial intelligence); (ii) modelling of the operating environment to provide context-awareness for the Cognitive System (advanced sensing and computer vision); (iii) integration of computational capacity to process data, models, and AI algorithms (low-power multicores and hardware acceleration); and (iv) supervision of internal performance metrics to evaluate the fulfilment of the desired goals (online monitoring).

There is a gap between the features offered by traditional systems and those that should be offered, instead, by cognitive systems to match complex reality:

- **Object vs Process**. An object is static and unchanged. A process or procedure is an action that unfolds in time. Reality is made of processes instead of defined objects. The change is the key information, and the edge systems must consider those information flows describing changes.
- **Product vs Service**. A product is an offering that can be sold to customers. It is common to think of products as having a physical presence whereas a service is an offering that includes management, customer service, maintenance and experiences. This is part of the new trend of microservices and services in the circular economy where the users pay for

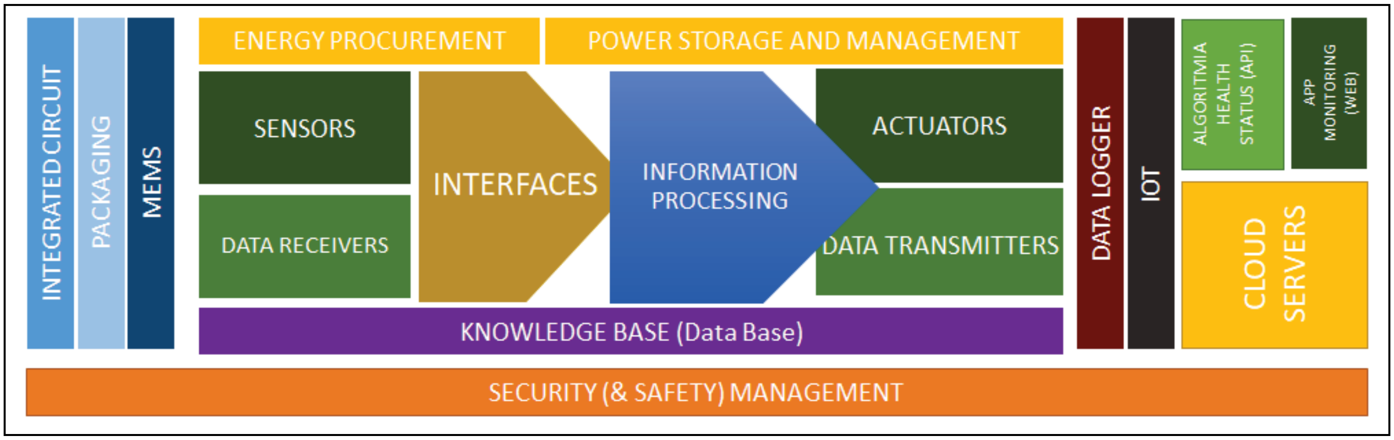

Fig. 1. Schematic representation of a Smart System and its connection through the Cloud as an Internet of Things.

use.

- **Closed vs Open system**. A networked system cannot be closed. The open systems are systems that allow interactions between their internal elements and the environment, presenting import and export, building-up and breaking-down of its material components.
- **Assembly versus Growth**. Networked Systems are not statically deployed, and they grow and shrink depending on the application's needs. Especially adequate is a FRACTAL topology that grows, expands, conquers the information space over any spatial configuration.
- **Defined vs Emergent properties**. Properties, behaviour patterns, or structures are not fully known, and they show up under interactions among the parts during the process of self-organization in complex systems.
- **Assembly vs Self-organized**. Self-organized systems do not need control by any external agent. It is often triggered by random fluctuations, amplified by positive feedback. The resulting organization is wholly decentralized, distributed over all the components of the system. As such, the organization is typically robust and able to survive or self-repair substantial perturbation. There are theories that discuss self-organization in terms of islands of predictability in a sea of chaotic unpredictability that could be used to ensure safe performance of complex systems [7].
- **Linear vs Nonlinear**. Most systems are inherently nonlinear in nature. Nonlinear dynamical systems may describe changes over time that may appear chaotic, unpredictable, or counterintuitive, contrasting with much simpler linear systems.
- **Ergodic vs Non-ergodic models**. Although there is a sense of repetitive cyclic states, the reality is not repetitive, and systems are no longer at the same state after long periods of time. They might be in a similar phase state but not exactly the same. This slight change may have important consequences in a nonlinear system that can be used to monitor the ageing and performance of products along time.
- **Programmable vs Cognitive**. Instead of programming a sequence in well-defined environments, cognitive systems will learn by experience how to keep performing under the required constraints.

The current architecture of this type of solutions can be seen in Fig. 1. Basically, it is a Smart System Representation plus an IoT connectivity to the cloud. The smart system represented is a mere node where information is collected, processed and sent upwards to the cloud. Unfortunately, there are still important barriers that prevent IoT systems to perform as a *cognitive system*:

- **Lack of cognitive computing.** The intelligence of current IoT systems relies on the cloud.
- **Lack of a non-ergodic model of the system**. A precise model is required in order to unfold all the functions and capabilities.
- **Lack of scalable and flexible solutions.** Under a current system configuration, there might not be enough bandwidth and energy resources to transmit all the data back and forth to the cloud in today's and future applications (e.g. population health monitoring).

Instead, complex reality needs the adoption of cognitive systems at the edge [7]. In particular, Edge computing can be defined as "cloud computing systems that perform data processing at the edge of the network, near the source of the data", so that only aggregated data is sent to the cloud, reducing communication bandwidth requirements and improving data transfer time [8]. Besides, the cloud will carry out edge controller functions for enabling condition awareness and node autonomy by storing and improving cognitive models. This approach provides the needed scalability for arbitrarily large and complex systems, but it requires a node architecture that provides intelligence and computational power using limited energy, time and space resources.

B. Project Objectives

The project will provide an agile engineering environment to support embedded platform development and customization. The diversity of the consortium partners' expertise and the variety of the use cases will allow a proper weight and balance of the needed features. The project specifications follow the multiple focus areas of the Multi-Annual Strategic Plan ("MASP"). The strategic objectives to implement and prioritize the different requirements of a FRACTAL node are:

- **O1**: Design and Implement an Open-Safe-Reliable Platform to Build Cognitive Edge Nodes of Variable Complexity
- **O2**: Guarantee extra-functional properties (dependability, security, timeliness and energy-efficiency) of FRACTAL nodes and systems built using FRACTAL nodes (i.e., FRACTAL systems).
- **O3**: Evaluate and validate the analytics approach by means of AI to help the identification of the largest set of working conditions still preserving safe and secure operational behaviours.
- **O4**: To integrate fractal communication and remote management features into FRACTAL nodes.

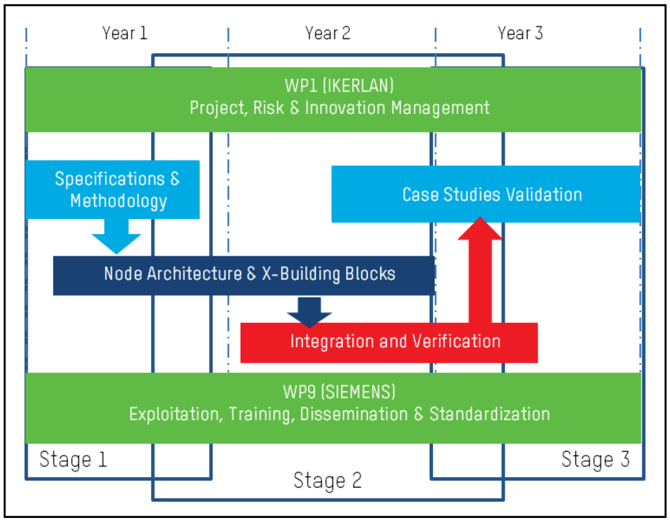

Fig. 2. The main FRACTAL activities in a V-shape configuration.

In the following, we describe application domains and discuss implementation issues.

II. FRACTAL NODES

FRACTAL cognitive edge nodes will be presented in two flavours: (1) a partially constrained commercial node with low time-to-market based on the Xilinx VERSAL computing platform and (2) a more research-oriented fully flexible customizable node based on RISC-V cores and acceletators for longer time-to-market exploration based on the open-source PULP (parallel ultra-low power) platform. Finally, FRACTAL technologies will be first integrated and verified in 4 industrial verification use cases, and secondly validated in 5 industrial validation use cases covering a wide range of applications and domains. Use-case descriptions are provided in Section III. FRACTAL leverages two different platforms offering different tradeoffs, one being the ***commercial node*** and the other the ***customizable node based on the open RISC-V PULP platform***. The aim of the former is offering soon a mature platform to end-users for the integration and assessment of their use cases already at the start of the project, as well as a relatively short path towards commercialization of the **FRACTAL** approach. This involves an extremely flexible FPGA-based development platform where resources in the node, as well as their organization, can be adapted as needed to enable a larger range of tradeoffs. The customizable node will be designed around the open RISC-V instruction set architecture (ISA) and based on the open-source PULP platform (maintained by ETHZ) allowing **FRACTAL** partners a powerful and flexible starting point for the development of the custom node and a viable path for longer-term product development without an early commitment to a proprietary ISA and platform.

Due to the ambition of the project, the number of partners, technologies and use cases, the FRACTAL project will be based on a classical V-shape with two prototype iterations (see Fig. 2). The project approach iterates on the cooperative tasks described above in each prototype iteration. It is crucial to maintain a V- Shape configuration in order to create and stimulate proper collaboration between partners.

In a first iteration, consisting of stage 1 and stage 2, as soon as initial users' requirements and needs are understood, key technologies/solution ideas/concepts will be validated from a conceptual perspective centred on the scientific and technical objectives of the project (**Stage 1: Conceptual/Research Development, Nodes and building blocks**). Technical development will deliver the first set of working solutions with results deployed in a lab environment.

As soon as key building blocks are ready, **Stage 2: Tool Implementation and Integration** will start by implementing a set of reference platforms in order to test those building blocks. By the end of this stage, the Platforms will be integrated and verified using real verification cases. The consortium will be ready to move to the following prototype iteration with the rest of use cases for validation.

Hence, a second iteration (**Stage 3: Case Study Implementation and Validation**) will be done during the final part of the project following the same process as during the first iteration with updated requirements, methodology and technological innovations. This iteration will end up with validation at in-situ trials as well as recommendations on how to generalize the project results to other related application domains not covered by the case studies that may need edge computing solutions.

III. FRACTAL INDUSTRIAL VERIFICATION AND INNOVATION METHODOLOGY

To validate the results obtained in the project nine use cases have been proposed. Divided into verification and validation use cases. To maximize generalization and scalability, the use cases have been chosen in different application fields:

- Transport: Autonomous vehicles
- Digital Life: Engineering
- Digital Industry: Indystry 4.0
- Energy: Energy Consumption and Environmental

Integration, verification and validation activities are essential to ensure the quality and relevance of the research. Hence, four use cases will be used to verify the integration and five use cases will be used to validate and benchmark the technology. In the following sub-sections, the use-cases driving the design of FRACTAL are being described.

A. *Engineering and maintenance works*

Two end-to-end solutions will be developed and tested, which will allow improving the safety conditions in the construction of civil engineering works. The first solution will monitor the infrastructure with UAVs, systematizing the piloted visual inspection in near-real-time to detect building hazards. This solution will deploy a computing edge infrastructure based in microservices. The second solution will deploy sensors both in workers and machinery, placed in the construction sites, for detecting dangerous situations related to the actions carried out during the construction process, especially the workers run-over by machinery. As we display in Fig. 3, WSN (Wireless Sensor Network) will provide information about position and status of the workers and machinery in real-time, which will be managed through an IoT platform in order to register possible dangers and alarms and establish a protocol to follow in case of emergency.

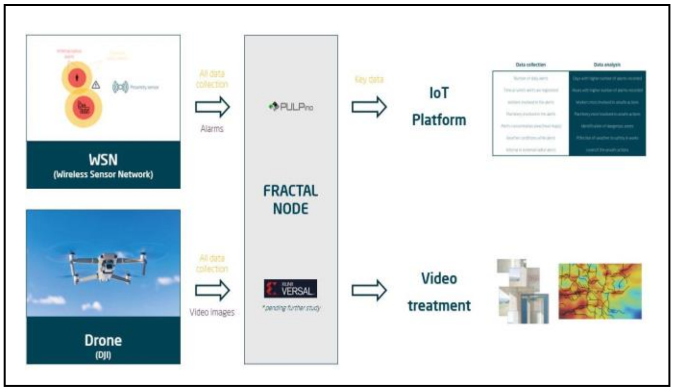

Fig. 3. Schematic representation of VER-UCI.

B. *Automotive air path control*

The use case deals with the development of a secure air-path diagram (Fig. 4) control strategy exploiting data-driven models, self-learning and self-adaption for the automotive sector. The main objective is to design intelligent control systems to reduce overall emissions and to enable the reaction to change in the environment (e.g., traffic situations, traffic light pre-emption). As such extensions to the state of the art require increased computational effort, the challenge of integrating such an intelligent system into a resource-constrained setting (e.g., electronic control units, mixed- criticality) needs to be addressed.

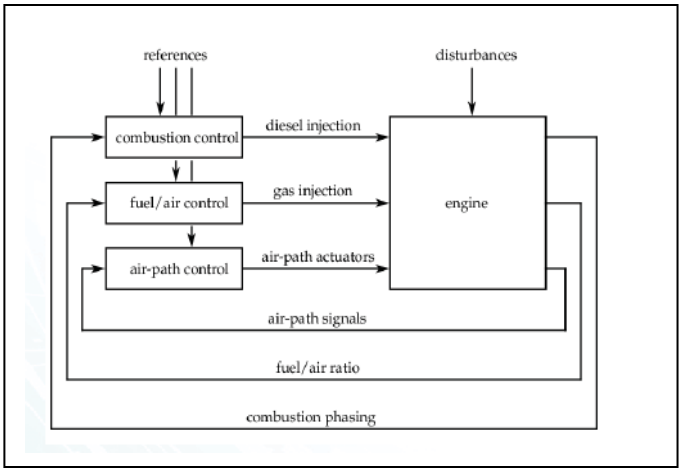

Fig. 4. AIR-path diagram.

C. *Smart meters for everyone*

Smart metering is a hot topic and one of the top use cases for the internet of things. The goal is to read the meters remotely by connecting them to the internet. This allows utility providers to remotely read the meters and would not be required to visit the customers and physically read the meters. In order to support smart metering, the meters and its infrastructure around the need to be electrified which is often not the case. Especially legacy utility meters such as gas, and water meters often work with pure mechanical principles. Such meters lack power supply and an electronic interface for accessing the meter stand. Electrifying the infrastructure and replacing these meters with a smart device that is connected to the internet is a big investment.

D. Low- latency Object Detection in Industry 4.0

A widely used object detection algorithm (e.g. YOLOv3, Tiny YOLOv3) will be implemented as a FRACTAL building block that guarantees execution time with advanced HW acceleration for vision-based object detection safe systems, guaranteeing bounds of execution time are critical for functional safety systems to build a sensor fusion for edge computing use cases.

Fig. 5 shows the links between FRACTAL Edge node and the FRACTAL cloud controller.

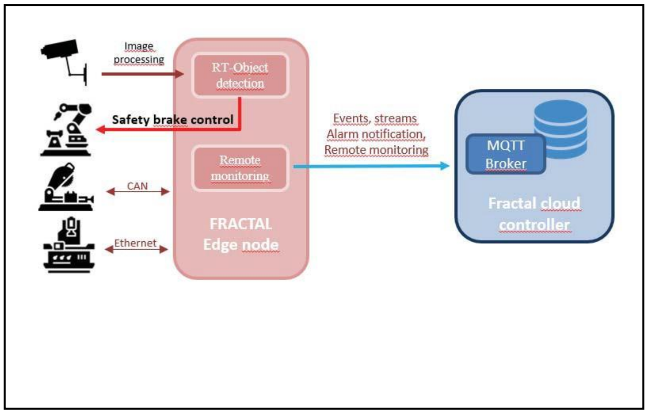

Fig. 5. Industry 4.0 use-case.

E. .Automatic accurate stopping and safe passenger transfer based on Computer Vision AI-enhanced techniques

An autonumus Urban Train use-case where artificial intelligence and high-performance computational capabilities are used to increase the dependability and the safety of the system. The objective is to apply Computer Vision (CV) and AI techniques to improve different autonomous train operation functionalities as precision stop, visual odometry, rolling stock coupling operation or person and obstacle detection-identification in railroads in order to reach a higher autonomy in urban vehicles and align them with railway European normative.

F. Intelligent totem

The goal of this use case is to apply the FRACTAL approach to develop an AI-based smart mobile totem, for advertisement and customer support inside shopping malls. These totems could have a disruptive impact on retail and shopping mall business providing personalized advertisements and product recommendations and driving customers towards their selected destination/product (wayfinding service). The platform will evolve into anthropomorphic robots with more advanced capabilities creating an even more immersive user experience. and enable their adoption not only in the retail sector but also in a smart city, providing service related to mobility, safety and security, logistics and goods delivery. Considering the processing algorithms (based on advanced AI approaches) which will be developed and used to extract meaningful proximity information, edge computing is needed to elaborate data collected using heterogeneous technologies. In fact, such context-aware mobile totem (Fig. 6) will be equipped with heterogeneous sensors (like cameras, microphones, proximity sensors, etc.) and therefore are able to collect a huge amount of data that can be processed to better understand their surroundings. Same sensors enable such autonomous objects to execute different tasks like patrolling and security monitoring during the night when the mall is closed.

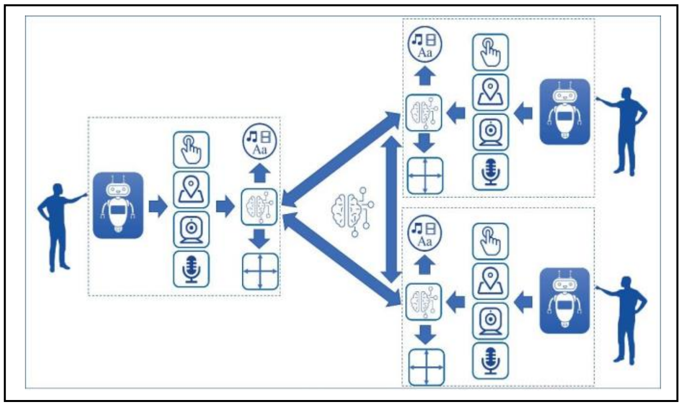

Fig. 6. Schemantic representation of the VAL-UC7.

G. SPIDER autonumous robot use case

The "Smart Physical Demonstration and Evaluation Robot" (SPIDER) is an autonomous robot prototype, shown in Fig. 7. Within this use case, they will integrate the Cognitive Edge Node developed in FRACTAL in their autonomous robot SPIDER and evaluate its applicability for performing computational intensive relevant vehicle functions of variable complexity at the edge of the network (near the source of the data) while still being able to guarantee extra-functional properties (dependability, timeliness) for preserving safety- and security operational behaviours.

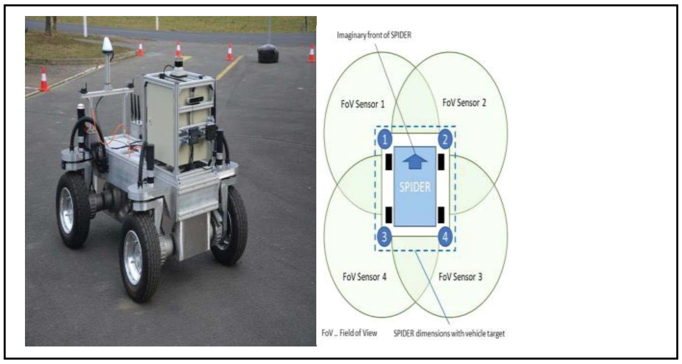

Fig. 7. SPIDER autonomous robot use case.

H. *Shuttle in Warehouse Systems*

The use case employs the FRACTAL technology for a warehouse with intelligent autonomous shuttles based on cognitive computing for swarm intelligence, thereby improving availability, throughput and safety. The goal is to improve the warehouse throughput, considering that delays in warehouse operation is critically undesirable, since it has a domino effect on the supply chain. The handling, storage and retrieval of warehouse goods by automated shuttles are optimized using Artificial intelligence techniques. AI will optimally organize and analyses the masses of generated data, in order to improve the warehouse throughput.

IV. IMPLEMENTATION

A. *Work plan — Work packages, deliverables and milestones*

The FRACTAL project will last 36 months and will be organized in 9 work packages as illustrated in Fig. 8.

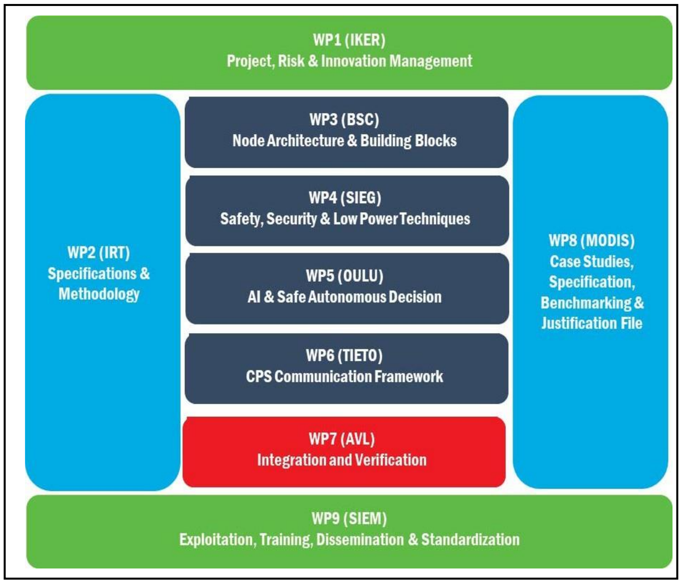

Fig. 8. FRACTAL WP structure.

The work plan can be summarized in:

WP1- Project, Risk and Innovation Management - This WP is devoted to project risk and innovation management to ensure progress at the technical level as well as administrative management allowing proper steering of the project and interactions with the EC and national authorities.

WP2-Specifications and Methodology - This WP represents our collective effort to fix the details and limit of how much we want to go ahead into the future and how much we can safely produce in three years. It is governed by **the fundamental principle of providing a fractal cognitive computing node** for edge computing. This WP is orchestrated by industrial partners at the beginning of the project and will bring the framework specification, the tools and interfaces needed, and their assessment in the use cases. The correctness and value of the FRACTAL technological innovations, methodology and tools, and the easy or taught of their integration depend upon the coherence and vision formalized in this initial effort of the project.

WP3-Node Architecture & Building Blocks - The main goal of this work package is to provide reference architecture of a cognitive edge computing node with FRACTAL properties. This reference architecture will be based on modularity and separation of concerns. Also, this WP will focus on the setting-up of a common repository of generic qualified components.

WP4-Safety, Security & Low Power Techniques - The goal of this work package is to develop safety, security and low-power services for individual FRACTAL nodes as well as hierarchical systems comprised of FRACTAL nodes with wire-bound and wireless networks. The services shall encompass fault-tolerance based on adaptive time-triggered computations and networks, security mechanisms in the presence of malicious attackers and taking into considerations intrinsic regulation and embedded platform constraints. Low-power techniques will ensure the suitability of FRACTAL for energy-constrained devices.

WP5-AI & Safe Autonomous Decision - WP5 focuses on FRACTAL approaches to AI, by giving emphasis to AI for context awareness and control as in the vehicle use cases and algorithms optimization for the edge as in the automotive and totem use cases. In addition, the mutability concept will be considered in order to autonomously adapt the FRACTAL system configuration and operation to the environmental conditions.

WP6-CPS Communication Framework - The goal of this work package is to design, develop and deploy the FRACTAL system engineering framework considering a microservices and containers-based software implementation. It consists of: (i) a processing platform at the edge with connection to different IoT devices and cloud platforms; (ii) and an edge controller infrastructure (in the cloud) to manage and control the edge nodes update and operation. This solution will follow a fractal configuration improving the scalability from Low Computing to High Computing edge node.

WP7-Integration and Verification - This WP will integrate the FRACTAL building blocks, technologies and methodologies apply to the cognitive nodes with well-identified performance, security and safety requirements. A verification task will be used to measure quantitatively and qualitatively the efficiency and effectiveness of the technological innovations, tools, methodologies, and asses the metrics established for the nodes. It has to be understood as a technological integration WP previous to the FRACTAL demonstration WP.

WP8-Case Studies, Benchmarking and Quality assurance - This WP demonstrates how the FRACTAL building blocks, technologies and methodologies apply to industrial applications with well-identified performance, security and safety requirements. The framework will also be assessed regarding productivity and usability aspects. Use-cases will be used to measure quantitatively and qualitatively the efficiency and effectiveness of technological innovations, tools, methodologies, and asses the metrics established for them.

WP9-Exploitation, Dissemination, Training and Standardization - This WP includes all the dissemination activities aimed at securing adoption at the edge industrial, CPSoS, Autonomous Applications and research stakeholder.

Basically, WP2 will develop the specifications and methodology that the rest of WPs will use. WP3 will develop the basic architecture of the FRACTAL node. WP4 to WP6 will develop the building blocks that will complete the FRACTAL node with Safety, Security, Low Power, AI, cognitive and communication capabilities. WP4 to WP6 will need to validate internally (intra-WP validation) each of the building blocks they provide. That intra-WP validation can be in many different means (simulation, emulation, etc.). When the basic FRACTAL node plus the building blocks are ready and validated internally into their WPs they will pass to the next phase in WP7. WP7 is a Verification Phase in which all building blocks will verify their functionality against what we call Verification Use Cases. This WP7 is an integration WP where WP3 to WP6 will interact with each other. Each building block has to choose a verification platform (PULP or VERSAL based FRACTAL node) and a Verification Use Case to verify the functionality of the blocks (this time is not an internal validation but a verification in an actual FRACTAL node). Once all the pieces of FRACTAL are correctly verified, they will pass to WP8 where FRACTAL overall technology will be validated against Validation UCs.

B. Consortium as a whole

FRACTAL consortium members have been carefully selected to cover all the required research areas in a well-balanced way, utilising their expertise, prior collaborations, and state-of-the-art technical background to match the project's objectives successfully. The partnership structure is based on excellence, complementarity, trans-nationality and multi-disciplinarily. The rationale for selecting organisations was to achieve:

- balanced consortium with an adequate inclusion of experts in all innovation domains;
- scientific and technical background excellence;
- high profile organisations for user involvement in the project;
- high exploitation and dissemination potential;
- top quality level of management.

The consortium brings together the resources of 28 participating organizations from 7 European countries (Spain, France, Italy, Austria, Germany, Switzerland & Finland), each excelling in their respective field. The FRACTAL partners cover important geographical areas in Europe and ensure that all the project outcome will have a lasting impact on European Technology Industry.

The FRACTAL consortium covers the whole value chain and represents a powerful balance between:

- Large enterprise (21,7% = 8 – CAF, PROI, LKS, MODIS, AVL, SIEM, XIL, TIETO, THALES);
- MindCaps/SMEs (34,8% = 9 – SML, ZYLK, RULEX; AITEK, ROT, QUA, BEE, ACP, OFFC);
- RTOs (34,8% = 4 – IKER, BSC, VIF);
- Universities (8,7% = 7 – UPV, UNIVAQ, UNIMORE; UNIGE, SIEG, ETH, OULU).

Scientific excellence: 10 knowledge providers representing the 44% of the FRACTAL consortium, from universities and research institutes brings excellence to the project. Furthermore, industrial partners bring not only their technical expertise and background into the project but also the prospect of commercial exploitation of FRACTAL results. FRACTAL brings together knowledge, expertise and innovation potential of major European actors that are among the leaders in the fields of edge computing technologies, as well as Key application areas (Autonomous Transport, Robotics, Maintenance & Inspection), and specifically in sectors where use-cases are framed:

- Autonomous Robots and vehicles;
- Inspection and Maintenance;
- Health;
- Advertising;
- Automotive;

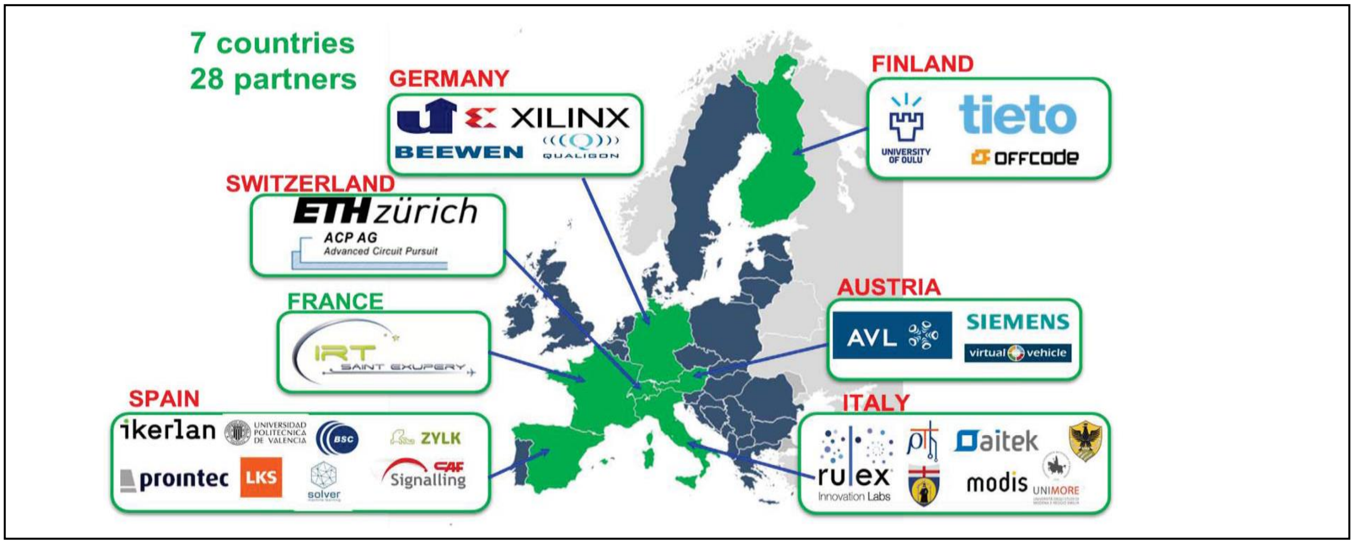

Fig. 9. Consortium Composition Map.

- Railway and Aircraft.

Furthermore, the consortium is led by IKERLAN, a RTO with extensive experience in the management of large EU projects and acknowledged expertise in integrating complex systems.

Top quality management: IKERLAN has a proven track record of managing large scale research and commercial projects. IKERLAN Innovation work leading big project can be demonstrated through recent examples such as SAFEPOWER, MULTIPARTES, LABONFOIL, INDUCTICE, ETEKINA, TEST-INN, BATTERIES2020, ANGELAB, VAR-TRAINER or Safe4RAIL-2 among others. Last but not least, IKERLAN will operate a dedicated Secretariat that includes a specialist that supports the amministrative management of the project.

V. CONCLUSIONS

This paper has presented the ECSEL FRACTAL project. The aim of the project is to create a reliable computing platform node, realizing a so-called Cognitive Edge under industry standards. The project builds on knowledge of partners gained in current or former EU projects and will demonstrate the newly conceived approaches to co-engineering across use cases spanning Transport and Industrial Control. As the paper is written at the beginning of the project, it focuses rather on the project introduction.

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