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► **To cite this version:**

Reda Nouacer, Mahmoud Hussein, Huáscar Espinoza Ortiz, Yassine Ouhammou, Matheus Ladeira, et al.. Towards a Framework of Key Technologies for Drones. *Microprocessors and Microsystems: Embedded Hardware Design*, 2020, 2020, pp.103142. <10.1016/j.micpro.2020.103142>. <hal-03185285>

HAL Id: hal-03185285

<https://hal.science/hal-03185285v1>

Submitted on 22 Aug 2022

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Towards a Framework of Key Technologies for Drones¹

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¹*This paper is a selected paper from EPDSD special session: European Projects in Digital System Design of Euromicro conference DSD 2019, “Réda Nouacer, Huáscar Espinoza Ortiz, Yassine Ouhammou, Rodrigo Castiñeira: Framework of Key Enabling Technologies for Safe and Autonomous Drones’ Applications, DSD 2019: 420-427”.*

Abstract- The potential applications for drones, especially those in manned areas or into non-segregated airspace, are currently not possible without the development and validation of certain key enabling technologies: “detect and avoid”, “air traffic management”, “command and control (C2) link”, and “security and cyber resilience”. This issue has a high impact on European innovation as identified by SESAR JU and demands R&D investments and incentives for the convergence of shared technologies and markets. In this paper, we discuss the vision of COMP4DRONES project to complement SESAR JU efforts with a particular focus on safe software and hardware drone architectures. COMP4DRONES will bear a holistically designed ecosystem ranging from application to electronic components. The ecosystem aims at supporting (1) efficient customization and incremental assurance of drone-embedded platforms, (2) safe autonomous decision making concerning individual or cooperative missions, (3) trustworthy drone-to-drone and drone-to-ground communications even in presence of malicious attackers and under the intrinsic platform constraints, and (4) agile and cost-effective design and assurance of drone modules and systems. Lead applications driving ecosystem development and benchmarking on the fields of transport, inspection, logistic, precision agriculture, and parcel delivery will be produced.

Keywords- Drones, Automation and Control Systems, Composition, Autonomy, Security, Safety, Interoperability.

I. TOWARDS AN EUROPEAN SINGLE MARKET FOR DRONES

Unmanned Aircraft Vehicles (UAV), also commonly referred to as **drones**, are air vehicles and associated equipment that do not carry a human operator, but instead fly autonomously or are remotely piloted. Drones are increasingly considered for commercial and government civilian applications, ranging from firefighting to agriculture through the generation of climate data, border surveillance, and so on. They can perform air operations that manned aircrafts struggle with, and their use brings significant **economic savings** and environmental benefits whilst **reducing the risk to human life**. They have already made the leap to leisure market, reaching millions of sales. Evolution on technology, regulations and society acceptance should favour an accelerated deployment of drones in professional applications. According to a 2017 study done by the Teal Group [1], the world civil drone production is forecast to make up \$73.5 billion in the next decade, soaring from \$2.8 billion worldwide in 2017 to \$11.8 billion in 2026, a 15.5 % compound annual growth rate in constant dollars.

Drone-based service and product **innovation** is curtailed by the growing dependence on poorly interoperable proprietary technologies as well as by the risks posed to people on the ground, to other vehicles and to property (e.g. critical infrastructure). In addition, the absence of a clear **regulatory framework** at EU level does not currently allow the creation of a truly European market for drone services and aircraft, which limits the potential for jobs and growth creation in this new sector of the economy.

For the **regulatory** aspect, because a professional drone is not an airplane, it is necessary to define an appropriate regulatory framework. For this purpose, the international regulatory bodies work together in the context of JARUS (Joint Authorities for Rulemaking on Unmanned Systems) initiative [2]. In addition to national authorities, Europe participates in

this work through EASA (European Aviation Safety Agency) [3].

Regarding the **innovation** aspect, the Single European Sky Air Traffic Management (SESAR) Joint Research Undertaking is developing a set of services and procedures to help drones access airspace safely and efficiently. In order to realize this potential, SESAR is developing the concept of U-space [4]. U-space is a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for large numbers of drones. SESAR’s vision is that of a harmonized, as opposed to a fragmented, single market for drones.

This issue was identified to have high impact on European innovation by the “*European Air Traffic Management (ATM) Master plan: Roadmap for the safe integration of drones into all classes of airspace*” [5] and the “*European Drones Outlook Study: Unlocking the value for Europe*” [6], both published by SESAR JU. These reports demand R&D investments and incentives for the convergence of shared technologies and markets as a remedy. Actions creating globally harmonized, commercially exploitable yet widely accessible R&D ecosystems in the following areas should be developed according to SESAR JU:

1. **Detect and avoid (D&A):** including cooperative and non-cooperative traffic, geofencing and resource constraint-based solutions to support smaller drone operations.
2. **Datacom and spectrum:** datalinks for command and control, communication for ATM, combination of different solutions: satellite, mobile phone networks, etc.
3. **Security and cyber resilience:** including risk mitigation related to malicious or accidental takeovers of datalinks leading to accidents, theft or deliberate use of drones to damage infrastructures.
4. **Human factors and training:** including situation awareness, transition to more automated drones, contingency and failure management.
5. **Validation and demonstration:** risk-based logic would enable the collection of data and observations to further refine concepts, while increasing public acceptance.
6. **Air Traffic Management (ATM):** to integrate drones in all classes of airspace.

The focus of **COMP4DRONES** complements SESAR JU efforts in regards to areas 1 to 5 with particular emphasis on software and hardware architecture of drone systems. The project is in its first year of solutions; technical work started on October 1, 2019 and will last 36 months.

II. PROJECT OBJECTIVES

The main goal of the COMP4DRONES project is to provide a *framework of key enabling technologies for safe and autonomous drones*. It brings to bear a holistically designed ecosystem, from application to electronic components, realized as a tightly integrated multi-vendor and compositional UAV embedded architecture solution and a tool chain complementing the compositional architecture principles [7]. The project will focus on the following specific objectives:

Objective O1: to ease the integration and customization of embedded drone systems. COMP4DRONES aims at developing a generic, modular/compositional and scalable

architecture to support efficient customization and incremental assurance of UAV embedded platforms.

Objective O2: to enable drones to take safe autonomous decisions. COMP4DRONES will design and develop safe and reconfigurable UAV software components that support autonomous decision-making concerning individual or cooperative missions.

Objective O3: to ensure the deployment of trusted communications. COMP4DRONES will develop a robust and efficient UAV communication infrastructure that ensures trustworthy drone-to-drone and drone-to-ground communications even in presence of malicious attackers and under the intrinsic platform constraints.

Objective O4: to minimize the design and verification effort for complex drone applications. COMP4DRONES will set-up and nourish an ecosystem of agile-oriented tools to support and automate the cost-effective compositional design and assurance of UAV modules and systems.

Objective O5: to ensure sustainable impact and creation of an industry-driven community. COMP4DRONES aims at building an open sustainable ecosystem around public, royalty-free and implementation-driven software platform standards



Figure 1 - U-Space roadmap calendar

In order to achieve its technical objectives, COMP4DRONES will use the outputs of other projects (methods, software / hardware components, tools, algorithms) that will be integrated with the new developments in order to exploit previous results as well as to continue the works in different technical areas addressed in different programs (H2020, ECSEL, EIT Digital, etc.).

H2020, RobMoSys [8] Setting up a system development framework for robotics (Papyrus4Robotics).

H2020, VI-DAS [9] Lightweight anomaly-based intrusion detection system for vehicles.

EIT, Cloud4Drones [10] IP-based reliable and high-QoS communications between a monitoring station and drones.

FUI, AIRMES [11] embedded and ground station technology for drone collaboration. Planning, tasks, zones definition for operations.

SESAR, CORUS [12] stands for Concept of Operation for European UTM Systems. CORUS aims to address VLL airspace, also including the airspace around airports.

ECSEL, AutoDrive [13] development of wireless communication technologies, including research on channel congestion, network topologies, protocols, etc.

ECSEL, PRYSTINE [14] development and implementation of (in hybrid CPU/SoC/GPU) advanced AI based fail-operational algorithms for sensor data fusion, object detection and classification, motion prediction and decision making.

that will ease the development of new UAV functionalities for multiple application domains.

III. RELATED WORKS

The European civilian drone roadmap, u-space, is piloted by EASA and SESAR. U-space is a set of new services aiming to enable drone traffic (including beyond visual line of sight (BVLOS)) to thrive while maintaining overall dependability and resolving security and privacy issues. Like the autonomous car, the u-space roadmap (Figure 1) is organized into four phases, COMP4DRONES project addresses phases U2 and U3:

- U1- e-registration, e-identification and geofencing.
- U2- flight planning, flight approval, tracking, airspace dynamic information, procedural interfaces with air traffic control.
- U3- capacity management, assistance for conflict detection, automated detect & avoid and C2 link reliability.
- U4- integrated interfaces with manned aviation, very high level of automation, connectivity and digitalization.

ECSEL, MegaMaRT [15] is developing a scalable model-based framework for continuous development and runtime validation of complex systems.

H2020, IntoCPS [16] tool chain for comprehensive Model-Based Design (MBD) of Cyber-Physical Systems (CPSs). COMP4DRONES will reuse multi-domain simulation framework of intoCPS.

H2020 Galileo, AUDITOR [17] will provide to exploit GNSS ground based augmentation techniques (e.g. improved ionospheric corrections), multi-band cost-effective receivers.

SESAR, ARIADNA [18] European Project led by Indra which objective is to allow drones to be able to operate in the area of the traffic of a conventional airdrome (non-segregated airspace). This is one of the first flying experiences undertaken in Europe for a drone to be able to operate in the area of the traffic of a conventional airdrome.

IV. WORK TO BE PERFORMED AND EXPECTED RESULTS

In the following sections, we indicate in detail the main ambitions that will be addressed by the **COMP4DRONES** consortium as follows:

- Integrated Modular Reference architecture for Drones
- Safe autonomous decisions
- Trusted communication
- Minimizing the design and verification

A. Integrated Modular Reference architecture for Drones

The main objective of this R&D challenge is easing the integration and customization of qualified systems embedded in drones. The goal is to provide reference architecture of a flexible embedded platform inspired from the avionic practice (i.e., ARINC-653). This reference architecture will be based on modularity and separation of concerns. In addition, we will focus on setting-up a common repository of generic qualified components maintained by the drone's community. The availability of such an integrated modular architecture will be a step forward with respect to the current state-of-the-art.

In existing open autopilots, even if a modular object approach is employed, to the best of our knowledge, there is no component-based autopilot approach. However, this would be a very important contribution to raise the diversity of sensors and actuators that can be used for piloting a drone, and especially in the scalability of drones in their different versions and improvements.

Nowadays, the coding of drone embedded software programs is manual and ad-hoc. That is, the reuse and adaptation of the open source software is a frequent practice. Numerous SME use an existing open source autopilot (e.g., Cloud Cap Technology [19], Paparazzi [20], ArduPilot [21] or PX4 [22]), where its customization is difficult and its mastery requires a lot of time and efforts. In fact, capitalization of drone software's product lines is limited due to the lack of a methodological framework dedicated to reusable software components. Drone SME have a multi-physics expertise but not necessarily a software expertise. Thus, developing this latter may represent a significant cost since they do not have the financial capacity to recruit security and/or certification experts. Furthermore, lack of tools and normative constraints lengthen deadlines, increase development costs, and generally hinder innovation (new manipulator arms, new sensors or actuators, new types of mission, etc.) that drones' manufacturers would like to integrate into their platforms.

There is no standard autopilot, however, there are many open source ones, like Paparazzi, ArduPilot or PX4, supported by many hardware platforms. These autopilots provide several versions depending on the type of underlying drone structure: rover, helicopter, quadcopter, hexa-copter, plane, vertical take-off plane, etc. The software architecture of ArduPilot, programmed in C++ is designed to be portable, however, still very complex to adapt. Given its size and versatility, it is very unlikely that the code can be certified according to avionics standards. In addition, to maintain its compatibility with versions running on architectures that do not support multithreading, ArduPilot uses a cyclic execution model that can only run on a one computing core.

The interest of open source autopilots is their versatility and their speed of adaptation to be supported by new hardware platforms thanks to the developers' community. Indeed, they are characterized by a layered architecture. The physical layer, device drivers' layer, and device driver glue layer (which is hardware platform dependent), but the autopilot software layers are almost independent, and require few or no adaptation for new platforms hardware. However, these architectures focus only on minimalist activities such as missions based on drone movements, integrating commands flight and navigation. Then, software layers are not changeable without having to

spend big effort in coding, and they only integrate typical sensors/actuators known by public.

In the vast majority of autopilots, there are two regulation loops. The attitude regulation loop, which is fast since its frequency generally, is from 50 to 400 Hz. The navigation loop serving in autonomous mode or in controlled mode like geofence mode, making possible to move the controlled drone from a point A to a point B, calculating a trajectory, and transforming this objective into an attitude setpoint forwarded to the fast loop.

Note that from a technological point of view, it is possible to have software components executed in external processes and to use them as inputs of the navigation loop. However, that will generate typical delays from few tens to hundreds of milliseconds. That is the use of external software components with the fast loop is impossible since that requires a deep code modification of this loop. Many autopilots use the MAVLink communication protocol, which is not a standard, but it can be considered as de-facto standard for drone-to-drone or ground station to drone communication. It allows in particular the use of different ground stations for the same drone.

In the early 1990s, basic internal architectures of large and medium-sized aircraft avionics were based on federated architectures, where each functionality of the aircraft, for instance flight control or navigation, was implemented by dedicated hardware and software. This was the easiest solution to isolate any potential failure, so as not to affect other features [23]. However, with the increase in the number of functions required for aircraft, the federated architectures presented scalability problems [24], which triggered a shift towards integrated modular architectures (IMA). The IMA architecture uses innovative technical solutions that allow various functionalities of the aircraft to share common hardware (processing modules, network, etc.) while maintaining the same safety integrity levels provided by the physical isolation of the federated architecture [25]. Since then, IMA-based architectures have been evolving towards increasingly distributed setups in which the I/O tasks are transferred from the centralized processing modules usually placed at the aircraft electronics bay, into decentralized elements called remote data concentrators (RDC). The RDCs connect to each other and to the processing modules through a high-capacity deterministic avionics network. With this modification it was possible to further optimize the architecture by placing the RDCs in the vicinity of the sensors and actuators of the aircraft, reducing the amount of cabling used.

Additionally, by focusing more on the software rather than in specific I/O tasks, it became possible to use off-the-shelf processors reducing the heterogeneity of the avionics system and consequently the cost. We believe this trend in the aircraft industry domain towards Distributed Integrated Modular Avionics (DIMA) architectures can be adapted into the drone world. It provides the advantages in terms of safety through modularity and isolation, and ease of certification and scalability by supporting the swapping of payloads/sensors without compromising the airworthiness of the drone (see Figure 2). This innovative approach will enable an unprecedented level of safety and reliability in these aircrafts, while maintaining a low system cost and flexibility.



Figure 2 - Composability & Modularity for Customized and Autonomous Civilian Drones

This however, requires adaptation of the architecture to the energy/weight ratio and cost class of drones in comparison with manned aircrafts. In particular, the underlying avionics communication network such as the Avionics Full-Duplex Ethernet Switching (AFDX) [26] presents several drawbacks. Its implementation is expensive, since it cannot be done using Commercial Off-the-Shelf (COTS). Ethernet components and the switch-based topology, designed for large aircrafts, is not adequate for small aircrafts due to the weight required. Thus, we seek to take advantage of the reduced distances between the various avionic components to implement a point-to-point digital network using COTS components where possible, in order to reduce costs, weight and space. In order to maintain an equivalent reliability however, it is necessary to develop mechanisms to ensure determinism in communications, in order to address the needs of redundancy, synchronization, traffic policing and routing.

However, this degree of predictability must not only be present at the communications but also at the software level. Another challenge we are tackling is the integration of this architecture with robotic software development frameworks such as the Robot Operating System (ROS), promoting software and tool re-use. ROS [27], maintained by Willow Garage [28] and Open Source Robotics Foundation (OSRF) [29] since 2007, is an open-source middleware that has undergone rapid development [30] and has been widely used to design robotics applications. ROS aims at easing the development process by providing multiple libraries (e.g., OpenCV and the Point Cloud Library (PCL) [31]), tools and algorithms, and a practical publish/subscribe transport mechanism.

Importantly, an effort is being made to avoid sources of non-determinism, towards supporting real-time safe memory allocation and synchronization, and an adequate communication middleware that is able to cope with real-time QoS requirements. Therefore, we will carry out an evaluation of ROS2 [32] in terms of real-time performance to identify a set of issues that need to be addressed to effectively support an effective integration with the avionics architecture. In addition, considering these proposals are very much in-line with ROS2 developers' road-map [33], we plan to actively contribute to the framework with the outputs from the project.

Moreover, we plan to unify the existing software bricks for drones, by creating a repository of software components. In

fact, libraries must be proposed in order to first unify the current software components (e.g., Paparazzi UAV project) and to enhance the reuse and interoperability. These shared components must be well defined and characterized, to check their non-functional properties and validate their use regarding a given context of new missions by taking into consideration accuracy and safety constraints.

B. Safe Autonomous Decisions

The drones' market is rapidly growing in both the consumer and business areas. Drones are ideals in many applications as safety & surveillance, construction, agriculture, logistic and many more [34]. One of the main challenges is that current drone systems are too complex to be safely operated by humans; this can result in harms to people and property. Relying on humans is not only unsafe but is also inefficient in any application. For this reason, in the **COMP4DRONES** project we will take an integrated and transversal approach to the problem. We will start from developing Artificial Intelligent systems capable of manoeuvring safely the drones as well as robust and communication systems for high reliability of the control connection (see Figure 3).

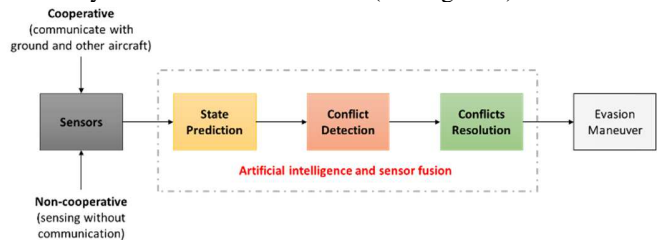


Figure 3 - Safe autonomous decisions

Until recently though, application of aerial robotics was limited to low-risk outdoor use cases based on GPS navigation, due to inability to navigate safely in close proximity of objects and humans. Collision tolerant systems have come to market that enable remotely piloted missions in GPS-denied environments, allowing the drone to hit walls, contact objects, and even fly into humans without compromising its mission. However, these collision tolerant drones have not yet made use of vision-based sensing for stabilization and navigation, making them difficult and demanding to operate and accessible only for trained pilots, and restricting options for automation. For wider adoption of unmanned technology in GPS-denied environments, the ease of use and level of autonomy of these solutions needs to be improved. R&D should therefore be focused on self-navigation without use of external beacons, instead using onboard sensing and simultaneous localization and mapping (SLAM) for positioning, obstacle avoidance, and navigation.

In general, mobile robots need to perceive and make sense of the environment to be able to navigate in it. For this reason, autonomous drones should carry lots of sensors such as cameras, inertial measurement units, sonars, lidar, etc. State of the art sensory systems that perform information fusion and big data analysis are based on high-performance computing architectures (GPUs or CPUS). Alternatively, these systems are based on cloud services because of the large power requirement of the complex algorithms. The aspect of combining multiple streams of information is a key element of

deep belief networks, a class of neural network that is currently setting state of the art performance in a broad range of classification tasks [35]. The great potential of sensory fusion and deep belief network has already been recognized by the academic as well as the industrial community [36]. The implementation of sensory fusion algorithms in dedicated hardware accelerators (such as neuromorphic systems) is beneficial for several reasons that include a) concurrency in processing (memory and computation are co-localized) b) event-based processing which enable to process information on demand c) low-power consumption d) compatibility with embedded systems e) ability to learn and adapt to specific situations. The exploration of sensory fusion to elaborate sensor's data on the robot itself without the need of transmitting high-data rate to cloud services is appealing for increasing security and the overall system abilities.

During the project, we will develop smart navigation systems that will exploit neuromorphic hardware together with safe ad-hoc software routines. The objective of our work is to provide neural network closed-loop perception and computational methods that can enable a new class of computing technologies for ultra-low power navigation and exploration in unknown environments. We will improve state of the art by developing efficient event-based neural network algorithms and on-line learning strategies in neuromorphic hardware for on-demand, massively parallel, and low-power computation. The tasks that we will explore are essential for autonomous navigation and include Simultaneous Localization and Mapping (SLAM), optic-flow computation, ego-perception and closed-loop motor control with a tight interconnection among perception and control. The output of the project will be novel data-driven neural network architectures validated in FPGA platforms. These computational architectures will target drones or other robotic platforms, enhancing security and performance of autonomous vehicles therefore stimulating the European industry with a new generation of adaptive computational architectures.

Part of our ambition is the development of sensory fusion technologies for real-time applications, such as visual object recognition, attention, and multi-sensory integration. To do so, we plan to improve state of the art by developing data-driven and event-based computational modules, that will perform on-demand processing and that will exploit the computational properties typical of neuro-biological systems, but embedded in novel neuromorphic architectures. This will result in an increase of the efficiency and robustness of computational architectures that will be finally able to be applied in autonomous vehicles with tight power constraints (as drones). The anticipation and the foresight of novel massively parallel and brain inspired IC architectures can greatly boost Information and Communication Technology (ICT) industry and it is one of the most relevant challenges when building autonomous cognitive systems.

In the specific, the robotic path planning and navigation problem is practically embedded in any robotic applications in both industrial and civil functions. Given a robot with a description of its dynamic, a description of the environment, the problem is to safely move the robot in the environment as planned by a mission controller, for example from location A to B. Most state-of-the-art systems are concerned with the construction of trajectories optimized for a specific purpose.

An example is the lane following task in autonomous driving. Recently, much research is being done on outdoor vehicles without a complete knowledge of the world. Sensory information is acquired and used during path planning to generate the next target. Many algorithms are sampling-based path planners, such as the Probabilistic RoadMaps (PRM) [37], the rapidly-exploring Random Trees (RRT) [38], the arbitration scheme, and the way-point type algorithms [39]. In general, these types of path planning schemes are incremental, in the sense that the sensory information is used to determine the 'best' local path segment based on some measurements. Even if these algorithms work well in practice, little efforts have been made in trying to develop energy efficient algorithms for embedded applications in which constraints of hardware are also considered.

With the recent advent of deep-learning, novel navigation and path planning algorithms based on deep networks have been proposed [40]. Here the challenge that we are after is the development of computationally efficient and low-latency neural-inspired algorithms that consider robot's computational and motor constraints as well as the complexity of the environment, while at the same time allowing for expressive task specification thanks to adaptation and learning mechanisms. The reasons to these explorations are multiples.

First, there are already several efficient, massively parallel, fast silicon architectures that have been designed to accelerate spiking neural networks [41]. These architectures are paving the ground in machine learning with novel and powerful computational algorithms that already are showcased in several applications [42]. Additionally, it has been shown that the accuracy and the precision of networks on classification tasks is guaranteed to improve when scaling the network to a larger size [43], implying that scaling network size in an ad-hoc architecture can give higher accuracy and better performances. This means that scaling and architectures are crucial factors when designing spiking neural network in accelerated platforms faster than general-purpose computers.

Secondly, using spiking neural network offer a fundamental advantage when used in very large-scale networks over traditional deep networks, this is because scale is not the dominant factor in processing time, because unlike standard computational architectures, the computational units (neurons and synapses) are both parallel and event-driven.

C. *Trusted Communication*

Regarding the security related aspects, the innovation that will arise by means of the present project will be a security component. This component will be in charge of dealing with the identification of cyber-security threats, their risk and scope evaluation and the deployment of the decision and/or actions to mitigate or protect against those attacks following the analysis carried out by [44]. This will be reflected on the following innovation aspects that will try to advance on the current state of the art.

Currently existing security/safety monitoring and control management methodologies and mechanisms are not focused or particularized for the drone domain. Thus, they do not satisfy the set of extra-functional requirements that this type of domain demands. For example, the monitoring of safety-relevant and security-relevant variables for drones such as (safety: battery life, signals intensity, trajectories, etc.; security:

software versions, abnormal execution partners, etc.) must be taken into account very carefully. This implies that an advanced Thread model that takes into account safety and not only security should be defined extending the model defined by [45].

The other innovation will arise from the fact that depending on the type of drone it will not be able to perform heavy security adaptation operations. Thus, it will be necessary to develop technologies that are able to guarantee certain simple logics that are enough to ensure safe and secure deployments of drones leveraging at the same time the energy consumption and communication capabilities of the drones [46]. The developed approach will be validated by means of representative attack scenarios that go beyond of simple attack scenarios that have been commonly evaluated [47].

Recent works [48], [49], [50] in the field of neural network-based anomaly detection for network threat detection have obtained very good results by means of original architectures. A good overview of latest trends in the area is found in [51], which also identifies interesting development axes. Among these, the need to adapt to architectures made up of constrained nodes and the identification of optimal network features have yet to be addressed.

Vehicular anomaly-based intrusion detection systems have recently been shown to achieve good results especially for deterring GPS spoofing attacks [52]. This is all the more useful as an interesting terrestrial attack scenario was successfully demonstrated [53] in 2017. Here again, the proposed scenarios have to be adapted so that the machine learning primitive can be operated (likely in a distributed manner) on an architecture involving constrained nodes. Additionally, the proposed approach would advantageously be extended so that anomaly detection can be carried out jointly on network metadata and sensitive data. To the best of our knowledge, works in this direction applied to unmanned vehicles have not proposed yet.

COMP4DRONES will design distributed lightweight machine learning primitive for carrying out anomaly-based intrusion detection based on network metadata and applicative data (see Figure 4). Especially, a neural network architecture will be conceived that will be able to intelligently parse data relevant to multiple network or applicative data and temporally match anomaly detection results on them with one another in order to refine the overall detection quality.

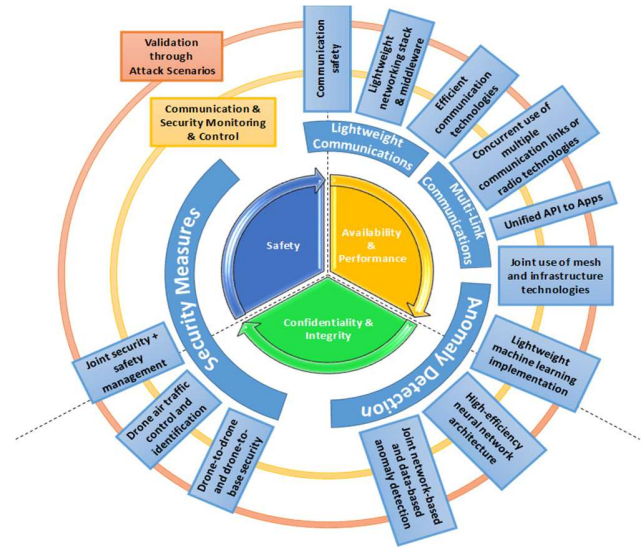


Figure 4 - COMP4DRONES trusted communication framework

The neural network framework will be specifically built for considered traffic that does not only include hyper optimization but also specify the best detection methodology (classification, prediction, network behaviour “coding” by means of an auto encoder) and the corresponding pre-processing steps (identification of the most relevant features and feature extraction). Special care will be taken in all steps of the neural network design to keep its surveillance operation affordable on the drone itself. The learning operation, on the other hand, will be designed in order to be remotely performed, since it would likely be too heavy for the drones.

Long flights away from the base means that the connectivity with the base station (BE-LE, 802.11-based, etc.) may get weak or lost, and other back-up measures are needed. Therefore, **COMP4DRONES** will develop connectivity aimed at drones to ensure higher availability by employing unified, heterogeneous technologies into a more robust single connection from vehicle to ground (and vice-versa). Even for a drone not intended to fly outside a short range, this is an essential safety feature. Current technologies to address these issues include multipath routing, in which a segment of the IP route is covered by multiple links, bonded into a single link with higher reliability, availability and bandwidth (depending on the configuration) than the single base links. The currently available implementation (actively developed and maintained by a strong community) in the open source networking community is Multipath-TCP (MPTCP) [54]. This system is currently at version 0.94, and slowly gaining foothold in the commercial world. Alternative systems (for instance based on UDP) exist, but have not reached maturity and are not being actively maintained. MPTCP includes a standard path manager for the monitoring and management of the underlying links, which is implemented at the kernel level, as a more or less integral part of the MPTCP-extended TCP stack of the operating system (Linux-based in the latest releases).

The ambition within **COMP4DRONES** is to develop an improved path manager for use in communication with (unmanned) aircraft, and enable it for multiple, heterogeneous communications technologies at OSI level 4 (see Figure 4). Specific technologies will be selected based on the concrete

demonstrator among, for instance, BT-LE [55], 802.11, relevant subtype to be determined [56], LTE/5G with LAN capabilities [57], VSAT or sat phone (if available), NB-IoT [58], etc. The path manager should select the best combination of technologies for the flight situation (phase of flight, position/altitude, speed, etc.) and the payload requirements (amount of data to transmit, time constraints (for instance, whether real time communication needed for the active mission).

The purpose of a higher-reliability connectivity system is to ensure that important information reaches the vehicle (or the ground). For that purpose, it is important that applications on board the vehicle (whether related to the control of the vehicle or information to/from the payload) are able to adjust the use of the communication channel to the available bandwidth and latencies. To facilitate such prioritized communication, an API will be developed to communicate connection quality and availability as well as available resources (unused channels, if any) that can be employed if needed by the applications. The API will also allow applications to send requests for higher levels of connectivity if needed.

D. Minimizing the Design and Verification Effort

One of the main objectives of **COMP4DRONES** is minimizing the design and verification efforts for complex drone applications, ensuring that new services based on drones can be devised and offered by companies of any kind, especially SMEs [59]. As a result of the research and development activities to be carried out in the project towards this objective, **COMP4DRONES** will deliver an agile, system engineering framework providing the system engineer with all the resources required in modeling, composing, optimizing, verifying and implementing complex services based on the use of fleets of drones. The availability of such an integrated design and verification framework will be a step forward with respect to the current state-of-the-art.

Drone systems is considered as open and distributed systems that can interact/coordinate in an autonomous manner to achieve certain specific goals [60]. These devices operate in an open environment, where there is no complete knowledge of the surrounding world (i.e. it is not possible to have the complete state of the world, thus, it is necessary to take into account the uncertain nature of the environment). Thus, new approaches (methodologies and technologies) for validation and verification are necessary to be able to deploy safe and secure system solutions.

In addition, these kinds of environments need a tight combination of the cyber capabilities (distributed application SW, communication protocols, cyber-security issues, etc.) of the corresponding devices with the physical world (different variety of sensors and actuators) requiring novel verification and validation challenges. These are the main challenges:

- Connectivity combining both open and closed networks,
- Plethora of resource constrained devices,
- Highly unpredictable non-controlled environments,
- Dynamic and heterogeneous environments, not only in terms of number of devices but also in terms of number of protocols, infrastructures and platforms,
- Non-functional requirements such as safety and security,

- Highly unpredictable behavior of autonomous devices/systems.

In this way, the application of UAV and UGV concerning surveillance and inspection tasks has spurred research in areas of localization, mapping and path planning. There are many different areas such as patrolling of infrastructures, search and rescue operations, infrastructure inspection, crops and orchards monitoring where the use of autonomous robotic platform can be advantageous. The path planning is traditionally tackled either using sampling-based algorithms such as RRT* or PRM or employing trajectory optimization methods based on optimal control. The optimal control-based solutions are often formulated as Model predictive control, Mixed-integer linear programming or Pseudo-spectral optimal control problems.

In order to be able to perform path planning tasks, it is necessary to acquire a map of the surrounding environment, i.e. to assemble the topology of configuration space and thus state the constraints of the problem, and then to localize the robot in the environment. These two problems are solved using SLAM methods providing both the map and pose of the robot. The SLAM methods use data from various type of sensors such as optical cameras or LiDARs or their combination and build maps represented usually as evidence grids, point clouds, meshes or topological graphs.

On the other hand, the safety regulation of drones is already a hot topic that is expected to be the focus of regulatory and standardization activities in the coming years with a strong impact on drone manufacturers.

The JARUS association defines the standard to be applied for drone operations [61]. This standard will prescribe conformance rules applying both to behaviors of drone fleets as well as on drones designing processes. A particular attention is paid to how AI components may question safety.

Workflow Engines are already used to enable standard compliant engineering and generation of certification reports in the automotive industry (follow ISO 26262 process and provide reports of standard-compliance). **COMP4DRONES** will extend currently available workflow engines for drone systems. Its adaption will mainly consist in extending the workflow engine for the usage by drone manufacturers. An important part is that the workflow engine can interact with other tools and integrate them in the complete system engineering framework.

Current practice for validation of correct path management in Multipath-TCP systems is to use manual methods based on observation of packet flows under varying connection conditions, as well as manually obtained statistics of packet distributions over subflows by parsing and analyzing TCP dump output. There are no commercially or open-source available tools to systematically analyze internal state of path management algorithms. Validation of the collection of connection metadata is made currently by manually compare measurements data obtained from cellular module firmware with data obtained from the TCP/IP stack. The two types of data are typically not congruent and/or protocol overheads obscure differences in the data obtained at different levels.

To enhance the possibility of more reproducible validation of connection metadata, **COMP4DRONES** will develop models to associate obtainable metadata from wireless connections (including radio connection quality, packet delays

and packet delay variation, etc.) with values of transport- and application-level connectivity quality. The project will further implement and demonstrate technology to validate the model via automated systems to run test suites and data collection for the validation in laboratory settings and controlled test flights. To enhance the possibility of more reproducible validation of path management of multipath communication for drones, **COMP4DRONES** will implement and demonstrate technology to validate the path manager's ability to direct communication packets over the most reliable path under constraints of desired packet delay times for the connection. This will be automated to run test suites and data collection for the validation in laboratory settings and controlled test flights.

As commented above, drone applications require the integration of various design and verification technologies into a coherent system-engineering framework. First, it is necessary to model in a generic, platform-independent way the complete application that the drones have to implement [62]. Model-driven engineering (MDE) is a form of generative engineering in which one or several parts of a computer application are generated from the models. In this perspective, several domain specific languages have been proposed for the embedded system domain like MARTE [63] and AADL [64] dedicated to design real-time systems, and RobotML [65] dedicated to design robotic application systems. These existing languages can be used to help the design of drone systems; however, they must be distilled and tuned according to the **COMP4DRONES** design methodology. MARTE and AADL are agnostic for any type of real-time and embedded system, focusing on hardware/software architecture, while RobotML is dedicated to robotics with lack of implementation support. The state of the art misses a DSL focusing on drone and addressing both the functionalities and the implementation and deployment.

The objective of **COMP4DRONES** is to provide modeling artifacts to model modular components, which should be characterized by their functional and non-functional requirements. These artifacts can lead to create a new DSL or to reuse existing ones and adapt them to **COMP4DRONES** design methodology needs. The language should allow to model components, platforms based on components and also ease the assembly of components for a functional verification and non-functional verification (e.g., time, energy, etc.) to be applied.

This holistic model will allow the development of the functionality and the exploration of the different mappings of the functional components to the computing resources being considered such as the drones, base stations, servers and, eventually, the cloud [66]. System verification will be made possible at the different design steps, from functional simulation (SW-in-the-loop), virtual models with different speed/accuracy trade-offs and even, HW-in-the-loop. In this verification steps, both functional and non-functional constraints have to be checked. In this sense, performance analysis is an essential technology to be integrated. Host-compiled simulation will play an important role, as the speed/accuracy ratio can be tuned to the required level [67]. Modeling the uncertain nature of the environment including human behavior is essential. Formal methods should be applied when necessary.

In the domain of formal verification and model checking, there has been considerable progress the past decade to

guarantee properties of system behavior. However, autonomous, embedded systems are characterized by being embodied in an environment, which it may not entirely control. As such, it is hard – if not impossible – to formally guarantee correct behavior of an autonomous system under any environmental assumptions. Such assumptions are necessary, yet obviously must be kept to a strict minimum to allow the autonomous system to behave correctly in a wide variety of environments.

COMP4DRONES builds upon achievements in guaranteeing correctness of automated planning systems under strict assumptions. While existing research can assure correct decisions, harsh environments may prevent a system to achieve its goals. Innovative approaches must assure that any step the system makes is expected to achieve strict progress, that is, no cycles can exist in the reactive behavior of the system. This may entail environment assumptions, yet we aim for an iterative process, where gradually minimal assumptions are added until the required correctness validation can be achieved. The end result will be a validated approach for reactive planning behavior, with predictable behavior under all circumstances with the boundaries of the assumptions. This can make the basis for the validation that can be crucial for certifying the system.

Having a flexible, reliable platform, that has the potential to be certified, and that can offer guaranteed behavior for specific missions, is primordial for automated missions. Such a platform and associated approach for mission development will bring a substantial competitive advantage over ad hoc approaches that exist today. Such missions are particularly important for offshore industrial inspection. People may not be continually available on offshore locations to perform inspection, and the potentially harsh conditions make that the operators will expect clear and precise indications of the assumptions that the autonomous system is relying upon to perform its mission.

If one cannot guarantee correct and safe behavior (e.g. under severe wind conditions pre-op), the autonomous system will not be entitled to perform its missions. As such, this project will make a major breakthrough – not because of hardware that is resilient to weather conditions, but because of additional guarantees of the autonomous behavior of the system. The developed test infrastructure, algorithms and methodologies for validating safety, robustness and flight performance of the navigation system (sensors, autopilot, flight algorithms) of inspection drones before performing test flights, will yield substantial benefits for drone service providers, end users, validation and certification service providers, and integrators.

Interactive user interfaces able to visualize the drone mission and provide the system engineer with the required information is an important art of the problem. Environments like Djnn will help in this respect [68].

The application tasks need development of suitable methods that properly incorporate the goal of these tasks. Therefore, path planning has to consider not only the immediate goal of the visiting predefined waypoint but it also should assess whether the proposed trajectory can provide the sought information for the task completion in the optimal manner. The problem formulation thus needs to incorporate additional constraints that reflect e.g. a request for the best

view of the inspected objects, full coverage or mapping of the inspected area in minimum period or combination of them.

When employing multiple robots, the optimal distribution of agents and/or assets must be assured where additional constraints have to guarantee trajectories without collisions. Such formulated problems require development of suitable methods that make the solution feasible and applicable in real time. Besides providing the constraints for the path planning in form of a map, the solution to the mapping problem should also provide information about frontiers that would be most valuable for exploration, i.e. the path planning and mapping should mutually support each other. The exploration of multiple changing environments presents also a challenging problem, which requires different sets of sensors. Thus, design of the algorithms for efficient sensor fusion is another important task that needs to be pursued. This incorporates also the problem of proper sensor modelling for the calibration and estimation tasks.

Drones are critical real-time systems whose designs should meet timing requirements otherwise a catastrophic failure may occur. For this reason, several scheduling analysis tests have been proposed, in the literature, dedicated to uniprocessor architectures [69], multi-processor architectures [70], mixed criticality [71] systems, etc. In the context of **COMP4DRONES** several scheduling analysis tests will be developed and existing ones will be tuned to cover specificities of different use cases (in terms of software platforms, communications and hardware execution resources). To ease the use of these analysis tests by non-experts via a collaborative engineering process, analytical models expressing drone's temporal requirements can be expressed in languages as MoSaRT [72] and Time4Sys [73].

An important specificity of **COMP4DRONES** is that the control components should have a special interest in order to enhance their quality. That is, usually in case of integrated control and real-time scheduling, the quality of control improvement is mainly based on the dynamic measurement process and the system task scheduling parameters (i.e., sampling period, execution time) [74]. Besides, the number of analysis tests and their accuracy which depends on the kind of system under-analysis. Thus, choosing the right tests (to avoid optimistic analysis result, which may lead to catastrophic failures) by a drone designer (who is not necessarily familiar with the scheduling analysis domain) is error-prone since it is a hard task and requires a deep knowledge and good experience.

We will develop and adapt scheduling analysis tests dedicated to the use cases architectures by taking into account their temporal requirements and specificities. We will also contribute by enhancing the MoSaRT and Time4Sys methodologies to the context of drones, by helping designers to be autonomous during the analysis phase, and to help analysts to share their tests easily. Thus, we propose to develop an analysis repository, which can be implemented according to chosen language used to specify the temporal properties of the system. The repository will orient designers to choose the right tests and will deal with the transformation from the drone designs formalism to performance analysis tools.

Flight time is a major limitation and design consideration of battery powered drones. Energy usage is primarily depended on the weight of the system as well as battery capacity. Planning of autonomously executed drone missions have to take into

account energy budget of the mission [75]. Energy budget have to take into account weather conditions as well as individual tasks of the mission. Drones that have modular payload have to also take into account variability of the physical setup of the drone. Aim is to develop algorithms and tools that can be used in mission planning to generate mission plans that can be executed with high success rate. Problem of mission planning also spans to wider scope when planned mission cannot be executed with single flight. In such cases task prioritization and mission breakdown must be done.

Finally, when the model satisfies the functional (mission, data transfers, AI, etc.) and non-functional constraints (safety, security, mission times, etc.), the code to be executed on each computing resource will be automatically generated from the model.

The availability of such holistic system-engineering framework for drone applications will be an innovative breakthrough over the design methods currently being used. The framework will simplify the design and verification effort of drone engineers and therefore, will enable the development of more advance, more complex drone projects at an affordable cost. This will open the way for a wide ecosystem of competitive European companies providing advanced services based on drones, most of them SMEs.

V. DEMONSTRATORS

Demonstration and validation activities are essential to ensure the quality and relevance of innovations. **COMP4DRONES** achievements will be benchmarked and demonstrated through the following domain specific use-cases:

- UC1 – Transport (Leader: INDRA - Spain): application of drones for optimization of transport control, operation and infrastructure management.
- UC2 – Construction (Leader: ACCIONA - Spain): smart application of drones for virtual design, construction and operation of transport infrastructures.
- UC3 – Logistics (Leader: TOTAL - France): logistic using heterogeneous drones' fleet.
- UC4 – Surveillances & Inspection (Leader: Thales - Netherlands): drone and wheeled robotic systems for inspection, surveillance and rescue operations with enhanced navigation and autonomous abilities
- UC5 – Agriculture (Leader: AIT - Austria): smart and precision agriculture from drone to rover

Nevertheless, **COMP4DRONES** framework could be used for other related application domains that should use autonomous or remotely piloted vehicles.

A. *Transport: Drones for optimization of transport control, operation and infrastructure management*

This use case will demonstrate the technology developed in **COMP4DRONES** in the Transport domain. Based on a recent law approved by the Spanish Government related to the use of civil drones for transport application, the aim of this use case is to optimize and enhance transport control, operation and infrastructure management activities, such as traffic management (traffic status and incidents), monitoring and maintenance of road conditions with the use of drones.

Drones can become key players in the monitoring and operation of transport infrastructures, in particular, due to their flexibility to take images/video and easy access to areas that may be congested or difficult to access and even to locate accidents in an early manner.

This Use Case will target the following main objectives:

- Development of drones' processing tools based on graphic cards for the capture, processing and analysis of images/video generated by aerial and maritime drones.
- Development of secure communication modules to ensure communication between the Control Center, different infrastructure elements and the drone for monitoring and inspection of the infrastructure.
- Integration of Artificial intelligence technologies (i.e. DEEP Learning/Machine Learning) to analyse the images received by the drones to perform operational and maintenance activities.
- The drones will be integrated with other transport monitoring devices (DAS/DAI) that launch incidents in order to verify these incidents without the need to mobilize human resources.

B. Construction: Drones for virtual design, construction and operation of transport infrastructures

During the construction phase of a Civil Infrastructure, it's very important to keep a good track of its progress in order to have an adequate control of cost, time and quality, as well as to be able to certify the state in which the construction process is at a certain moment. Nowadays, the construction process of an infrastructure is monitored through traditional processes, processes that have changed little in recent decades.

The new LIDAR and photogrammetric technologies allow a great digitalization of the state of construction. In addition, these data must allow greater control in all phases of the construction process (e.g. Measurements, Advance Control, Digitalization, Certifications).

By current drone technology, it is possible to ship sensors (Lidar / RGB) that allow the digitization of the state of the construction process, and make all data capture without causing any interference in the development of activities undertaken in the work. In addition, the use of the aforementioned technology allows to reduce the costs and times of data acquisition in relation to traditional technologies such as traditional surveying and terrestrial methods.

The digitization of the state of the construction process will allow generating products that allow approximating the development of construction in a BIM Model, a work methodology that will be of mandatory use by 2020 in the European Union for the Construction of Civil Infrastructures.

C. Logistics: Logistic using heterogeneous drones' fleet

All human activities have a part of logistics:

- You are lost in the depths of the forest and you need a spare part or a new sensor for your machine.
- You are in town, at home on your couch and you order food in a famous restaurant on the other side of town.

- You are in a hospital for surgery, but they need to have emergency samples tests done in a laboratory a few kilometres away.
- You need to transport something (parts, hardware, food, drink, etc.) as fast and secure as possible.

In these cases, you need automated logistics. Drones is useful for the solutions, as they are not depended on paths in modern urban environment and are able using higher speed, so making deliveries easier and faster. For some tasks, ground vehicles are better suited, that makes demand for combined UAV and UGV solutions for logistics applications.

D. Surveillance & Inspection: Drone and wheeled robotic systems for inspection, surveillance and rescue operations with enhanced navigation and autonomous

The main goal of this use case is the realization of autonomous Unmanned Aerial Vehicles (UAV/Drone) with enhanced sensory abilities by means of sensory systems and novel control strategies augmented by real-time data-analytics algorithms. These enhanced drones can then be safely applied in indoor and outdoor environments in many applications such as industrial inspection, security, surveillance, and in rescue operations (for example, in finding targets and mapping indoor or outdoor environments).

Many companies have developed innovative solutions for in-flight diagnostic of the avionics systems including wireless HUMS and other game-changing systems. Diagnostic of the electromotor is a crucial functionality that not only save the drone but also lower the cost of maintenance. It is therefore fundamental to develop autonomous and adaptive diagnostics to increase the confidence level in autonomous drone, lowering the costs of maintenance and increasing the overall autonomy of the system.

However, to achieve safe control in uncontrolled environments there is still the need for developing efficient computational strategies that are adaptive and that can cope with the limited computational resources of the drones and robots. For this, in this use case, the focus is on the development of drones and robotic systems in which sensing, perception, planning and control of each component will be determined by a high-level data analytics system that will be able to achieve high-level decision strategies. Novel formal verification approaches will be developed that will be aware of future certification. These formal verification approaches will reduce the time and cost of the verification process by finding defects earlier in the development process.

Novel communication channels, which offer high-availability, robotic controllers, and closed-loop algorithms implemented in FPGA-based accelerators, will be developed during the execution of this use case. Hardware and software components as well as services toward end user will be developed and qualified. One of the main goals is the cooperation within project partners and open communities to enable the reuse of software components thereby to enable the reduction of costs for customized solutions.

Outcomes of this use case will be readily applied in a variety of situations ranging from infrastructure monitoring, crowd monitoring, autonomous scanning and control of wind turbine structures, to assessment of disaster sites (e.g. after

earthquakes) as well as indoor environments when entering inside a damaged structure could be unsafe.

Two distinct demonstrators will be developed within the context of this use case: inspection of off-shore infrastructures and mapping a disaster site.

E. Agriculture: Smart and Precision Agriculture: From drone to Rover

Agriculture is the science, art, or practice of cultivating the soil, producing crops, and raising livestock as well as the preparation and marketing of the resulting products.

To achieve tangible results in the project, two demonstrators will be implemented. On the one hand, we will focus on technology needs for crop monitoring, focusing on health and growth crop management, while on the other we will focus on specific technology needs of wine cultivation.

On smart agriculture and precision farming topics, COMP4DRONES will enable technologies for real-time monitoring and more accurate analysis purposes and trustworthy interaction between land-bound sensors and drones as gateways.

Both *inspective missions* (i.e. digitized data about leaf chlorophyll used on the go to apply fertilizer-N using variable-rate techniques or to decide on soil and crop management strategies), and *precise spraying* is enabled by drone usage (see Biermacher et al. (2006)). Digital and/or spectral information, (i.e. indices obtained in real time or with short time post-processing), acquired by RGB and Near Infra-Red (NIR) camera, mounted on unmanned aerial systems or vehicle (UAS and UAV) linked to unmanned ground vehicle (UGV) vehicle, in vineyard, horticultural crops and in olive trees determine best management practice (BMP) in field. Data will be used to: detect the status of health of fields and plants (i.e. early pests detection using image processing and computational intelligence); compare the data collected periodically with (i.e. definition of best soil and crop management strategies); obtain and compare different vegetation indexes (i.e. fertilizer distribution management); construct 3D models (i.e. optimal water and fertilizers distribution).

The COMP4DRONES will provide the agricultural domain with a basic drone platform which can be configured as a modular system for multiple and generic tasks as well as for specific tasks in the agricultural domain. Development of the drones and components will be supported by a workflow and toolchain environment as well as dependability modelling system.

In both demonstrators of this use-case (i.e. crop monitoring, and wine production), the architectures for drone systems-of-systems composition to enable self-adaptability and secure communication will be demonstrated. This relates to the challenges of extending drones capabilities by embedding more features and by setting up a system engineering framework and development workbench.

VI. POTENTIAL IMPACTS

The integration of the professional drones into the airspace, especially for operations beyond visual line of sight, may influence all classes of airspace and have a much greater impact on the airspace than leisure drones. This is expected to be especially true in the long-term for delivery and public

safety & security drones operating in urban environments. Professional drone operators will need to safely operate alongside manned aviation and delivery drones in dynamically changing environments.

With particular emphasis on software and hardware architecture of UAV systems, COMP4DRONES is in line with ECSEL JU R&D priorities and complements SESAR JU efforts in regards to the following drone's awaited features: detect & avoid, datacom & spectrum, security & cyber resilience, human factor and training, and validation & demonstration.

The COMP4DRONES achievements will have the following impacts:

1) Reinforcing the ecosystems of drones' industry by providing methodology and a reference software architecture framework that meets performance and safety requirements. This architecture will ensure:

- On the one hand, interoperability of specifications and components between integrators and solution provider;
- On the other hand, will enable incremental certification through separation of concerns and reuse of qualified components.

The realization and adoption of this architecture will be facilitated by the fact that it is based on recognized and used industry standards in the aeronautical (ARINC-653) and robotics (ROS) domains. The architectural reference framework will build on existing software component repositories (e.g. Paparazzi and Dronecode). Beyond the ecosystem formed by the COMP4DRONES consortium partners, in WP7 we will focus on expanding and promoting its use on a European and global scale through several workshops and tutorials.

2) Improving innovation capacity and the integration of new knowledge. A structuring aspect of COMP4DRONES is the adoption of a "safe-by-design" approach which covers the activities of (1) specification, (2) design, (3) implementation, and (4) validation & verification. This component-based and model-based approach has already proven itself in other application domains such as automotive and aerospace. Adapting this approach to the UAV industry will enable the design of innovative and competitive UAVs capable of performing more sophisticated missions while ensuring a high level of safety.

3) Enabling and easing delivery of new services using drones in Europe. The biggest security risk for drone use is not the drone itself, but the technology inside of it. The R&D challenges addressed by COMP4DRONES cover most of the concerns related to the design of safe embedded system for drones. Mastering the design of high-quality drones will encourage their acceptance by society and should accelerate the realization of uses that seem today very far away, especially delivery and public safety & security drones operating in urban environments. Ability to produce drones of quality both in terms of functionality and safety, will increase the competitiveness of the European drone industry and allow it to increase its share of global market.

VII. WORK PLAN AND METHODOLOGY

The approach is cooperative between end-users, techno-providers and researchers, and consists of three streams of tasks illustrated in Figure 5.

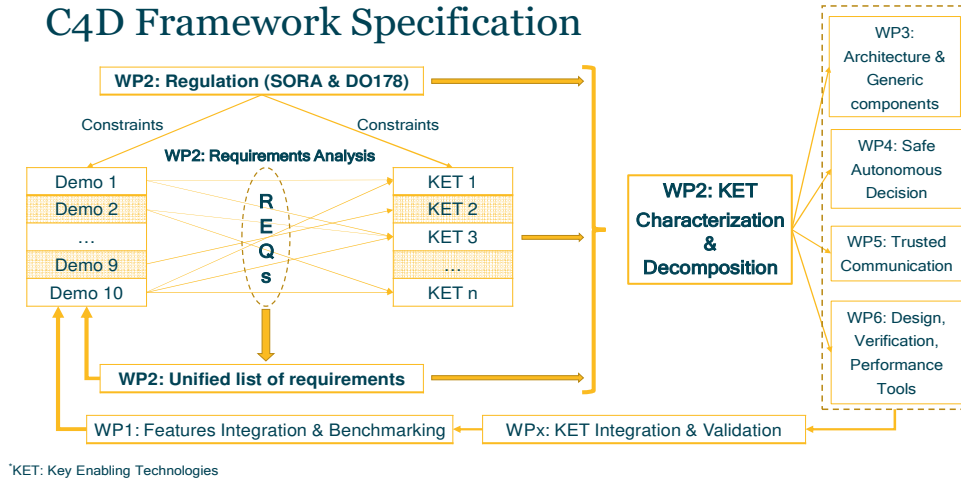


Figure 5 - COMP4DRONES methodology

- The end-user partners will provide high-impact use cases, and specify their needs and requirements ensuring compliance with civilian drone regulations, in terms of non-functional properties, safety, tools and process.
- In parallel, additional research and development will be done to solve the technical problems described above about reference architecture, qualifiable generic self-contained components, intelligent navigation system, trusted communication, tools, modelling, code generation, and verification & quality assurance.
- The driver of the project will be the research on the methodologies that will take into account the end users' needs and define a methodology for using the project results to satisfy these needs. Understanding the needs will help developing efficient and usable framework (architecture, component, etc.), quality measurement instruments and tools for guiding the end-users in an optimal manner to produce safe and efficient embedded software for drones, especially those using modern architectures.
- The process will iterate on the three activities:
 - As soon as initial users, requirements and needs are understood, it will be validated key technologies (solution ideas/concepts) to be used in the applications (Stage 1: Technology validation);
 - Technical development will deliver a first version by month 22 with results deployed in a test environment (lab/field); a first methodology can be defined and test cases will be set up within the use-cases to validate them (Stage 2: Technology experimentation).
 - A second iteration will be done during the last part of the project (remaining 14 months) with an updated methodology and technological innovations. It will

end up with a deployment and validation at in-situ trials as well as recommendations on how to generalize them to other related application domains that should use autonomous or remotely piloted vehicles (Stage 3: Technology Integration).

VIII. CONCLUSION

COMP4DRONES project is centered on the development of an ecosystem that is realized as a tightly integrated multi-vendor and modular drone embedded architecture solution and a corresponding tool-chain.

Research and development challenges addressed in the project cover most of the concerns related to the design of safe embedded systems for drones.

Four technical objectives support the general concept of the project that allows the development of this ecosystem: Integrated Modular Architecture for Drones, Safe Intelligent Navigation, Trusted Communication, Design and Verification Tools.

Five use cases cover a wide spectrum of potential drone applications and are strong aspects of COMP4DRONES project. Use cases are segmenting applications for autonomous drones into different areas: transport, construction, logistics, surveillance and inspection as well as agriculture.

ACKNOWLEDGEMENT

This work was financially supported by European commission through ECSEL-JU 2018 program under grant agreement N° 826610, and it get national financing from France, Spain, Italy, Netherlands, Austria, Czech, Belgium and Latvia.

As shown in Figure 6, the COMP4DRONES partners cover important geographical areas in Europe and ensure that project outcomes will have lasting impact on European Drones Technology Industry.

The total project budget is 28,590,748.75 EUR (excluding ESIF partners) while the requested grant is 7,983,731.61 EUR to ECSEL JU, and 8,874,523.84 EUR of National and ESIF Funding.

The European and national grant agreements have been signed and technical work has started on 1st of October 2019.



Figure 6 - COMP4DRONES partners

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