"5G for Drone-based Vertical Applications"

D1.6 – 5G!Drones system architecture refined design

Document ID:	**D1.6**
Deliverable Title:	**5G!Drones system architecture refined design**
Responsible Beneficiary:	**NCSRD**

Topic:	**H2020-ICT-2018-2020/H2020-ICT-2018-3**
Project Title:	**Unmanned Aerial Vehicle Vertical Applications' Trials Leveraging Advanced 5G Facilities**
Project Number:	**857031**
Project Acronym:	**5G!Drones**
Project Start Date:	**June 1st, 2019**
Project Duration:	**42 Months**
Contractual Delivery Date:	**M24**
Actual Delivery Date:	**May 28th, 2021**
Dissemination Level:	**PU**
Contributing Beneficiaries:	**NCSRD, COS, THA, CAF, EUR, AU, UO, RXB, ALE, DRR, NOK, FRQ, UMS, OPL, INV, ORA, AIR, HEP, INF.**

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 857031.

Document ID: D1.6
Version: V2.0
Version Date: 28.05.2021
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Security: Public (PU)

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Document History

Version	Contribution	Authors	Date
0.1	Initial table of content	NCSRD	04/04/2020
0.2	Updated table of content according to partners' comments	NCSRD, ALL	10/06/2020
0.4	First Draft of Sections 1, 2, 3	NCSRD, COS, INF	29/09/2020
0.5	Updates on requirements' section with consolidation of RTMs	NCSRD,	10/10/2020
0.6	Updates on section 5.3	AIR, DRR, FRQ, ORA, INV, AU, UO, UMS, NOK, ALE, HEP, CAF	15/10/2020
0.7	Updates on section 5.3	AIR, DRR, FRQ, ORA, INV, AU, UO, UMS, NOK, ALE, HEP, CAF	30/10/2020
0.8	Updates on section 3.2	INV, CAF, NCSRD	10/11/2020
0.9	Updates on sections 3.1.6, 3.1.7, 3.1.8	FRQ, EUR,	26/11/2020
0.10	Updates on LCM, security requirements and facility gap analysis section	NOKIA, CAF, INV, AU, UO	13/01/2021
0.11	Sections 5.2, 4.2.3, 2.2, 2.3	THA, RXB, FRQ, OPL	19/02/2021
0.12	Section 5.1	AU, UO, EUR, NCSRD, COS,	07/03/2021

0.13	Updates on section 5.1, 4.1	AU, UO, EUR, NCSRD, COS, NOK	30/03/2021
0.14	Full Review with feedback	COS, FRQ, NOK	07/05/2021
1.0	Final editorial refinements	NCSRD	25/05/2021
2.0	Final version	NCSRD	26/05/2021

Executive Summary

5G!Drones aims to trial focal UAV use-cases covering eMBB, URLLC, and mMTC 5G services, and to validate 5G KPIs for supporting such challenging use-cases. The project will drive the UAV verticals and 5G networks to a win-win position, on one hand by showing that 5G is able to guarantee UAV vertical KPIs, and on the other hand by demonstrating that 5G can support innovative use-cases that put pressure on network resources, such as low-latency and reliable communication, massive number of connections and high bandwidth requirements, simultaneously. 5G!Drones is being built on top of the 5G facilities provided by the ICT-17 projects and a number of support sites, while identifying and developing the missing components to trial UAV use-cases.

The main contribution of this deliverable is the description and specification of the 5G!Drones system, which updates the initial design (as described in D1.3 [1]). The deliverable is divided into two parts. The first part provides an analysis of the 5G!Drones stakeholders, followed by an overview of the 5G!Drones architecture including per building block its key services and functional requirements. The high-level workflows among the architectural building blocks for a set of basic service operations are also presented and described. The second part focuses on the advancements made since the initial design of the 5G!Drones system. It mainly addresses the changes on the baseline design and includes the UAV and facility enablers' updated status exploiting the feedback of the development work done in the respective work packages.

Moreover, the document intends to incorporate insights and directions from the implementation and integration activities during the first year of the project, as well as, to describe the evolution of the enablers of the trial facilities.

In more details, the main contributions in this deliverable are the following:

- Description of the 5G!Drones architecture functional requirements,
- Refinement of the overall 5G!Drones architecture design and description of the main building blocks to support the new features and enhancements of the system,
- Detailed presentation and analysis of the Facility, UAV and Cybersecurity enablers, identified in the project
- High-level evolution analysis related to the 5G facilities.

This deliverable concludes the work of Task 1.4 on 'System architecture for the support of the vertical use-cases'. Subsequent work on the implementation of the architecture is documented as part of WP2 and WP3 activities. More specifically deliverables D2.4 'Definition of the trial controller architecture, mechanisms and APIs' to be submitted at the same due time as the current document, describes in more details the internal operations of the main components of the 5G!Drones system. D3.1'Report on infrastructure level enablers for 5G!Drones' and D3.2 'Report on vertical service-level enablers for 5G!Drones' (to be delivered on M26), will support the holistic picture on the 5G!Drones system.

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List of Abbreviations

3GPP	3rd Generation Partnership Project
5G	5th Generation
5GC	5G Core
5G PPP	5G infrastructure Public Private Partnership
5GS	5G System
5QI	5G QoS Indicators
ABAC	Attribute Based Access Control
AF	Application Function
AMF	Access and Mobility Management Function
ANSP	Air Navigation Service Provider
API	Application Programming Interface
ATM	Air Traffic Management
AUSF	Authentication Server Function
C2	Command and Control
CN	Core Network
CRUDL	Create Read Update Delete
dFPL	Drone Flight Plan
DLNDS	Drone Logistics Network Delivery Software
DTLS	Datagram Transport Layer Security
E2E	End to End
eMBB	enhanced Mobile BroadBand
eNB	enhanced Node-B
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FCC	Flight Control Center
FIDO	Fast IDentity Online
FPV	First Person View
GBR	Guaranteed Bit Rate
GCS	Ground Control Station
GMLC	Gateway Mobile Location Centre
GMS	Group Management Server
gNB	Next Generation Node-B

GNSS	Global Navigation Satellite System
HTTP	Hypertext Transfer Protocol
IAM	Identity and Access Management
IdMS	Identity Management Server
IMEI	International Mobile Equipment Identity
IMSI	International Mobile Subscriber Identity
ITU	International Telecommunications Union
JSON	JavaScript Object Notation
JWTS	JSON Web Tokens
KMS	Key Management Server
KPI	Key Performance Indicator
LBO	Local Breakout
LCM	Life Cycle Manager
LIDAR	Light Detection and Ranging
LRF	Location Retrieval Function
MANO	MANagement and Orchestration
MCCoRe	Mission Critical Services Common Requirements
MCD	Mission Critical Data
MCPTT	Mission Critical Push To Talk
MCS	Multimedia Mission Critical Services
MCV	Mission Critical Video
MDAF	Management Data Analytics Function
MDT	Minimization Driving Test
MEC	Multi-access Edge Computing
MEP	MEC Platform
ML	Machine Learning
mMTC	massive Machine-Type Communications
MSISDN	Mobile Station Integrated Services Digital Network
N3IWF	Non 3GPP Inter-Working Function
NBI	North Bound API
NEF	Network Exposure Function
NFV	Network Function Virtualisation
NG-RAN	Next Generation - Radio Access Network
NR	New Radio
NRF	Network Repository Function

NSA	Non-Standalone
NSI	Network Slice Instance
NSMF	Network Slice Management Function
NSSAAF	Network Slice-Specific Authentication and Authorization Function
NSSF	Network Slice Selection Function
NSSI	Network Slice Subnet Instance
NST	Network Slice Template
NWDAF	NetWork Data Analytics Function
OAI	OpenAirInterface
OFDM	Orthogonal Frequency Division Multiplexing
OPA	Open Policy Agent
OSM	Open Source MANO
PCF	Policy Control Function
PDU	Protocol Data Unit
PEP	Policy Enforcement Point
PKI	Public Key Infrastructure
PNF	Physical Network Function
ProSe	Proximity Services
QoS	Quality of Service
QI	QoS Indicators
RAN	Radio Access Network
REST	Representational State Transfer
SA	StandAlone
SBA	Service-Based Architecture
SBI	Service-Based Interface
SD	Slice Differentiator
SDN	Software-Defined Networking
SIP	Service Initiation Protocol
SLAM	Simultaneous Localisation and Mapping
S-NSSAI	Single Network Slice Selection Assistance Information
SORA	Specific Operations Risk Assessment
SST	Slice Service Type
TLS	Transport Layer Security
TSD	Trial Service Descriptor
TTI	Time Transmission Interval

UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UDM	Unified Data Management
UDP	User Datagram Protocol
UE	User Equipment
URLLC	Ultra-Reliable Low Latency Communications
UTM	UAS Traffic Management
vPEP	Virtual Policy Enforcement Point
WLAN	Wireless Local Area Network
W3C	World Wide Web Consortium
WP	Work Package
XACML	eXtensive Access Control Markup Language

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1. INTRODUCTION

1.1. Objective of the document

This deliverable contributes to the 5G!Drones project overall Objective 2 'Design and implementation of the 5G!Drones software layer (or system) to execute UAV trials'. It provides the final specifications of the architecture, the software and system components required by the project, and explores the gaps of the target facilities to be fulfilled for conducting the planned trials. The Deliverable is also instrumental in being able to reproduce the functionality required to run 5G!Drones trials in any other facility in the future. The current document, deliverable D1.6 '5G!Drones system architecture refined design', describes the final 5G!Drones end-to-end architecture, and focuses on the technical design refinements and updated system specifications of the target platform, as initially introduced in D1.3 '5G!Drones system architecture initial design' [1]. It also builds upon the work of D1.1 'Use Case Specifications and Requirements' [1], D1.2 'Initial description of the 5G trial facilities' [3], D2.1 'Initial definition of the trial controller architecture, mechanisms and APIs' [4] and jointly with D2.4 'Definition of the trial controller architecture, mechanisms and APIs' (to be delivered at the same due time as this document). D3.1 'Report on infrastructure level enablers for 5G!Drones' [5] and D3.2 'Report on vertical service-level enablers for 5G!Drones'(to be delivered on M26), set out to provide the holistic picture on the 5G!Drones platform and act as a reference point for all technical deliverables that shall follow by describing in details the specific components of the platform.

1.2. Structure of the document

The document is divided into the following parts:

- Section 2 outlines the 5G!Drones ecosystem and its relationship with the 3GPP principles.
- Section 3 focuses on presenting a refined extensive list of the functional requirements relative to the final architecture design.
- Section 4 comprises a dedicated description of the 5G!Drones system. It provides an analysis of the updated 5G!Drones architecture including for each component key functionalities over the federated, multi-domain 5G infrastructure.
- Section 5 focuses on a dedicated description of the identified enablers within the project and their development progress.

1.3. Target Audience

This document mainly targets the following audience:

- The Project Consortium and Stakeholders, such as the contributing beneficiaries of the design and implementation work packages WP2-3. In this regard, the refined architecture design delivered by this document will support the continuous elaboration of the components, with the aim to provide the necessary infrastructure finalization for the selected use cases. That includes all the necessary 5G system components, as well as the specific 5G!Drones enablers.
- The Research Community, Industry and funding EC Organization to i) summarize the 5G!Drones scope, objectives and intended project innovations and ii) provide details of the final design of the 5G!Drones system architecture. The objective is to facilitate the understanding of which architectural components have been designed by the project so as to be able to fully demonstrate and measure the provided technological advancements on all target ICT-17 5G Facility sites.
- The broadest possible technical and non-technical audience (General public) to obtain a better understanding of the scope, objectives and general architecture of the 5G!Drones project.

2. 5G!DRONES ECOSYSTEM AND RELATION 3GPP

2.1. 5G!Drones Ecosystem

5G!Drones platform builds on top of the 5G-enabled UAV vertical use cases the experimentation plane, aiming to deliver an end-to-end 5G UAV trial platform that can be used to create, schedule, execute and validate UAV test cases and the respective 5G KPIs. Each of the 5G!Drones ecosystem instantiations that conforms to the 5G!Drones platform has the flexibility to govern its own physical topology, architecture and particular technological features. Nevertheless, towards harmonizing the different platforms and experimentation infrastructures, elements of the common reference architecture are to be replicated across the four instantiations of the 5G!Drones project platforms. In this way, each platform can be administratively independent, yet interoperable with the other platforms.
Such deployment, execution and validation that can be considered as an Experiment, involves the following stakeholders:

- Experimenter: Executes the experiments on behalf of the vertical industry using the experimenter interface provided by the 5G!Drones portal.
- Platform Operator: Hosts, manages and operates the platform's software and infrastructure. This stakeholder is also the interface to the experimenters, being in charge of the telecommunications infrastructure, as well as the coordination, management, orchestration and monitoring systems.
- Platform Technology Provider: This role is acquired by vendors that support the testbed infrastructure with hardware and software components.
- Testers and End Users: The users of the services deployed in the 5G!Drones platforms by the Experimenter. They can be either individuals or corporate end-users.
- UTM Providers have real-time and reliable connectivity with digital air traffic management systems that will support the safe integration of all drone traffic with other aircraft through the 5G!Drones system.
- UAV Use Case Owners: Represent the vertical industry that is interested to the experiment validation results, so that to build the respective business case for the use case under trial.
- Other Stakeholders, with more specialised role in the fields of UAS and U- space. 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. These services rely on a high level of digitalization and automation of functions, whether they are on board the drone itself, or are part of the ground-based environment. U-space provides an enabling framework to support routine drone operations, as well as a clear and effective interface to manned aviation, ATM/ANS service providers and authorities.

2.2. 5G!Drones in relation to 3GPP

5G!Drones depends on the 5G technology to demonstrate innovative UAV use cases. At the same time 3GPP, as the primary Standards Development Organisation (SDO) for the 5G specifications, considers the tight integration of UAV requirements to its future releases. As a result, the relevance of the 3GPP developments with the 5G!Drones UAV use cases must be considered in the following aspects:

- Assess compatibility of the 3GPP approach (standardized fundamental and UAV-specific service requirements as well as the general architecture and mechanisms) with specificities of the 5G!Drones use cases and test scenarios
- Follow the standardization progress of 3GPP solutions and mechanisms relevant to the UAV service requirements, and their consequent f implementation in the 5G experimental and commercial platforms, which are part of the 5G!Drones project test-beds.

The 3GPP approach follows the three-stage methodology according to ITU [6]: Stage 1 – overall service description from the user's standpoint; Stage 2 – overall description of the organization of the network functions to map service requirements into network capabilities; Stage 3 – definition of switching and signalling capabilities needed to support Stage 1 services.

While potential gaps in the 3GPP 5G service requirements for UAV-related services and supporting 5G system mechanisms may drive the development of the 3GPP standardization by the 5G!Drones project, the timely readiness of standards and their follow-up implementation may impair the 5G!Drones' trials and force replacement solutions in the form of existing mechanisms-based workarounds or additional enablers.

The following subsections summarise 3GPP's vision on UAV requirements, as well as the 5G System capabilities that are considered relevant to the project's work.

2.2.1. 3GPP Vision of UAV Requirements

The 3GPP 5GS architecture, functionalities and mechanisms' ability to support communication services for UAS is driven by the two fundamental Stage 1 documents, which standardize the service-related requirements for the 5GS [7]: – dedicated to generic service requirements, common for various use cases, and [8], which deals with UAS support by the 3GPP system, i.e. the context of communication services for UAS and specific problematics in the field of unmanned aviation. Below are the requirements, which are associated with the 5G!Drones use cases and test scenarios.

- *Network Slicing:* replacement of one multi-purpose and multi-service communication network (inherently providing unsatisfactory compromise between conflicting requirements of distinct service classes) by a federation of specialized networks tuned to the specificity of service classes – a UAS needs several communication links (each with specific requirements) both for non-payload (i.e. C2, telemetry, UTM or FPV) and payload (use case-related, e.g. still images, real-time video, sensoric information etc.).
- *Mobility management*: adaptation of network behaviour to mobility patterns, maintaining the IP address during the session (if required), minimization of interruption time and packet loss – a UAV with a 5G UE will manifest high mobility across individual base stations and high demand of service continuity.
- *Efficient user plane*: optimized user plane for communication between UEs or from a UE to application-hosting environment (e.g., edge cloud) for low latency or low bandwidth pressure – both non-payload and payload links may need application-level enablers near to the location of a UAV and its further following.
- *Priority, QoS, and policy control*: different services may share the same QoS characteristics, but have different priority requirements – different UAS communication links or UAS links and other services.
- *Network capability exposure*: ability to expose 5GS APIs to trusted 3rd parties for creation, modification, deletion or monitoring of network slices as well as defining or updating services or capabilities and UEs supported by these slices – this is important for interfacing with the Trial Controller.
- *QoS monitoring*: exposure of a mechanism for supporting real time E2E QoS monitoring – dependability of network and services for UAS.
- *Positioning services*: by different single and hybrid positioning methods (3GPP and non-3GPP positioning technologies) – to provide validation of position reported by UAV.
- *Remote Identification of UAS*: enabling the UAS-UTM communication with the network user and UE identity (IMEI, IMSI, MSISDN, IP address), UE capabilities and other aviation/flight-related information, "certification" or augmenting of data sent by UAS provided by the network operator, supplementing them with location information, and involving the UTM in the authentication.
- *UAS traffic management*: communication between UAS and UTM with latency less than 500 ms, short-range (up to 600 m) broadcasting of UAV identification and position for collision avoidance (also cross-network) with latency less than 100 ms between UAVs with relative speed up to 320 km/h.

- *Security*: protection against spoofing attacks of the UAS identities, non-repudiation, integrity and privacy of UAS-UTM exchange.
- *UAV service status and restriction*: exposure of real-time monitoring of UAV UE status information, providing 4D (3D space + time) information about UAV services availability, network-based 3D space positioning in a given range of altitudes and early warning of possible UAV connectivity loss.
- *Service performance requirements both for non-payload and payload transmission*: definitions of KPI targets (uplink/downlink data rate, end to end latency, etc.) are provided; in case of payload transmission services for very specific use cases, it may be useful to refer to standards devoted to message service video [9], imaging and audio for professional applications [10] or cyber-physical control applications in vertical domains [11].

Furthermore, among the 5G!Drones scenarios, there is a subset (Use Case 2) dedicated to public safety. The requirements for Mission-Critical Services (MCS), initially defined for LTE, have already been updated and extended to span also the 5GS: Mission Critical Services Common Requirements (MCCoRe) [12], Mission Critical Push To Talk (MCPTT) [13], Mission Critical Video [14], and Mission Critical Data [15]. The MCS class allows public safety users to access professional communication in groups and in private calls. The following services are required:

1. Group and individual calls;
2. Group and individual messaging;
3. Group and individual multimedia messaging;
4. Group and individual video calls;
5. Emergency calls;
6. Location and map services;

2.2.2. 3GPP 5G Systems relevant to UAV Use Cases

Exploring the 5G architecture and system domains as depicted in Figure 1, support for the UAV services is identified at various levels: at the 5G Core and extensions such as the Location Services, at the radio Access level and the New Radio specifications including non-3GPP access systems, and at the all-encompassing management and orchestration level. UAVs are considered special types of User Equipment (UEs) that will integrate and on-board 5G capabilities. Following subsections discuss system and design considerations at each of these levels that are especially important for UAV use cases.

2.2.2.1. 5G Core and Architectural Framework

The generic 5GS architectural framework [16] provides fundamental mechanisms and functionalities, which directly respond to the majority of the abovementioned UAV use cases requirements:

- *Network slicing:* within the Core Network (CN), it is supported by the various Control Plane (CP) functions: AMF (Access and Mobility Management Function), which coordinates the entire UE-related signalling and involves Network Slice Selection Function (NSSF) during the attach to specific Network Slice Instance (NSI) requested by UE, with authentication performed by Authentication Server Function (AUSF) and optional support of Network Slice-Specific Authentication and Authorization Function (NSSAAF) if special security measures to access the slice are needed. The authentication and authorization procedures are performed based on user profile stored in Unified Data Management (UDM). The important aspect of providing the access to certain type of a slice is also validation of the terminal capabilities regarding slice type support which can be done based on the information contained in 5G Equipment Identity Registry (5G-EIR). The signalling between UE and CN-gateway point (AMF) is enriched with S-NSSAI parameter (Single-Network Slice Selection Assistance Information), which is composed of Slice Service Type (SST) and optional Slice Differentiator (SD) to provide unique identifier of an NSI within the network. Currently there are 4 types of SST: eMBB, URLLC, MIoT, and V2X, (the first three follow the basic classification by ITU-R, the last one is the first example of possible use case-driven distinction). UE may be connected to up to 8 different NSIs at the same time. The NSI-specific User Plane Function is controlled by its individual CP counterpart, Session Management Function. The network slices can be enhanced by customized network functions implemented in form of Application Function (AF) that can access other core functions via Network Exposure Function (NEF).

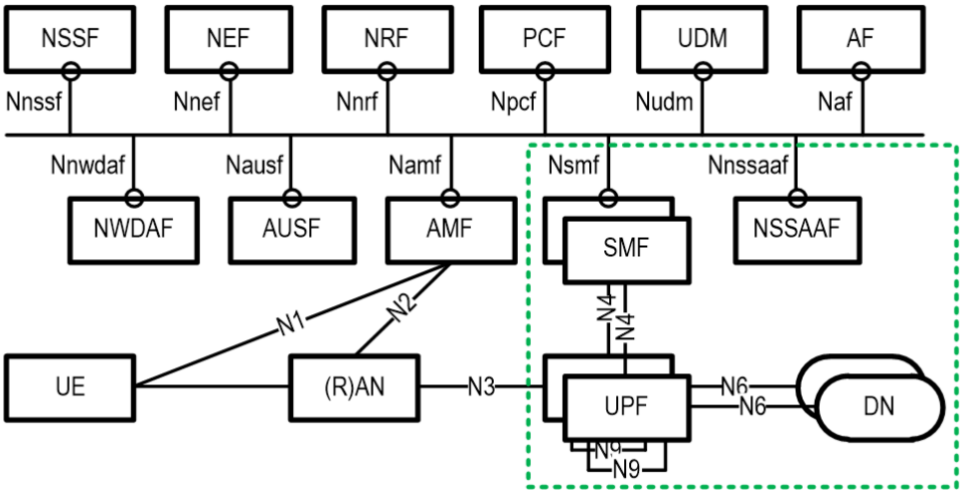

Figure 1: Basic 5G System architecture framework

- *Service-Based Architecture (SBA):* 5GS is defined as the Network Function Service Framework, which functionalities include basic mechanisms of service registration/de-registration, consumer authorization, service discovery, and standardized inter-service communication options (direct/indirect exchange, direct/delegated service discovery and selection). Network Function (NF) service (single or multiple per NF) is exposed by NF (Service Producer) to another authorized NF (Service Consumer) through a Service-Based Interface (SBI), which supports two mechanisms Consumer-Producer interactions: “Request-Response” and “Subscribe-Notify”. The exchange utilizes a common message bus for exchange between given NFs, instead of use of predefined point-to-point interfaces between communicating parties. The communication is implemented with a message broker, which organizes messages into specific queues (“topics”), and on sets of publishers and subscribers, each defined per specific topic. Mechanisms of service discovery are implemented via the Network Repository Function (NRF). Service Consumer authorization (also for inter-operator interactions) is based on policies both at the level of NF instance/service discovery permission and service access permission. For SBI CP exchange the following protocols have been selected: RESTful framework (API) based on JSON (serialization), HTTP/2 (application layer), and TCP (transport). The described mechanisms of message bus communication, service discovery and authorization enable the 5GS CP scalability, easiness of extending or upgrading without mutual impact between NFs and ability to be partitioned into common, partially shared and individual functional areas to support such concepts as common/dedicated slice or lightweight CP.
- *Priority, QoS, and policy control (including also network slicing, roaming, and mobility management policies):* they are supported by Policy Control Function (PCF). The 5GS QoS framework defines standardized 5G QoS Indicators (5QI) of service QoS classes that characterize resource type (the issue of flow Guaranteed Bit Rate: non-GBR, GBR, delay critical GBR), default priority level, packet delay budget, packet error, default maximum data burst volume, and default averaging window. The 5QI received from PCF is enforced by SMF for its UPF. The detailed specification of the policy and charging control framework for the 5GS, including interactions of PCF with other Network Functions (NFs), has been defined in [17].

- *Network capability exposure:* it is enabled through Network Exposure Function (NEF), which supports integration of 5G CP with an external environment of any aviation domain actor. The specific functional UAV enablers may be also embedded within the CP as special cases of generic Application Function (AF), either still using NEF as a proxy, due to security reasons, or interacting with CP functions directly, if considered as trusted (subject to network operator's policy).
- *UTM Network context awareness, QoS monitoring, and UAV Service Provider early warning:* they will be based on Network Data Analytics Function (NWDAF) and Management Data Analytics Function (MDAF, a part of the 5G Management and Orchestration Architecture Framework [18]. Specific monitoring of managed objects of interest (related events, performance indicators) may be subscribed and threshold-crossing notifications may be exposed through NEF or trigger special algorithms implemented within AFs in CP or Management Functions.
- *Augmenting/supplementing UAS data and security requirements:* these can be met by the UPF, which in addition to a hitherto mobility-supporting data tunnel anchored at the IP network gateway point, may also embed a service-specific chain of UP data processing functions (Deep Packet Inspection for packet selection/marking/enrichment/alteration, firewall, anti-viral protection, parental control, images down-sampling, selective traffic redirection etc.).

2.2.2.2. 3GPP Location Services Framework

The 3GPP Location Services (LCS) framework [19] is a 5GS CP extension to support UE positioning. The positioning requests can be network-induced (by AMF for some regulatory service), mobile-terminated (by LCS client or other AF), mobile-originated (by UE itself) both as immediate and deferred (in case of occurrence of a specific event). The procedures of UE-based/assisted (with UE involvement as a position data source) and Network-assisted (UE-independent) positioning are supported. The LCS architecture contains a Gateway Mobile Location Centre (GMLC) answering the positioning requests, which is supported by a Location Retrieval Function (LRF) responsible for retrieval and validation of location data.

2.2.2.3. 3GPP Radio Access

The 3GPP has already established the principles regarding the operation of 5G Next Generation Radio Access Network (NG-RAN) as well as characteristics of the radio interface i.e., New Radio (NR). Multiple of the proposed mechanisms can significantly contribute to UAV use cases, where the majority is related to the radio interface adaptation to enable RAN slicing. The main principles of RAN slicing have been defined in [20]. Firstly, gNB has to support traffic handling for each slice by using different PDU sessions each associated with a specific slice. Such an approach facilitates the network to create slices by providing different L1/L2 configurations and scheduling. Purposefully, the details concerning RAN slicing have not provided by 3GPP so as to leave implementation to vendors. The other key features needed for support of Network Slicing in RAN include:

- RAN awareness of slices i.e., the ability of NG-RAN to provide traffic handling depending on the slice type by using specific mechanisms (e.g. grant-free access for URLLC traffic);
- Support for selection of RAN part of the network slice on the basis of the Single Network Slice Selection Assistance Information (S-NSSAI) provided by the UE or 5GC;
- Mechanisms of resource management between slices, i.e. policy enforcement between slices as per service level agreements;
- Support QoS differentiation within a slice;
- Capabilities of RAN selection of CN entity on the basis of S-NSSAI;
- Maintenance of resource isolation between slices;
- Access control policies;
- Maintenance of awareness of slice availability;
- Support for UE associating with multiple network slices simultaneously;
- Granularity of slice awareness, i.e. slice awareness at PDU level by indication of S-NSSAI corresponding to the PDU session;

- Validation of the UE rights to access a network slice;

Typically, RAN slicing is based on Physical Resource Blocks (PRB) scheduling mechanisms. The 3GPP has proposed basic approaches to scheduling: reservation-based and dynamic scheduling that enables handling latency critical traffic. Static reservation involves periodic allocation of PRBs to slices so as to mitigate potential packet collisions. This approach, however, might result in overhead and resources underutilization in case of no data transmission in the pre-allocated slots.

The dynamic scheduling mitigates this risk by enforcing the access to the channel on the basis of transmission priorities. In case of downlink, so called pre-emptive punctured scheduling is performed by insertion of packets of latency-critical transmission into slots reserved for high bandwidth and latency tolerant services, i.e. eMBB in form of a micro slot (overriding the part of the transmission). Dynamic scheduling in the uplink relies on sending the data directly (multiple times if necessary) without pre-allocation of the PRB and related resources negotiations. The aforementioned mechanisms use as their basis the 5G NR Numerology that is a set of different lengths of OFDM sub-carrier spacing for the transmission (and OFDM symbol length respectively) as well as configurable Time Transmission Interval (TTI) [20]. The provided flexibility aims to facilitate URLLC (small subcarrier spacing and short TTI induces smaller delays) and eMBB traffic (large subcarrier spacing induces shorter duration of OFDM symbols and consecutively higher transmission speed).

One of important mechanisms in the Radio Access Network (RAN) is interference management. So far, the mobile networks were designed to provide the “terrestrial” services. Appearance of highly mobile UEs at the altitudes of even 120 m will have an impact on Cross-Link References. The currently designed mechanisms [20] will probably need at least validation. Other techniques to be applied in the future are related to dynamic modification of UE and base station antenna’s radiation patterns to maintain direct facing of the main lobes. The RAN support for related mechanisms (beamforming, beam steering and beam switching), however, is still in early stage. The 5GS also supports integration with other Non-3GPP radio access technologies instead of NG-RAN such as IEEE 802.11 series. It is provided via generic Non 3GPP Inter-Working Function (N3IWF). In terms of communication with UAVs, it can be used to implement the interface UAV5 as depicted in [8].

The 3GPP vision of 5G System management, as depicted in Figure 2, assumes the 4-level hierarchy of Management Functions (MFs): Communication Service, Network Slice, Network Slice Subnet, and Network Function (i.e. CSMF, NSMF, NSSMF, and NFMF, respectively). The 3GPP 5G System management framework, similarly to 5G CP, also applies the SBA model of interactions (management service Producers/Consumers, message bus-based exchange between MFs). The ETSI NFV MANO framework [21] is adopted on the principle of complementarity with the 3GPP management layer [22]; individual EMs of VNFs or shared EMFs for NF level management of multiple VNFs/PNFs (Domain Managers – DMs) for VNF and PNF management play a role of the 3GPP NFMF, while OSS/BSS contains the 3GPP NSMF and 3GPP NSSMF.

Additionally, two management functions are defined: Exposure Governance Management Function (EGMF) and Management Data Analytics Function (MDAF) [18]; they fulfil the same role as NEF and NWDAF in CP, respectively. As the 3GPP 5GS will be inherently multi-domain (composed of at least of RAN and CN domains), the NSMF will be responsible for multi-domain coordination of management and orchestration.

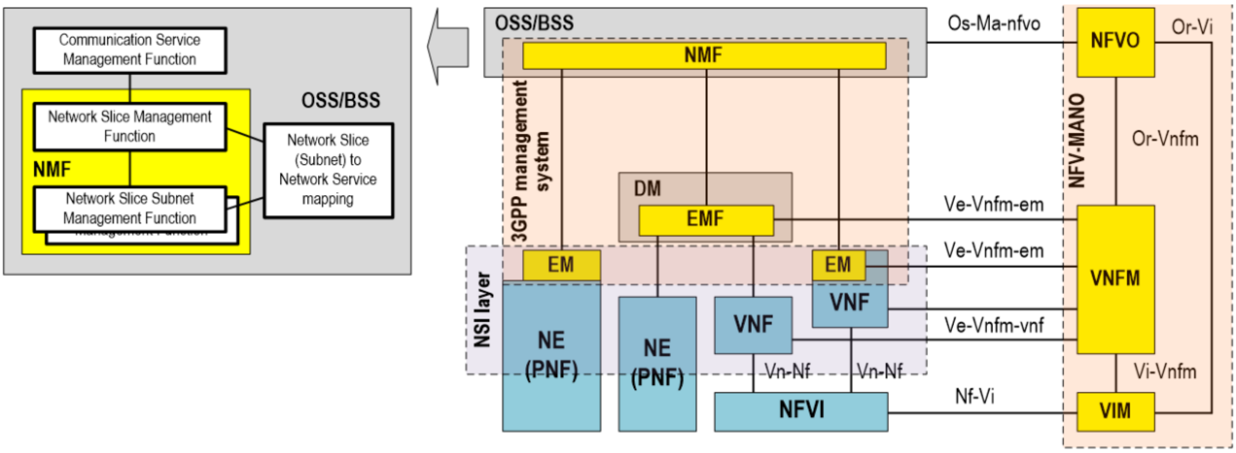

Figure 2: High-level 5G network management architecture by 3GPP

2.3. 5G!Drones Facilities and 3GPP 5G UAV System Capabilities

In the light of the above identification of system capabilities relevant to UAV use cases, while the individual readiness at the 5GS level of the 5G!Drones testbeds will be analysed in detail further on in the document, some initial observations can be reported:

The open-source 5G network solutions like OAI or free5GC used for experimentation implement fundamental functionalities of 5GS, without NWDAF/NEF, standardized API exposure or management layer functions (especially real-time management). In case of advanced services (LCS, MCS), the open-source solutions for experimenters are inexistent. Regarding commercial 5GS solutions, their vendors follow the 3GPP standardization roadmap. Currently, the Release 16 is officially declared as completed since June 2020 session. However, the 3GPP v16 documents are still being developed and quarterly upgraded. The 3GPP Release 17, officially started at the beginning of 2020, is currently yet before its halfway point. Up to the date of submission, commercial launch of enterprise solutions with advanced features, such as NEF API exposure, is not yet advertised.

The support of network slicing in 5G system is constantly evolving and generic features are still developed within the standardization documents. The CP support of network slicing will be enhanced in the Release 17 and the study work has been started on slicing mechanisms [23] and its management [24] to feed further standardization. In the RAN area, the network slicing is currently recognized at the level of general principles and requirements [20], but the standardization of mechanisms of network slicing support by RAN (especially at the level of radio resources management) is also a part of the Release 17 scope.

However, the principal issue related to network slicing is the multi-slice attachment ability of UE. Currently, the commercial implementations of 5G network are multi-purpose networks, which may be referred as “boosted LTE”. *Ipso facto*, the slicing is substantially inexistent, even if present at the CP signalling level. As the differentiation of handling of traffic fractions belonging to different UAV communication channels is cardinal, the workarounds for emulation of UE multi-slice attachment ability need to be applied. The possible solutions, based on existing mechanisms, are:

- Multiple UEs on-board or dual/multi-SIM UEs attached to different and differently engineered/configured 5G networks;
- Utilization of NSA 5G network with carrier aggregation disabled and allocation of traffic fractions in LTE and NR RANs separately;
- Utilization of WiFi and N3IWF for additional separation of traffic in RAN;

The mechanisms of Proximity-based Services (ProSe) and Sidelink relay are fundamental for providing direct, cross-network communication between UAVs for presence and location broadcasting and use of a neighbouring UAV as a network connectivity relay in case of coverage loss. They are, however, missing in the 5GS standardization yet and belong to the scope of the 3GPP Release 17, currently at the stage of study (cf. [25] and [26], respectively). They are currently available in LTE, only. Similarly, the commercial MCS solutions are available for LTE only, because there is no MCS Stage 2/3 standardization for 5G. Moreover, it is not yet included in release scopes. In case of LCS, the Stage 2 standardization is provided, as it was described in the previous section, but the Stage 3 standardization for is still in progress in the scope of Release 17.

Sharing of 3D information about network coverage and performance is a very important aspect of the integration of the 5G network with the U-space ecosystem, especially in terms of flight plans validation and environmental awareness needed for real-time UAV traffic management. 5G RAN physical layer measurements at UE have been defined [27], but no mechanisms similar to 3G/4G measurements collection (Minimization of Drive Tests – MDT, a part of 4G Self-Organizing Network – SON, cf. [28]) have been specified in the 5G SON framework yet [29]. It is a part of the 3GPP Release 17. Therefore, the only way to provide such information is interfacing network operator's RAN planning tool (outside of 5GS) with the U-space domain. Alternatively, the U-space provider may collect such data from UAVs using a special system and telemetry agents embedded in UAVs, based on a U-space service agreement terms. The data in this system would have only a historical and illustrative meaning.

The issue of specific UAS requirements support by 5GS is in the scope of the Release 17. However, after issuing the document dedicated to UAS services requirements [8] mentioned above, the architectural study dedicated to supporting UAS connectivity, identification and tracking [30] has been recently finished, and the study on application layer support for UAS [31] is still going on.

One of the fundamental enablers of UAV use cases is integration of the 5G network with the MEC framework, upgraded with network slicing support. There is a common consensus the Multi-access Edge Platform (MEP) will be integrated with the 5G CP as a specific case of AF (*Mp2* interface exposed as *Naf* interface). The currently proposed visions of Standard-Developing Organizations assume loose integration of ETSI NFV, ETSI MEC and 5GS frameworks.

Hence, there are many architectural inconsistencies, duplicate functionalities and competing mechanisms. The integrated framework needs to be thoroughly rethought and redesigned with reuse of valuable mechanisms for simplification and synergy. There are already some proposed approaches (cf. [32], [33]). 3GPP also works on integration of MEC within the Release 17 scope. Currently, there are non-normative studies reports available ([34], [35], [36], [37]), but works on the standardization document [38] have already been initiated.

2.4. 5G!Drones Initial Architecture

Building on top of the 3GPP 5G architecture specifications, 5G!Drones proposes a 5G architecture blueprint to serve as a common architectural reference, including an accessible framework, with APIs for exposing the Experimentation Framework to UAV verticals, taking into consideration the capabilities and demands of the associated stakeholders. This blueprint, is to be implemented in a complementary way on top of the ICT-17 experimental platforms 5G facilities 5GEVE and 5GENESIS, as well as full deployment on top of non-ICT17 platforms, i.e., X-Network and 5GTN facilities, defining and developing in the process the missing components necessary to trial the defined UAV use cases.
5G!Drones platform is driven by the selected UAV vertical use cases, which cover the three 5G service classes (i.e., eMBB, URLLC, mMTC). Based on these, 5G!Drones will identify the necessary 5G components to enable the trials, and the needed 5G KPIs to validate, as well as the UAV application performance aspects to test.
The guiding principles, upon which the project is built, are summarised below:

- 5G!Drones is comprised of geographically dispersed platforms;
- The instantiations that are built on top of the four 5G facilities are complementary in terms of features, nevertheless fully aligned to the proposed common reference architecture;
- To ease and automate the execution of trials by the UAV verticals the project builds a software layer that exposes a high-level API to be used in order to request the execution of a trial;
- The instantiations are administratively independent, exposing open interfaces for interplatform coordination and UAV verticals experimentation;

In the deliverable D1.3 [1], we have introduced the high-level architecture of the 5G!Drones platform, as illustrated in Figure 3 below. According to this representation, the architecture is broken down into boxes, each embodying a 5G!Drones architectural component. Furthermore, the high-level architecture shown was broken down into several entities, each representing a component: the Portal, the Trial Controller, the Abstraction Layer, the 5G Facility Infrastructure Monitoring, the U-Space entity and the U-Space Adapter. In addition, the potential interactions between the components were assessed, together with their directionality, represented by the arrows. This initial high-level architecture was conceptually described by three distinct actors, namely the UAV Vertical, the 5G!Drones trial controller and the 5G Facility, whose interactions are guiding the overall approach taken by the project, regarding how the selected UAV use cases will be trialled over the 5G facilities.

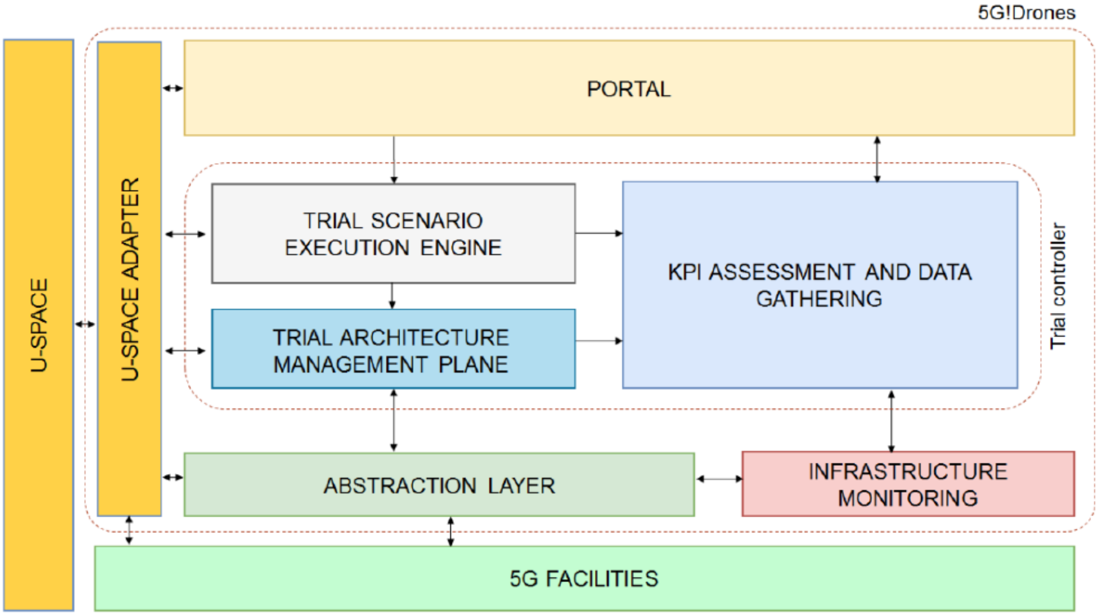

Figure 3: Initial 5G!Drones architecture blueprint

The 5G!Drones project trials are expected to be carried out in four 5G facilities. These include two ICT17 facilities and two non-ICT-17 facilities. The ICT-17 facilities are of 5GEVE and 5GENESIS projects (in France and Athens respectively), while the non-ICT-17 facilities include Aalto University's X-Network and the University of Oulu's 5GTN. To support the trial architecture, each 5G facility is expected to have interfaces to the trial controller. The interfaces will allow the 5G facility managers and orchestrators to dynamically create the required 5G network services and slices based on the use case requirements.

Hence, while the trial controller manages the overall operation of a 5G drone trial across UAVs, U-space and the 5G facility, the facility managers and orchestrators will manage the 5G service deployment within the facility.

The 5G facilities manager and orchestrator shall be responsible for the deployment of following network services, crucial for the overall operation of the trial architecture:

- End to end network slicing across the Radio Access Network (RAN), Core Network (CN) and Transport Network (TN);
- Edge computing or MEC deployment and availability of the required infrastructure resources;

VNF instantiation across the facilities;

3. REQUIREMENTS FULFILLED BY 5G!DRONES SYSTEM

3.1. Functional Requirements

To evolve from the high-level architecture to the refined and detailed design, it was deemed mandatory to drill into the specific requirements and capabilities per component, considering the stand-point of all involved stakeholders. To that end, a presentation of the driving functional requirements of the several components and modules of the 5G!Drones system, reflecting appropriately the work carried, is provided below. The functional requirements of the several components within the 5G!Drones platform architecture, have been categorized based on the three distinct domains of the 5G!Drones concept, the trial controller, the U-space and the 5G facilities.

This following subsection describes the functional requirements of the components in the **Trial Controller domain**.

3.1.1. Web Portal-1

The Web Portal 1 is flight planning part and will guide the experimenter through the wizard forms. The perceived role of web portal is presented in Table 1.

Table 1: The role of Web portal-1

<table>
<tr><th></th><th colspan="3">Web Portal-1</th></tr>
<tr><td>Significance</td><td colspan="3">Essential</td></tr>
<tr><td>Description</td><td colspan="3">Web Portal 1 shall define the Drone Flight Plan (dFPL), select the 5G facility, as well as obtain the flight permission if necessary and 5G coverage verification.</td></tr>
<tr><td>Affected Component(s)</td><td>Trial validator, Trial Registry, Dashboard, Web Portal2 (Facility)</td><td>Role/Stakeholder</td><td>Experimenter</td></tr>
</table>

Towards the design and development of Web Portal-1, a number of requirements are distilled, as presented in Table 2.

Table 2: Functional requirements of Web Portal-1

	Functional Requirements
WEBPTL-R1	User should be able to login to the 5G!Drones Web Portal using assigned login name & password
WEBPTL-R2	Different user types should be defined with different privileges
WEBPTL-R3	User should be able to select the action according to his intent (different actions are specified in the next points below).
WEBPTL-R4	User should be able to create new flight plan.
WEBPTL-R5	User should give mandatory as well as optional information for flight plan
WEBPTL-R6	Facility Web Portal should fetch trial status/configuration from Trial Repository (based on trial id)
WEBPTL-R7	User should be able to create new plan and save it as a template in Trial Repository. Template has no mandatory fields.
WEBPTL-R8	User should not be able to modify template.

	Functional Requirements
WEBPTL-R9	User should be able to delete template from Trial Repository.
WEBPTL-R10	User should be able to modify/delete existing flight plan
WEBPTL-R11	User should be able to submit flight plan to validation by USSP
WEBPTL-R12	User should be able to add UAV (one or more) to the UAV repository
WEBPTL-R13	When creating or modifying flight plan, user shall be able to select desired UAV type from the list
WEBPTL-R14	Facility list is managed by admin
WEBPTL-R15	User shall be able to select desired facility from the list.
WEBPTL-R16	User should be able to add /delete VNF to the VNF repository
WEBPTL-R17	User should be able to select desired VNF (one or more) from the list.
WEBPTL-R18	User should be able to save new or modified flight plan. Plan is stored in Trials Repository.
WEBPTL-R19	User can see the saved or modified flight plan with basic information in the Dashboard.
WEBPTL-R20	User shall be able to submit selected flight plan (not template) for validation. As result, Trial Validator is receiving the request containing trial_id.
WEBPTL-R21	Web portal should retrieve list of UAVs from UAV repository
WEBPTL-R22	Web portal should retrieve list of VNFs from VNF Repository
WEBPTL-R23	Web portal should retrieve facility capabilities from 5G Facility Repository

3.1.2. Web Portal-2 /Facility Portal

The Web Portal-2 is used to setup 5G facility environment. Each facility has its specific interface, so the Web Portal-2 will be different, managed by facility and exposed to the experimenter as a link from Web Portal-1. Regarding Web portal-2, the perceived role is presented in Table 3.

Table 3: The role of Web Portal-2

	Web Portal-2		
Significance	Essential		
Description	Web Portal-2 is important for definition, configuration, verification and triggering the experiment in regards to 5G and MEC setup aspects.		
Affected Component(s)	Trial Translator	**Role/Stakeholder**	Experimenter

Stemming from its role, the functional requirements for Web Portal-2, are presented in Table 4.

Table 4: Functional requirements of Web portal-2

	Functional Requirements
WEBFCLT-R1	User selects validated plan from Dashboard and is redirected to appropriate Facility Web Portal.
WEBFCLT-R2	Facility Web Portal will fetch available KPIs and Test Cases from Facility Repository.
WEBFCLT-R3	Facility Web Portal will fetch information about available VNFs and their minimum requirements for configuration from VNF Repository
WEBFCLT-R4	User in Facility Web Portal will define the telecommunication specific parameters for the test using wizard and forms. It will contain: -Slice info -RAN info -NSD (Network Service Description) info - description of VNF -KPIs and monitoring parameters
WEBFCLT-R5	Added information is used to update the trial definition in Trial Repository (Trial-ID is the key)
WEBFCLT-R6	User from Facility Web Portal will trigger the Trial Service Descriptor (TSD) creation in Trial Translator.
WEBFCLT-R7	Facility Web Portal should fetch trial status/configuration from Trial Repository (based on trial id)

3.1.3. Dashboard

The Dashboard serves the role presented in Table 5.

Table 5: The role of 5G!Drones Dashboard

	Dashboard		
Significance	Essential		
Description	The 5G! Drones Dashboard is a graphical user interface for the purposes of visual representation towards authentication, experiment planning, managing and analysing.		
Affected Component(s)	Trials Repository, UAV Repository	**Role/Stakeholder**	Experimenter

The functional requirements identified for Web portal-2 are presented in Table 6.

Table 6: Functional requirements of 5G!Drones Dashboard

	Functional Requirements
DASH-R1	User is redirected to Dashboard after successful authentication
DASH-R2	User can see all saved test plans with their status
DASH-R3	User can start new test creation from Dashboard
DASH-R4	User can select one plan and see its details (detailed view)
DASH-R5	User can select one plan and make action on it: modify, delete, duplicate, start execution, see more details, analyse or download results

DASH-R6	During the plan execution, user will be able to see basic information about test, like the flight status, UAV position, selected KPIs
DASH-R7	User can see/add/modify/delete entries in UAV register

3.1.4. Trial Engine

The trial engine is the module responsible for translating the description of the scenario to an execution script involving the full UAV and network service components to run over the 5G facilities. This module is composed of several submodules as well as a number of repositories engine in order to perform its functions at the different levels. The requirements related to each submodule within the trial engine, are described in the following sections.

3.1.4.1. Trial Translator

The role of the Trial Translator is presented in the following Table.

Table 7: The role of 5G!Drones Trial Translator

	Trial Translator		
Significance	Essential		
Description	The trial translator maps the trial requirements entered in the web portal by the UAV verticals, to the required components in terms of 5G facilities and UAVs.		
Affected Component(s)	Web portal-2 (Facility), Trial Repository	**Role/Stakeholder**	Experimenter

The functional requirements identified for Web Portal-2 are presented in the table below:

Table 8: Functional requirements of 5G!Drones Trial Translator

	Functional Requirements
TT-R1	The Trial translator should be able to parse the Web Portal 2 blueprint.
TT-R2	The Trial translator should use the Trial Repository to appropriately map to components and facility capabilities.

3.1.4.2. Trial Validator

The role of the Trial Validator is presented in the following Table.

Table 9: The role for trial validator

	Trial Validation		
Significance	Essential		
Description	Trial Validator shall reflect the module for dispatching the validation requests to other internal or external modules as well as collecting and presenting the answers to these requests. Trial Validator shall then present validation results to Dashboard for updating the status of the dFPL.		
Affected Component(s)	Web portal 1, U-space adapter, Trial repository	**Role/Stakeholder**	Experimenter

Table 10: Functional requirements of trial enforcement

	Functional Requirement
TV-R1	The trial validator should keep the state of requests and be able to administer all entities necessary to process the specific trial request.

3.1.4.3. LCM (Lifecycle Manager)

The LCM is involved in the lifecycle of the trial execution service at different phases, each having different requirements. The phases are automation trial enforcement and mission execution. Initially in Table 11 we present the role related to the LCM that is followed by the functional requirements specifically identified for the aforementioned distinct phases.

Table 11: Role of Lifecycle Manager

	LCM		
Significance	Essential		
Description	The LCM module shall manage the lifecycle of the trial execution. This module will communicate with the trial enforcement in order to configure and run the required 5G components along with the associated UAV operators, to run the selected scenario.		
Affected Component(s)	Trial enforcement, Trial translator, trial repository	**Role/Stakeholder**	Experimenter/Facility owner

The functional requirements that are relevant to the LCM component are provided in the tables below and have been divided based on the two main processes that the LCM is responsible for, namely the automatic trial enforcement and the mission execution. The identified requirements regarding the automation execution phase are presented below in Table 12.

Table 12: Requirements for the automation execution phase

	Automation trial enforcement Functional Requirements
LCM-R1	Cron type job shall trigger trial resources instantiation well in advance before trial execution is scheduled.
LCM-R2	LCM shall be able to fetch trial information from Trial Repository based on trial ID.
LCM-R3	After successful trial information retrieval, based on this information, LCM shall be able to submit to Trial Enforcement slice deployment request with NST (Network Slice Template). Alternatively, it should only trigger Trial Enforcement, which prepares on its own NST based on the data in Trial Repository.
LCM-R4	LCM shall receive slice deployment confirmation from Trial Enforcement with Slice ID and User ID.
LCM-R5	LCM shall update trial status in Trial Repository after receiving slice deployment confirmation to "slice created".
LCM-R6	LCM shall trigger Trial Enforcement with cloud VNF on-boarding request (VNFDs).
LCM-R7	LCM shall receive on-boarding confirmation from Trial Enforcement (VNF-IDs).
LCM-R8	LCM shall trigger Trial Enforcement with cloud VNF deployment request (VNF-IDs).

	Automation trial enforcement Functional Requirements
LCM-R9	LCM shall receive VNFs instantiation confirmation from Trial Enforcement (Instance-IDs).
LCM-R10	LCM shall trigger Trial Enforcement with edge cloud VNF on-boarding request (VNFDs).
LCM-R11	LCM shall receive on-boarding confirmation from Trial Enforcement (VNF-IDs).
LCM-R12	LCM shall trigger Trial Enforcement with edge cloud VNF deployment request (VNF-IDs).
LCM-R13	LCM shall receive VNFs instantiation (edge cloud) confirmation from Trial Enforcement (Instance-IDs).
LCM-R14	LCM shall update trial status in Trial Repository after successful VNFs on-boarding/instantiation to “apps deployed”.
LCM-R15	LCM shall trigger UAV plan enforcement with Trial Enforcement.
LCM-R16	LCM shall receive UAV plan enforcement confirmation.
LCM-R17	LCM shall update trial status in Trial Repository after successful VNFs on-boarding/instantiation to “UAV plan deployed”.
LCM-R18	LCM shall trigger Trial Enforcement with KPI deployment request (Slice-ID, User-ID).
LCM-R19	LCM shall receive KPI enforcement confirmation (Slice-ID, User-ID).
LCM-R20	LCM shall request list of available/instantiated KPI components from KPI Monitoring based on trial ID.
LCM-R21	LCM shall receive KPI Data Array for requested trial ID.
LCM-R22	LCM shall update trial configuration in Trial Repository with KPI-List links / Data Array.
LCM-R23	LMC shall trigger Trial Enforcement with start 5G resource testing.

During the mission execution phase the trial and related services are running. The LCM tracks changes in data and different modules states. The LCM receives trial’s KPI values from the KPI-monitoring module. The initially identified requirements regarding the mission execution phase are presented in Table 13.

Table 13: Requirements for mission execution

	Mission execution Functional Requirements
LCM-ME-R1	LCM shall receive trial activation request from Dashboard.
LCM-ME-R2	LCM shall forward trial activation request to Trial Enforcement.
LCM-ME-R3	LCM shall receive trial activation confirmation from Trial Enforcement.
LCM-ME-R4	LCM shall update in Trial Repository trial's status to "IDLE".
LCM-ME-R5	LCM shall send to Dashboard pre-flight check request upon receiving trial activation confirmation.
LCM-ME-R6	LCM shall receive request for adding "ACTIVE" label to measurements from Dashboard.
LCM-ME-R7	LCM shall forward "ACTIVE" label request to KPI Monitoring.
LCM-ME-R8	LCM shall update in Trial Repository trial's status to "ACTIVE".
LCM-ME-R9	LCM shall receive trial close/release request from Dashboard.
LCM-ME-R10	LCM shall request KPI Monitoring to label measurements as "FINISHED".
LCM-ME-R11	LCM shall receive from KPI Monitoring info data received and collecting “FINISHED”.

LCM-ME-R12	LCM shall forward close/release request to the Trial Enforcement.
LCM-ME-R13	LCM shall receive from Trial Enforcement 5G sources release confirmation.
LCM-ME-R14	LCM shall update trial status in Trial Repository to "FINISHED".

Table 14: Requirements for status and error handing

	Mission execution (Status and Error Case Handling) Functional Requirements
LCM-EH-R1	LCM tries to connect again to component/service if connection failed.
LCM-EH-R2	LCM will try to recover connection between other component/service in a set time window (future work).
LCM-EH R3	LCM sends error message to user after fail to get connection to component/service despite attempts.
LCN-EH-R4	LCM shall have the ability to start and stop and recover itself.
LCM-EH-R5	LCM Execution Engine has an ability to save the status of an Engine instance with LCM.
LCM-EH-R6	LCM Scheduler has an ability to restart an Engine instance based on saved Engine status in case of an Engine instance failure.

3.1.5. Trial Enforcement

Table 15: The role of the Trial Enforcement

	Trial Enforcement		
Significance	Essential		
Description	The trial enforcement designates the module that runs the trials, as per the requests of the trial execution engine. This includes request for deployment as well as request for run time configuration and update.		
Affected Component(s)	LCM, Abstraction layer	**Role/Stakeholder**	Experimenter

Table 16: Functional requirements of the Trial Enforcement

	Functional Requirements
TE-R1	All resources dedicated to the NST shall be created and configured to a state that is ready for operation.
TE-R2	The Trial Enforcement modules shall return the Slide ID to the LCM for life cycle procedures and creating the KPI measurement.

3.1.6. Repositories

A number of repositories have been defined within the framework of the trial engine, with the aim to organize the data storage that is essential for the experiments. These repositories include the 5G facility repository, the VNF repository, the UAV repository and the predefined trial repository. The following tables include the basic requirements for the distinct aforementioned repositories.

3.1.6.1. VNF Repository

Table 17: The role of VNF repository

	VNF Repository		
Significance	Essential		
Description	The VNF repository shall hold the different virtualized network functions required to run UAV scenarios on the top of the 5G trial sites. The use of these VNFs will therefore depend on the target scenario.		
Affected Component(s)	LCM, Trial repository	**Role/Stakeholder**	Experimenter

Table 18: Functional requirement of VNF Repository

	Functional Requirement
VNF RE-R1	As for VNFs, the possible operations are onboarding, offboarding, resource scaling and migration.

3.1.7. UAV Repository

Table 19: The role of UAV repository

	UAV Repository		
Significance	Essential		
Description	The UAV repository holds information about hardware available for use-cases, including available sensors, availability in time & location, as well as flight characteristics.		
Affected Component(s)	Web portal-1, web portal-2 (Facility), dashboard	**Role/Stakeholder**	Experimenter

Table 20: Functional requirements of UAV Repository

	Functional Requirements
UAV RE-R1	UAV repository shall access information about the UAV from U-Space services.
UAV RE-R2	The UAV interface shall provide methods to create, read, update, delete, and list UAV records.

3.1.8. Repository of predefined trials

Table 21: The role for the Predefined Trials' Repository

	Predefined Trials Repository		
Significance	Essential		
Description	The trial repository acts as the center piece of the trial controller's storage and shall include attributes referencing both UAVs and 5G facilities. Moreover, the specific repository shall enable the status verification of a given trial.		
Affected Component(s)	Abstraction layer, LCM	**Role/Stakeholder**	Experimenter

Table 22: Functional requirements of Predefined Trials' Repository

	Functional Requirements
PTR-R1	The trial repository's attributes shall come after a trial is validated.
PTR-R2	The trial repository shall provide server-side filtering.

3.1.9. KPI Monitoring

Table 23: The role of KPI Monitoring

	KPI Monitoring		
Priority	Essential		
Description	The KPI monitoring is responsible for collecting data during the trials and persisting data for performing analytics. Based on the collected data, a variety of statistics and analysis can be executed and exposed to the experimenter.		
Affected Component(s)	LCM	**Role/Stakeholder**	Experimenter

Table 24: Functional requirements of KPI monitoring

	Functional Requirements
KPI-R1	The KPI Monitoring shall provide interfaces to receive KPI monitoring data.
KPI-R2	The KPI Monitoring shall persist all received KPI monitoring data.
KPI-R3	The KPI Monitoring shall allow to mark events during a Trial.
KPI-R4	The KPI Monitoring shall provide information which other components are providing KPI monitoring data for a specific Trial.

3.1.10. Abstraction Layer

This section describes the basic requirement of the abstraction layer, which acts as the main component in the Infrastructure abstraction domain.

Table 25: The role of the Abstraction Layer

	Abstraction layer		
Priority	Essential		
Description	The abstraction layer shall provide a unified API on top of the project facilities, which will be used by the LCM element to manage the trial life-cycle. The unified API covers the Network Slice LCM, and monitoring management. The abstraction layer includes an API translator for each facility.		
Affected Component	LCM, KPI monitoring, trial enforcement, VNF repository	**Role/Stakeholder**	Experimenter/Facility owner

Table 26: Functional requirements of the Abstraction Layer

	Functional Requirements
AL-R1	The Abstraction Layer shall receive the generic requests sent by the trial controller to the trial facilities and translates them to facility-specific requests.
AL-R2	The Abstraction Layer shall cover the NS LCM management procedures: commissioning, operation and decommissioning.

3.1.11. U-space Adapter

This section describes the basic requirement of the abstraction layer, which acts as the main component in the U-space domain.

Table 27: The role of U-Space Adapter

<table>
<tr><th></th><th colspan="3">U-space adapter</th></tr>
<tr><td>Priority</td><td colspan="3">Essential</td></tr>
<tr><td>Description</td><td colspan="3">The U-space Adapter is a component which allows the integration of the 5G!Drones architecture with UTM and more generally the U-Space entity. To allow this integration, several IRPs are identified, thereby defining interaction points with the U-Space, Portal, Trial Scenario Execution Engine, Trial Architecture Management Plane and the 5G!Drones UAV Enablers</td></tr>
<tr><td>Affected Component(s)</td><td>Portal, Trial Engine, Trial Architecture Management Plane, UAV Enablers</td><td>Role/Stakeholder</td><td>Experimenter</td></tr>
</table>

Table 28: Functional requirements of U-Space Adapter

	Functional Requirements
UA-R1	The U-space adapter shall provide interfaces to the U-space components.
UA-R2	The U-space adapter shall allow other components to exchange data and information with the U-space components.
UA-R3	The U-space adapter shall allow exchange of telemetry (position) information.
UA-R4	The U-space adapter shall allow validation of dFPL and reservation of UTM airspace.

3.2. Security Requirements

The list of security requirements is the outcome of the collaboration of Security Task Force composed of several members of 5G!Drones project. It's mainly related to the software component of the project's deliverable, but not limited. We assured a wide diversity of this group to cover all possible aspects of the security and work was done in several iterations. At the beginning, we have listened to the subject matter experts from Thales and Orange, and we read the documents recommended by them, related to the security in the domain of drones. We have adopted the classification of security related aspects into several categories, according to the classification presented in Figure 4 below.

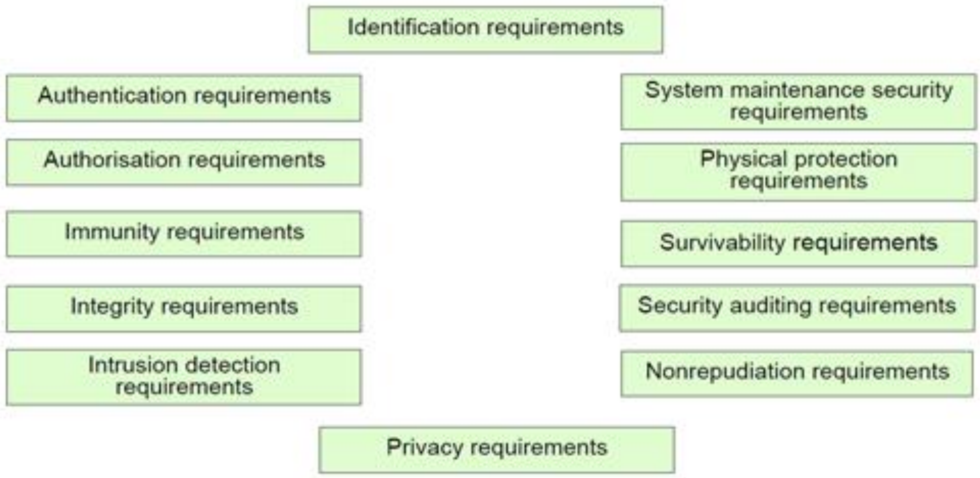

Figure 4: Security requirements classification (source: Firesmith, 2003)

In the last iteration, we have weighted the importance of each requirement, by assigning priorities – High/Medium/Low. In total, we have registered 58 requirements common for all use cases and have been categorised in nine major categories:

- Authentication towards Experimenter, Pilot, UAVs and Trial Engine
- Authorization towards the Pilot and the Experimenter
- Non-repudiation services
- Integrity of data
- Audit of the data and services
- Immunity services
- Survivability of the Trial Engine
- Availability of the C2 link
- Confidentiality of the exchanged data within the system

It is worth mentioning that certain use cases may have additional specific requirements, i.e. logistic delivery use case has two requirements, which are related to the intelligent box for storage of delivered goods.

Table 29: Authentication requirements of 5G!Drones platform

ID	Authentication requirements	Priority
SEC-AU-R1	Experimenter, Pilot, Customer will define login/password (or certificate, OTP) during registration or will be granted login/password by system administrator	Medium
SEC-AU-R2	Strong enough password is required (i.e. min 8 characters, small and big letters and special characters) or other strong enough method	High
SEC-AU-R3	Experimenter, Pilot, Customer should authenticate by using login/password or certificate, or OTP to use the Web Portal and Trial Engine	High
SEC-AU-R4	UAV should authenticate GCS and vice versa	High
SEC-AU-R5	UAV should authenticate serving UTM and vice versa	Medium
SEC-AU-R6	Trial Engine should authenticate serving UTM and vice versa	Medium
SEC-AU-R7	Web Portal should authenticate Trial Engine and Trial Engine should authenticate Web Portal	Medium

SEC-AU-R8	GCS should authenticate serving UTM and vice versa	Medium
SEC-AU-R9	GCS should authenticate serving MEC server and vice versa	Medium
SEC-AU-R10	Trial Engine should authenticate UAV and vice versa	Medium
SEC-AU-R11	Trial Engine should authenticate GCS and vice versa	High
SEC-AU-R12	Trial Engine should authenticate Facility and vice versa	High
SEC-AU-R13	Software controlling IoT sensor or camera should authenticate it and vice versa	Medium
SEC-AU-R14	All Trial Engine components should use authentication for internal communication between components	Medium
SEC-AU-R15	Test SIM cards used in the experiments are issued by 5G facility and recognised by their HSS	High

Table 30: Authorization requirements of 5G!Drones platform

ID	Authorization requirements	Priority
SEC-AT-R1	Pilot should have authorisation to fly/supervise specific UAV	High
SEC-AT-R2	Experimenter should have authorisation to create dFPL	Medium
SEC-AT-R3	Experimenter should have authorisation to modify dFPL	Medium
SEC-AT-R4	Experimenter should have authorisation to submit dFPL to validation	Medium
SEC-AT-R5	Experimenter should have authorisation to analyse dFPL	Medium
SEC-AT-R6	All persons authorised to access and work with 5G!Drones system should have appropriate training/qualifications	Medium

Table 31: Non-repudiation requirements of 5G!Drones platform

ID	Non-repudiation requirements	Priority
SEC-NR-R1	Only one serving UTM at the time	Medium
SEC-NR-R2	Services/applications can migrate from one MEC to other, but should prove it's still the same process	Medium
SEC-NR-R3	Handover between different UTMs possible	Medium

Table 32: Integrity requirements of 5G!Drones platform

ID	Integrity requirements	Priority
SEC-IN-R1	Integrity of deployed software components - they should have valid checksums	Medium
SEC-IN-R2	APIs and other data exchanged between different modules should have integrity protection	Medium
SEC-IN-R3	Stored experiment data should be resistant to modifications	Medium
SEC-IN-R4	5G facility is secured according to 3GPP specifications in terms of messages modification	Medium

Table 33: Audit requirements of 5G!Drones platform

ID	Audit requirements	Priority
SEC-AD-R1	UAV telemetry data should be accessible and visualized in real time during the flight	High
SEC-AD-R2	UAV telemetry data should be stored and available to analyse after mission is completed	High
SEC-AD-R3	GCS logs should be available after the mission is completed	High
SEC-AD-R4	Logs documenting UTM - Trial Controller messages exchange should be kept after mission is completed	High
SEC-AD-R5	All contingency situations should be logged and stored for analysis	High
SEC-AD-R6	5G C2 communication link parameters (RSCP, RSRQ, RSSI) should be logged and stored for analysis	Medium
SEC-AD-R7	Continuous health monitoring of important components	High
SEC-AD-R8	Alarm should be raised for defined thresholds (i.e. exceeding 80% of disk usage)	Medium
SEC-AD-R9	After long inactivity, the user should be logged out from the Web Portal	Medium
SEC-AD-R10	IoT box should send periodically its status to DLS 2.0 (CAFATECH solution)	Medium

Table 34: Immunity requirements of 5G!Drones platform

ID	Immunity requirements	Priority
SEC-IM-R1	Trial Controller software should protect itself from malicious attacks (i.e. scan the incoming messages)	High
SEC-IM-R2	5G facilities infrastructure should be protected from malicious attacks	High
SEC-IM-R3	Secure exchange (authenticated and confidential) of messages between Trial Controller and external peers should be assured	High
SEC-IM-R4	Suspected patterns or attacks should be notified to administrator	High

Table 35: Survivability requirements of 5G!Drones platform

ID	Survivability requirements	Priority
SEC-SU-R1	Trial Engine should be able to get autonomously to operational status after unexpected restart	High
SEC-SU-R2	Trial Engine should be able to treat congestion situations	High
SEC-SU-R3	Trial Engine should be able to take actions in occurrence of unexpected error/situation	High

SEC-SU-R4	The system should be on-line for 99.9999% of experiment time	High

Table 36: Availability requirements of C2 and Payload link

ID	Availability requirements	Priority
SEC-AV-R1	C2 link should be available for 99.9999% of time (unavailability due to unforeseen reasons, natural or intentional - malicious attack))	High
SEC-AV-R2	C2 link can be unavailable for x seconds, if it's predicted due to lack of coverage or another predicted natural event	High
SEC-AV-R3	C2 link can be unavailable for x ms due to handover from serving to target gNodeB (serving system characteristics)	High
SEC-AV-R4	Payload link should be available for 99% of time (unavailability due to unforeseen reasons, natural or intentional - malicious attack)	Medium
SEC-AV-R5	Payload link can be unavailable for x seconds, if it's predicted due to lack of coverage or another predicted natural event	Medium
SEC-AV-R6	Payload link can be unavailable for x ms due to handover from serving to target gNodeB (serving system characteristics)	Medium

Table 37: Confidentiality requirements of the data exchanged in 5G!Drones platform

ID	Confidentiality requirements	Priority
SEC-CO-R1	Secure data exchange (mutually authenticated, encrypted, integrity protected) between UAV and MEC apps should be ensured	High
SEC-CO-R2	Secure data exchange (mutually authenticated, encrypted, integrity protected) between UAV/MEC apps and positioning database should be ensured	High
SEC-CO-R3	Secure data exchange (mutually authenticated, encrypted, integrity protected) between trial controller and positioning database should be ensured	High
SEC-CO-R4	Secure data exchange (mutually authenticated, encrypted, integrity protected) between 5G radio access network and remote 5G core should be ensured	High
SEC-CO-R5	Secure data exchange (mutually authenticated, encrypted, integrity protected) between UAV/MEC and Flight Control Center (FCC) should be ensured	High
SEC-CO-R6	Secure data exchange (at minimum authenticated & integrity protected) between beacons (e.g., Bluetooth, WLAN) and UAV should be ensured in order to mitigate beacon spoofing	Medium

4. 5G!DRONES REFINED ARCHITECTURE

4.1. 5G! Drones Refined Architecture

The objective of this section is to provide the refined and final architecture of 5G!Drones platform with a twofold approach. First, this final architecture has been elaborated so that the trial controller allows the simultaneous run and control of multiple UAV use cases, demonstrating the capability of 5G to guarantee different service requirements at the same time. Likewise, the architecture has been designed with the intention to support the selected use cases over a federated, multi-domain 5G infrastructure. An overview of the 5G!Drones architecture is illustrated in Figure 5. According to this representation, the architecture is broken down into boxes, each embodying a 5G!Drones architecture component enabler. The refined design of the 5G!Drones architecture follows the same concepts and design defined in the initial version of the baseline architecture reported in D1.3. However, there are a number of added functionalities and extended features which are described in a dedicated way in the following subsections.

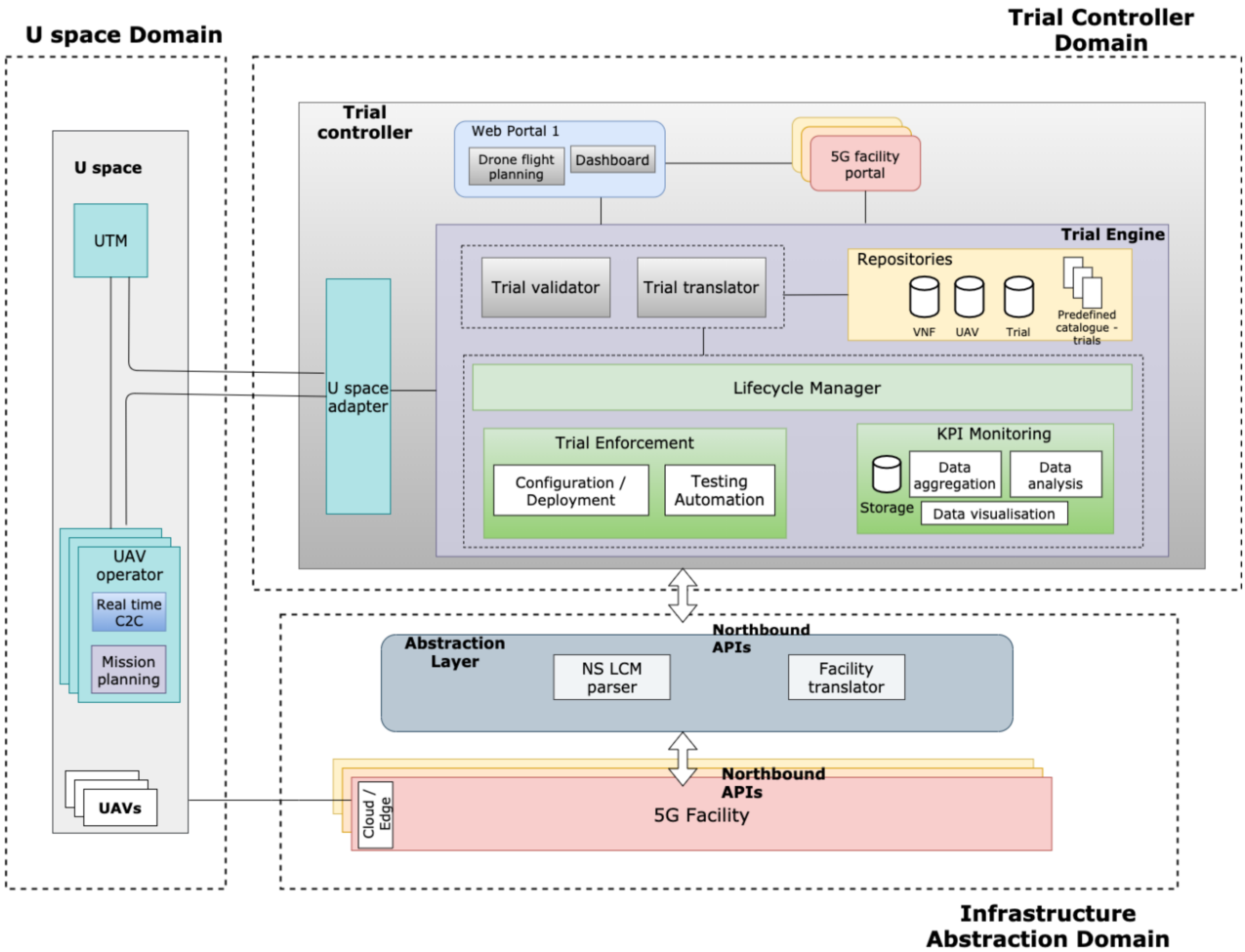

Figure 5: Final 5G!Drones refined architecture

A high-level description indicates that the experimenter initially interacts via the web portal with the trial controller domain to describe the scenario, along with the technical description of the network slices and the target KPIs to be evaluated. The trial controller domain coordinates with the infrastructure controller domain so as to run the different experiments on top of the 5G facilities. Furthermore, in order to validate the trial and ensure safe access to the airspace by the drones, the trial controller domain also interacts with the U-space domain through a dedicated interface. Figure 6 below illustrates the mapping of the components on the 5G!Drones system's architecture, as well as the interactions between these components. The blue colour represents the enablers of the trial controller domain, the orange colour the enablers within the infrastructure abstraction domain and the green colour the enablers within the U-space domain respectively.

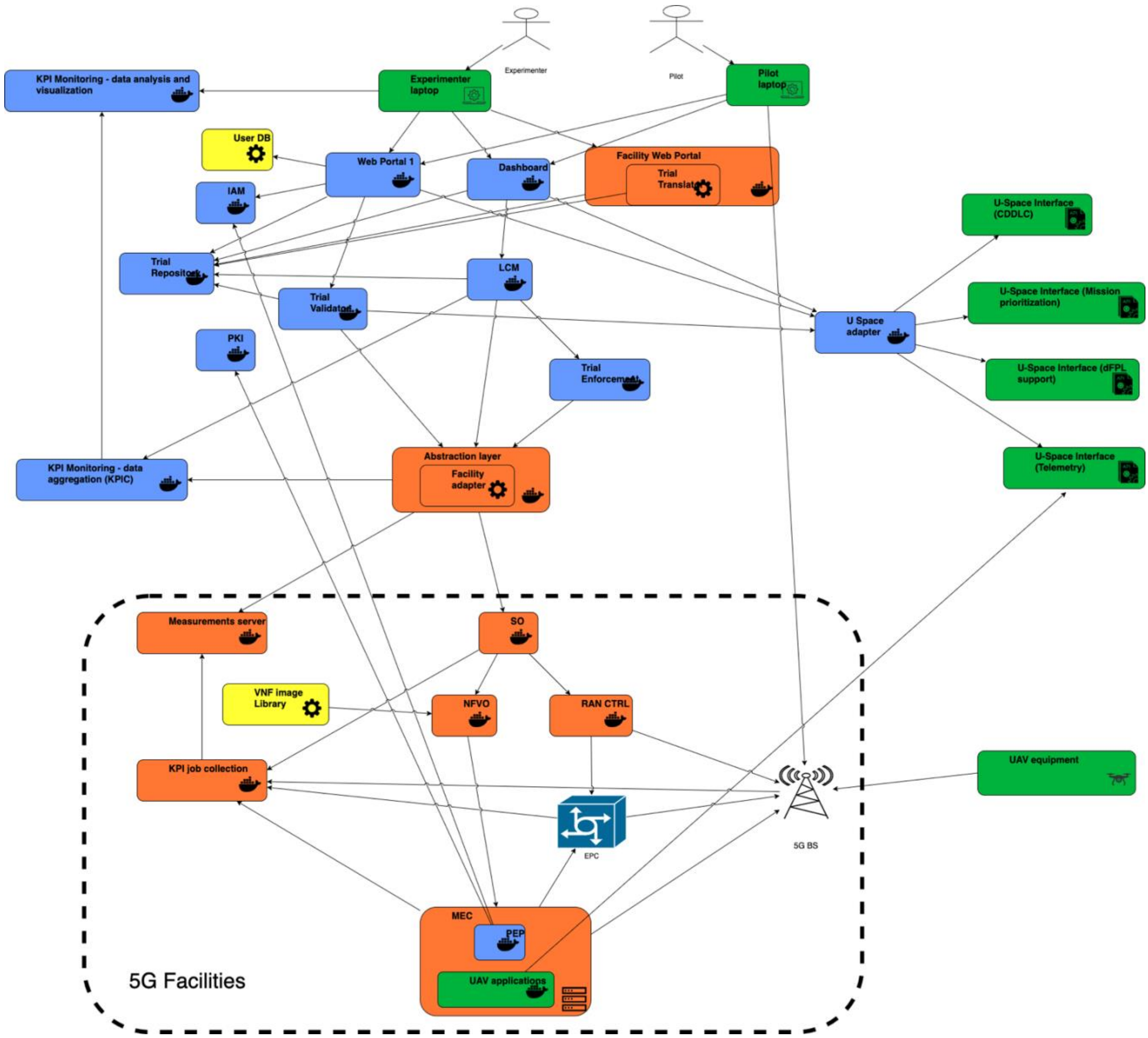

Figure 6: Interaction of the components in 5G!Drones architecture

Above interactions between the components, also reflect the information scope that the trial controller main user (Experimenter) has while using the system through three main phases:

- Trial planning phase
- Trial implementation on 5G premises phase
- Trial execution – monitoring and results presentation

The workflow in Figure 7 describes the steps/processes that need to be performed during the trial planning phase that are respectively initiated by the four distinct actors, the Experimenter, the Trial Controller the U-space and the 5G Facility.
Those processes include:

- Authentication and authorisation of the user
- Mission validation of which main step is to gather the flight mission approval from U-Space perspective
- Verification of mission's feasibility from 5G network's capability perspective (availability of required resources)

The first step is the logon process where the experimenter enters the credentials. After a user is authenticated, the trial planning starts by sending his request to the trial controller in order to verify the flight plan (dFPL) to the U-space domain, as well as the coverage and availability of the resources from the facility. The trial controller needs to gather the different information about facility, UAV and the trial's requirements through iterations which describe the trial planning and validation process. Finally, it returns the response to the experimenter, containing validation or rejection of the mission request.

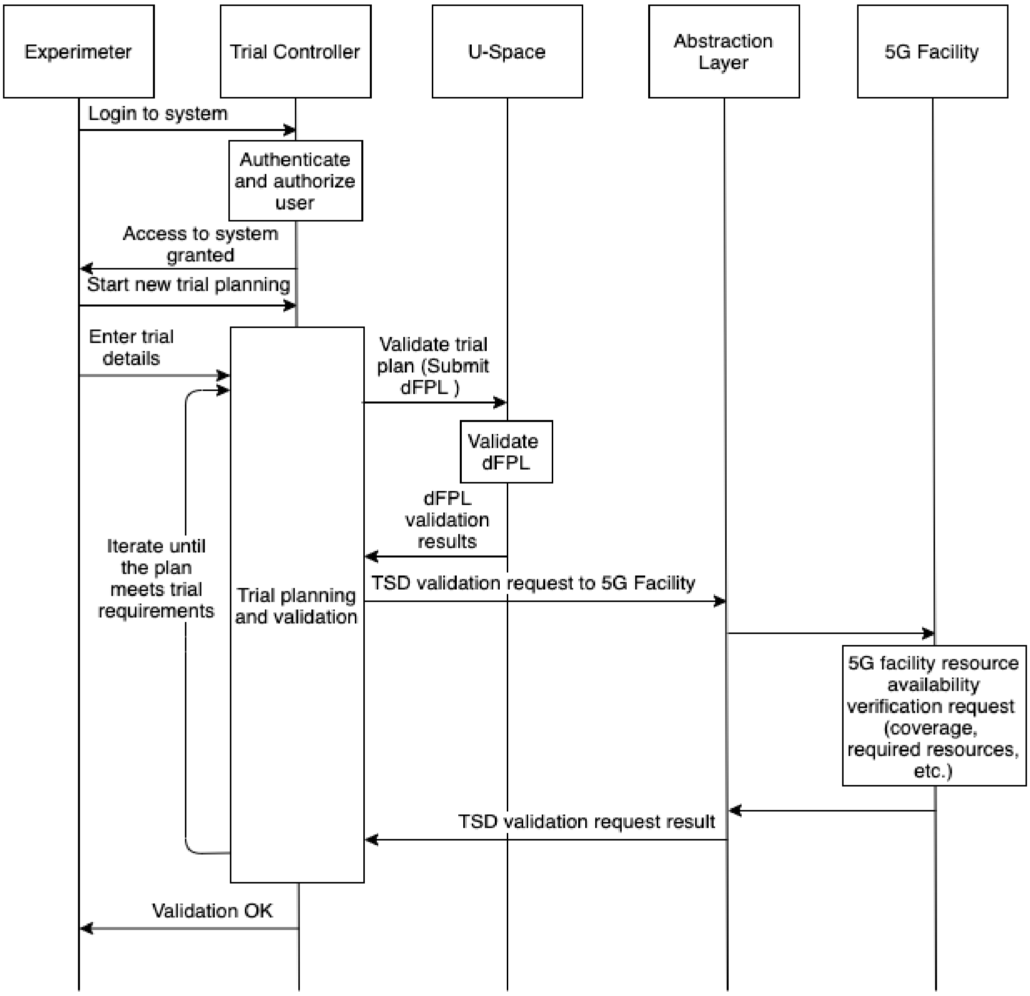

Figure 7: High level sequence diagram of the dFPL

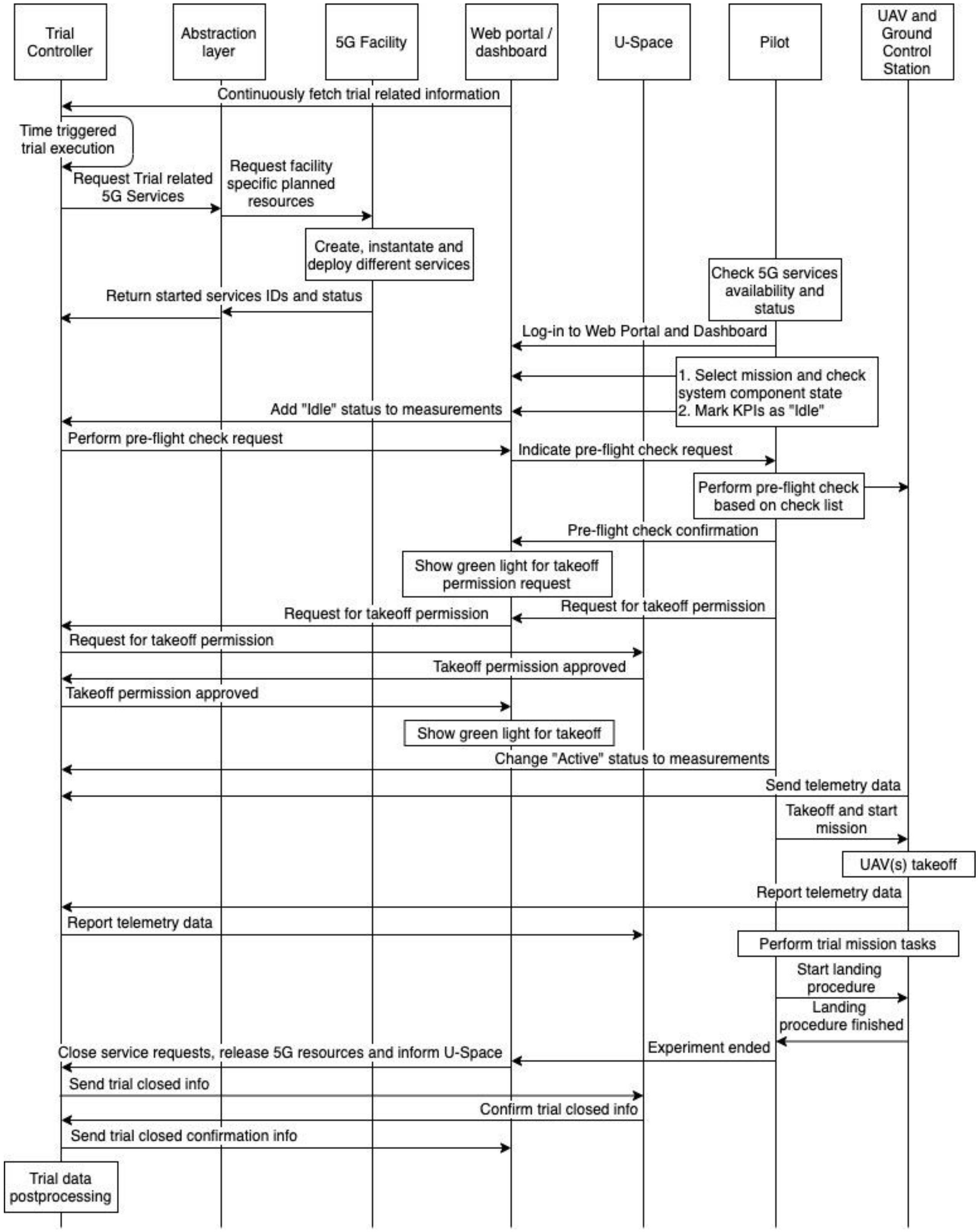

Figure 8: High level sequence diagram of the execution and post-processing phase

The sequence diagram as illustrated in Figure 8, describes the steps towards the execution and post processing phase. The trial execution phase starts when the defined trial time triggers the Trial Controller. The Trial Controller starts defined services automatically based on the pre-defined trial plan. After the pilot has performed pre-flights checks, U-Space and 5G!Drones services shows green light to the actual flight, the pilot can take off the drone(s).

After the UAV(s) are landed and services are closed, the post-processing phase starts. During the post-processing phase, the collected data is pre-process, refined, analyzed, presented and stored for the future use. The post-processing phase is a critical phase from privacy point of view, the general data protection regulation (GDPR) requirements related aspects require particular attention. The stored data needs to be useful for further use, however, at the same time contain only pseudonymized data.

The following subsections provide a description of the components and their role in the overall architecture, while implementation information, detailed description of interfaces and the internal workflows are provided in the related deliverables of WP2 and WP3.

4.2. Trial Controller

The trial controller is the entity of the 5G!Drones system architecture responsible for running the use case scenarios on the top of the 5G facilities. Based on the scenario description introduced by the user via the web portal, the trial controller will thereafter translate the scenario into the required network resources and ensure the validation of the trial. Furthermore, the trial controller will also manage the execution of the trial throughout its lifespan, ranging from the deployment to the post-processing phase. Therefore, the trial controller can be broken down to the following functional modules: Trial translator, Trial validator, the repositories and the lifecycle manager (LCM).

4.2.1. Portal

The Web Portal is the interface between the experimenter and the 5G!Drones Trial Engine. It is used to create, modify and analyse experiments and manage additional tasks, like adding the UAV equipment to the UAV register. It shall expose open APIs enabling the Experimenter to access the platform, define and conduct experiments as well as retrieve the results. In order for the web portal to fulfil the aforementioned functions it has been divided into two parts.

During our investigation about the workflow regarding the trial planning, we have noticed the clear division to two parts. The first one is defining the drone mission and requires the SORA approval. This phase can be iterative (rejection – modification steps) and take quite a lot of time – getting approval can be counted even in weeks. The second part is defining and implementing the telecommunication part of the trial, which is managed differently in each facility due to different implemented technologies, processes and diversities.

- **Web Portal-1** that is used for accessing the Trial Engine, to define the drone Flight Plan (dFPL), and selecting the 5G facility. It also hosts the Dashboard and will be used to start the mission execution, after receiving the permission from Airman.
- **Web Portal-2** (5G Facility Web Portal) is the place where the Experimenter will submit his requirements and configure the parameters related to 5G connectivity, services and hosting the vertical’s application (VNF) in MEC.

4.2.2. Dashboard

The 5G!Drones Dashboard is a graphical user interface for authentication, experiment planning, as well as managing and analysing an experiment. The Dashboard has two main functions:

- List View for planning and managing experiments
- Analysis and Replay View for analysing and replaying after experiment.

The goal is to integrate all information flows that come to the Drone Operator and the experimenter to the Dashboard. The main goal is to avoid using several different computers on the table which makes it difficult to monitor the situation comprehensively. Therefore, the goal is to integrate the Dashboard with other business applications used by the UAV Operator, if possible, in addition to the three basic blocks that the Dashboard must reflect anyway. However, it should be noted that it is more difficult to integrate UAV Operators' business applications into Analysis and Replay View. Dashboard functions are described in D2.1 subsection 2.3.2. [4]. No significant changes are currently planned to the Dashboard compared to the features described in D2.1. The figure below describes a high-level architecture of the Dashboard.

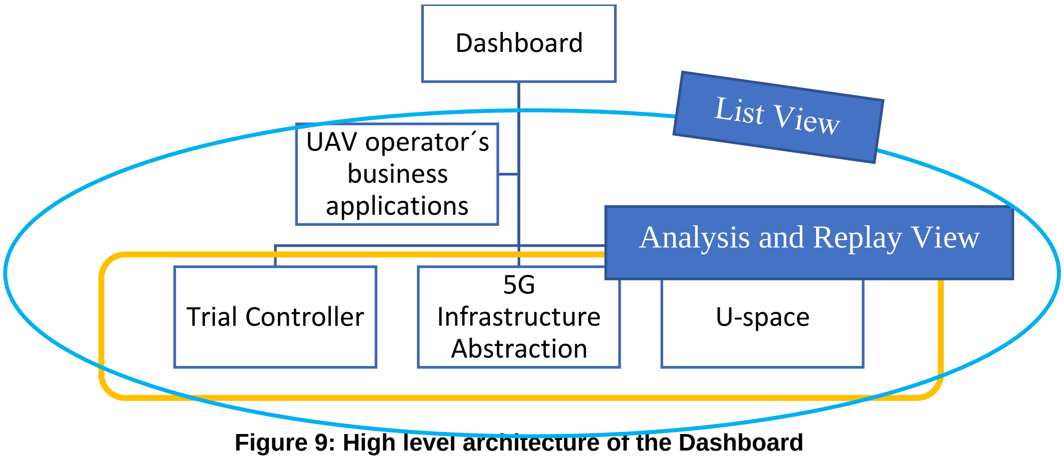

Figure 9: High level architecture of the Dashboard

4.2.3. Trial Engine

4.2.3.1. Trial Translator

The main objective of the trial translator is to map the trial requirements entered in the Web Portal-2 by the UAV verticals to the required components in terms of 5G facilities and UAVs. The necessary information for the trial is provided in the form of a Blueprint through the Web Portal-2. The latter creates a Trial Service Descriptor (TSD) including KPIs, trial duration, RAN information, Network Service Descriptor (NSD), and Virtual Network Function Descriptors or Application Descriptor. The trial translator translates the TSD into a Network Slice Template (NST) to be used by the LCM entity to deploy a trial into the form of a Network Slice on top of one of the fourth 5G!Drones facility. Since each facility uses its own template to deploy a network slice, the TSD is translated to a NST understandable by the 5G Facility Slice orchestrator or manager where the trial will be run.

4.2.3.2. Trial Validator

The main objective of the Trial Validator is to ensure that the different components of the 5G!Drones ecosystem are functioning the way they are supposed to function. This includes verifying the slicing templates, flight plan, network availability, coverage information, pre-flight authorization and a variety of other requirements. The frontend of the Trial Validator is supporting Web Portal 1 and will be available for all partners to check the status of the components during the trial planning phase and up to the execution of the trial. The responsibility of the trial validator starts from early stages of trial planning, preparation and extends up to "clear to take-off" is given and the UAV is approved to take-off.
The trial validator receives input from the following components of the trial:

- Web Portal-1
- U-space adapter
- 5G facility repository
- Trial repository

The output will be a Go or a No-Go status light, either in Red, Green or Orange indicating the status of the component and the trial. Figure 10 and Figure 11 below show the architecture of the Trial Validator & the Trial Sequence Diagram, respectively.

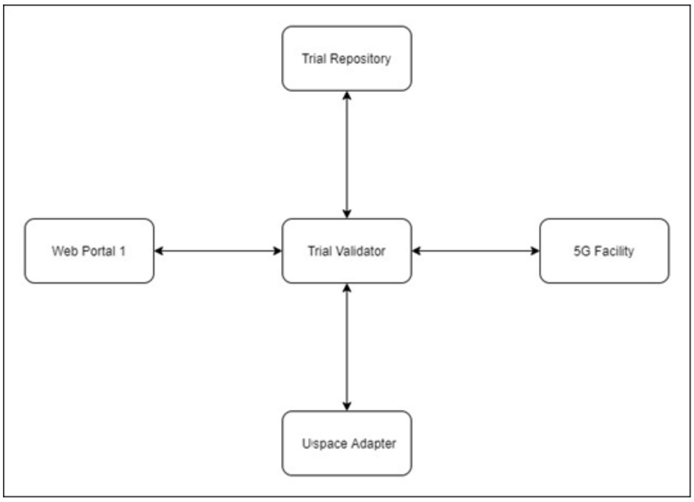

Figure 10: Trial Validator Architecture

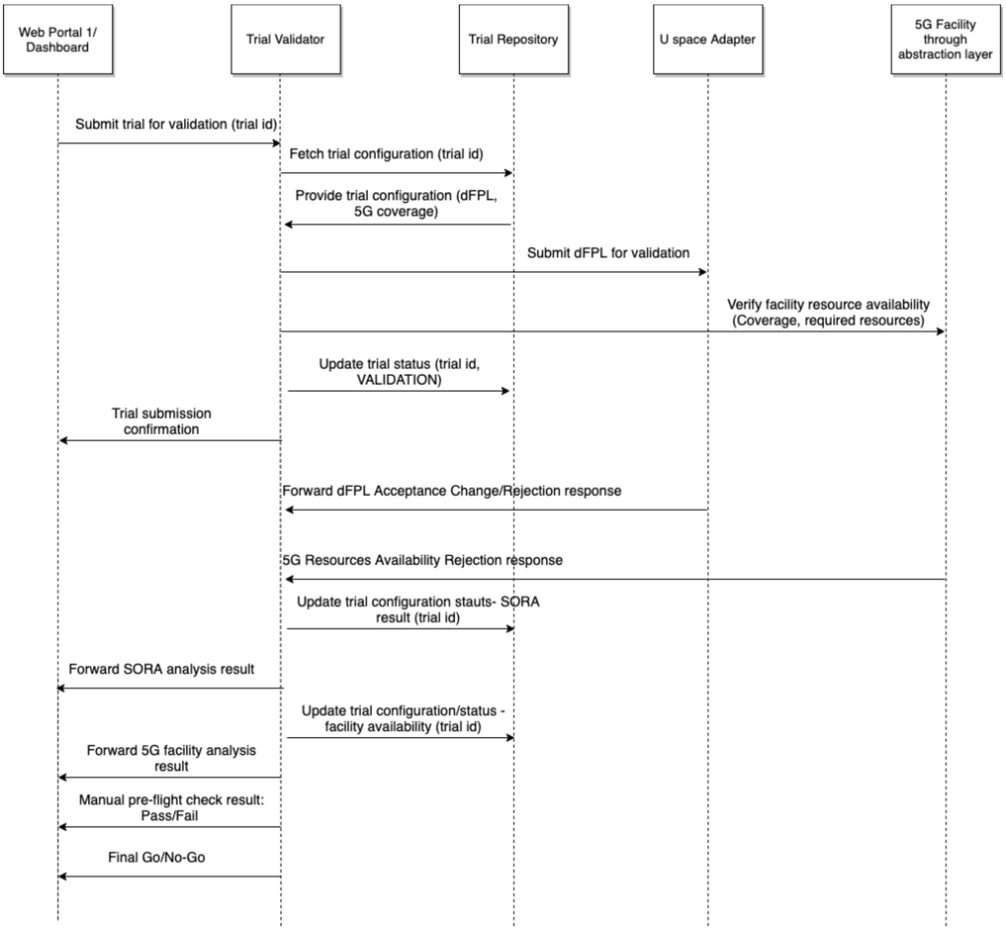

Figure 11: Trial Validator Sequence Diagram

4.2.4. Repositories

4.2.4.1. VNF Repository

The main objective of the VNF repository is to store and contain the vertical applications, which will be deployed during 5G!Drones trials. The VNF repository is a safe environment where the applications can be stored, and it is stored within the trial engine, only exposing well-defined APIs for access. The repository content is available to an experimenter during experiment planning phase. Each application to be stored in the repository shall have a description of its basic information: purpose and whom to contact in case of problem with its execution. The VNF repository shall also have control and tracking of modifications enabled.

4.2.4.2. UAV Repository

The goal of the UAV repository is to hold information about hardware available for use-cases, including available sensors, availability in time & location, and flight characteristics. Mandatory information about the UAV elements is provided based on the regulations specified by the U-Space Services. In the context of the project, this will allow experiences with the UAV repository to drive recommendations for associated standards developments organizations. This is expected to have synergies with ongoing work in U-Space e-Registration services, particularly in defining connectivity models for UAVs. Additionally, the UAV operator can provide some optional information about their hardware capabilities. The experimenter can select the parameters from the list of elements in the UAV repository and choose his preferences for conducting a trial. The overall architecture of the UAV repository architecture is depicted in Figure 12.

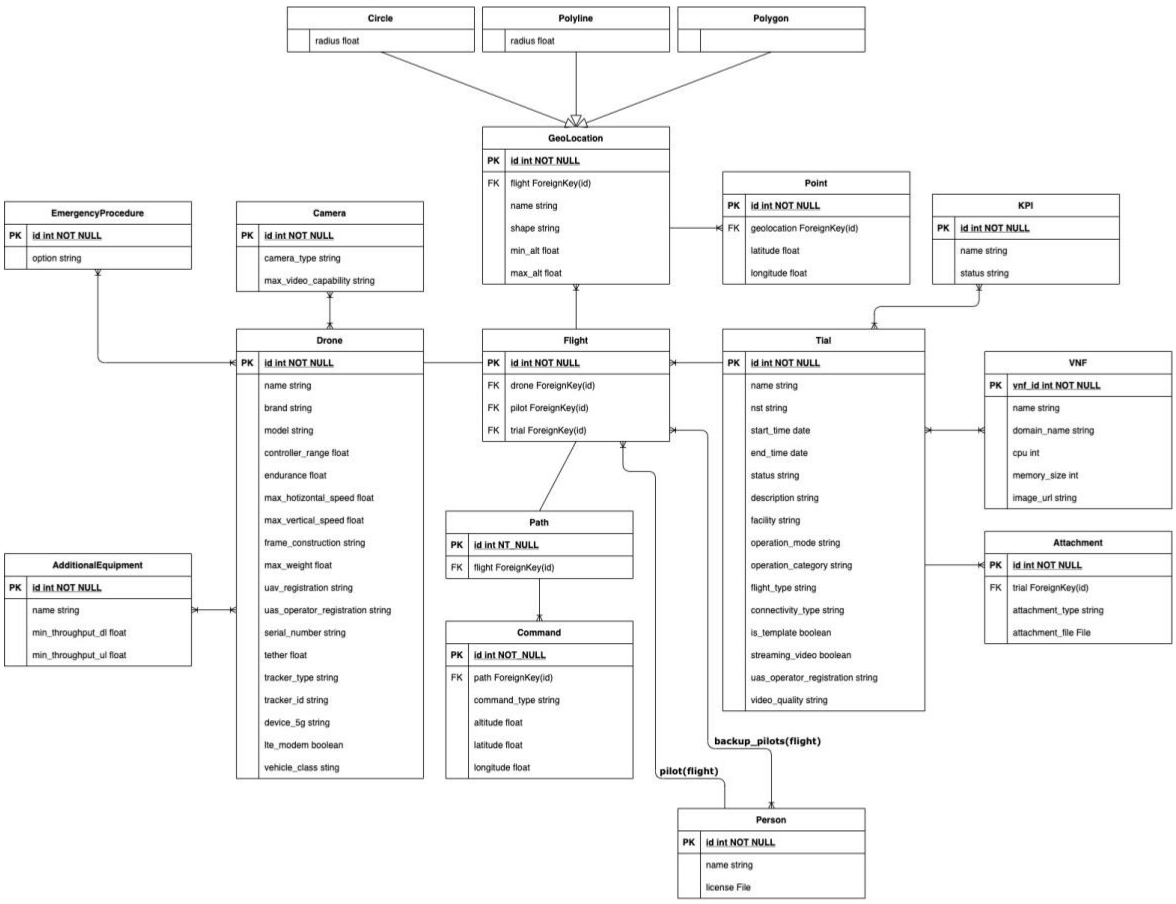

Figure 12: UAV Repository database architecture

The UAV repository is implemented as a basic persistent storage interface, providing methods to create, read, update, delete, and list (CRUDL) UAV records. The UAV repository will additionally provide server-side filtering for listing records. This will allow clients of the UAV repository to search for UAVs appropriate for their use-case (e.g., listing UAVs that are available in a given location during a given date range) while minimizing reimplementation efforts of filtering records throughout the Trial Controller. Database architecture that has been developed as part of the UAV repository is given below.

4.2.5. LCM

The Life-Cycle Manager's objective is to start different services just before, during and after the trial. The LCM is not active during the trial planning phase. The LCM has interfaces to many 5G!Drones components and it is acting as a kind of state machine to start different trial enforcement and KPI monitoring services based on the planned trial content. The LCM is activated by a pre-setting trial time, which is defined in the planning phase by the experimenter. Therefore, the LCM scheduler becomes the wake to start the trial at the right time. The LCM's work for a trial starts by sending a request for TSD creation via the trial enforcement to the 5G facility. The LCM's work for a trial ends when the LCM notices in the Trials repository that trial status is changed to "Finished".

Figure 13 summarizes the LCM internal elements, interfaces and interactions from the LCM point of view. The components including time which trigger the LCM actions, are defined on the left side of the figure. On the right side the components that the LCM manages or interacts with during the trial are listed accordingly.

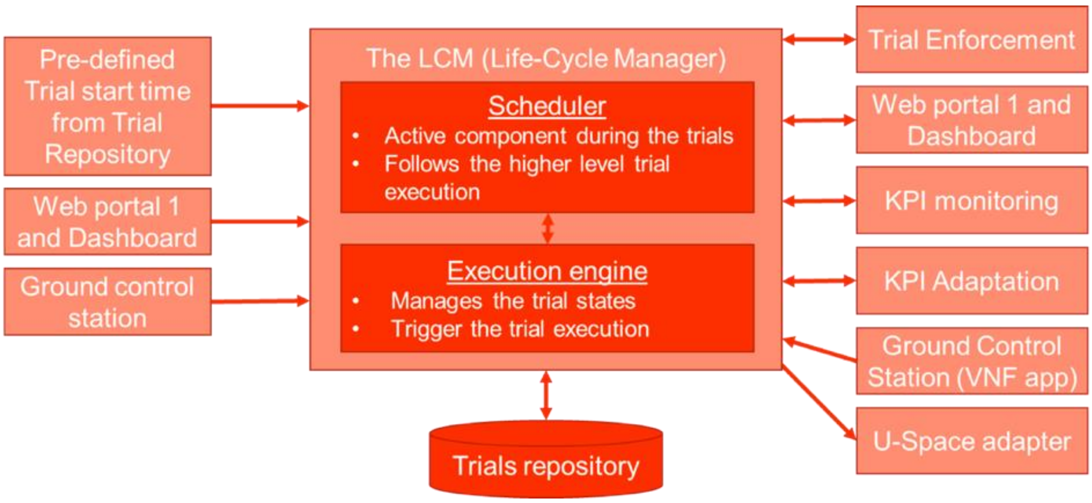

Figure 13: The LCM architecture

4.2.6. Trial Enforcement

The Trial Enforcement component of the Trial Controller is responsible for the execution and automation of the trials planned, as well as, for the monitoring of the trial's progress status. To accomplish these functions, it receives commands from the LCM and then utilizes the developed interfaces towards the 5G facilities, through the Abstraction Layer. Additionally, it can also request test execution depending on the deployment facility. It should be noted that the Trial Enforcement module has no intelligence on its own and doesn't make its own decisions as it always expects the LCM to call it though the REST API endpoints.

Trial Enforcement, as depicted in Figure 14**,** is composed by two sub-modules, namely Configuration & Deployment (C&D) and Test Automation. During the pre-trial stage, the C&D module is responsible for the preparation of the trial with actions such as network slice creation and network service deployment.

Moreover, during the pre-trial stage, all resources shared or solely dedicated to the NSI have been created and are configured to a state where the NSI is ready for operation. The activation step includes any actions that make the NSI active (i.e., if dedicated to the network slice, otherwise this takes place in the preparation phase). Network slice creation, configuration and activation includes instantiation, configuration and activation of other shared and/or non-shared VNFs. In the Run-time phase, the NSI is capable of handling traffic to support communication services. It provides interfaces to manage the Network Slice or Service, such as modifications to the NS, start, stop as well as monitor the status of NS from a functional perspective.

The Decommissioning phase includes deactivation of the NSI, as well as, the reclamation of dedicated resources (termination or re-use of VNFs) and configuration of shared/dependent resources. After decommissioning, the NSI does not exist anymore.

The second sub-module, Test Automation is responsible for the execution of automatic infrastructure tests. This is only possible when the trial is executed upon the 5Genesis platform as it utilizes API calls to OpenTAP [39] [40], which is a testing automation tool used on that specific facility. The module sends a request for the execution of pre-defined tests, such as latency test, in order to assess the infrastructure and network slice capabilities.

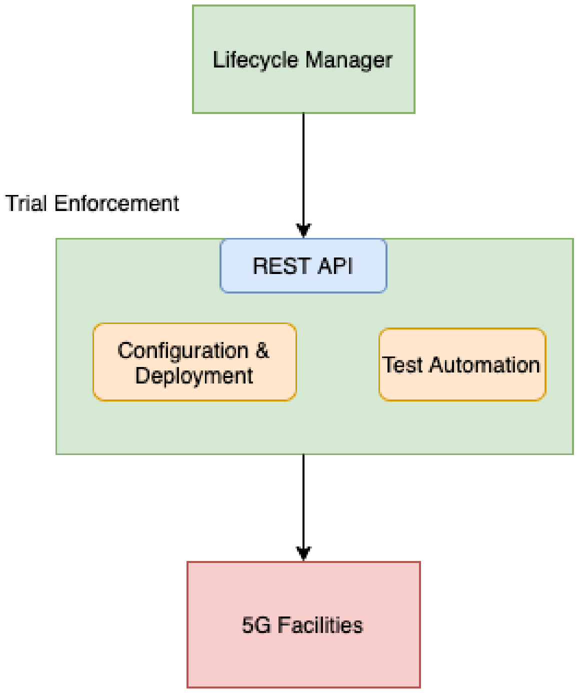

Figure 14 Architecture of the Trial Enforcement module

4.2.7. KPI Monitoring

4.2.7.1. KPI Component

KPI Endpoint provides REST Interface - live KPI data, indexes, upload Offline KPI data, get connected components sends data to ActiveMQ KPI Service, receives data from ActiveMQ and saves data to Elasticsearch. The overall architecture of the KPI component is depicted in Figure 15.

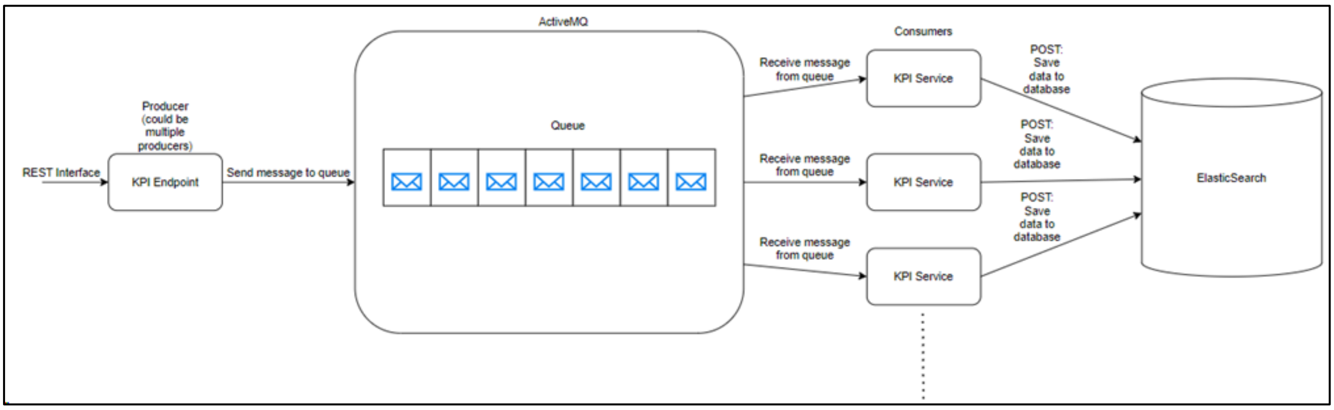

Figure 15: Architecture of the KPI component

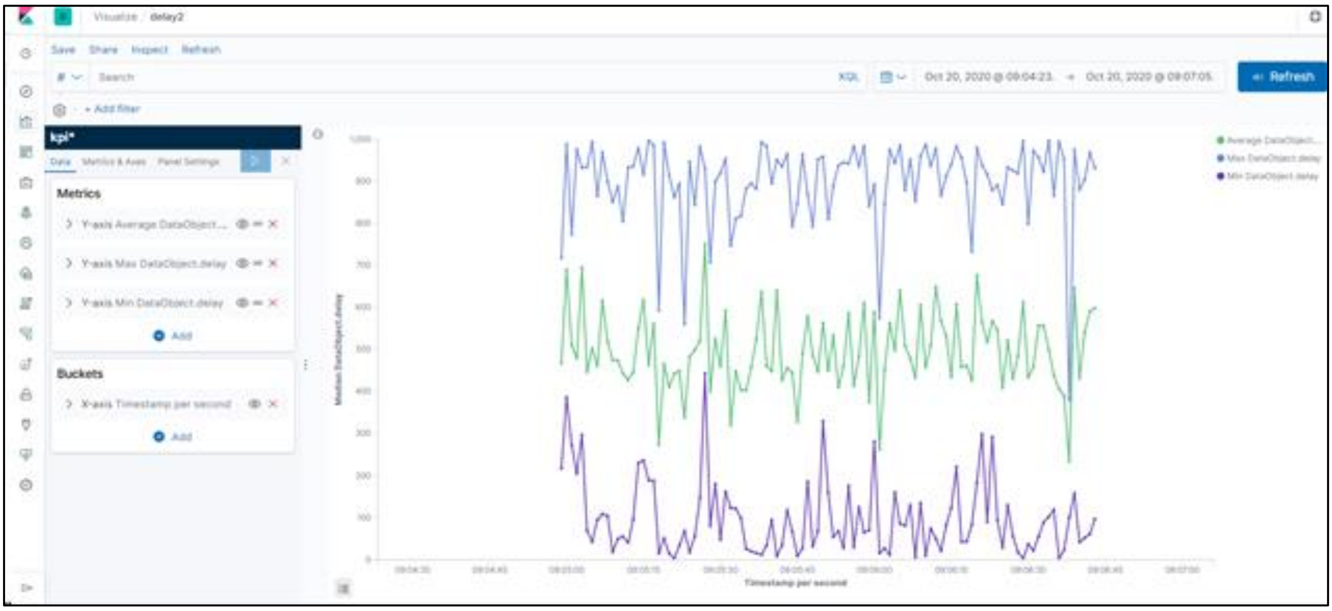

Figure 16: Example of Kibana KPI Analysis

4.2.7.2. Data collector

Data collector is a Python 3-based application created for collecting data from target devices for monitoring and analysis purposes. In the scope of the project, a reference implementation of Data collector is provided. It provides a framework for collecting data from one or multiple target devices, referred to as nodes, with specified collection intervals and durations. It does not restrict the type of data or the means of collecting the data, therefore, they can be implemented as needed. The reference implementation supports collection of memory and CPU data from Linux OS based target devices over SSH connection. The data is timestamp-based, and for saving purposes, it is formatted into nested JSON and saved to JSON-files locally.

For KPI monitoring, Data collector can be utilized to collect various parameters to further enable more encompassing monitoring and analysis of the utilized systems and devices. The primary purpose of Data collector is to act as a means to access data sources. Data collector is capable of uploading data for real-time monitoring purposes as well as saving large amounts of data for further refinement and analysis. For example, the reference implementation of Data collector, which is able to collect memory and CPU data, can be used to track and analyse the utilization of resources and other performance metrics of a system composing of one or multiple target devices.

As Elastic Stack is utilized as a part of data aggregation and monitoring in 5G! Drones, support for saving data to Elastic-search from Data collector is also available. With the included Elastic-search client implementation in Data collector, the collected data can be indexed to an Elastic-search instance. The indexed data can be viewed with Kibana, as it is illustrated in Figure 16, a visualization tool functioning on top of Elastic-search, that enables analysis and monitoring of the target devices both in real-time and historically. Figure 17 depicts a general, high-level use case architecture of Data collector and Elastic Stack.

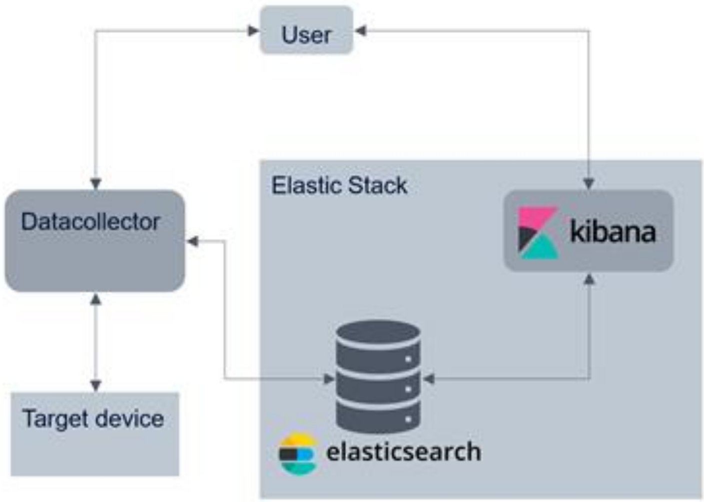

Figure 17: A high-level architecture of utilizing Data collector and Elastic Stack.

In Figure 18, a basic use-case with the reference implementation of Data collector is described. A user can control the Data collector via the implemented API, which collects memory and CPU data from a remote Linux OS -based target device. Within the Data collector, the Elastic-search client indexes the collected data to an Elastic-search instance, and the data can be viewed in Kibana in real-time.

Figure 18: A basic use-case with the reference implementation of Data collector

4.2.8. Abstraction Layer

The abstraction layer provides a unified interface to expose facility capabilities for the LCM of NS and monitoring management. As shown in Figure 19, the abstraction layer is composed of a front-end that exposes a NorthBound API (NBI) towards the LCM. This API covers the NS LCM management procedures: commissioning, operation and decommissioning, as detailed in TS28530 [41]; and monitoring management procedures. The abstraction layer includes, for each facility, a translation module that translates the NBI exposed API to facility-specific API. According to the facility, the request is forwarded from the front-end to the appropriate translator.

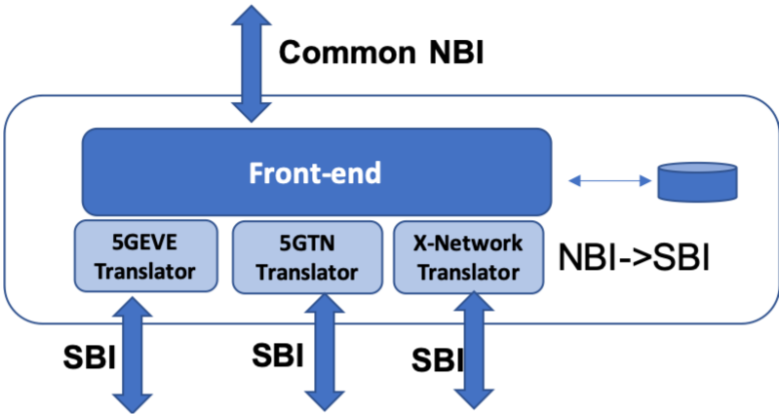

Figure 19: High level architecture of the abstraction layer

4.2.9. U-space adapter

Information exchange between the trial controller and U-space is managed by the U-space adapter component, responsible for assuring the proper connection between the 5G facilities (numerous trial controller components used during different stages of the experiment) and the different local/national instances of U-space components. The adapter enables flight monitoring (focus on telemetry/position data), connecting respective U-space services with the corresponding enablers.

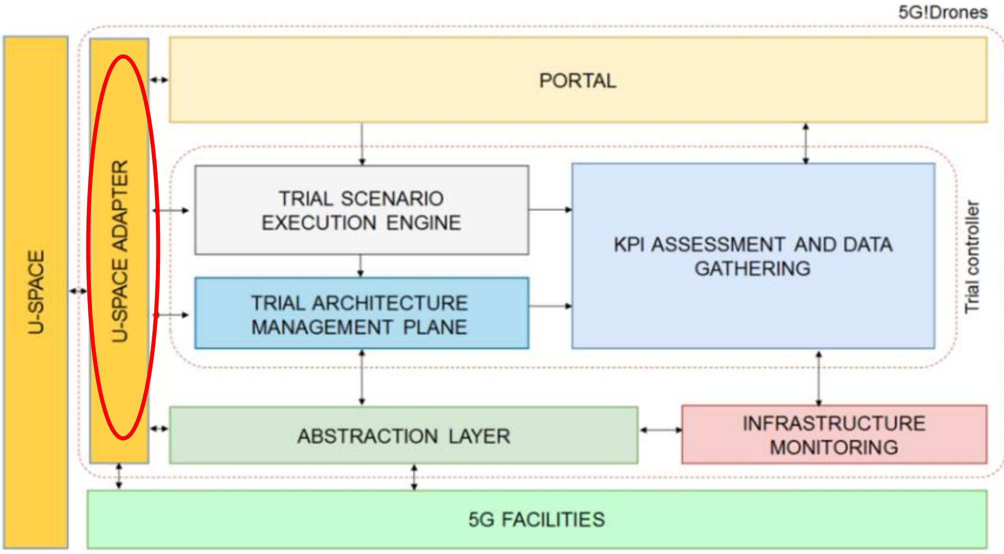

Figure 20: High Level overview of the 5G!Drones architecture

As described in the initial architecture, in section 2.4 of this document, a two-phased approach is taken, first achieving common understanding by documenting information exchange services on a logical level, i.e. without technology specifics. This baseline, a so-called service specification, enables further technical interoperability on API level. Further integration is foreseen, evolving in the area of network coverage information services, flight planning and eventually airspace data.

Details of implementation of the agreed service specifications by each partner may vary depending on the used technologies, as well as, the respective environments and solution details. The high-level overview of the U-space adapter concept as already described in D1.3 is still valid and worked on by many partners. Practical evaluation through validation trials, according to the timeline of the project will further enhance the scope and implementation of the U-space adapter.

5. 5G!DRONES ENABLERS

The 5G!Drones project has initially reported a high-level description of enablers in D1.3. With the term "enablers" the project encompasses all the necessary 5G system components, all the 5G!Drones components as well as all the 5G relevant security components, that are more specifically needed by the service logics of the target use cases.

In the light of the above, these enablers have been categorised into three groups namely Facility enablers, UAV enablers and Cybersecurity enablers. Thus, the objective of this section is to delineate the project's enablers and to showcase the progress towards their development within the project's WP2 and WP3, with the aim to meet the requirements of their trials in WP4.

5.1. Facility Enablers

MEC and Network Slicing are the two key facility enablers for the project, particularly to empower URLLC services required to control and command remotely the drones, related to each use case scenario. With the aim to describe how the existing 5G architectures can meet the UAV service requirements, this subsection presents a gap analysis that identifies the specific 5G system components and their updates and refinements, within the context of each Facility. A general overview of the facility enablers that have been identified by the 5G!Drones project categorised per facility are presented in Table 38.

Table 38: Enablers to be deployed per facility

Facility Enablers	X-Network	5GTN	5G-EVE	5GENESIS
Sliced MEC		✓	✓	
Private cloud (server)				✓
Network Slice Management Service		✓		
MEC Capabilities		✓		
Integration of MEC ETSI			✓	
Management and Orchestration layer				✓
Platform Coordination layer				✓
Integration of MEC / Edge cloud enablers in X Network facility	✓			
Service migration in the MEC		✓		
Implementation of slicing support in the vMEC		✓		
Edge Computing		✓		
Network Slicing as a service		✓		
5G smartphones	✓	✓	✓	✓
MEC Orchestrator (MEO)			✓	

Facility Enablers	X-Network	5GTN	5G-EVE	5GENESIS
MEC Services			✓	✓
LCM (Scheduler)				✓
MEC RNIS usage for radio connectivity quality of flying drones (EUR)			✓	
Life-cycle manager				✓
Slice KPIs collector	✓			
Slice orchestrator	✓	✓		
Follow-Me Edge Cloud control service manager	✓			
Follow-Me Edge Cloud mobility manager	✓			
LCM (Execution engine)				✓

5.1.1. 5GTN facility enablers

5GTN is implemented using commercial eNB, gNB and core network components. On top of the 4G and 5G it supports NB-IoT, WiFi/BLE and LoRa connectivity. 5GTN currently uses NSA mode but SA is planned to be taken into use in 2021. 5GTN Radio contains frequency bands 700 MHz, 2.6 GHz and 3.5 GHz, depending on the requirements.

University of Oulu (UO) has a detailed facility enabler roadmap that it is the following. With regards to hardware and software enablers, UO has functional 5G macro base station and 4G pico BSs to append the test network coverage. UO is extending the 5G network coverage by having ordered a new 5G macro base station and 5G pico BSs, which have arrived by end of May 2021. These 5G macro and pico BSs ensure the UO-based planned UAV trials will have sufficient 5G coverage. In addition, UO has stand-alone 5G supporting mobile phones for the trials, where it can install Qosium probes for detailed KPI collection feature. UO also has Nemo Handy and Outdoor software for detailed air-interface evaluation.

With regards to facility implementation, UO has functional virtualised EPC based on nextEPC and it is currently working towards a virtualised SA 5G core based on the Free 5GC and Open 5GS cores that support slicing VNFs. The expectation is to have the SA 5G core online by the end of June 2021. The Nokia vMEC with BS connectivity and S1 local breakout is functional and work is being done to enable external application instantiation capability by the end of May 2021. Open source MANO and OpenStack are used to manage the virtualised 4G and 5G cores and local VNF instantiation capability is expected soon after the SA 5G core gets online, before the end of June 2021. The northbound interface for the parsers is expected to be ready early June 2021.

4G/5G NSA slice integration work is scheduled for June, 2021 period following proprietary mechanisms. As 3GPP Rel-16 5G slicing specifications are delayed, it has an impact on 5G SA slice integration activity. For UO, 5G!Drones related 5G slice integration activity is currently scheduled to be available early July, 2021, supporting virtualised 5GC and vMEC-based applications. Some of the end-to-end slicing related challenges are as follows. 5G RAN slicing is conducted as a side activity due to not being in scope of planned activities. Hence, there is no guarantee it will be available during at least 1st set of

UAV trials, if at all. Furthermore, currently there are no 5G UEs supporting slicing, which creates a challenge not in control of the 5GTN facility. To that end UO is looking into what are the impacts of not having UE side slice support.

Core Network

- Selected orchestration solution that 5G!Drones uses with 5GTN is Open Source MANO (OSM). Therefore, if there are limitations with the current OSM orchestration feature support, they will affect 5GTN. The current orchestration tool supports only NSSMF and NSMF (i.e. Network service (NS) creation for VNFs and Network slice instance creation from the NS).
- Network slice service definition is not implemented in the current OSM. This means that even though the slice service types such as eMBB, URLLC and mMTC are defined in the slice template, the implementation is the same for all types.
- The current OSM does not support the Communication Service Management Function (CSMF) which determines how a network slice will be transmitted and distributed to end users.
- The current OSM does support slice creation across multiple domains, but it does not support multiple NSIs (i.e. slice services) which might be relevant to one UAV; A feature that is very vital to implement slicing in many use cases. Since many use case scenarios require multiple slice services (e.g. eMBB and URLLC for UTM 2, safety 1, etc.).
- Planned enhancements: New 5G small cells are expected to be deployed to 5GTN during 2021.
- 5G Core taken into use by Q1/2021, thus removing the NSA deployment limitations.
- OSM future release should support the implementation of multiple slice services but timing is unknown.

The following table summarizes the roadmap of 5GTN facility enablers.

Table 39: 5GTN Oulu Evolution Analysis

	Availability at 5GTN Oulu Site	Evolution	Alternative
Trial Descriptor	Non-available	To be developed by 5G!Drones (WP2)	X
Trial Engine	Non-available	To be developed by 5G!Drones (WP2)	X
Facility Resources Access API	Available but proprietary to equipment supplier	Abstraction layer implemented by 5G!Drones (WP3)	X
UTM Connection	Non-available	To be developed in WP2 or added by UAV partner in 5G!Drones	UTM connection will be performed by simulation in 5GTN Facility
UAV Deployment	Most trial deployments will happen in a corridor within the university. For indoor test Facilities, UO provides a cable drone; i.e. a drone that is not actually flying, but moving in 3D space using cables, similarly to so called Spider Cameras use in for example sport events. This device can be equipped with same sensors as flying drone and the interface for moving it in the test		X

	Availability at 5GTN Oulu Site	Evolution	Alternative
	space is the same as for flying drones. The advantage of this type of drone replacements is that it can make test series automatically, periodically, and with high precision without human operator. The infrastructure trials will happen in outdoor testing area.		
UAV Devices	UO provides 1xDJI Matrice 210 RTK drone, payload up to 1.4 kg https://www.dji.com/ee/matrice-200-series/info For UAVs automated flights, UO provide a ROS interface for the drone and online data provided by the sensors on board.	X	Use another drone from UO
Orchestration and Management	OSM orchestration is used in 5GTN VNF/PNF management. OSM orchestration supports the following: • Virtual Network Function Descriptor (VNFD), • Network Service Descriptor (NSD), • Network Slice Template (NST) • Monitoring and performance of the usage of virtualisation resources • Juju charm is used to implement specific actions or services in VNFs • Day1, Day2 and Day3 configuration can be established on VNFs	OSM orchestrator is expected to be used for MEC application and MEC orchestration 1. Application Descriptor (AppD), 2. On-boarding and instantiation of AppD on top of cloud infrastructure, including Edge	
Virtualisation Infrastructure Manager (VIM)	OpenStack service is used	X	X
Multi-access Edge Computing (MEC) - ETSI	Nokia vMEC is supported	Nokia vMEC will be supported	Edge services are to be used
5G Core Components	4G core currently available Virtualised open source EPCs (NextEPC) is used	5G Core (Open 5GS) deployment planned for 1Q/2021	X
Radio Access Network	5GTN currently deploy two 5G and two LTE outdoor macro cells and 10+ LTE (eNB) small indoor cells.	5G indoor base stations are planned to be deployed 3Q/2021	X

	Availability at 5GTN Oulu Site	Evolution	Alternative
	The eNBs operate in LTE bands 7 and 28. 5G operates at band n78.		
Frequencies	LTE 700, 2100 and 2600 MHz 5G 3500 MHz	No further extensions	X
Network Slicing	Core Network Slicing is achieved using OSM orchestrator Current slicing solution is implemented based base on NST instantiated in the OSM Different slice services can be created Fully Virtualised NextEPC is used to implement slicing based on OSM where separated Network component are sliced to form a single network Performance analysis is done for all the slices Juju charm is used to implement specific actions or services in VNFs to support instantiated slices. No RAN slicing at the moment.	To be developed by 5G!Drones (WP3): KPI monitoring interface will be created Slicing support for MEC	X
Mobility Management	Currently between LTE eNB's and 5G gNB	5G to 5G handovers introduced when indoor 5G base stations are deployed	X
5G Devices	Several LTE and 5G NSA/SA end devices available	More devices are taken into use continuously	X

5.1.2. X-Network facility enablers

X-Network developed a home-made orchestrator that manages network slices and vertical applications. It also exposes those functionalities to be used by the upper layers. The slicing functionalities are mainly focusing on the virtualized resources and include the core network part. The latter implements a separation between the control and the user planes, and several user planes can be instantiated to accommodate the requirement of different users. The orchestrator can dynamically create and manage network slices on the top of the facility. The slicing at the X-Network facility does not include the RAN part.

With regards to MEC extension, Aalto University makes use of an edge server to host the vertical applications. This MEC is not considered as ETSI compliant. However, it allows reducing the latency by hosting vertical applications near to the end user, which is the requirement of the use case scenario to be trailed at AU facility. The network slice orchestrator has been extended to deploy and manage vertical applications at the MEC side.

Two deployment of the core network are currently available. While the first one is based on an experimenter 5G core, that includes some 5G AF such as SMF, AMF, UPF, and UDM, the second one is based on an LTE CUPS, where there is a separation between the control plane and the user plane. Both core networks support slicing feature; several user planes can be created and controller by the same control plane. However, the current setup supports slicing per UE and not per traffic (a UE can be associated to one network slice at a time). In terms of facility integration steps, the current setup of AU operates in the NSA mode. The Rel-16 of 3GPP has delayed and the transition to the SA mode will be performed when the updates are available.

For the RAN part, X-Network makes use of a commercial gNB. The management of the gNB is ensured via an embedded controller. The latter requires a human manipulation and does not expose APIs. Consequently, the X-Network facility does not expose interfaces allowing the dynamic control of the RAN part.

Table 40: Network Facility Enablers Evolution Analysis

	Availability at X-Network	Evolution	Alternative
Trial Descriptor	Yes	Being used/adapter following the evolution of WP2	X
Trial Engine		Under development as part of WP2	X
Facility Resources Access API	Interfaces are available and accessible via the abstraction layer	Adaptation of the interfaces is being developed as part of T3.3	X
UTM Connection	No	Under development as part of WP2	
UAV Deployment	Trials will be conducted at the Otaniemi campus UAV software (of partners willing to perform trials at AU) can be hosted at the servers of the University	X	X
UAV Devices	AU uses its own drones (Registered in Traficom)	X	X
Orchestration and Management	A home-made orchestrator has been developed, as part of WP3	X	X
Virtualisation Infrastructure Manager (VIM)	Open stack	X	X
Multi-access Edge Computing (MEC) - ETSI	Only an edge platform, which is not ETSI compliant	X	X
5G Core Components	Currently operating an LTE core that supports CUPS An experimental 5G core is also considered	X	X
Radio Access Network	Commercial gNB (Nokia)	X	X
Frequencies	3640 to 3700 MHz	X	X
Network Slicing	Slicing is performed at the level of the core network and the virtualized resources	X	X

Mobility Management	Not considered (only one gNB is operational)	Not planned	X
5G Devices	Huawei Mate20 5G	AU is testing other 5G devices	X

5.1.3. 5G EVE facility enablers

Regarding the 5GEVE Sophia-Antipolis facility, one of the missing features related to the facility enablers, is the 5G SA deployment. The current deployment of 5G is NSA, where the core network is still based on 4G EPC. Therefore, Network Slicing features as described in 3GPP documents are not yet available. Another limitation of the facility currently, is the lack of support of RAN Slicing in 5G RN gNodeB. The 5GEVE supports RAN slicing, but only on top of eNB. The facility enablers of 5GEVE as well as their evolution are identified in Table 41.

Table 41: 5GEVE Evolution Analysis

	Availability at 5GEVE-SA	Evolution	Alternative
Trial Descriptor	Non-available	To be developed by 5G!Drones (WP2)	X
Trial Engine	Non-available	To be developed by 5G!Drones (WP2)	X
Facility Resources Access API	Abstraction layer already deployed	X	X
UTM Connection	Non-available	Added by UAV partner in 5G!Drones	X
UAV Deployment	Outdoor	X	X
UAV Devices	Provided by the UAV partners	X	Use another drone from EUR
Orchestration and Management	Home-made Cloud-native NFVO • Application Descriptor (AppD) for Cloud-native micro services deployment • Support Openshift containers • Alternative Network Service Descriptor (NSD), • Network Slice Template (NST) • Monitoring and performance of the usage of virtualisation resources	X	X
Virtualisation Infrastructure Manager (VIM)	Home-made Cloud Native VIM for Openshift	X	X

	Availability at 5GEVE-SA	Evolution	Alternative
Multi-access Edge Computing (MEC) - ETSI	ETSI MEC platform supporting the following MEC services: Radio Network Information Services (RNIS), traffic redirection, DNS and MEC LORA	X	X
5G Core Components	OpenAirInterface (OAI) supporting 5G NSA	5G Core (OAI) deployment planned for 2Q/2021	X
Radio Access Network	4G RAN (OAI) • Release (part) 14 and 15 • Functional split (RRU, DU, CU) support, where RRU PHY lower layer, DU PHY upper layer, MAC and RLC functions are located at the DU and PDCP functions at CU. • Operates in FDD or TDD 5G NR (OAI) • Release (part) 15 and 16 • Support of different 5G NR PHY numerologies • Support of 5G NR PHY Bandwidth part • Support NSA LORA	5G SA gNB by Q2/2021	X
Frequencies	• LTE: 2580 – 2610 Mhz (band 7) • 5G – FR1 (< 6Ghz): 3600 – 3680 Mhz (band 78) • 5G – FR2 (Millimeter waves): 27 Ghz (n257/N258)	No further extensions	X
RAN Controller	• Real-time (change the MAC scheduling policy, Slice resources) and non-real-time controller (update the configuration of the eNodeB) based on FlexRAN protocol • Support of 4G OAI eNB	5G OAI Q4/2021	X
Network Slicing	Support of end-to-end network slicing including RAN 4G	• RAN 5G Q4/2021	X
Mobility Management	5G NSA	X	X
5G Devices	Pixel 5G, Oppo 5G, Quectel module	More devices are taken into use continuously	X

5.1.4. 5G EVE facility enablers

The 5GENESIS Athens platform comprises an open 5G Platform, set up in the city of Athens, Greece. The platform evolves into an end-to-end experimental 5G Facility, showcasing features of next generation networks, with particular focus on software network technologies (NFV and SDN) and edge computing for small cell deployments.

Table 42: 5GENESIS Evolution Analysis

	Availability at 5GENESIS-SA	Evolution	Alternative
Trial Descriptor	Trial descriptor for vertical experimentation is supported, following the 5GENESIS methodology	To be further complemented with UAV vertical specific parameters by 5G!Drones tests and trials	X
Trial Engine	The equivalent 5GENESIS ELCM is already in place for the automation of the 5G experiments and trials	To be developed further complemented with the integration of the U-SPACE	X
Facility Resources Access API	The equivalent 5GENESIS Open API that supports the experimentation by Vertical Industries that wishes a tight integration of their application with the 5G experimentation facility is already supported	The expansion of the Open API with UAV specific functionalities will be considered, based on the results of the 5G!Drones Trials	5G!Drones Abstraction layer as alternative to current OpenAPI
UTM Connection	Non-available	Added by UAV partner in 5G!Drones and further expanded with the support of multiple UTMs	X
UAV Deployment	Outdoor carrying 5G-phones on-board	5G-enabled UAVs with C2 delivered over 5G	X
UAV Devices	Provided by the UAV partners	Use of multiple drones and use of Drones carrying gNodeBs/5G-Antennas forming opportunistic networks	Use another drone from NCSRD or Third Parties
Orchestration and Management	OSM	X	X
Virtualisation Infrastructure Manager (VIM)	Openstack	X	X
Multi-access Edge	ETSI MEC powered by ATHONET	X	X

Computing (MEC) - ETSI	Edge-computing with SDN traffic steering		
5G Core Components	NSA/SA 5G Core AMARISOFT NSA/SA 5G Core NOKIA	5G Core OPEN 5GS deployment planned for 4Q/2021	X
Radio Access Network	4G RAN (Nokia) 5G NR (Nokia) SA/NSA 5G NR (Amarisoft) SA/NSA	X	X
Frequencies	NCSRD Academic License (N. 4727/2020) 3400-3410 MHz COSMOTE Commercial 5G Frequencies	No further extensions	X
RAN Controller	AMARISOFT NOKIA	X	X
Network Slicing	KATANA Slice Manager	New Monitoring Module (Grafana, Prometheus server & Prometheus node exporter) Integrate ODL prometheus exporter to collect traffic metrics per flow Per slice Network Service Status monitoring Per slice VM monitoring Katana Home Dashboard on Grafana Create a Grafana Dashboard for every new slice Support OSM8 and OpenStack Stein as MANO components Support shared NSSIs among multiple slices Support Jenkins CI/CD Pipelines for both development and operational workflows	X
Mobility Management	X	X	X
5G Devices	5G Oneplus 5G TCL 10 5G Samsung Note s20	More devices are taken into use continuously	X

	5G Xiaomi Mimix 3 5G Xiaomi M10		

5.2. Cybersecurity enablers

This section presents and describes in details the updates towards the cybersecurity enablers since the initial report in D1.3. Cybersecurity enablers have been updated to meet certain objectives including:

- Better adaptation to Use Case security requirements (e.g. UC1) presented in the Security Requirements section 0;
- Better integration with 5G!Drones facilities;
- Alignment with industry roadmaps (e.g. Thales roadmap).

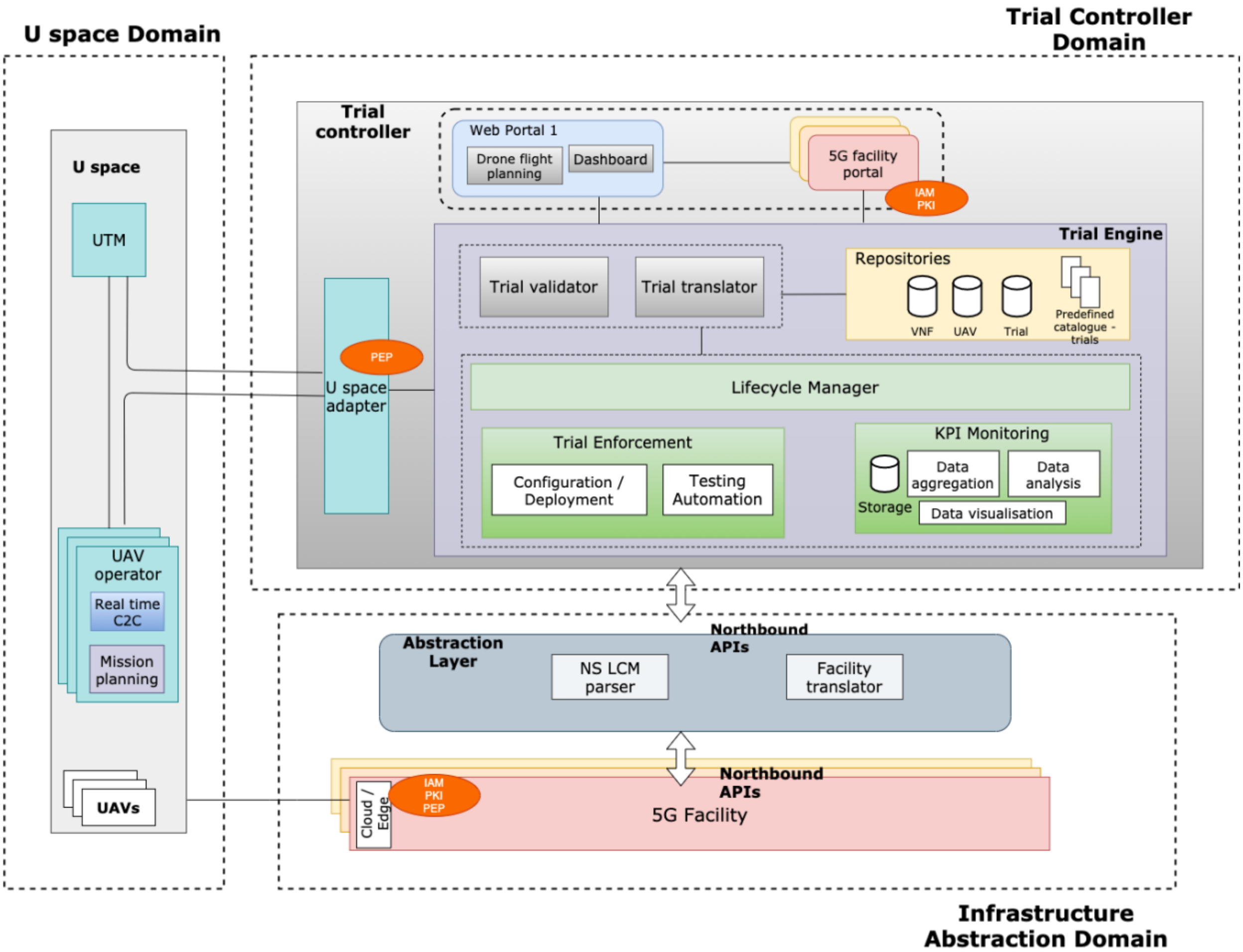

Figure 21: Cybersecurity enablers mapped in the architecture of 5G!Drones

Cybersecurity support in 5G!Drones encompasses both cybersecurity of 5G network and services in scope. To have it framed we propose the 5G!Drones high-level security architecture to mostly follow the 5G security architecture originating from 5G-ENSURE, exploited at 5G-PPP Architecture WG, and continued in SENDATE (see its description in the following documents [42], [43] (§2.5) and [44]).

Figure 21 illustrates the 5G Security approach and how the enablers that are advocated for 5G!Drones are aligned with the overall 5G!Drones architecture while figure 22 presents the cybersecurity enablers and their interactions with the components of the 5G!Drones system.

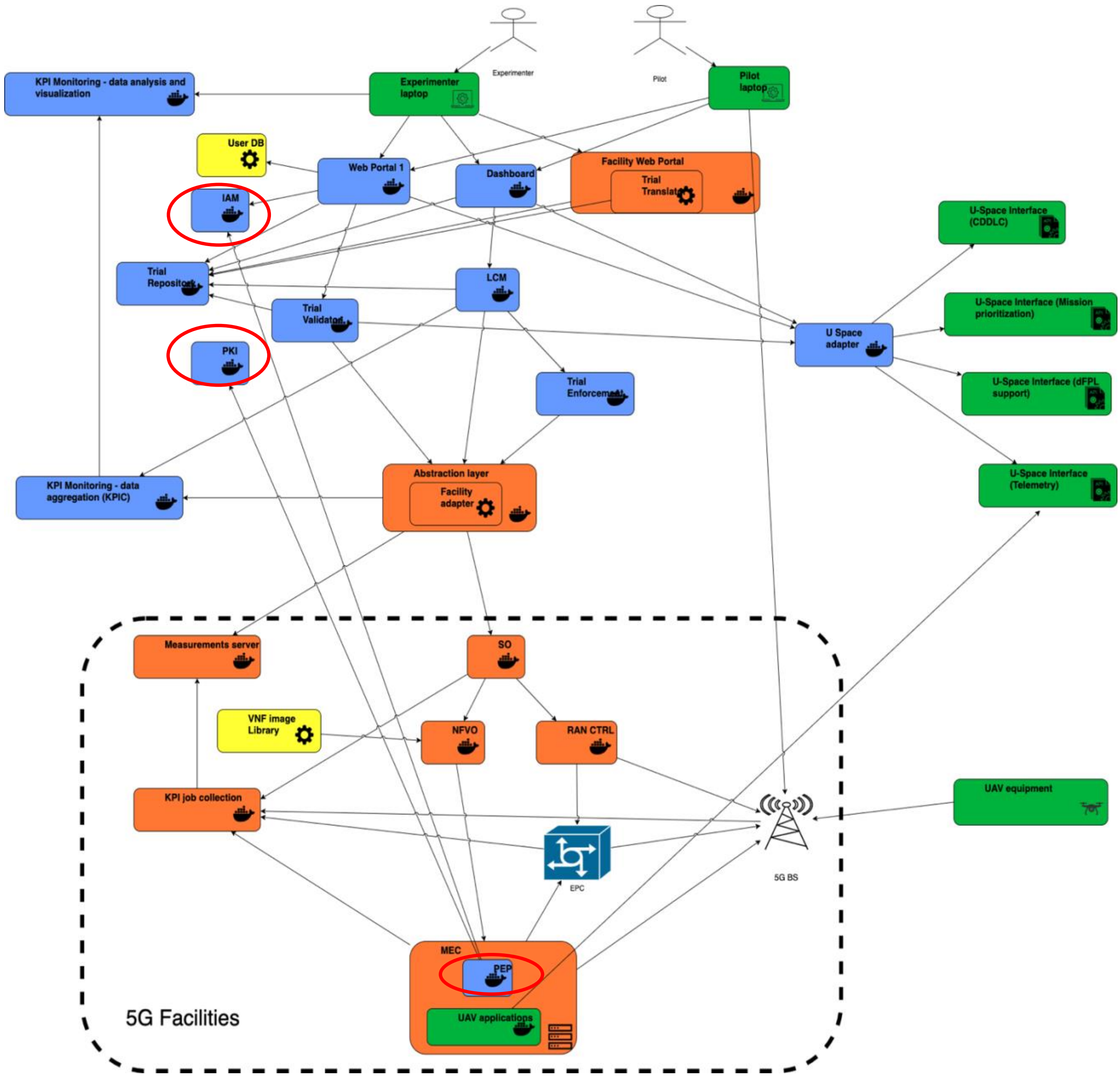

Figure 22 Cybersecurity enablers' interaction with 5G!Drones components

5.2.1. Identity and Access Management (IAM) Services

The IAM enabler is more focused on authentication and authorization requirements from the Security Requirements section 0. Compared to D1.3 status, the IAM enabler has been improved to facilitate cloud-native deployment, i.e. in particular on a Kubernetes container orchestration platform. Using such a platform brings the following benefits:

1. IAM instances are more easily deployed, updated, replaced in an automated way, compared to virtual machines and benefits from Kubernetes features (horizontal scaling, software-defined

networking and storage and computing, deployment automation, self-healing); in particular, security patching can be more agile, and day-to-day information security continuity easier to achieve.
2. IAM as-a-service: the IAM enabler can become part of a micro services architecture and therefore benefit from micro services technologies such as Service Mesh.
3. Containerization enables the polyglot approach, i.e. mixing our IAM implementation with different technologies/platforms/frameworks - even different versions of the same applications - on a single host without interference or compatibility issues. De facto, this enables developers to choose the best software security technologies for their needs on the same platform, regardless of the IAM enabler's software base.
4. Fully Software-Defined Security policy orchestration is also facilitated thanks to previous benefits, as we can rely on container orchestrators (e.g. Kubernetes), and higher-level cloud-native application orchestrator (e.g. TOSCA orchestrators) based on such container orchestrators, in order to deploy specific instances of IAM services matching specific security policy.

The IAM enabler supports a new feature for strong (two-factor) authentication of end-users called WebAuthn (W3C standard), based on FIDO 2.0. FIDO is a more secure authentication method than well-known OTP while being easier to use (better user experience) and more universally supported (most mainstream devices and operating systems have native FIDO support today) than PKI certificates. WebAuthn is also supported by all major web browsers today. Thales is an active contributor (board member) to the FIDO alliance.

Besides, the IAM enabler integration of Open Policy Agent's REST service as a PDP (Policy Decision Point) for attribute-based access control (as an alternative to AuthzForce XACML server) is almost complete and supported in beta version. OPA is a general-purpose policy engine that enablers context-aware ABAC policy enforcement, using a high-level declarative language (Rego) for authoring policies.

Last but not least, there is new work in progress for:

- Multi-tenant and multi-slice deployment of IAM instances, more specifically policy-driven deployment of slice-specific IAM instances.
- Support deployment of performance-critical IAM services (e.g. authentication service) to the MEC (cf. D3.1).
- Integration with the Trial Controller architecture (cf. D2.1[4], §4.3) for authenticating/authorizing different types of users with different roles and permissions (Experimenter, UAV operator, IoT Device manager).

5.2.2. Digital Certificate Services

The PKI (Public Key Infrastructure) enabler focuses more on authentication, integrity, confidentiality and non-repudiation requirements from the Security Requirements section 0. The PKI enablers now provides a REST API for automated creation, renewal or revocation of PKI entities: (Intermediate) Certification Authorities, certificates, key pairs.

Compared to D1.3 status, the PKI enabler is being improved to facilitate cloud-native deployment, i.e. in particular on a Kubernetes container orchestration platform. Using such a platform brings the same benefits as mentioned in the previous section for the IAM enabler. Last but not least, there is new work in progress for:

- Support deployment of performance-critical PKI services (e.g. cert validation service) to the MEC (cf. D3.1);
- Multi-tenant and multi-slice deployment of PKI instances.
- OpenID Connect authentication on the new REST API.

5.2.3. Security Policy Enforcement Point Services (PEP)

The PKI enabler focuses more on authentication, integrity, confidentiality and non-repudiation requirements from the Security Requirements section 3.2. Compared to D1.3 status, the PEP enabler is being enhanced to facilitate cloud-native deployment, i.e. in particular on a Kubernetes container orchestration platform. Using such a platform brings the same benefits as mentioned in the previous sections for the IAM and PKI enablers. We also want to emphasize the fact that a cloud-native environment supports efficient technologies for Zero Trust Network security; in particular the techniques of network micro-segmentation and service mesh which allow the PEP - combined with software-defined network policies – to intercept any inbound/outbound communication to/from specific containerized applications or (micro)services in the data plane, and apply network-layer, transport-layer or application-layer security policies on the data flows.

Besides, the PEP enabler now supports the extra feature of requesting access control decisions from Open Policy Agent's REST service as a PDP (Policy Decision Point) for attribute-based access control (as an alternative to AuthzForce XACML server). As already mentioned, OPA is a general-purpose policy engine that enables context-aware ABAC policy enforcement, using a high-level declarative language (Rego) for authoring policies.

The PEP also now supports the extra feature of validation of signed JWTs (JSON Web Tokens) issued by the IAM enabler for authentication, as part of the OpenID Connect protocol.

Last but not least, there is new work in progress for:

- Support deployment of vPEPs to the MEC, as Service ME apps (VNF), cf. D3.1.
- Multi-tenant and multi-slice deployment of PEP instances, to enable end-to-end security policy enforcement.
- Support security policy enforcement for UDP communications, in particular DTLS (TLS for UDP datagrams) policies.

5.3. UAV Services Enablers

To fully support the scenarios to be trialled, different service enablers have been identified. These enablers are software functions that are either directly running on the UAV, running remotely (e.g. on edge servers or clouds) or supporting UAV operations. They are responsible for control or application functionalities and interacting together, they constitute the specific UAV application that a scenario will to trial. In this section, an update of the current development status of the UAV-enablers defined in D1.3 will be presented. Particularly, information regarding the current development status as well as the expected release date will be included. Besides, as it was the case for ORA, new enablers that were not considered in that document (D1.3) will be also introduced.

5.3.1. Multimedia Mission Critical Services (MCS) - AIRBUS

This section describes the components and technologies of the Multimedia Mission Critical Services (MCS) which provides voice services, instant messaging, video communication and emergency calls. It will be especially relevant in use case UC2SC1 wildfire scenario.

The Mission Critical Services (MCS) solution allows public safety users to access professional communication in groups and in private calls. The following services are enabled by this solution:

- Group and individual calls
- Group and individual messaging
- Group and individual multimedia messaging
- Group and individual video calls
- Emergency calls
- Location and map services

Refinements from first project period will bring us to focus on the following services:

- Group calls
- Group messaging
- Video streaming
- Location and map services

5.3.1.1. Multimedia Mission Critical Services (MCS) architecture

The following components are deployed as part of the Airbus MCS solution:

Infrastructure components

- **MCS Server:** the MCS Server provides the control and management of voice, video and data communications for both private and group calls. This functionality is divided into Controlling Server(s) and Participating Server(s):
  - The MCS Controlling Server is responsible for:
    - Communication control (e.g. policy enforcement for participation in the MCS group communications) towards all the MCS users of group communication (i.e. a group of users capable to communicate with the rest of users at once), as well as for private communication;
    - Managing floor control entity for a group communication and private communication;
    - Managing media handling entity;
  - The MCS Participating Server is responsible for:
    - Communication control (e.g. authorization for participation in the MCS communications) to its MCS users for group communication and private communication;
    - Relaying the communication control and floor control messages between the MCS client and the MCS server performing the controlling role;
    - Media handling for its MCS users for unicast media;
    - Management of the quality of service (QoS) by interfacing with the network using the 3GPP Rx interface with a Policy and Charging Rules Function (PCRF) or using the 5G equivalent;
- **Identity Management Server (IdMS):** this server is provisioned with the user's MC ID, MCPTT ID and password. The user is also provisioned with its MC ID and credentials. The IdMS authenticates a MCS user by verifying its credentials.
- **Key Management Server (KMS):** this server stores and distributes the security information such as encryption keys for private and group calls to the key management client on the UE, to the group management server and to the MCS servers. It enables integrity and confidentiality of the signaling and media flows. The encryption keys are generated by a separate tool and imported to the KMS.
- **Group Management Server (GMS):** this server is used to perform the management of communication groups. It manages the group call policy information and media policy information to be used by a given UE.
- **Configuration Management Server (CMS):** this server is used to configure the MCS application with non-group management related information and configure data on the configuration management client. The configuration management server manages MCS configurations (e.g. user profile, UE configuration, functional aliases and service configuration).
- **SIP Core:** it is the entity responsible for registration, service selection and routing in the SIP signalling control plane.
- **HTTP Proxy:** acts as the proxy for all hypertext transactions between the HTTP clients (on the mobile device) and HTTP servers. The HTTP proxy terminates the TLS session with the HTTP

client of the MCPTT UE in order to allow the HTTP client to establish a single TLS session for hypertext transactions with multiple HTTP servers.

- **MCS Configuration Server:** it is used by the MCS system administrators for the management of tactical and technical configuration information.

Client component:

- **MCS Client application:** it runs on the mobile device and implements the MCS protocols, the MCS client entities which are communicating with the servers mentioned above, and the graphical user interface.

5.3.1.2. Multimedia Mission Critical Services (MCS) application programming interfaces (API)

The following application programming interface (API) features have been developed during the first period of the project:

- Connection and authentication to server
- Controlling audio/video stream
- Remote controlling of audio/video stream
- MCData communications

Other features could be of interest and developed during the course of the project:

- Connection in order to receive video streams from an external video source
- Sending of a video stream to an external receiver

Each scenario, based on what it aims to achieve, requires a different set of UAV service functions. Part of the functions (e.g. command and control related functions) can be common to different scenarios. The rest of them are specific to the application targeted by a given scenario. These UAV Service Enablers are presented in the following tables, categorized per partner. The tables include seven cells namely the enabler, the ID of the enabler, as has been identified by the consortium, the description of each enabler, the type, the use case that the enabler will be used, and finally the status of the development process and the expected delivery date.

5.3.2. UAV Service Enablers - Droneradar – Frequentis

Table 43: UAV Service enablers DRR-FRQ

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
Telemetry	6	The telemetry enabler fulfils four key needs: E-identification, Tracking, Traffic information, Collaborative interface with ATC	Service	Multiple	In progress	-
CDDLC 2-way verbal comm	6	Utilization of 5G based C2 link to provide bi-directional communication between UAV operator and UTM	Service	Multiple	In progress	-

Drone Flight Plan	6	dFPL support (dFPL validation, SORA analysis)	Service	Multiple	In progress	-
Mission Prioritization support	6	Requesting 5G network reconfiguration for priority missions	Service	Multiple	In progress	-

5.3.3. UAV Service Enablers- Orange

Two UAV service enablers are under development by Orange:

The first one is the implementation of an algorithm for localizing a UAV in 3-dimensional plane considering the knowledge of parameters such as MNO site positions, antenna height, tilt, signal transmission power received by the UAV from multiple antennas. Before implementing it, the algorithm has been evaluated with an analytic method in order to determine relevant parameters. The current challenges of the implementation reside to get the appropriate values for these parameters from real devices (e.g., UAV modem). These enablers aim to provide an alternative to GNSS that could be used in specific situations.

The second enabler is the implementation of an algorithm for optimizing the position a flying base station UAV, acting as a Base Station, e.g., during crowded events (UC4) or after disaster (UC2), in order to improve user throughput. Before its implementation, the algorithm has been evaluated with an analytic method in order to choose the best strategy among several. The enabler is standalone. Its implementation just relies on parameters such as RSRP and RSRQ values.

Table 44: UAV Service enablers – Orange

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
Geo-location of an UAV based on signal strength from 1 BS	124	Geo-location of an UAV based on signal strength received from 2 cellular base stations	Algorithm	UC4 or UC2SC2	In progress	Expected delivery in H2 2021 or H1 2022
Optimal trajectory of UAV Base Station	130	The goal is to optimally position the UAV, acting as a Base Station, in order to maximize the data rate with served users as well as the interconnection link with serving ground stations	Algorithm	UC4 or UC2SC2	In progress	Expected delivery in H2 2021

5.3.4. UAV Service Enablers - Involi

Table 45: Table 32 UAV Service enablers Involi

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
INVOLI Central Server	45	INVOLI live stream: Providing the UTM system with high/low level traffic situation, collected from our K-1090 sites	Self-contained module, able to stream the data to external systems	UC1SC1	Operational - ready to use	Internal API available, which will be used for providing the service.
INVOLI's KIVU/LEMAN tracker	82	Tracker	Remote ID tracker	UC1SC1	KIVU tracker is depreciated and will be withdrawn. LEMAN will be the available option. INVOLI is working on adding the broadcast functionality to LEMAN tracker. The availability of broadcast is forecasted to end of May 2021.	New version of LEMAN tracker with broadcast function (M28). LEMAN 4G tracker is available since 2020
K-1090 receiver	98	K-1090 is an air traffic receiver capable of receiving signals on 1090MHz coming from ADS-B, transponder Mode S and Mode A/C	HW	UC1SC1	Ready	-

5.3.5. UAV Service Enablers – Aalto University

Table 46: UAV Service enablers - Aalto University

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
AU IoT HAT	91	Contains a set of sensors that are used to collect IoT data	HW	UC3 SC2	Ready	-
AU IoT HAT driver	92	Interaction with the IoT-HAT via the electronic buses: I2C, SPI, UART. Exposes queuing APIs for collecting IoT data from the HAT	SW	UC3 SC2	Ready	-
AU IoT data collection module	93	An agent that runs on-board the UAVs to collect IoT data using the embedded sensors.	Self-contained	UC3 SC2	In progress	To be delivered in M24
AU Virtual flight controller	95	A service that runs in virtualised environment for enabling the control of UAVs using MAVLink protocol.	Self-contained	UC3 SC2	Ready	-

5.3.6. UAV Service Enablers – University of Oulu

Table 47: UAV Service enablers – University of Oulu

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
5G Smartphone	47	-	Device		Ready	
Virtual flight controller	51	-	SW	UC1, UC1:S2	In progress	To be delivered in M28
Positioning analysis application	52	Provide positioning information to interested parties via secure connection	Module	UC1, UC1:S2, UC3	In progress	To be delivered in M24
Data collection and mapping	53	Data from UAV, 5G equipment and facility to edge position software	SW	UC1, UC1:S2	In progress	To be delivered in M24

5.3.7. UAV Service Enablers – Unmanned Systems

Table 48: UAV Service enablers - Unmanned Systems

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
UL-ACE	126	Computing device pre-loaded with software for interfacing to UL-CCP	SW	UC2:SC2, UC4	Completed: a) Integration of hardware and installation of software to enable UL-ACE for autonomous control operations b) Waypoint navigation c) Mission functionalities (play, pause, RTH, emergency stop)	Alpha release was delivered in M22
UL-CCP	127	Software pilot designed to control swarms of heterogeneous robots in a common context	SW	UC2:SC2, UC4	Completed: a) Creation of behaviour tree nodes b) Creation of a behaviour tree for use cases c) Integrating the output of the object recognition tool with the behaviour tree	Alpha release was delivered in M22
UMS Video Analysis	128	Module for receiving and analyzing video streams from the drones for potential humans in the disaster area	SW	UC2:SC2, UC4	Completed: a) Streaming video from the drone to the UL-CCP for object recognition b) Video analysis and image processing of pre-recorded video feed	Alpha release was delivered in M22
UMS WiFi Access Point	129	Provides on-demand hotspot connectivity to end-users on the ground.	HW	UC2:SC2, UC4	Completed: a) Hardware setup	Alpha release was delivered in M22

5.3.8. UAV Service Enablers – Nokia

Table 49: UAV Service enablers - Nokia

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
Nokia Drone	83	Nokia existing asset	Drone	UC2:SC2 UC3:SC3	Ready	-
UWB based drone positioning system	84	A system to get drone position information indoor	System	UC3:SC3	Ready	-
5G Modem	85	A 5G modem to Nokia Drone	HW	UC2:SC2 UC3:SC3	In progress - In testing phase	To be delivered in M26
5G smartphone & camera holder	86	A holder to DJI Mavic 2 Pro	HW	UC3:SC3	Ready	-
DJI Matrice 600 payload adapter	135	A back-up system to collect data	HW	UC3:SC3	Ready	-

5.3.9. UAV Service Enablers – Alerion

Table 50: UAV Service enablers - Alerion

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
Alerion's GCS	50	Receiving FPV video stream and telemetry from UAV and controlling UAV	Visual Interface	UC3:S1: SS3	In progress	Initial tests expected to be conducted during pre-trials (M24)
Data processing	80	Application for analysing and processing data from drone	Docker Container	UC3:S1: SS3	In progress	Expected Release in M28
Sensor data streaming	81	Sensor streaming from UAV	ARM Binary	UC3:S1: SS3	In progress	Initial tests expected to be conducted during pre-trials (M24)
Hydradrone	87	Drone	Drone	UC3:S1: SS3	In progress	Tests of Hydradrone V1 in M28

5.3.10. UAV Service Enablers - Hepta

Table 51: UAV Service enablers - Hepta

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
Hepta's Data Cloud	48	Data from 4K camera processed on cloud by ML model to identify defects	SW	UC3:SC1: SSC2	In progress	To be delivered in M27
Hepta's GCS	49	Receiving FPV video stream and telemetry from UAV and controlling UAV	SW	UC3:SC1: SSC2	In progress	To be delivered in M27
Hepta's drone with tether	120	Hepta's heavy lift drone with power tether	Drone	UC2SC2; UC4SC1	In progress	To be delivered in M24
Payload - Lidar for 3D mapping	122	To be used for 3D mapping	SW	UC2SC2; UC4SC1	Ready	Rel. 1 was delivered in M22
Interface with AP	132	Edge container for C2 & telemetry and interfacing with trial controller & UTM	SW	UC2SC2; UC4SC1	Ready	Rel.1 was delivered in M23
Sensor data streaming	133	Dynamically control data rates based on connection speed to achieve real time coverage	SW	UC3SC1 SSC2	Ready	Rel.1was delivered in M22
Data processing	134	SLAM with LIDAR data	SW	UC3SC1 SSC2	In progress	To be delivered in M27

5.3.11. UAV Service Enablers - Cafatech

Table 52: UAV Service enablers - Cafatech

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
IoT device (camera) based on LTE-M Cat1/2 technology	7	Provides information about Delivery box status and helps parcel drop-off	Device	UC1:SC3 sLogistics	In progress	Rel.3 To be delivered in M33
CAFA Tech UGCS based platform (CUP)	10	UAV Command and control container	SW	UC1:SC1, SC3 UC2:SC1, SC3 UC3:SC1:SSC1 UC4:SC1	Ready to use	Rel. 1 was delivered in M20

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
Video streaming system	12	From 5G UE to video server application and from there to end users	SW	UC1:SC1, UC1:SC3; UC2:SC1; UC2:SC3; UC4:SC1	In progress	Rel.1 To be delivered in M24
CAFA Video analyzer (VideoLyzer)	13		SW	UC2:SC1 Wildfire, UC2:SC3 Police, UC4 Connectivity	In progress	Rel.2 To be delivered in M28
Drone Logistics Network Delivery Software (DLN DS)	14	DLN DS coordinates delivery information between customer delivery box, UAV and logistics centre. CAFA Tech central server stores data and videos and provides Big Data analyse.	SW	UC1:SC3 Logistics	In progress	Rel.3 To be delivered in M33
3D map for analyzing QoS of 5G (CAFA Analyzer)	16		SW	UC3:SC1:SS1 3D map of 5G QoS, UC4 Connectivity	In progress	Rel.2 To be delivered in M28
Police Command Centre Server (CAFA Tech Central server)	17		SW	UC1:SC3 Logistics, UC2:SC3 Police	In progress	Rel.2 to be delivered in M28
3D Mapping MEC software	18		SW	UC3:SC1:SS1 3D map of 5G QoS, UC4 Connectivity	In progress	Rel.1 to be delivered in M24
IoT sensor C2 system with security enablers	21		System		In progress	To be delivered in M26

ENABLER	ID	DESCRIPTION	TYPE	USE CASE	STATUS	COMMENTS
DJI Mavic drone	24		Drone	UC1, UC1:SC3 Logistics, UC2:SC1 Wildfire, UC2:Sc3 Police, UC3:SC1:SS1 3D map of 5G QoS, UC4 Connectivity	Ready	-
CAFA drone (Pixhawk platform based) supporting onboard 5G commands via 5G UE	25		HW	UC1, UC1:SC3 Logistics, UC2:Sc1 Wildfire, UC2:Sc3 Police, UC3:SC1:SS1 3D map of 5G QoS, UC4 Connectivity	In progress	Rel.2 to be delivered in M28
Police drone attachments and accessories for drone	131	Speaker etc.	Device	UC2:Sc3 Police	In progress	To be delivered in M32
Teleoperation hardware and software for low latency teleoperated flight	136		HW	UC1:Sc3 Logistics; UC2:SC3 Police	In progress	Rel.2 To be delivered in M28
GNSS positions corrections system	136		HW		In progress	Rel.2 To be delivered in M28
Latency measurement script	137		Docker Container	All Scenarios	Ready	-
Dock for drone automated flights (charging etc.).	125		Device	UC1:Sc3 Logistics	In progress	Rel.3 To be delivered in M33

Conclusion

In this deliverable, we presented the final iteration of design and update of the 5G!Drones architecture, which constitutes a reference point for the technical design of the 5G!Drones system. Task 1.4 is driving the current deliverable and one of the primary purposes of the specific task, during the lifetime of the project, is to tightly interact with the WP2 and WP3, in order to consistently collect the relevant architectural information that are included in the current document.

To that end, several structuring sections from deliverable D1.3 have been updated. More specifically the progress and the updates made by the different standardisation bodies such as 3GPP to consider the interoperability of 5G systems with UTMs was presented in Section 2. Section 3 provided insights into the functional requirements and the interactions between the several components of the 5G!Drones system. On that basis, deliverable D1.6 then provided in Section 4 a representation of the overall 5G!Drones architecture, notably giving a breakdown of this architecture into its major components and their role in the system.

This description was followed, in Section 5, by a dedicated presentation and analysis of the enablers that the project has identified. In this context, D1.6 started the outline, of the 5G system enablers per facility as well as the UAV Enablers which are currently being developed by the 5G!Drones Project. Section 5 also embraces cybersecurity support by providing an updated approach of the 5G relevant security enablers.

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