H2020 5G Dive Project
Grant No. 859881

D3.1: Definition and setup of vertical trial sites

Abstract

This deliverable provides a description of the end-to-end trial sites for the two major vertical pilots (namely, Industry 4.0 and Autonomous Drone Scouting) to support the vertical applications as well as the integration aspects from each developed trial site.

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Disclaimer

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List of Acronyms

3GPP	3rd Generation Partnership Project
ZDM	Zero Defect Manufacturing
5G NSA	5G Non-StandAlone
5G SA	5G StandAlone
5GC	5G Core
5G-DIVE	5G-eDge Intelligence for Vertical Experimentation
API	Application Programming Interface
APP	Application
AQM	Active Queue Management
BLE	Bluetooth Low Energy
COCO	Common Objects in Context
CPE	Customer Premises Equipment
CPU	Central Processing Unit
CUDA	Compute Unified Device Architecture
DC	Data Centre
DEEP	5G-DIVE Elastic Edge Platform
DPDK	Data Plane Development Kit
DSS	Decision Support System
EFS	Edge and Fog computing System
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
GPS	Global Positioning System
GPU	Graphics Processing Unit
GUI	Graphical User Interface
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
KPI	Key Performance Indicator
LTE	Long Term Evolution
MEC	Mobile Edge Computing
MIRC	Microelectronics and Information System Research
MQTT	Message Queuing Telemetry Transport
NR	New Radio
OCS	Orchestration and Control System
OpenCV	Open Source Computer Vision Library
OPTUNS	OPtical TUnnel Network System
OSM	Open Source MANO
OVS	Open vSwitch
PID	Person-In-Distress
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technologies
ROS	Robot Operating System
RRU	Remote Radio Unit
SDN	Software Defined Network
SLA	Service Level Agreement
UC	Use Case
UE	User Equipment
URLLC	Ultra-Reliable Low-Latency Communication
VIM	Virtualized Infrastructure Manager
VM	Virtual Machine

VNF	Virtual Network Functions
WFQ	Weighted Fair Queuing
WP	Work Package

Executive Summary

One of the main goals of the 5G DIVE project is to develop and validate through trials end-to-end 5G connectivity customized to the targeted vertical applications in the scope of Industry 4.0 (I4.0) and Autonomous Drone Scouting (ADS) in their actual deployment environments while, at the same time, demonstrating and validating the technology components designed and developed in the project. To accomplish this objective, two end-to-end 5G-enabled trial sites, one for each vertical pilot, are considered to support the integration, experimentation, and validation of the considered use cases on each vertical pilot. Also, 5G connectivity and intelligent adopted in different tires will be demonstrated in trial sites.

To achieve the aforementioned goals, this first deliverable defines the end-to-end trial sites. This includes trial site description, an overall overview of trial site use cases, the trial site requirements in order to support use cases, the needed hardware components, the in-lab validation strategy, and the relationship with 5G-DIVE project objectives, the integration and validation timeline. Then, it addresses the potential risk associated with the vertical site during the execution of 5G-DIVE project for ADS and I4.0 vertical pilots. Finally, a summary of ADS and I4.0 vertical pilots are provided.

The key achievements in this deliverable are highlighted below:

- Trial sites, i.e., (ADS trial site, I4.0 trial site), description, including available hardware, technologies and services that the partners of the 5G-DIVE provide to the project.
- Trial site requirements to operate ADS and I4.0 verticals
- Relationship of vertical pilots with project objectives
- A roadmap of each vertical pilot throughout the timeline of the project.
- Trials site risk investigation for both vertical pilots.

1. Introduction

One of the main goals of the 5G DIVE project is to demonstrate and validate the technology components designed and developed in the project. To accomplish this objective, the aim of work package 3 (WP3) is to integrate all components developed in WP2 in the trial sites for two vertical pilots (i.e. autonomous drone scout (ADS) and industrial 4.0 (I4.0)). In the trial site, 5 G connectivity and intelligent adopted in different tires will be demonstrated. To achieve the aforementioned goals, this first deliverable defines the end-to-end trial sites. This includes the description, requirements, and hardware components of trial sites. Besides, it includes the relationship with the project objective. Later this deliverable the integration and validation timeline for ADS and I4.0.

This deliverable D3.1 presents the description of trial sites, as well as trial site requirements, and also defines all the use cases that will be deployed, tested and validated during the project.

Section 2 describes the risks of COVID-19 effects on the trial site timeline.

Section 3 describes the I4.0 trial sites in real-world environments. It highlights the technologies and infrastructures to be integrated into each site, present three uses cases, presents the corresponding integration, relationship with project objectives, and risk at the trial site and provides a summary for the I4.0 trial site setup

Section 4 describes the ADS trial sites in real-world environments. It highlights the technologies and infrastructures to be integrated into each site, present two uses cases, presents the corresponding integration, relationship with project objectives, and risk at the trial site and provide a summary for the I4.0 trial site setup.

Finally, **Section 5** presents the main conclusions, highlighting the next steps for the integration and evaluation of the vertical pilots in the two trial sites.

2. Risks of COVID19 Outbreak

The risk of Coronavirus (COVID-19) pandemic is affecting the consortium as a whole. In this section, we foresee and elaborate the impact to both vertical pilots as follows:

2.1.1. Risk of Coronavirus Outbreak on I4.0

The current situation of the Coronavirus (COVID-19) widespread and the countermeasures taken by the different governments around Europe could have a direct impact in the chronogram and deployment plans in the test site in Taipei, Taiwan. The 5G-DIVE consortium had a meeting in order to determine what should be done in regards to the previously acquired responsibilities and planned project timeline.

It is important to note that for I4.0 use cases, the key partners involved in this trial (UC3M and IDG, since they are the ones with a robotic arm for testing) cannot access the equipment, therefore it is impossible to develop anything meaningful at this stage. The partners involved in I4.0 are currently working in the official simulator of the robot arm, but it is not the same and a further stage of code validation will be needed. Consequently, the I4.0 expected to be delayed 4-5 months (i.e. 2020 milestones will move to 2021).

2.1.2. Risk of Coronavirus Outbreak on ADS

Due to the widespread of the Coronavirus (COVID-19), governments all of the world have placed travel restrictions to reduce the spread of the virus. Because of these necessary measures, we foresee a direct impact on the progress of the deployment and the experimental trials in Taiwan and Europe. This delay is not affecting ADS, therefore we plan to split WP3 milestones into two sets, ADS related and I4.0 related. The ADS ones will be delayed by a couple of months to account for the delay of the pandemic.

3. Industry 4.0 Trial Site

This section describes all the aspects related to the Industry 4.0 trial site. It highlights the technologies and infrastructures to be integrated in the vertical site. It provides an overall overview of the trial site use cases, the trial site requirements in order to support such use cases, the needed hardware components, the in-lab validation strategy, the relationship with the 5G-DIVE project objectives, the integration and validation timeline. As a final point, it addresses the potential risk associated with the vertical site during the execution of the 5G-DIVE project.

3.1. Description

The Industry 4.0 trial site is located at ADLINK's headquarters in Taipei, Taiwan. The selected location provides facilities for performing experiments and pilot deployments in a realistic scenario, both regarding infrastructure and connectivity. The machinery testing laboratory is located in 235, Taiwan, New Taipei City, Zhonghe District, Jianyi Road, No. 166. B1 floor, building 9F. Figure 3-1 depicts the location and the premises of the trial site.

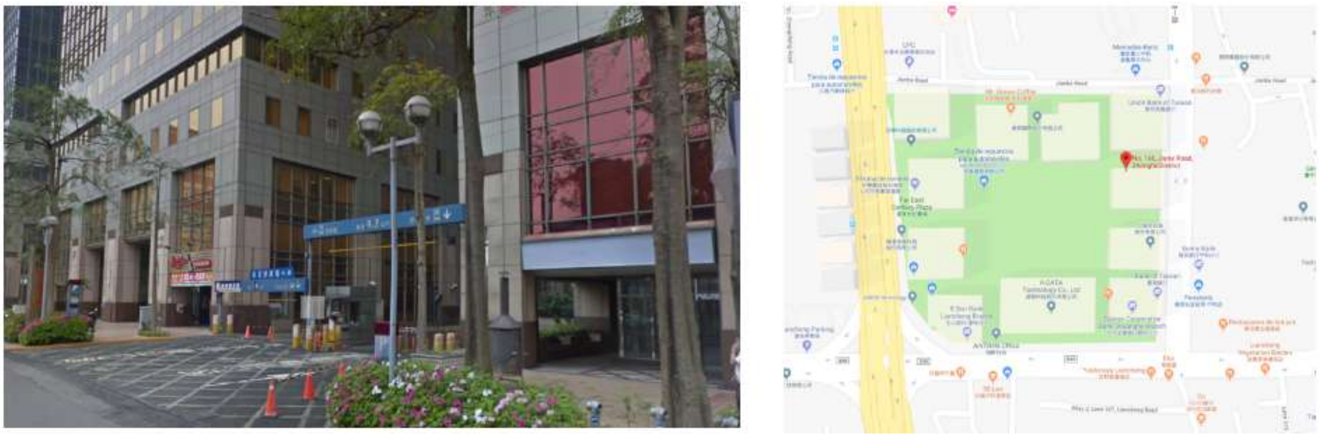

FIGURE 3-1: LOCATION OF INDUSTRY 4.0 FIELD TRIAL

The trial site is approximately 120 square meters in area and it is currently used by ADLINK as a machinery testing laboratory. Currently, the laboratory has the following machinery available:

- Laser cutting
- Panel testing
- Camera calibration
- Compressor system
- Conveyor motion belt
- Conveyor vision belt.

In addition to this facility, where the actual vertical field trial will be performed, early validation of the technology, prior to its deployment in Taiwan, is going to be performed in the ICT-17 5TONIC laboratory in Leganés, Spain. Note that a support letter from 5TONIC as a hub of the ICT-17 5G-EVE and 5G-VINNI projects can be found in Appendix 7.1.6.

The trial site located in Taiwan offers a suitable environment, comparable to a TRL 5/6 environment, to test the developed 5G-DIVE solution in the scope of a Digital Twin and Connected Worker Augmented Zero Defect Manufacturing (ZDM) applications. For example, the Digital Twin, Zero Defect Manufacturing and IoT applications will take advantage of the existing machinery in the testing lab like the conveyor motion belt kit and the conveyor vision belt kit. Formerly, this machinery testing laboratory was used to evaluate the characteristics of product's pilot version to be deployed later on production lines. Figure 3-2 presents a landscape of the current state of the Industry 4.0 trial site.

FIGURE 3-2: INDUSTRY 4.0 FIELD TRIAL SITE

Besides that, it is being considered the addition of a robotic arm (Section 3.4.1), video cameras (Section 3.4.2) and IoT sensors (Section 3.4.6) to the set machinery available in the trial site, required for the testing and validation of both the Digital Twin, ZDM and IoT applications.

5G-DIVE is mainly about trialling the 5G connectivity for vertical use cases with intelligence at the Edge. Thus a 5G indoor system, namely the Ericsson Radio Dot System (RDS), will be deployed in the trial site to provide high-speed wireless connectivity for the robotic arm and the camera to be connected to the remote controller at the Edge, in order to support the Digital Twin and Zero Defect Manufacturing use cases, respectively.

Figure 3-3 is depicted the expected setup for the I4.0 trial site to be deployed in ADLINK facilities. This includes the different machinery (i.e., robot manipulators and conveyor belt) and a set of cameras used for both Digital Twin and ZDM use cases, as well as the IoT sensors/actuators and radio heads (based on software defined radio kits like USRP used for the trial purpose) for massive MTC use cases.

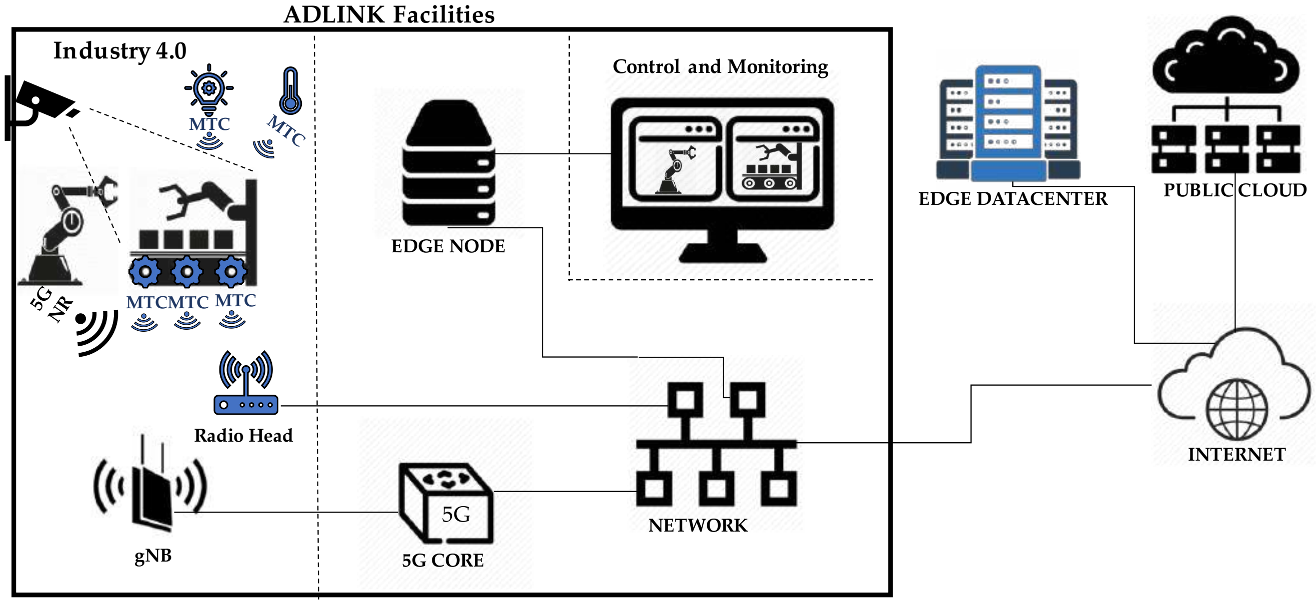

FIGURE 3-3: INDUSTRY 4.0 FIELD TRIAL SITE

The robots and cameras will be connected to the network using 5G connectivity, enabling low latency and high bandwidth connectivity, allowing the realization of the vision of "5G empowering vertical industries", by connecting machines, workpieces and systems. The IoT sensors and actuators are connected via massive MTC connectivity provided by the radio heads and the virtualized IoT gateway hosted in the Edge node and Edge data center (potentially can be in Cloud). All these aims to demonstrate to enable businesses to create intelligent networks along the entire value chain that can control digital factories autonomously.

3.2. Trial site use cases

Two main use cases are going to be showcased in the I4.0 trial site with 5G connectivity: (i) Digital Twin; and (ii) Connected Worker Augmented Zero Defect Manufacturing. Complementary to eMBB type of 5G technologies with low-latency and high-speed, the 3rd use case regarding massive MTC will trial a novel cloud-native design for increasing the scalability of the massive MTC type of connectivity, which is also a key part of the IoT infrastructure of future factories in I4.0. In the trial, IEEE 802.15.4 and LoRa will be trialled as examples for wireless sensor networks, though NB-IoT and LTE CAT-M can be supported also for cellular IoT networks. To understand the requirements that these use cases demand from the trial site, they are described in the following subsections.

3.2.1. I4.0-UC1: Digital Twin

The Digital Twin use case will demonstrate 5G performance of interconnecting a real robot to its digital twin, which implies sharing the computing resources and the software with the real robot and will virtually replicate the same function. Digital twins are digital replicas of physical assets, processes, and systems that also interact with the real system – with the digital replica reproducing changes as they occur in the actual physical system. The concept has been around for some time now, but it has found a limited application until recently, due to storage costs, processing power, and bandwidth performances.

The robot arm will be controlled in real time, by a remote virtual controller located on a powerful dedicated computer or a virtual machine, to exploit the computational power provided by the edge and fog resources. The robot arm will receive instructions about its position in a stepwise manner by the remote controller, while sensor data will be sent back to provide a real-time feedback. Both control instructions and information from sensors will be used to update the virtual model in real-time. Said model can be used to highlight critical conditions inferred by sensors data and to provide alarms and preventive maintenance information to humans. In case that critical or dangerous situations are detected, the remote control could stop in real time the operations for safety reasons. Safety requires a very reliable and fast track for transmission of data and, among wireless technologies, only 5G can satisfy these tight requirements.

In industrial applications, the overall end-to-end latency budget (time delay between data being generated at a sensor and the data being correctly received by the actuator) is spent for the processing time of the data received by sensors; the remaining part of the latency budget limits communication time to few milliseconds. 5G connectivity will guarantee the reliability and the low latency remote control and, at the same time, full support to the safety functions. In addition, the fixed connectivity with ultra-short delay will be provided between the Fog/MEC (see Appendix 7.1.1 and 7.1.2) used for example for heavy off-line training and Cloud by using OPTUNS (see Appendix 7.1.4), which is an SDN-based next-generation datacentre technology, while splitting of the computational needs across the different tiers from the cloud to fog continuum will allow a reduced reaction time of the use cases. The initial concept of Digital Twin will be implemented using the MEC infrastructure. OPTUNS will be used later on to enhance the Digital Twin use case with AI/ML based capabilities in order to improve the robot operation and complement the life cycle automation for the vertical service.

3.2.2. I4.0-UC2: Connected Worker Augmented Zero Defect Manufacturing (ZDM)

The Connected Worked Augmented ZDM use case deals with aspects of 5G Fog and Mobile-Access Edge Computing (MEC), and their enhanced performance capabilities for supporting real-time analysis of HD/4K video of goods being produced in a production line, in order to detect possible defects. The main idea is to deploy in the Fog/Edge devices, algorithms able to detect characteristic patterns for defects recognition in the production line. Due to the number of cameras and the bandwidth required by the video streaming, it becomes very difficult to centrally process the information gathered, both in terms of data storage and fast data analysis, and consequently to extract and capitalize on the corresponding knowledge.

3.2.3. I4.0-UC3: Massive MTC

Massive MTC (mMTC) is also a key part of the IT infrastructure of I4.0, as described in D1.1 [1]. In the previous project 5G-CORAL, virtualized IoT stacks were developed and demonstrated, which lacks orchestration and automation features. In 5G-DIVE, one focus is to further develop orchestration and automation for container and service life-cycle management (LCM) with horizontal scaling capability to provide web-scale scalability, to tackle the future challenges providing mMTC connectivity to trillions of IoT devices. To optimize dynamic scaling, a new paradigm of Cloud Native Design (CNN) [12] will be explored to re-design the IoT communication stacks for increasing scalability. We will investigate to break the stacks into smaller components to achieve independent scaling among the components to have better resource scaling with IoT traffic. Another focus is to demonstrate the intelligent applications at the edge which can exploit the data collected from the IoT communication stacks and ML technologies to improve security and RAT coordination for IoT services.

Figure 3-4 shows a system-level illustration of the end-to-end setup of a massive MTC use case. The IoT nodes will be deployed in the trial site. In this project, IEEE 802.15.4 and LoRa will be used as examples, due to the availability of open-source software which facilitates the research work. One idea is to have some IoT nodes deployed on the conveyor belt and one can be connected to the controller of the conveyor belt to provide operation and infrastructure monitoring. More IoT nodes can be deployed around to measure work-environment related metrics, e.g. temperature, humidity, noise, etc.

Multiple SDR-based radio heads will be deployed in the site to provide the wireless connectivity to the deployed IoT nodes. For the uplink, the radio heads will send the detected IQ samples back to the Edge data center for IoT processing. The connectivity between radio heads and Edge data center can reuse the existing LAN infrastructure available in factories. Or it can be done with capillary networks, where the radio heads are connected to cellular networks of 4G or 5G. This option is relevant to mobile operator deployed and managed IoT services, while the former option is for factory self-managed IoT networks.

The Edge data centre can be at the factory premises, e.g. for self-managed networks, or at remote sites, e.g. for operator managed networks. For the trial, the data centre with multiple servers will be likely deployed locally at the trial site. The data centre will be shared by all 3 use cases, hosting all their software components. For mMTC use case, virtualized IoT communication stacks will be deployed in the data center and orchestrated by an orchestrator (Kubernetes or Fog05) for service LCM and automation. The EFS service platform will provide the data bus for publishing/subscribing the data between applications and functions. Intelligent applications of RF security and RAT coordination will exploit the subscribed data and the developed IE (intelligence engine) for improvements in security and interference management. IoT application is developed to manage the IoT nodes, gather and manage the measurement reports from the IoT nodes. A Web-GUI will be developed to provide IoT dashboard and performance monitoring etc.

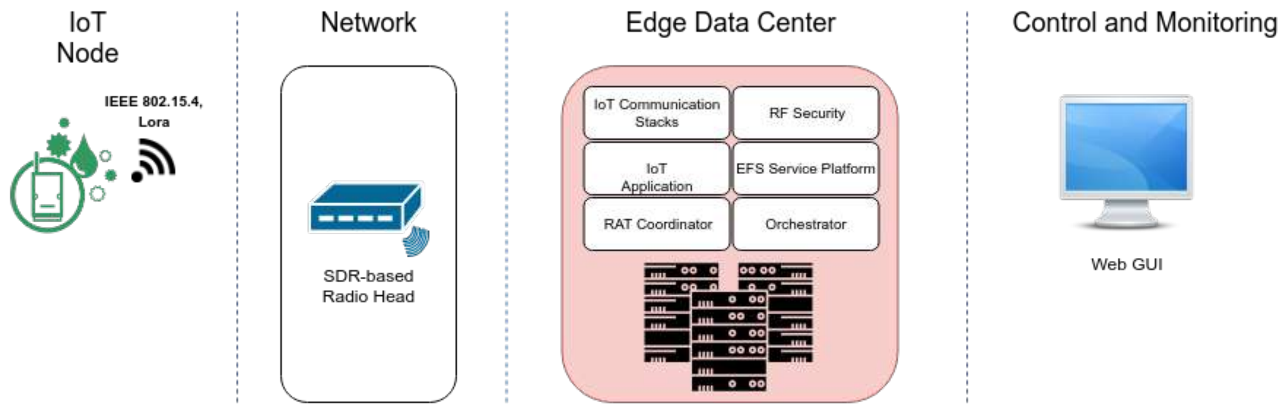

FIGURE 3-4: ILLUSTRATION OF THE END-TO-END SETUP - MASSIVE MTC

3.3. Trial site requirements

This subsection describes the installation requirements on the trial site in order to support the components necessary to implement the Digital Twin and Zero Defect Manufacturing (ZDM) use cases. Note that the massive MTC use case has no special requirements identified as the equipment required are small and low power.

5G-system hardware requirements

The following list described the necessary elements to support the 5G network installation in the trial site:

- Spectrum: it is important to have access to a trial license for using the spectrum in the trial site during the trial period. The currently supported NR bands are B41 and n78, where n78 is preferred.
- At least one or two Radio Dots should be mounted in the roof. Currently, Ericsson is looking into if they can run standalone mode (SA). Then it would be enough with NR-equipment only, i.e. one Radio Dot. To run non-standalone mode (NSA), it would need both NR and LTE equipment, i.e. two Radio Dots.
- 19" half-rack for mounting of the core and RAN related equipment. Physical size ~ 60x90x120 cm (WxDxH), baseband units, radio units and servers for core networks will be mounted in it.
- Power ~ 2-3 kW, preferably on 2 different fuses for back-up.
- Sync – Preferably access to a GNSS signal. For low-power indoor without interference and no coordination needs, it might be enough with a local clock reference (adds cost to the system)
- Cabling – radio heads (referred to as Radio Dots in Ericsson RDS) should be mounted in the ceiling. These need to be connected to the radio units with CAT6a or CAT7 cables. PoE (Power over Ethernet) is used so no local powering is needed.

3.4. Hardware components

This subsection describes the hardware components necessaries to implement the three use cases in the trial site.

3.4.1. Robot manipulator

In order to implement the Digital Twin and the Connected Worker Augmented Zero Defect Manufacturing (ZDM) there is a need of having a robotic arm. Niryo One robotic arm will be used in I4.0UC1 as the robotic manipulator, its control loop of 10ms, the compatibility with ROS 1 and ROS 2 and the opensource APIs available to control it made it the best fit for the use case. Niryo One robotic arm gives also the possibility to craft part of the robots with open blueprints for 3D printers.

Notably, in the UC1, the Niryo One robot arm will be controlled remotely by its digital replica. The communication between both entities requires low latency and high bandwidth capabilities leveraged by 5G new radio and core. Niryo One is a 6-axis open source collaborative robot manufactured in France. Affordable and easy to use, it has been designed for higher education, vocational training and R&D laboratories. This industrial type robotic arm is based on ROS, Arduino and Raspberry Pi, and allows programming with Scratch (Blockly), Python, C++, Matlab, Modbus TCP/IP, TCP ASCII Serve The full technical specifications of the robotic arm are shown in Table 3-1.

TABLE 3-1: NIRYO ONE ROBOT ARM

Property	Value	Image
Weight	6kg	
Dimensions	600 x 300 x 300 mm	
Number of axis	6	
Payload	300g	
Max reach	440 mm	
Base joint range	+/- 175	
Repeatability	+/- 1 mm*	
Power Supply	11.1 Volts / 6A	
Communication	Ethernet WiFi: 2.4 GHz Range 802.11n Bluetooth 4.1: 2,4 GHz; 2,5 mW (4 dBm)	
Power consumption	~60 W	
Materials	Aluminum, PLA (3D printing)	
Hardware	Raspberry pi 3 + 3 x NiryoSteppers + 2 x Dynamixel XL – 430 + 1 x Dynamixel XL – 320	

3.4.2. Camera and Image recognition hardware

In Table 3-2 are shown the cameras and the hardware components needed to perform the AI/ML image recognition. More details on the object detection algorithm employed in this use case can be found in Appendix 7.1.3.

TABLE 3-2: CAMERA AND IMAGE RECOGNITION HARDWARE COMPONENTS

Hardware component	Image
Orbbec Astra Camera: 30 fps Both Depth and RGB images 640x480 pixel resolution for Depth Image 1280x960 pixel resolution for RGB Image Short Range 3D scanning Long sensing range	
Nvidia Jetson TX2 (32GB eMMC) w/ 256Gb SSD	
NDI PTZ Camera 60 FPS NDI (1GbE interface) SDI interface 30x Optical Zoom High Sensitivity Sensor	
NDI Encoder / Decoder HW encoder / Decoder	1GbE in – HDMI out
HDMI to USB Converter	Low latency HDMI serializer

The Orbbec Astra Camera is a reliable standalone 3D camera widely used in robotics and gesture control. It includes the proprietary Orbbec 3D microchip and VGA color and can deliver depth resolution image capture and high performance. For this reason, this camera is a typical choice for object recognition and will be deployed to identify the faulty item. In addition, we look to deploy an NDI PTZ camera, which allows us to remotely change the view angle and zoom in or out. Such PTZ camera can help a human operator supervise the process and identify any potential issue in the object detection phase. Finally, an Nvidia Jetson TX2 will be employed to make inferences and detect the faulty item based on the images provided by the camera. The Jetson TX2 is a high-performance AI computing device largely adopted in computer vision and deep learning applications, running a Linux OS and boasting a wide community of users and developers.

3.4.3. Conveyor Belt kits

In a similar way, in order to implement the Digital Twin and the Connected Worker Augmented Zero Defect Manufacturing (ZDM) there is a need of a conveyor belt. Thus, in the first stage of in-lab validation the Dobot Magician conveyor belt kit will be used in the 5TONIC lab premises. For a detailed specification please refer to Table 3-3. For the real test scenario, the conveyor motion kit and the conveyor vision kit will be used in the ADLINK field trial in Taipei.

The conveyor belt kits will enable the scenario where pieces are been moved along while been monitored by a video camera with image recognition functionalities. In the case a defective piece is detected, the conveyor belt will be stopped, and the defective product will be removed with the help of supporting mechanisms. This supporting mechanism for removing the defective piece is still under study.

The first in-lab implementation of this use case will be done using the Dobot Magician Conveyor belt kit used for testing and validation of the I4.0-UC2 in the ICT-17 5TONIC laboratory. Such conveyor belt characteristics are close to a production line used in the industry; on the other hand, it has open-source APIs to control it and it is possible to manage it using the robotic manipulator available at the trial site. The full set of specifications can be found in the following Table 3-3.

TABLE 3-3: CONVEYOR BELT KIT SPECIFICATIONS IN 5TONIC

Property	Value	Image
Payload	500g	
Effective delivering distance	600 mm	
Net weight	4.2 kg	
Weight (Including packing)	5.34 kg	
Dimensions	700 x 215 x 60 mm	
Measurable range	20~150 mm	
Input	4.5 – 5.5 V	

In a similar scenario the pieces moved along the conveyor motion kit, will be continuously monitored by cameras installed on it, to detect anomalies, in case defective piece is detected, the conveyor belt will be stopped and the defective product should be removed with the help supporting mechanisms, detailed specifications can be found in the following Table 3-4.

TABLE 3-4: CONVEYOR MOTION BELT IN THE TRIAL SITE

Property	Value	Image
Size	1865mm x 100mm x 2mt (WxLxH)	
Maximum speed	425mm/sec	
Motor behaviour (including speed)	Must be controlled by the axis control card in the computer, such as AMP-204C [2] or PCIe-8154 [3].	

Additionally, to the previously mentioned conveyor motion belt, there is the conveyor vision belt that has a camera already integrated on it. The Ethernet interface is described in [4], and more detailed specifications can be found in the following Table 3-5**.**

TABLE 3-5: CONVEYOR VISION BELT IN THE TRIAL SITE

Property	Value	Image
Size	150mmx525mmx260mm (WxLxH)	
Speed	6-12 m/min, control by EMX-100 (motion control module with Ethernet interface [4]	
Motor behaviour	60W, single phase, 220V	

3.4.4. 5G network

For I4.0 trial, a 5G indoor system referred to as Ericsson Radio Dot system will be used. As one example, Figure 3-5 shows our 5G lab setup for performance evaluation and trial preparation, e.g. regarding system configuration. Two Radio Dots are connected to two Radio Units which are connected to two Baseband Units. The two Radio-to-Baseband chains are used to provide the Non-Standalone (NSA) mode of 5G connectivity, where the user plane is served by the 5G NR chain for band n78 (3.5 GHz) and control plane is served by the LTE chain for B3 (1.8 GHz). The 5G connectivity supports 100 MHz bandwidth with 4T4R MIMO.

In the lab at Ericsson premise, a 5G EPC is currently deployed remotely at a different location than the RAN equipment but with a dedicated fiber link in between. This is sufficient for lab tests and will have minor impact on performance such as latency. For later trials, it will be replaced by a local Core integrated with the RAN equipment in the same rack. Further, we are also looking into the possibility to upgrade to 5GC to run Standalone (SA) mode for the final trials. For SA the LTE equipment will no longer be needed since both control and user plane will be running over NR. It is also beneficial to increase the understanding of the performance difference, e.g. latency, etc., between SA and NSA in this project.

For UE, we currently have acquired two WNC 5G Routers which support 5G NSA. For NR, it supports 4x4 MIMO with up to 4 layers in DL, while UL supports 1x4 MIMO with 1 layer and maximum 64 QAM constellations only. If the system is changed to SA the UEs need to be replaced, likely to a version based on the Qualcomm X55 chipset.

Also, our lab setup also has a MIMO channel emulator (Spirent Vertex) to emulate different air-interface channel models (e.g. standardized models from 3GPP, ITU, etc., as well as customized channels) for real-time performance evaluation. A traffic tester (IXIA XM2) is also used to generate and analyze traffic for throughput and delay measurement.

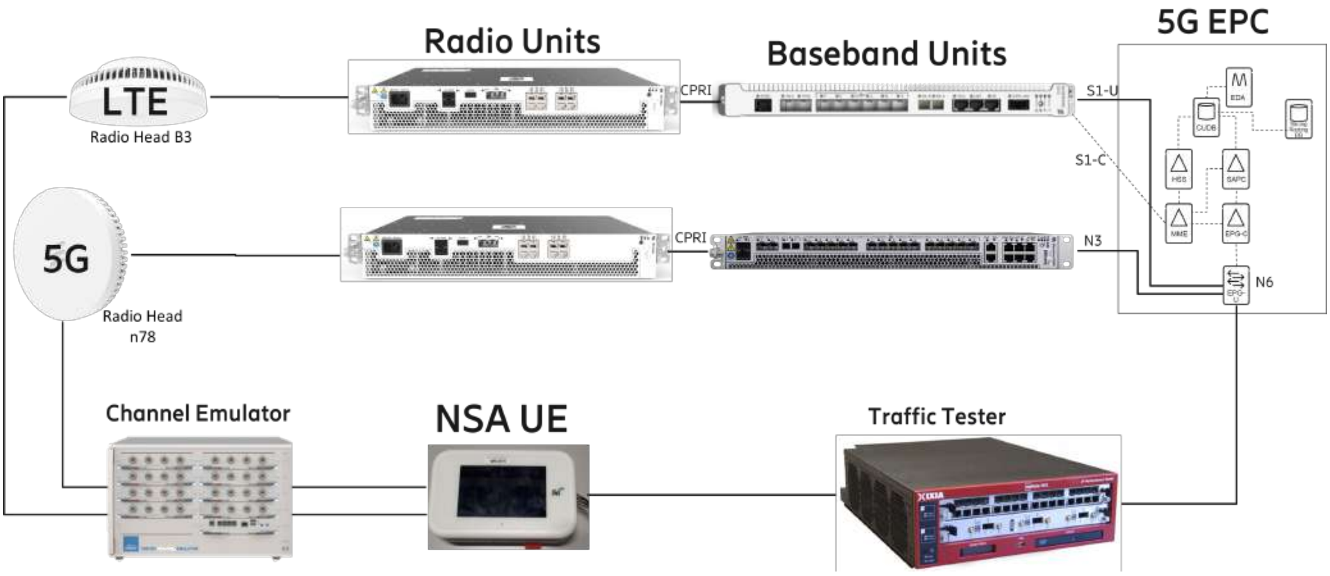

FIGURE 3-5 : ERICSSON 5G-NSA LAB SETUP

3.4.5. Network SLA Enforcer and Virtual Network Actuator

For the Industry I4.0 use cases, an Open vSwitch (OVS) or P4 Switch using advanced queueing, namely Virtual Network Actuator, is going to be deployed. This actuator will be fed by a Network SLA Enforcer which is capable of controlling the queues and flows using Weighted Fair Queuing (WFQ) and/or Active Queue Management (AQM). This latter component is going to collect real-time telemetry from the monitoring probes installed in the Virtual Network Actuator and other system components.

Ideally, the OVS or P4 switch, namely Network Virtual Actuator, will be shipped as virtual components. Deployment of this component will be done at the aggregation points of the computing nodes, possibly using a standard x86 Linux box to host them with the characteristics described in Table 3-6.

TABLE 3-6: QOTOM MINI PC Q555G6 SPECIFICATION

Property	Value	Image
Dimensions	187X111X50mm	
Net weight:	1Kg	
Power Input:	100-240V ~ - 50/60Hz 2.0A	

3.4.6. SDR-based radio head and IoT nodes

As described in Section 3.2.3, regarding mMTC use case, SDR-based radio heads and IoT nodes will be deployed in the trial site. The following paragraphs will provide more details about the HW components used.

Table 3-7 summarizes the specs of the radio-head HW components. Basically, USPR B210 is an SDR kit used as the RF frontend, which can support any band between 70 MHz and 6 GHz with up to 56 MHz signal bandwidth. This makes the radio heads sufficient to support both IEEE 802.15.4 and LoRa at 2.4 GHz band and any sub GHz band. The mini PC of Intel NUC is used as the digital frontend of radio heads. It is connected to the USRP via a USB 3.0 interface and connected to the Edge data center via an Ethernet interface. The mini PC not only does the conversion between the USB interface on USPR B210 and the Ethernet interface, but also perform packet detection on the uplink to avoid sending too much necessary IQ samples to the Edge data center.

Table 3-8 summarizes the specs of the IoT nodes HW components. For IEEE 802.15.4 IoT nodes, sensor boards of Silicon Labs Thunderboard Sense 2 will be used, which both the connectivity module and various sensor modules have integrated on the same board. For LoRa IoT nodes, we use two components, i.e. Fipy board extended with Pysense board, where Fipy board is used as the connectivity module for LoRa and Pysense provides the sensing capability with various sensors embedded.

TABLE 3-7: HARDWARE COMPONENTS OF SDR-BASED RADIO HEADS

Hardware Components	Image
USRP B210: used as the RF frontend of radio head • Dual-channel, fully integrated RFIC AD9361, with continuous coverage from 70MHz-6GHz • Full-Duplex MIMO with up to 56 MHz real-time bandwidth. • Open and reconfigurable Spartan 6 XC6SLX150 FPGA • USB 3.0 connectivity	
Mini PC (Intel NUC Hades Canyon NUC8i7HVB): used as the digital frontend of radio head • Processor: Intel Core i7-8809G • Graphics: Radeon RX Vega M GH graphics • RAM: 16GB DDR4-24000 • Storage: 512 GB M.2 SSD • Connectivity: Intel® Wireless-AC 8265 + Bluetooth 4.2, Intel® Ethernet Connection i219-LM and i210-AT • USB Connectivity: 7-ports with USB 3.1 Gen 2 Revision	

TABLE 3-8: HARDWARE COMPONENTS OF IOT NODES

HW components	Image

Silicon Labs Thunderboard Sense 2: used as IEEE 802.15.4 IoT nodes (embedded with both connectivity and sensor modules)
• EFR32 Mighty Gecko Wireless SoC
  o Arm Cortex M4, 256 KB RAM and 1024 KB Flash
  o 38.4 MHz Clock
  o 2.4 GHz multi-protocol radio
• Sensors
  o Silicon Labs Si7021 relative humidity and temperature sensor
  o Silicon Labs Si1133 UV index and ambient light sensor
  o Silicon Labs Si7210 hall effect sensor
  o Bosch Sensortec BMP280 barometric pressure sensor
  o AMS CCS811 indoor air quality gas sensor
  o TDK InvenSense ICM-20648 6-axis inertial sensor
  o TDK InvenSense ICS-43434 MEMS microphone
	

PyCom FiPy: used as the connectivity module of LoRa IoT nodes
• Espressif ESP32 SoC
  o Dual Processor: application processor and network processor for handling WiFi connectivity.
  o 32 MHz RTC, 4 MB RAM, 8MB Flash
• Encryption
  o SHA. MD5, DES, AES
• Communication Stacks
  o LoRa, SigFox, LTE-M, Bluetooth v4.2, WiFi 802.11b/b/n
	

PyCom PySense: used as the sensor module of LoRa IoT nodes • LTR-329ALS-01 Ambient Light Sensor • MPL3115A2 Barometric Pressure Sensor • SI7006-A20 Humidity and Temperature Sensor • LIS2HH12 3-axis Accelerometer • All sensors connected over I2C bus	

3.5. 5TONIC lab for prior-trial validation

Prior to the experimentation and validation in the trial site, two I4.0 use cases of Digital Twin and ZDM are going to be tested and validated in the ICT-17 5TONIC laboratory in Leganés, Spain. For a massive MTC use case, the lab validation will be done at the premises in Ericsson and RISE in Stockholm, Sweden.

In this deliverable, the focus is on the 5TONIC lab facility, as the Swedish premise is much simpler. The following information is a summary of the lab facility description of 5TONIC testbed.

3.5.1. Infrastructure layer

This layer incorporates the network elements/functions that provide the connectivity required for the implementation of the different use-cases in a self-contained way, i.e., not requiring the support of external elements.

There are several components of this layer that is continuously evolving in order to incorporate the latest developments of the 5G standard:

Radio access, which provides 4G coverage and 5G NSA coverage and support, LTE, NR NSA and NB-IoT access in different frequency bands. 5G SA support is expected to be supported during the first quarter of 2020.

The packet core network, which in the current implementation supports 4G virtualized EPC and 5G NSA virtualized core, ready to evolve to 5GC SA. The core also implements the elements required for the support of different policies and the management of the users' data.

Transport network, that implements or emulates different transport alternatives for fronthaul and backhaul.

3.5.2. Service and application layer

This layer incorporates the network elements/functions that provide the capabilities to implement different use-cases on top of the infrastructure layer. For these purposes, the site provides processing capabilities that can be deployed either at the edge of the network or in the cloud. It also provides mechanisms to measure and evaluate different indicators in order to characterize the services and application performance in different operational conditions.

It should be noticed that in some cases elements from the infrastructure and service layers share the same hardware platform.

3.5.3. Control and management layer

The main function of this layer is to support the flexible configuration of the infrastructure and the service layers in order to support the requirements of different layers. In this sense, the layer is based on the use of cloud, software, and virtualization techniques, including the support of the container-based deployment of VNFs. It also incorporates architectural elements from Software Defined Network (SDN) to manage the 5TONIC transport network.

The orchestration platform, that constitutes the core of this layer, is currently based in ETSI OSM, with different options as VIM (OpenStack, SONA).

3.5.4. Interaction and security layer

This layer is in charge of facilitating the interaction with the potential user, as well as other sites, in a secure way.

The security layer is also in charge of guaranteeing the privacy requirements between the parties that may be involved in the support of different use cases, as well as preventing any intrusion or attack from outside

3.5.5. Infrastructure

The infrastructure deployed at 5TONIC site is represented in the following figure:

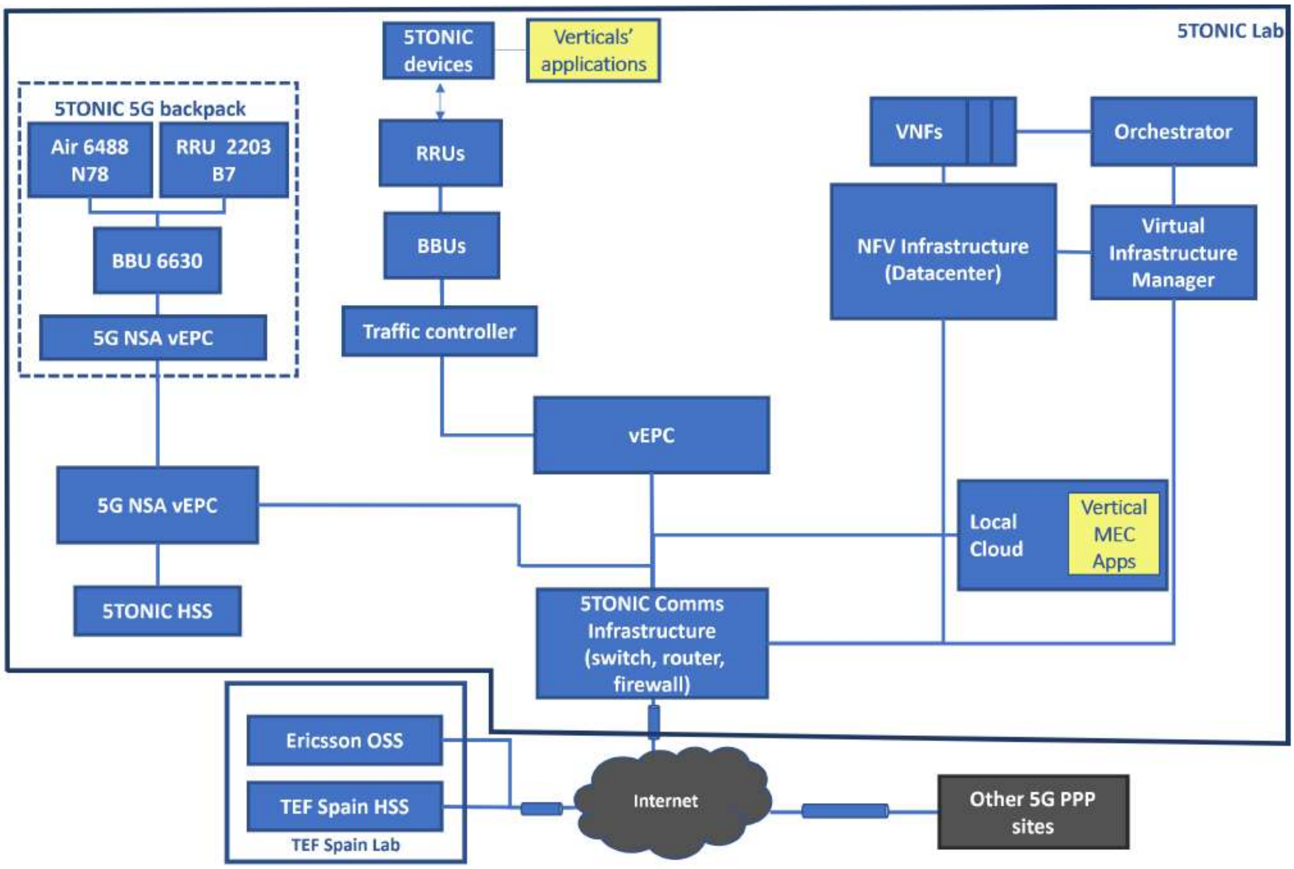

FIGURE 3-6: 5TONIC FACILITY DEPLOYED INFRASTRUCTURE

Current 5TONIC radio infrastructure incorporates the following elements:

- 4 baseband processing units (BBUs) from Ericsson, 3 units of BB 6630 (that can support both LTE and NR) and 1 unit of BB 5216 (that currently support LTE only).
- 3 units of Ericsson Radio 2203 that support LTE in band 7.
- 1 unit of Ericsson Radio 2217 that supports LTE in band 20.
- 1 unit of Ericsson Radio 8823 that supports LTE in band 42 (TDD).
- 2 units of Advanced Antenna Systems (AAS), both with 64 TRX for supporting multiuser MIMO, 1 unit of AIR 6468 that supports LTE in band 42 (TDD) and 1 unit of AIR 6488 that supports LTE and 5G NR in band 43/n78 (TDD).

Several of these elements are expected to be software upgraded (e.g., Radio 8823) to support NR radio interface. The upgrade is expected to be carried out in the laboratory during 2020.

To support the radio connectivity, the lab has acquired several devices that include:

- 4G smartphones, including 3 of them that support band 42 and also 256QAM
- 4G LTE routers, including one that supports 256QAM
- 5G NSA smartphones from different vendors (LG, Samsung, Xiaomi, Huawei)
- Raspberry Pi boards with LTE NB-IoT HATs.

In terms of core infrastructure, 5TONIC implements two vEPC from Ericsson, one of them just supporting 4G access and the second one supporting 5G NSA access. The first one is deployed on a Dell commercial server, while the second is based on Ericsson HDS 8000.

5GC supporting SA connectivity is scheduled to be deployed by the end of Q1 2021. The transport infrastructure of the site includes 4 units of Ericsson Router 6675, as well as several HP SDN enabled switches. For supporting the control and interaction layers a set of servers have been deployed at the site.

3.5.6. Services

Hitherto, the services provided by the site have been adapted to the specific requirements of the different use-cases that have been deployed at 5TONIC. In this sense, several options have been supported:

- Provision of basic 4G and/or 5G connectivity, e.g., to test the impact of 5G connectivity on a UE application performance.
- Provision of performance parameters measurement capabilities, e.g., to evaluate KPIs like throughput, latency or reliability.
- Provision of network configuration capabilities in order to define the test's topology as well as other network parameters.
- Provision of service and applications support capabilities, so the user of the site services can rely of the lab processing infrastructure for supporting the implementation of the use cases.
- Provision of adequate space and facilities for deploying its own infrastructure by the site user.
- Maintenance services of the infrastructure deployed by the user.
- Provision of security services

3.5.7. Test environment

5TONIC premises have several environments to carry out different kinds of experiments, including both indoor (in two different rooms) and outdoor coverage at IMDEA Networks premises. Also, there is an open area that allows the movement of a small vehicle.

3.6. Relationship with the project objectives

The trial sites and selected vertical pilot's use cases (in the form of PoCs) aim at demonstrating that the solutions developed can showcase and validate the main objectives of the 5G-DIVE project. Table 3-9 shows the I4.0 use case relation with the project objectives.

TABLE 3-9: I4.0 USE CASE RELATION WITH 5G-DIVE OBJECTIVES

Project Objectives	How this demo will tackle the project objectives
Objective 1: Design and validate 5G-DIVE technologies for specific applications, including the Industry 4.0 and Autonomous Drone Scouting verticals	
R&D Topics #3: Design and validation of the 5G-DIVE platform for the specific vertical use cases based on the results of the field trials.	I4.0 UC1, I4.0 UC2 and I4.0 UC3 will contribute to the validation of the 5G-DIVE platform.
Verification #1: Demonstration of two verticals, namely Industry 4.0 and Autonomous Drone Scouting over the 5G-DIVE platform, having diverse 5G technical and business requirements, by conducting four E2E field trials in Europe and Taiwan.	I4.0 UC1, I4.0 UC2 and I4.0 UC3 are going to demonstrate the Industry 4.0 vertical pilot and contribute validation of the 5G technical and business requirements.
Objective 2: Design and develop the 5G-DIVE Elastic Edge Platform (DEEP)	
R&D Topic #2: Enhance the connectivity layer of 5G-CORAL with 5G NR and its connectivity with a distributed 5G Core.	Both I4.0UC1, I4.0 UC2 and I4.0UC3 will use 5G NR and 5G Core as connectivity to fulfil the high-bandwidth and low-latency requirements of the use cases.
R&D Topic #3: Develop the 5G-DIVE Elastic Edge Platform (DEEP)	I4.0 UC1, I4.0 UC2 and I4.0 UC3 will use components of the DEEP platform, namely the BASS for service automation, the DASS for data collection, and IESS for enabling smart automation of the use cases.
Verification #2: Develop and demonstrate proof-of-concept prototypes (TRL 4/5)	I4.0 UC1, I4.0 UC2 and I4.0 UC3 will be implemented through proof-of-concept prototypes. I4.0 UC1 and UC2 PoCs will be initially tested and validated in 5TONIC Lab (IMDEA Networks, Madrid, Spain). I4.0 UC3 PoC will be initially tested at Ericsson and RISE premises in Stockholm, Sweden. Then the 3 PoCs will be integrated and showcased in ADLINK trial site in Taiwan.
Objective 3: Perform field trials and showcase vertical use cases	
R&D Topic #1: Integrate novel 5G-DIVE DEEP strata developed in WP2 into 5G-CORAL baseline architecture.	In I4.0 UC1, I4.0 UC2 and I4.0 UC3, 5G-DIVE DEEP strata will allow the verticals to interact with an end-to-end Platform-as-a-Service (PaaS). Moreover, it will offer the necessary support for providing AI capabilities as part of the vertical services.

R&D Topic #2: Deploy the 5G-DIVE platform across all trial sites, including software and hardware components for all use cases planned such as, e.g., 5G access based on 5G NR and CORE, unlicensed/licensed spectrum, multi-RAT technologies, Multi-access Edge Computing (MEC).	I4.0 UC1, I4.0 UC2 and I4.0 UC3 software and hardware components will be deployed in ADLINK trial site in Taiwan, where 5G NR and CORE, MEC and multi-RAT IoT stacks will be deployed.
R&D Topic #3: Field trial the 5G-DIVE pilots over the E2E European and Taiwanese testbeds.	Industry 4.0 field trials will be initially tested 5TONIC Lab (IMDEA Networks, Madrid, Spain) and in the Ericsson and RISE lab premises in Sweden. Afterward they will be trialled in ADLINK trial site in Taiwan.
Verification #1: Demonstration of Industry 4.0 Digital Twin use case in Taiwan ADLINK facilities with a TRL 5/6, showcasing 5G low latency capability.	I4.0 UC1: Demonstration of the Digital Twin demo in ADLINK (Taiwan) which is comparable to a TRL 5/6 environment, providing 5G connectivity through NSA 5G NR and Core which enables low latency capability required by the use case.
Verification #2: Demonstration of Industry 4.0 Connected Worker Augmented Zero Defect Manufacturing (ZDM) Decision Support System in Taiwan ADLINK facilities with a TRL 5/6, showcasing intelligent algorithms in Fog devices for pattern recognition.	I4.0 UC2: Demonstration of the Connected Worker Augmented Zero Defect Manufacturing (ZDM) Decision Support System in ADLINK testbed facilities in Taiwan which are comparable to a TRL 5/6 environment.
Verification #2: Demonstration of Industry 4.0 massive MTC use case in Taiwan ADLINK facilities with a TRL 5/6, showcasing infrastructure monitoring capability and orchestration features for service automation and resource auto-scaling.	I4.0 UC3: Demonstration of Industry 4.0 massive MTC PoC demo in ADLINK testbed facilities in Taiwan which are comparable to a TRL 5/6 environment.

3.7. Integration and Validation Timeline

This subsection proposes initial planning to integrate the different hardware components in the trial sites of I4.0 use cases as shown in Table 3-10. Currently, several initial implementations have been completed. The following describes the implementation progress I4.0 components:

- The refinement of functional and non-functional requirements for I4.0 field trial.
- The definition of the software and hardware components for I4.0 field trial.
- The roadmap and timeline definition for the initial deployments in the field trial.

TABLE 3-10: I4.0 VALIDATION TIMELINE DESCRIPTION

Quarter	Tasks
Q4 - 2019	• Refine functional and non-functional requirements for Industry 4.0 field trial – December 2019 (M3)
Q1 - 2020	• Define Software/Hardware components for Industry 4.0 field trial – Jan 2020 (M4)

	• Define a roadmap and timeline for initial deploying in the field trial – Feb 2020 (M5) •
Q2 - 2020	• Initial architectural components definitions and functionalities • Initial components development regarding IESS, BASS, DASS and I4.0 use cases.
Q3 - 2020	• Further components development regarding IESS, BASS, DASS and I4.0 use cases.
Q4 - 2020	• Further components development (BASS, IESS, DASS and I4.0 components) • Initial validation of some components in the field trials
Q1 - 2021	• Further components development
Q2 - 2021	• Final development and review of components regarding BASS, IESS, DASS and use cases components
Q3 - 2021	• Final integration of components in the field trials and performance evaluations based on KPI

3.8. Trial site risks and measurements of risk mitigation

There are known risks regarding the implementation of the use cases in the trial site:

3.8.1. Risk of relocation.

There is a risk of ADLINK to relocate its headquarters in Taipei Taiwan by the Q2 of 2021. This decision has a big impact on the trial site because all the hardware and software setup has to be migrated to the new location provided that the new space has a similar configuration in terms of space and connectivity infrastructure as the current one ADLINK's machinery testing lab.

There has been official request addressed to the direction of ADLINK to keep a place of similar characteristics to the current trial site. This new place will be set up meeting the technical requirements mentioned in this chapter in the new facilities.

3.9. Summary of I4.0

The work conducted within WP3 during the first six months of the 5G-DIVE project has allowed us to determine the technical requirements, software and hardware components associated to the three applications scenarios of the Industry 4.0 field trials: (1) the digital twin, (2) the connected worker augmented zero defect manufacturing, and (3) the massive machine type communications. The section then elaborates in the proposed in-lab validation in the 5TONIC lab and its infrastructure. Followed by stating the relationship of the PoCs aiming at validating the main objectives of the 5G-DIVE project. It was also presented the expected integration and validation timeline as well as the end-to-end validation plan. In this section, it was presented the available testbeds and provided a solid foundation for the assessment and evaluation of the technology being developed within 5G-DIVE. To conclude the section, it was presented the known risks associated at the implementation of I4.0 vertical pilot in the trial site and the measures of risk mitigation put on place.

4. Autonomous Drone Scout Trial site

In this section, the aspects related to ADS trial site are addressed, including the general description, an overall overview of trial site use cases, the trial site requirements, hardware components, relationship with 5G-DIVE project objectives, integration and validation timeline. Also, it highlights the technologies and infrastructures to be integrated in this vertical site. Finally, it addresses the potential risks associated with the vertical site during the execution of 5G-DIVE project.

4.1. Description

The showcase of the ADS vertical will be performed in Taiwan. The main candidate for this vertical testing is NCTU campus at Microelectronics and Information System Research (MIRC) building with the address: No. 1001, Daxue Road, East District, Hsinchu City as shown in Figure 4-1. Since the ADS vertical pilot focuses on using drones for the rescue of people in distress at the proximity of buildings, MIRC is chosen to provide a realistic outdoor environment for the targeted use case scenario. Also, the other candidates for ADS vertical is ITRI campus. The address of ITRI campus is Building 11, 195, Sec. 4, Chung Hsing Road., Chutung, Hsinchu County. ITRI team utilize this site for testing related to the drone to drone communication and collision avoidance system.

FIGURE 4-1: LOCATION OF AUTONOMOUS DRONE SCOUTS TRIAL SITE

Figure 4-2 depicts the end to end architecture in the ADS trial site. Basically, this system consists of three important parts namely the drone system, edge DC and 5G network. In this trial site, multiple drones are equipped with drone-to-drone communication modules to enable real-time sensory data broadcast for collision avoidance. In addition, drones utilize 5G network to transmit other sensors data such as images and GPS location. At the edge DC, service gateway is deployed to provide traffic breakout function which enables receiving sensory data directly to edge application instead of going through the core network. The drone fleet is managed by a cloud drone control software through 5G-Core.

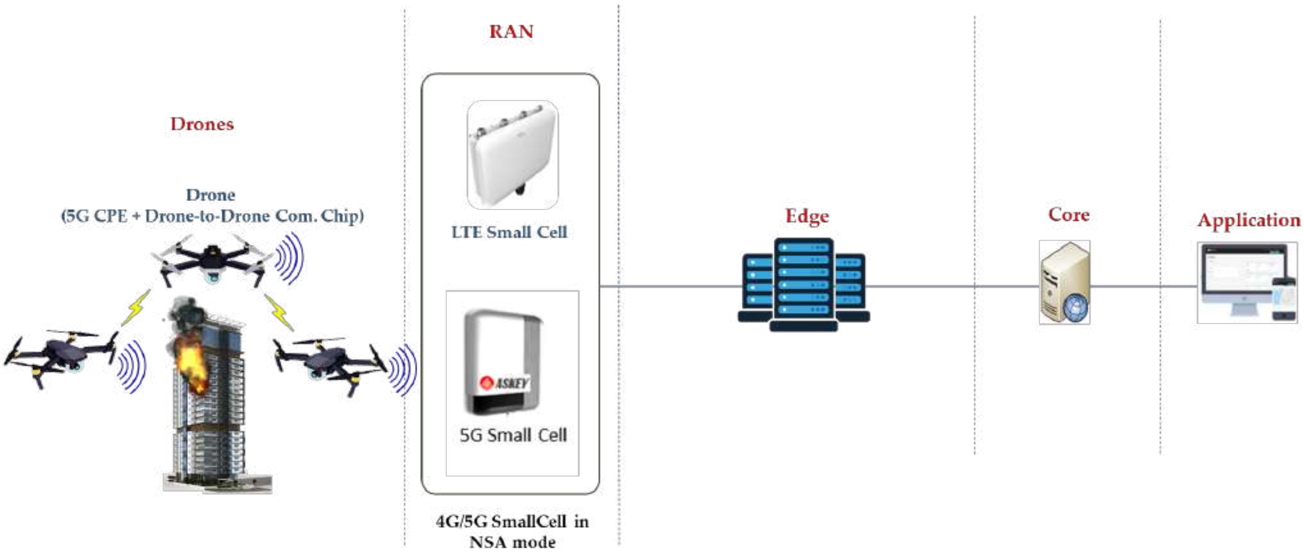

FIGURE 4-2: ADS FIELD TRIAL SITE

Currently, the involved partners of ADS are planning the network setup and wiring of CPE and Small cells in the trial site. Also, the flying area of the drones is under study. This required several site surveys to identify the requirements and deployment options in this trial site. These site surveys include the following investigation:

- Decide on the appropriate floor of MIRC building for power supply and network wiring for small cells.
- Determine the antenna angle, measure the transmit power and the effective area.
- Determine the position of the Small Cell.
- Measure the penetration distance of the small cell above and below the field signal
- Determine the source of power and network signal lines throughout the building
- Determine the thickness of the measured windows of the building
- Determine the wheelbase of the drone flying in the field
- Make a 4G CPE & eNB measurement on the first floor of the building
- Floor plans that require building equipment

In this stage, we use 4G network measurements to obtain the above data as we prepare for future demonstrations using 5G network. After setting all the above conditions, ADS trial site can perform the actual data stream transmission via 5G network. Also, drone-to-drone avoidance will be integrated as well to perform the needed measurements.

4.2. Trial site use cases

Two main use cases are going to be showcased in the ADS trial site: (i) Drone Fleet Navigation; and (ii) Intelligent Image Processing for Drones. Both use cases will rely on joint operation of the resources deployed in the Drones, Fog (see Appendix 7.1.1 and 7.1.2), MEC and Cloud, where based on the computing requirements of the algorithms, resources hosted at different locations must work together to obtain the expected result. In order to understand the requirements that these use cases demand from the trial site, they are described in the following subsections.

4.2.1. ADS-UC1: Drone Fleet Navigation

The ADS-UC1 aims at enhancing the current navigation system to enable local and remote data processing, as well as autonomous flight trajectory change for the drone fleet. To accomplish this, a coordination mechanism among drones in the drone fleet is required. Fundamentally, there are two independent drone control systems in the ADS system, namely drone collision avoidance and drone edge navigation. For the edge-enabled navigation, each drone captures and transmits images and GPS data to the edge DC. In particular, drones utilize low latency and high bandwidth 5G connectivity. Also, a drone fleet navigation server is deployed to perform several real-time tasks such as providing drone status (i.e. in flight or not, GPS accuracy quality, GPS coordinates, air condition, rain condition, etc.) and waypoint setup. Also, each drone in the fleet can be controlled based on the aforementioned features for flight plan which includes single-point destination and multi-point flight.

On the other hand, drone collision avoidance (see Appendix 7.1.5) is essential for drones in a drone mission. A drone-to-drone direct link is used to synchronize the drones within the fleet to cover a larger area and avoid a possible collision. In particular, the drones may operate in close proximity to each other and bad weather conditions (e.g., windy). The drone collision avoidance system is deployed on each drone to ensure that the drones can seamlessly accomplish successful missions. Each drone continuously broadcasts GPS and altitude information, while simultaneously processing the same information from other drones to detect possible collisions. If a potential collision is detected, the drones involved in the collision situation calculate alternative paths e.g., calculate new clear path, or hold current location. When such a situation occurs, drone collision avoidance temporarily takes over the drone control. After the collision risk is eliminated, the drone collision avoidance system releases the control of the drone back to the drone edge navigation system.

4.2.2. ADS-UC2: Intelligent Image Processing for Drones

The ADS-UC2 takes advantage of the edge platform to enable two potential applications, namely image stitching and pattern recognition. In particular, the drone image and GPS data are processed in real-time for emergency detection and response (see Appendix 7.1.3 and 7.1.5). Based on pre-processing and cognitive techniques, the edge DC aids in making dynamic trajectory changes for each drone in the fleet.

Machine learning models are developed and trained for object detection and classification. This model is designed to identify a Person-In-Distress (PID) (i.e., a victim in a disaster situation) captured by the drones. Based on video streaming and GPS information. Furthermore, 2D image stitching application is designed to reconstruct a progressive aerial map of the areas taken by multiple drones. The progressive map is displayed on the drone control dashboard. Finally, and equally important, iMEC will help break out the traffic at edge DC rather than pass it to the core network. This will allow the low latency services for the operational drones.

4.3. Trial site Requirements

In this section, the requirements of the operational ADS trial are described in detail. The aforementioned requirements are essential and cover different aspects especially in the outdoor environment for flying drones and 5G connectivity system as follow:

Drone navigation requirements

For the drone to fly, there are several requirements need to be ensured for public safety. For example, if the wind is strong, it will be dangerous to allow the drone to fly. The most suitable requirements for drone flight in our trial site are

- In the daytime, to ensure darkness does not affect visibility
- Gusts speed < 7.9m/s at 50-100 meters altitude
- Precipitation = 0%
- Visibility > 500 meter

5G-system hardware requirements

To ensure reliable connectivity to the drone during airborne operation, the 5G network infrastructure should be designed in ways that link quality is only marginally affected in the case of mobility at altitude. Experiments with airborne vehicles over cellular networks has shown that 4G/LTE cellular networks are often deployed in ways not to efficiently support data transfers at altitude [13].

The network design is, in fact, thought to favour users at ground level. This is expected as telecom operators expect the majority of the transmitting station to be located on the ground; therefore, antennas are oriented according to these expectations. The 5G system in the ADS trial should guarantee a minimum 10Mb/s bandwidth and 5 ms ICMP latency throughout the operational range of the drone at the target altitude.

iMEC requirements

iMEC does not support to deploy GPU-required applications. However, in ADS use case, both Image stitching and Pattern recognition need to have GPU resources to accelerate computing. Therefore, iMEC will need to support to deploy GPU-required applications.

In ADS use case, Pattern recognition will send calculated results to the Drone fleet controller so to navigate drones. Therefore, inter-Application communications are required and iMEC has to meet this requirement when deploying these applications.

4.4. Hardware components

In this subsection, the hardware components necessaries to implement ADS use cases in the trial site are described as follows.

4.4.1. Drone system

Each drone in the ADS trial site are equipped with different hardware as shown in Figure 4-3. The drone hardware components are camera (GoPro7), Raspberry Pi 4 (RPI-4), Wi-Fi adaptor and Flight control (Pixhawk) [5], 5G CPE. The RPI-4, WiFi adaptor and flight control are the hardware components to create drone-to-drone communication which is responsible for collision avoidance. 5G CPE is responsible to transmit the sensory data to gNB or eNB. Last but not least, the camera will be responsible to capture high-quality images of the target area. In the following subsection, the specification of drones and its hardware components are elaborated.

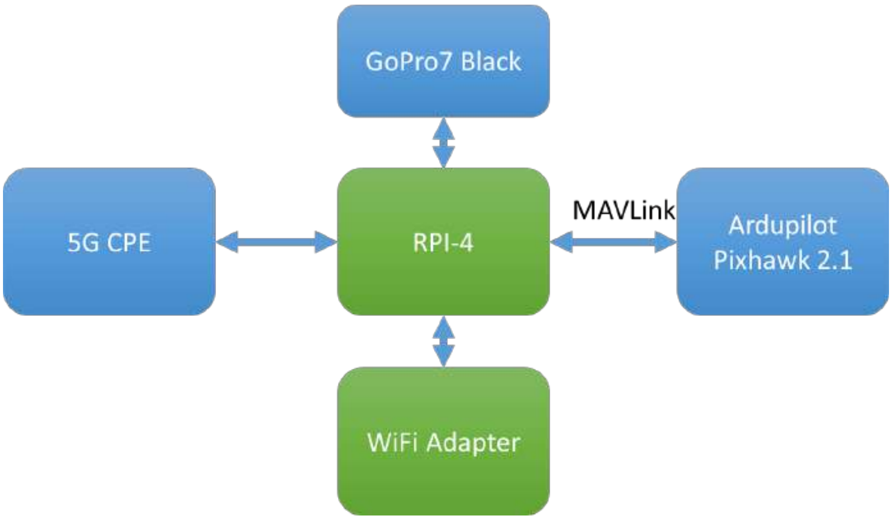

FIGURE 4-3: DRONE HARDWARE COMPONENTS IN ADS TRIAL SITE

4.4.1.1. Drone

In the trial site, three to five drones will be utilized in scouting the MIRC building, the drone specification are list in Table 4-1. Also, the drone flight control specification is shown in

Table 4-2.

TABLE 4-1: DRONE SPECIFICATION FOR ADS

Property	Value	Image
frame dimension	1150 mm×1150 mm×550 mm	
Maximum takeoff weight	14 kg	
Operating weight (excluding battery)	7.5 kg	
Standard Payload	5 kg	

Battery	10500mah 25C	
Power consumption	1750W@Take-off weight 14 kg Hovering	
Maximum flight speed	12 m/s	
Operation time	16 min(weight 9 kg)/9 min(weight 14 kg)	
Motor Maximum Power	800 W(KV value 280 rpm/V)	
Working voltage	25.2 V（6S LiPo）	
Maximum current	36 A	
Propeller	22×6.5 inch (Foldable propeller)	
Height Measurement	1 - 5 m	
Fixed Height Range	1.5 - 3.5 m	
Measuring Accuracy	< 20 cm	

TABLE 4-2: FLIGHT CONTROL OF DRONE

Property	Value	Image
Frame dimension	50mmx81.5mm (WxL), Thickness: 15.5mm, Weight: 38g	
Microprocessor	• 32-bit STM32F427 Cortex M4 core with FPU • 168 MHz/256 KB RAM/2 MB Flash • 32-bit failsafe co-processor	
Sensors	• MPU6000 as main accel and gyro • ST Micro 16-bit gyroscope • ST Micro 14-bit accelerometer/compass • MEAS barometer	
Ports	• 5x UART serial ports, 1 high-power capable, 2 with HW flow control • Spektrum DSM/DSM2/DSM-X Satellite input • Futaba S.BUS input • PPM sum signal • RSSI (PWM or voltage) input • I2C, SPI, 2x CAN, USB • 3.3V and 6.6V ADC inputs	
Power System	• Ideal diode controller with automatic failover • Servo rail high-power (7 V) and high-current ready • Output peripherals are over-current protected, all inputs are ESD protected	
Available Autopilot Software Suite	• Ardupilot • PX4	

4.4.1.2. Camera

Also, the camera mounted on the drone has the specifications shown in Table 4-3 :

TABLE 4-3: CAMERA ON DRONE SPECIFICATION FOR ADS

Property	Value	Image
Light sensor value	12MP	
Effective Pixels	12MP	
Photosensitive element type	CCD	
Maximum resolution	4000 x 3000	
Water Resistant	10 m	
Video Resolution	• 4K(16:9) @ 60/30/24fps • 4K（4:3 ） @ 30/24fps • 2.7K（16:9 ） @ 120/60/30/24fps • 2.7K（4:3 ） @ 60/30/24fps • 1440p（4:3 ） @ 60/30/24fps • 1080p（16:9 ） @ 240/120/60/30/24fps	
Video File Format	MP4 (H.264/AVC）MP4（H.265/HVEC）	
Max. shutter speed	1/2000s	
Max. sensitivity	1600 ISO	
Storage	microSD / microSDHC / microSDXC	
Weight	116 g	
Dimensions	62.3 x 44.9 x 33mm	

4.4.1.3. Drone-to-Drone communication

In each drone, companion computer (Raspberry Pi 4) is used as shown in Table 4-4. Also, the drone-to-drone communication module (Wi-Fi adaptor) for each companion computer is shown in

Table 4-5. Collison avoidance is adopted in Raspberry Pi 4 and it will send the flight command to the flight control of drone shown in

Table 4-2.

TABLE 4-4: RASPBERRY PI 4 SPECIFICATION FOR DRONE COLLISION AVOIDANCE SYSTEM

Property	Value	Image
Broad	Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz 4GB LPDDR4-3200 SDRAM	
Wireless/wire communication	2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE Gigabit Ethernet	
Power Input:	5V DC via USB-C connector 5V DC via GPIO header Power over Ethernet (PoE) enabled	
Ports	Gigabit Ethernet 2 USB 3.0 ports; 2 USB 2.0 ports. 2 × micro-HDMI ports (up to 4kp60 supported) 2-lane MIPI DSI display port	

	2-lane MIPI CSI camera port	
Multimedia support	H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode) OpenGL ES 3.0 graphics	

TABLE 4-5: WIFI ADAPTOR SPECIFICATION FOR DRONE COLLISION AVOIDANCE SYSTEM

Property	Value	Image
Broad	ASUS-USB-AC68 Driver: rtl8814au	
Wireless/wire communication	WiFi: IEEE 802.11a/b/g/n/ac	
Power Input:	Interface (Power): USB3.0 (5V, 0.9A)	
Size	115 x 30 x 17.5mm	
Weight	44g	

4.4.1.4. CPE

Askey is developing 5G CPE now by extending the completion of 4G CPE development. Particularly, the modem in 5G CPE has also evolved from Qualcomm's SDX 50 to SDX55, which enables the CPE to support MMwave. Table 4-6 shows the hardware specification of CPE.

TABLE 4-6: 5G CPE SPECIFICATION

Property	Value	Image
Spectrum	5G-NR mmWave: n257, n260, n261 5G-NR sub-6G: n78 , n41	
3GPP Release	3GPP R15.3+. Release LTE: Global Bands	
WiFi	802.11ac 2x2 wave 2	
SIM	4FF Nano SIM	
Battery	5800m Ah	
Size	210 x 130 x 46 mm	

4.4.2. Edge DC

OPTUNS Edge Data Centre is located in the MIRC, National Chiao Tung University, Taiwan and is available for the field trials. As shown in Fig. 3-9(C), OPTUNS Edge DC consists of 25 OADS and five OSIS prototypes interconnecting 25 racks evenly located in five pods. Each rack has 16 servers that are up-connected to an OpenFlow-based ToRS. Each ToRS (Agema AG7648) is equipped with 48 10GbE quad small form-factor pluggable (SFP+) ports and six 40 GbE quad small form-factor pluggable (QSFP) uplink ports, operating with PicOS version 2.9.2.26. Among the 48 10GbE ports, 16 ports are down-connected to 16 servers via 10G active optical cables. The other 16 ports are up-connected to an OADS, with 16 10 Gb/s DWDMSFP+ transceivers pre-plugged, respectively.

FIGURE 4-4 : OPTUNS PROTOTYPE TESTBED (A) TIER 1 OADS PROTOTYPE. (B) TIER 2 OSIS PROTOTYPE. (C) 25-RACK TESTBED.

OPTUNS adopts 40 wavelengths ranging from ITU channel numbers 21 (1560.61 nm) to 60 (1529.55 nm) with a channel spacing of 100 GHz. All the components in OPTUNS, including WSSs, MUXs, cyclic DEMUXs, band MUXs, and EDFAs, which are custom made by vendors, are compliant with this 40 wavelength 100 GHz spacing setting. As shown in Figs. 3-9(a) and 3-9(b), the OADS and OSIS prototypes are built using commercially available optical components. The server specification of OPTUNS Edge DC are summarized in Table 4-7.

TABLE 4-7: OPTUNS SERVER SPECIFICATIONS

No.	Component	Server Type #01	Server Type #02
1.	Model	HP Enterprise ProLiant DL380 Gen10	HP Enterprise ProLiant DL380 Gen10
2.	HDD	280 GB	280 GB
3.	RAM	128 GB	8 GB
4.	CPU	2x Intel(R) Xeon(R) Gold 6136 CPU @ 3.00GHz (12 Core, 24 Thread)	intel(R) Xeon(R) CPU E3-1225 v5 @ 3.3GHz
5.	GPU	NVIDIA Tesla V100 32 GB	-
6.	Network	4x 1GbE Ethernet; 2x 10GbE SFP+	2x 1GbE Ethernet; 2x 10GbE SFP+
7.	Public IP	1 Public IP available	No Public IP
8.	Inter-server latency	158–313 μs.	

Several modules will use servers in the OPTUNS Edge DC. Object detection and 2D image stitching modules are deployed in GPU-enabled Servers, while other modules, such as database, FFServer, dashboard, and monitoring system, are deployed in non-GPU servers.

Besides, the edge DC will host the drone fleet navigation server to be in near proximity of the drones flying around the MIRC building. This server specification is listed in Table 4-8.

TABLE 4-8: DRONE FLEET NAVIGATION SERVER SPECIFICATION

Property	Value	Image
CPU	Intel Core i7 6700	
Motherboard	MSI Z270 KRAIT GAMING(MS-7A59)	
Memory	DDR4(8G) 2400MHZ	
OS	Windows Server 2012 R2 Standard	
Network Interface	10/100/1000Mbps x1	
Disk	CT275MX300SSD4	

4.4.3. 5G Network

For the ADS trial, a 5G outdoor system will be used. This system consists of 5G-CPE (see section 4.4.1.4), gNB and core network. The following subsection elaborated the system configuration and specifications

4.4.3.1. gNB

Askey will provide gNB for the ADS trial. Currently, Sub 6 is the development target, and MmWave is also in the roadmap. The below table shows the hardware specification of gNB.

TABLE 4-9: GNB SPECIFICATION

Property	Value	Image
Spectrum	• 5G NR n78	
Bandwidth	• 100 MHz	
Power	• 125mW x2 MIMO	
DL/UL	• 800 Mbps/400 Mbps	
External Antenna	• One RJ45 GbE Port • One SFP+ Port	

4.4.3.2. iMEC

In addition, the iMEC will be deployed in this edge DC with the following hardware requirements:

- 3 servers are required. Server 1 is for iMEC-core, Server 2 and Server 3 are for container-based and VM-based applications, respectively.
- Server 1 requires four NIC ports, while Server 2 and Server 3 require two NIC ports. Those ports will be configured in different subnets as the colours shown in the figure. By the Management subnet, iMEC can deploy applications in Server 2 and Server 3. By Data subnet, iMEC can steer traffic to the applications in Server 2 and Server 3.

- While intra-rack communications between servers will go via OPTUNS switch, inter-rack communications will further go via Router.

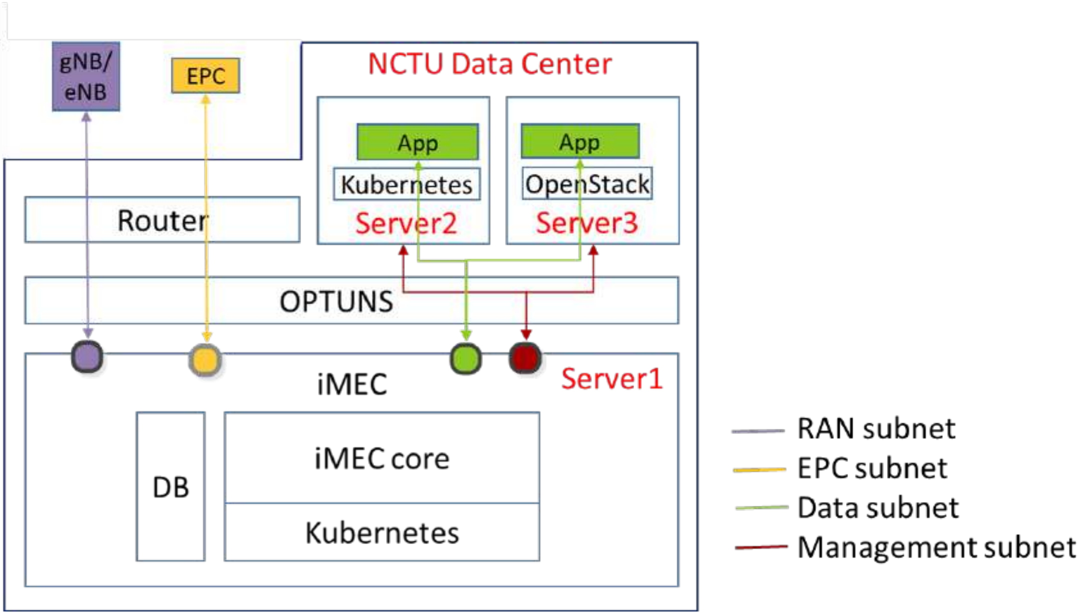

FIGURE 4-5: THE INTERWORKING ARCHITECTURE OF IMEC AND NCTU DATA CENTRE

iMEC is developed by ITRI. The underlying network architecture of ADS use case is 5G NSA (Non-Standalone) as shown in below figure. Therefore, the SGW function inside iMEC supports S1-u, S11, and SGi interfaces so to provide local breakout feature. In addition, iMEC also facilitates automated deployment and management for containerized applications under the Kubernetes platform

[6].

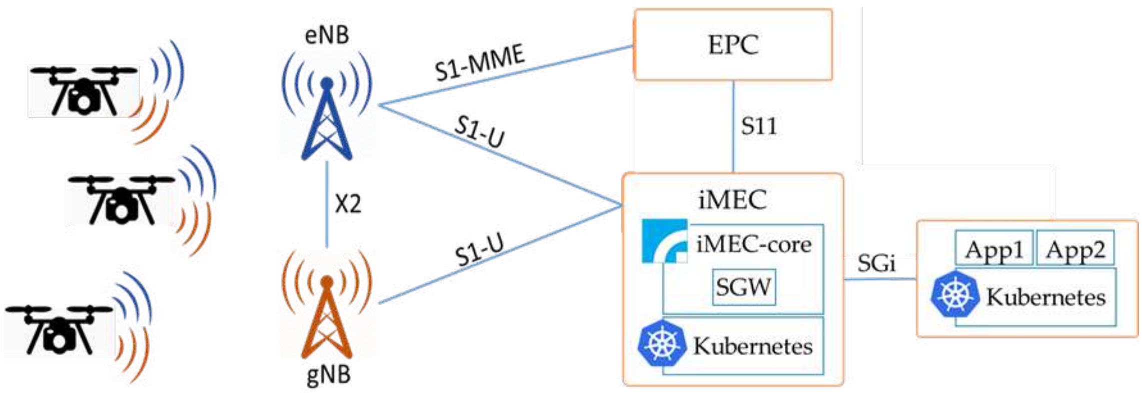

FIGURE 4-6: NETWORK ARCHITECTURE OF ADS USE CASE

4.4.3.3. Core network

The core network vEPC is developed by III as shown in Figure 4-7, which implements the container-based with C/U split system. All the virtualized modules can be managed by kubernetes(K8S) platform. For the reduction of the data plane latency, the Smart NIC (i.e. NIC with network traffic processing function, could programming by P4 language) is used on the data plane with SGW-U and PGW-U servers. The latency can be shortened to less than 300us with no additional server computing resources required.

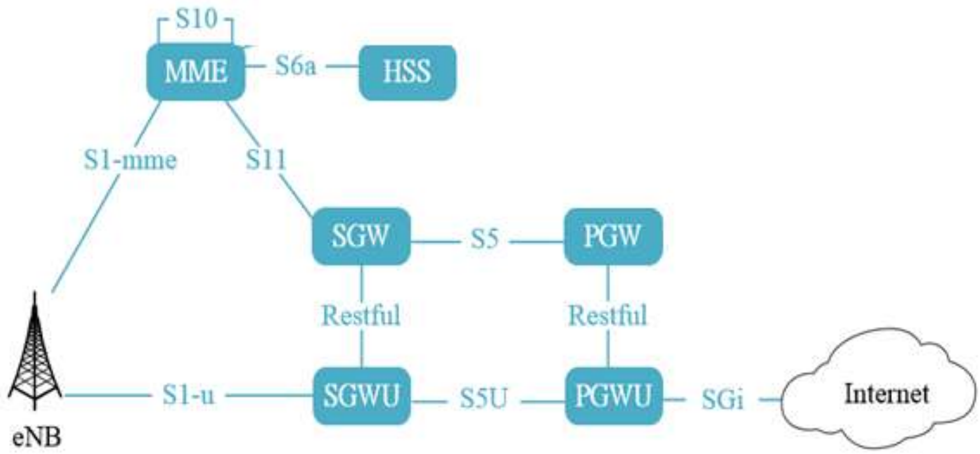

FIGURE 4-7: THE ARCHITECTURE OF VEPC

For non-standalone (NSA) core network architecture, implement the LTE-NR dual connectivity (EN-DC) feature within 5G architecture option 3, where the vEPC can support eNB connected via S1 interface and en-gNB connected via X2 interface.

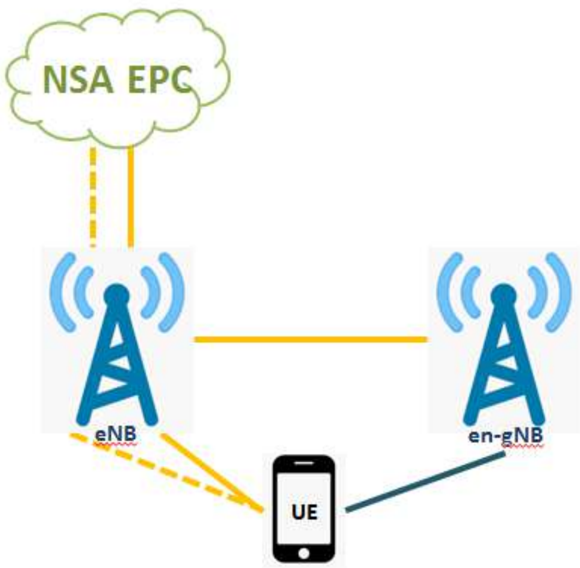

FIGURE 4-8: THE ARCHITECTURE OF EN-DC OPTION 3

The 5G core network is developed by III and followed 3GPP R15 Spec. which design for serviced based architecture (SBA). The 5GC can support features such as UE mobility management, session management, idle mode supported and Xn & N2 Handover functions. Thus, 5GC supports the interworking with MEC by NEF module.

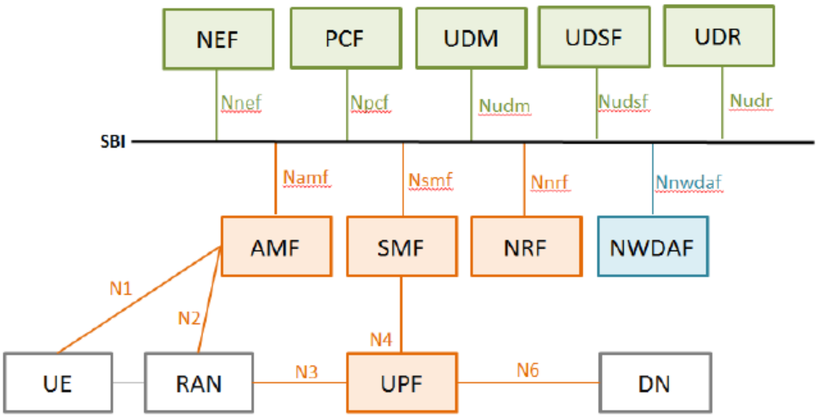

FIGURE 4-9: THE ARCHITECTURE OF SBA 5GC

The core networks both NSA EPC and 5GC will be deployed in NCTU data centre. Both of NSA EPC and 5GC are implement for container-based system for improve the scalability and provide resiliency.

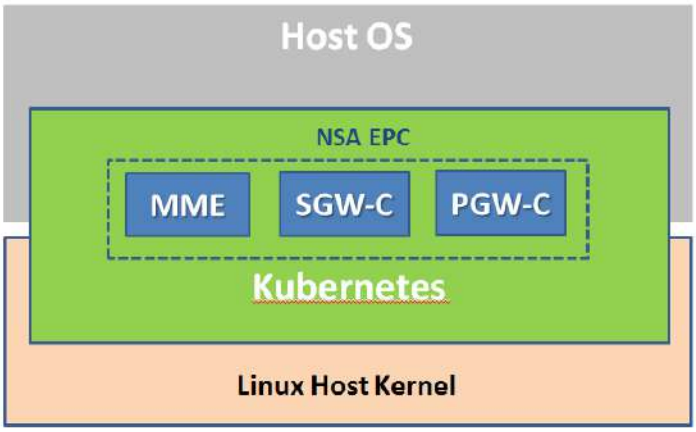

FIGURE 4-10: THE VIRTUALIZATION ARCHITECTURE OF NSA EPC WITH K8S PLATFORM

The deployment requirement lists for hardware as bellow:

TABLE 4-10: THE REQUIRED HARDWARE FOR DEPLOYING CORE NETWORK

Hardware Spec.	Image
Server • Intel Xeon Gold series 2.1 GHz 16 cores • 16GB DDR4 (at least) • SR-IOV & Intel Data Plane Development Kit (DPDK) supported • OS：ubuntu 18.04.2 • kernel：4.15.0-52-generic	
SmartNIC • 2-port 10GbE, SFP+ • 2GB DDR3 onboard memory • Programming with P4 language	
Switch L2/L3 Protocol supported	

4.5. In-Lab validation

5TONIC Lab at IMDEA Networks (Madrid, Spain), as previously described in Section 3.5 , can also provide the facilities for an early deployment of the ADS vertical in a lab environment. Due to the many restrictions regarding flying drones in outdoor environments without permission, this indoor scenario can be leveraged for initial experiments of the ADS vertical pilot. As shown in Figure 4-11, the size of the room allows more than one drone to fly without the risk of collision. Also, 5TONIC Lab has already a working 5G Network which can be used to leverage the low latency and high bandwidth requirements necessary for the ADS vertical pilot use cases.

5TONIC Lab as an indoor environment is being used already for testing in projects that involve drones. An example of this is the 5G RANGE project where they used unmanned aerial vehicles as computational nodes to configure virtualized network functions. More details can be found on the official project webpage.

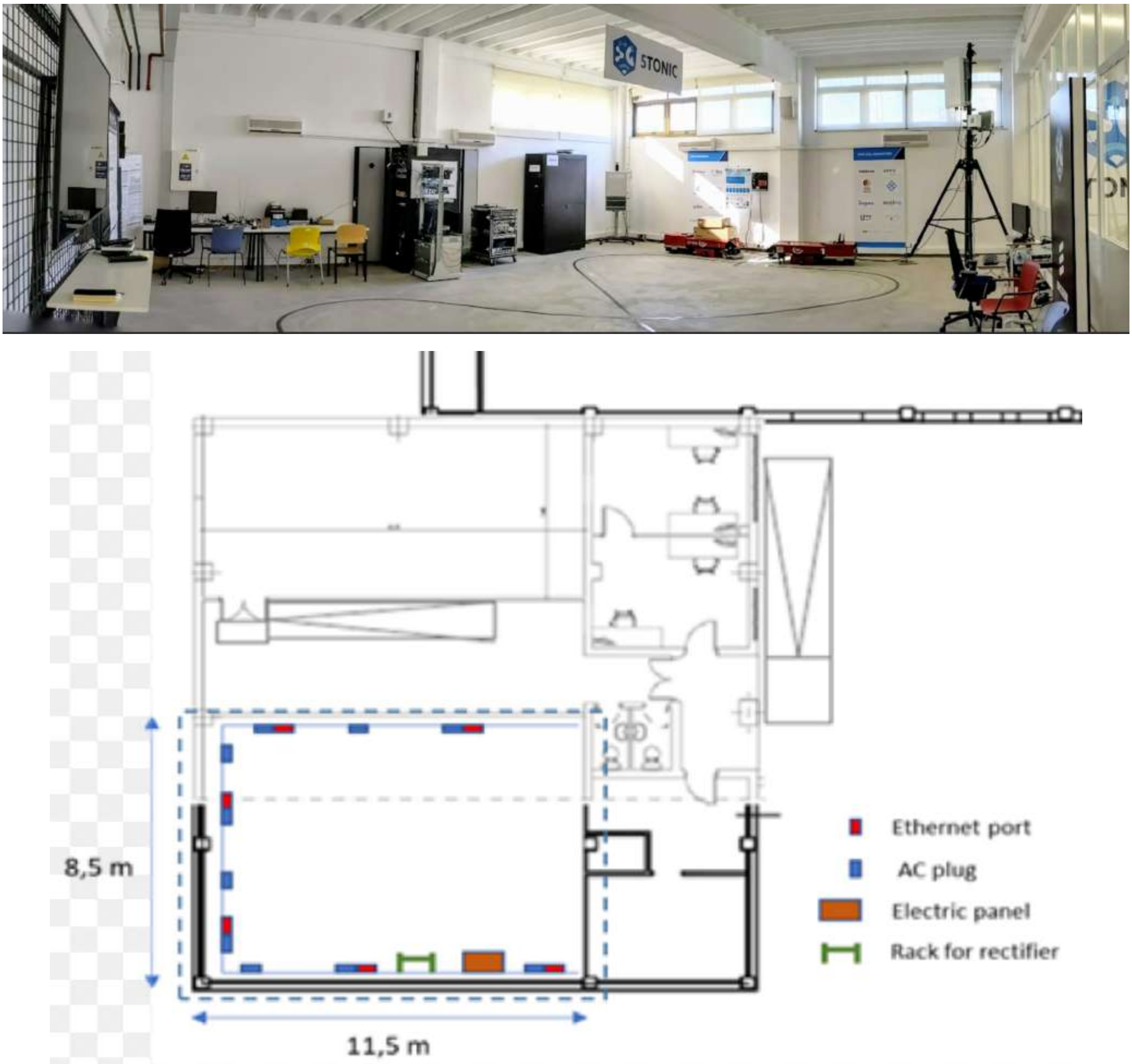

FIGURE 4-11: 5TONIC INDOOR SITE FOR ADS VERTICAL PILOT

4.6. Relationship with the Project Objectives

The trial sites and selected vertical pilot's use cases (in the form of PoCs) aim at demonstrating that the solutions developed can showcase and validate the main objectives of the 5G-DIVE project. Table 4-10 shows the ADS use cases related with the project objectives of 5G-DIVE.

TABLE 4-10: ADS USE CASE RELATION WITH 5G-DIVE OBJECTIVES

Project Objectives	How this demo will tackle the project objectives
Objective 1: Design and validate 5G-DIVE technologies for specific applications, including the Industry 4.0 and Autonomous Drone Scouting verticals	

R&D Topics #3: Design and validation of the 5G-DIVE platform for the specific vertical use cases based on the results of the field trials.	Both ADSUC1 and ADSUC2 will contribute to the validation of the 5G-DIVE platform.
Verification #1: Demonstration of two verticals, namely Industry 4.0 and Autonomous Drone Scouting over the 5G-DIVE platform, having diverse 5G technical and business requirements, by conducting four E2E field trials in Europe and Taiwan.	Both ADSUC1 and ADSUC2 are going to demonstrate the ADS vertical and contribute validation of the 5G technical and business requirements.
Objective 2: Design and develop the 5G-DIVE Elastic Edge Platform (DEEP)	
R&D Topic #2: Enhance the connectivity layer of 5G-CORAL with 5G NR and its connectivity with a distributed 5G Core.	ADSUC2 will use 5G NR and 5G Core as connectivity to fulfill the high-bandwidth and low-latency requirements. Besides, the traffic breakout function inside iMEC is able to provide local breakout to reduce transmission latency.
R&D Topic #3: Develop the 5G-DIVE Elastic Edge Platform (DEEP)	ADSUC2 will use components of the DEEP platform, namely the IESS for model training, BASS for service-level monitoring and autoscaling, and the DASS for geolocation and image data preprocessing and storage.
Verification #2: Develop and demonstrate proof-of-concept prototypes (TRL 4/5)	Both ADSUC1 and ADSUC2 will be implemented through proof-of-concept prototypes. Such PoC will be initially tested in ITRI and Askey Labs with possible testing in 5TONIC Lab (IMDEA Networks, Madrid, Spain) if needed and afterwards showcased in NCTU trial site in Taiwan.
Objective 3: Perform field trials and showcase vertical use cases	
R&D Topic #1: Integrate novel 5G-DIVE DEEP strata developed in WP2 into 5G-CORAL baseline architecture.	In ADSUC2, 5G-DIVE DEEP strata will allow the verticals to interact with an end-to-end Platform-as-a-Service (PaaS). Moreover, it will offer the necessary support for providing object detection and classification to detect emergency situations.
R&D Topic #2: Deploy the 5G-DIVE platform across all trial sites, including software and hardware components for all use cases planned such as, e.g., 5G access based on 5G NR and CORE, unlicensed/licensed spectrum, multi-RAT technologies, Multi-access Edge Computing (MEC).	Both ADSUC1 and ADSUC2 software and hardware components will be deployed in NCTU trial site in Taiwan. This will leverage the use of 5G NR and CORE and Multi-access Edge Computing.
R&D Topic #3: Field trial the 5G-DIVE pilots over the E2E European and Taiwanese testbeds.	ADS field trials will be initially tested in ITRI labs and ASKEY labs and afterward showcased in NCTU trial site in Taiwan.
Verification #3: Demonstration of Autonomous Drone Scouting/Drone Fleet Navigation in Taiwan test field with TLR 6/7, showcasing URLLC, Drone-	In ADS use cases, drone collision avoidance runs on drones and utilises the Drone-to-Drone direct link. Compared to cloud-based collision avoidance, this

to-Drone direct link and Drone fleet relay operating in parallel.	allows low latency reaction between drones. Besides, the detection of the emergency will take part to demonstrate how the Drone will autonomously be reallocated to provide the necessary action needed.
Verification #4: Demonstration of Autonomous Drone Scouting Intelligent processing of images in the Drones in Taiwan test field with TLR 6/7, showcasing processing of images in a multi-tier scenario including intelligence in the Fog devices.	Object detection and classification may utilise the cloud or edge DC for model training. As for inferencing, the trained models will be deployed in the edge DC for lower response latency. Furthermore, 2D aerial image stitching may utilise edge DC to assist in the emergency response under TRL 5/6 environment.

4.7. Integration and Validation Timeline

This subsection proposes initial planning to integrate the different hardware components in the trial sites of ADS use cases as shown in Table 4-11. Currently, several initial implementations have been completed. The following describes the implementation progress ADS components:

- The design and implementation of SGW has been completed with basic PFCP messages support. This includes EN-DC feature and PFCP as the protocol between SGW-C and SGW-U.
- The initial design and implementation of the intelligent engine for the disaster aerial relief have been completed. This includes a basic detection of person in distress using object detection and classification. The initial implementation has been tested and evaluated in a simulated environment.
- The initial design and implementation of drone-to-drone collision avoidance system has been completed. This includes a broadcast mechanism of flight status among drones and an algorithm to calculate possible collision in a simulated environment.

TABLE 4-11: ADS VALIDATION TIMELINE DESCRIPTION

Quarter	Tasks
Q1 - 2020	• Initial implementation of drone-to-drone collision avoidance system using drone-to-drone communication module • EN-DC feature support • Initial implementation (i.e., basic detection) of aerial disaster relief response system using pattern recognition on top of OPTUNS.
Q2 - 2020	• System integration with drone navigation server (i.e., priority of drone control). • 5G NSA integration Part 1(iMEC+simulated EPC, RAN, and CPE) • Application integration with iMEC and drone navigation server • Initial testing for Drone Fleet navigation with full HD camera
Q3 - 2020	• Integration Test: System integration with drone navigation server. • Implementation refinement according to the integration Test. • 5G NSA integration Part 1 (iMEC+simulated EPC, RAN, and CPE)

	• Integration Test: Application integration with iMEC and drone navigation server • Implementation refinement (i.e., gesture recognition added) of aerial disaster relief response system • Initial testing for Drone fleet with the image stitching and pattern recognition
Q4 - 2020	• ADS field trials with full integrated system including drone, RAN, iMEC, OPTUNS and EPC. • Implementation refinement according to the field trials. • 5G NSA integration Part 2 (iMEC + EPC + simulated eNB/gNB and CPE • ADS field trial in 4G environment (iMEC + EPC + eNB + CPE + Applications + Drone) • Initial testing for Drone fleet with image stitching and pattern recognition over 5G network •
Q1 - 2021	• Collision avoidance system and iMEC integration with fog05. • Initial implementation of 2D aerial image stitching application on top of OPTUNS. • iMEC integration with fog05 • Continue ttesting for Drone fleet with image stitching and pattern recognition over 5G network
Q2 - 2021	• Full 5G NSA integration (iMEC + EPC + eNB/gNB + CPE) • Implementation refinement (i.e., algorithm update, collision avoidance parameter optimization) of drone-to-drone collision avoidance system. • 5G NSA integration Part 2 (iMEC + EPC + simulated eNB/gNB and CPE • ADS field trial in 4G environment (iMEC + EPC + eNB + CPE + Applications + Drone) • Application integration with iMEC and drone control application • Field trial testing
Q3 - 2021	• ADS field trials with full integrated system including drone, RAN, iMEC, OPTUNS and EPC • ADS field trial in 5G NSA environment (iMEC + EPC + eNB/gNB + CPE + Applications + Drone) • Field trial testing

4.8. Trial site risks and measurements of risk mitigation

There are several risks and measures regarding the deployment of the ADS vertical pilot as follows:

4.8.1. Risk of Thermal Overheating in OPTUNS

One of the risks common in running a datacentre is thermal overheating. Due to the heat dissipated by the servers in OPTUNS, maintaining thermal conditions is necessary to ensure peak operation. To mitigate that, OPTUNS employs the use of Chilled Water System, Cold Aisle/Hot Aisle Design, and Air Conditioner system for cooling.

4.8.2. Risk of Inter-Server Disconnection in OPTUNS

There are some risks associated with the connection between servers in a datacentre. One of them is the disconnection between servers. Although the disconnection issue is uncommon, we have taken some precautions when designing OPTUNS to mitigate for that. First, OPTUNS employs the use of high reliability optical components for its optical switching. Secondly, OPTUNS provides additional fault tolerance through the use of dual fibre rings in its optical switch and automatic failover module for redundancy.

4.8.3. Risk of Drone Interference

Drone-to-Drone communication of Drone Collision Avoidance is using WiFi, the interference with the WiFi signal at the trial site should be measured and coordinated. In general, The WiFi communication between drones are Line-of-Sight, and the signal strength becomes better when drones are closer. In case we face the WiFi interference risk, we can select different operation frequency of WiFi or install WiFi signal booster for all drones.

4.8.4. Risk of Unfulfilled Connectivity Requirements

In the case when the 5G connectivity requirements elicited in Section 4.3 are not be fulfilled in the trial site, a software re-tuning of the antenna beams may be carried out. Alternatively, the operational altitude range of the drones will be redefined to match the minimum bandwidth and latency requirements.

4.8.5. Risk of Delayed Project Funding

For AsKey team, the funding has been granted yet has not been received until the moment (the time of the document writing). Even so, Askey team including Askey Computer and its drone partner have strived their best efforts to move the project progress forward without much delay to the scheduled milestones. Consequently, the lack of funding will impact the Askey's team initial schedule for the ADS trial site demonstrations.

4.9. Summary of ADS

The main focus of the work conducted in ADS vertical pilot is to determine the technical requirements, software and hardware components associated with the two use cases namely: (1) drone fleet navigation and the (2) intelligent image processing for drones. Also, this section elaborated on the proposed in-lab validation and the relationship with the project objectives. In addition, the expected integration and validation timeline as well as the end-to-end validation plan are presented. Finally, and equally important, this section presented the available testbeds and laid out a solid foundation for the assessment and evaluation of the technology being developed within 5G-DIVE.

5. Conclusions

This deliverable has presented a detailed view of the different trial sites provided by the partners of the project. We have elaborated a list with the main technologies required for all use cases in the vertical pilots, and it is used to summarize all components available in each trial site. This deliverable presents initial planning of the trials. This includes trial site description, an overall overview of trial site use cases, the trial site requirements in order to support use cases, the needed hardware components, the in-lab validation strategy, and the relationship with 5G-DIVE project objectives, the integration and validation timeline. Also, it addresses the potential risk associated with the vertical site during the execution of 5G-DIVE project for ADS and I4.0 vertical pilots. Finally, a summary of ADS and I4.0 vertical pilots are provided.

For vertical pilots, it is important to highlight that many of the required technologies and services will be developed during the lifetime of the project. Also, ADS and I4.0 verticals have multiple requirements inputs and several risks to consider in real-time implementation at the trial site. This will play important validation factor in guaranteeing the target functionalities for ADS and I4.0. In addition, one important result of this deliverable is the initial proposal to deploy the integrated components using 4G connectivity in trial sites. Then, 5G connectivity will be utilized base to demonstrate 5G-DIVE DEEP and showcasing the intelligence in the targeted vertical pilot.

We have detected some risks such as funding issues and the risk of the Covid-19 crisis, these risk could delay the trial site experiments and validations in the labs of partners. We anticipate that the timeline of the project will be delayed especially for the partners who have shutdown conditions.

In the next deliverables, we will report on the pre-commercial proof of concepts, the related experimentation and evaluation activities, of the validation campaign performed in partner's laboratories and the trial site as well.

6. References

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7. Appendix

7.1. Software components of Industry 4.0 and ADS trial site

7.1.1. Eclipse Fog05

Eclipse Fog05 is a decentralised IaaS solution for provisioning and managing compute, storage, and communication and I/O resources available anywhere across the network. Eclipse fog05 functional blocks are depicted in Figure 7-1.

- FIM (Fog Infrastructure Manager) provides a unified abstraction over the decentralised Fog infrastructure. Such abstraction allows via a common set of APIs to monitor and discover each resource in the Fog environment as well as provide primitives for the deployment and lifecycle management of the application components (FDUs).
- FOrcE (Fog Orchestration Engine) is the component providing resource orchestration, interaction with existing OSS/BSS and manages the lifecycle of the applications in the Fog environment. It leverages the information provided by the FIM to keep track of the available resources and running application in the Fog environment.

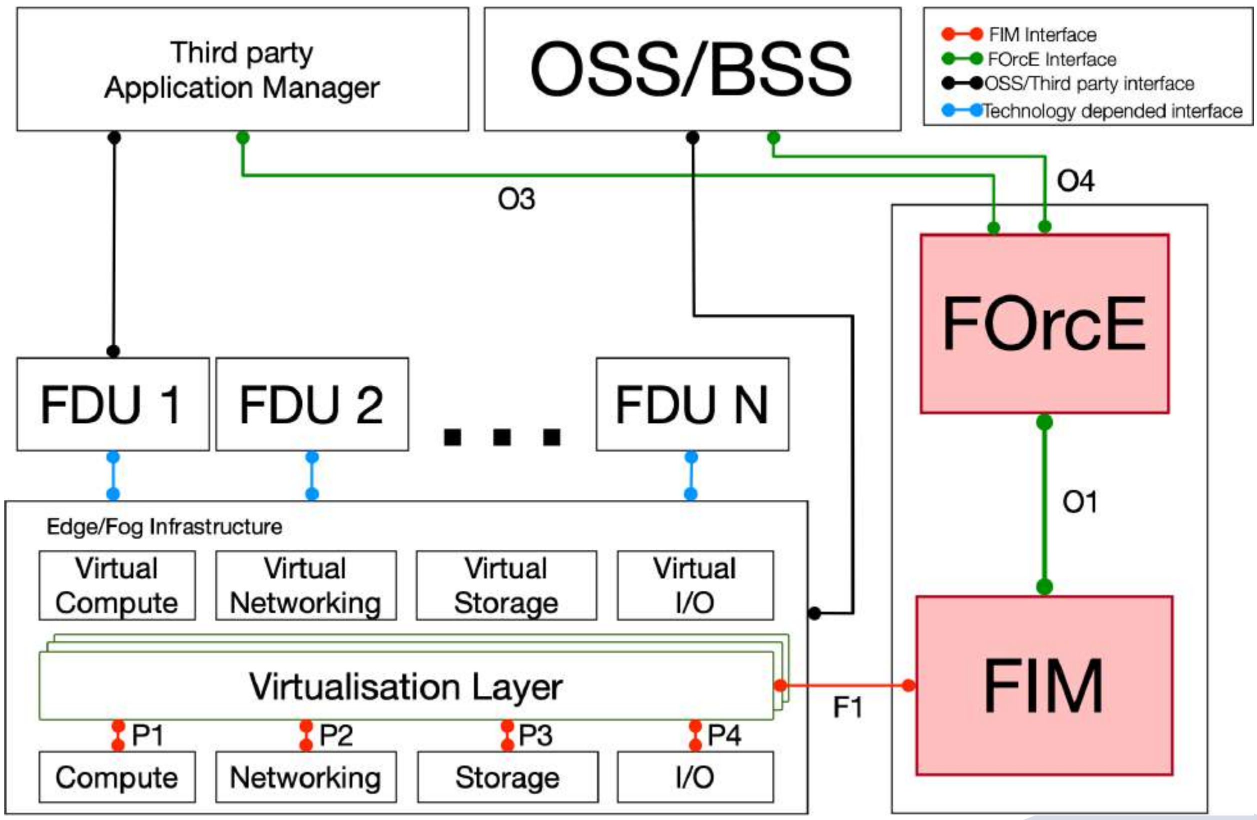

FIGURE 7-1: ECLIPSE FOG05 FUNCTIONAL DIAGRAM

7.1.2. Eclipse Zenoh

Eclipse Zenoh is a lightweight communication protocol with zero overhead pub/sub, store/query and compute capabilities. Eclipse zenoh unifies moving data, data in use, data at rest and calculations. It carefully mixes traditional pub / sub with geo-distributed storage, queries and calculations, while maintaining a level of efficiency in time and space that is far beyond any traditional stack. A functional diagram of zenoh showing how data can be publish to subscribers and storages, computed on demand and queried from storages and evals, is depicted in Figure 7-2.

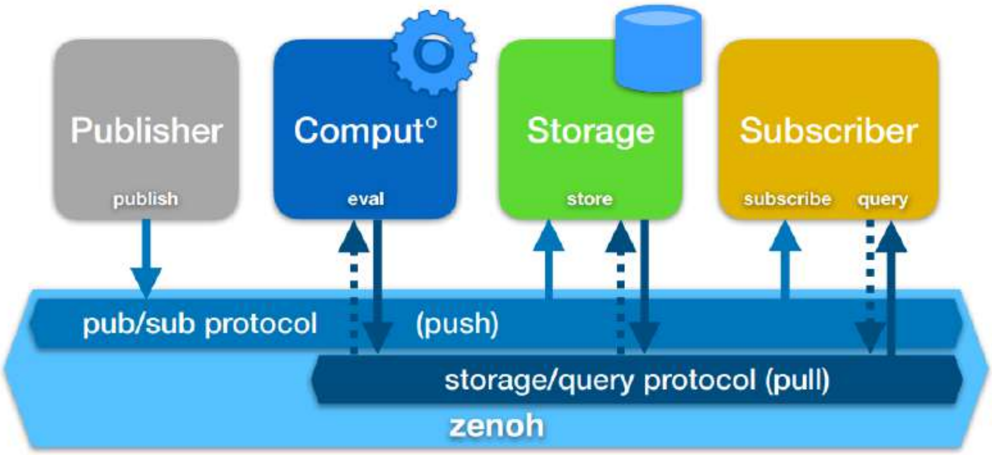

FIGURE 7-2: ECLIPSE ZENOH FUNCTIONAL DIAGRAM

7.1.3. OpenCV and YOLO

The I4.0 trial relies on an object detection algorithm in order to identify a malfunction in the conveyor belt and send an alert message to the robotic controller. In the following, we provide a brief description of the SW components necessary to execute the object detection.

OpenCV (Open Source Computer Vision Library) [7] is an open-source BSD-licensed library that includes several hundreds of computer vision algorithms. The OpenCV version used by the 5G-DIVE project is OpenCV 3.4.

The Deep Neural Network module used by the 5G-DIVE project is YOLO (You Only Look Once) [8] model. YOLO applies a single neural network to a full image. This network divides the image into regions and predicts bounding boxes and probabilities for each region. These bounding boxes are weighted by the predicted probabilities.

The data set that is used is COCO (Common Objects in Context) [9] http://cocodataset.org/ [Accessed 24 March 2020]

[10] dataset. The dataset is gathering images of complex everyday scenes containing common objects in their natural context. Objects are using per-instance segmentations to aid in precise object localization. The COCO dataset contains photos of 91 object types and total of 2.5 million of labelled instances of images.

YOLO and OpenCV are accelerated with Nvidia Jetson GPU that supports CUDA [11] programming framework. CUDA (Compute Unified Device Architecture) is a parallel computing platform and application programming interface (API) model created by Nvidia. The CUDA uses data parallel programming model that maps data elements to parallel processing threads which results gains in DNN and Image Processing. OpenCV and YOLO has implemented support for CUDA acceleration.

Figure 7-3 shows some of the current GPU applications and related embedded platforms. The Jetson AGX Xavier is the reference platform that will be employed for the object detection algorithm.

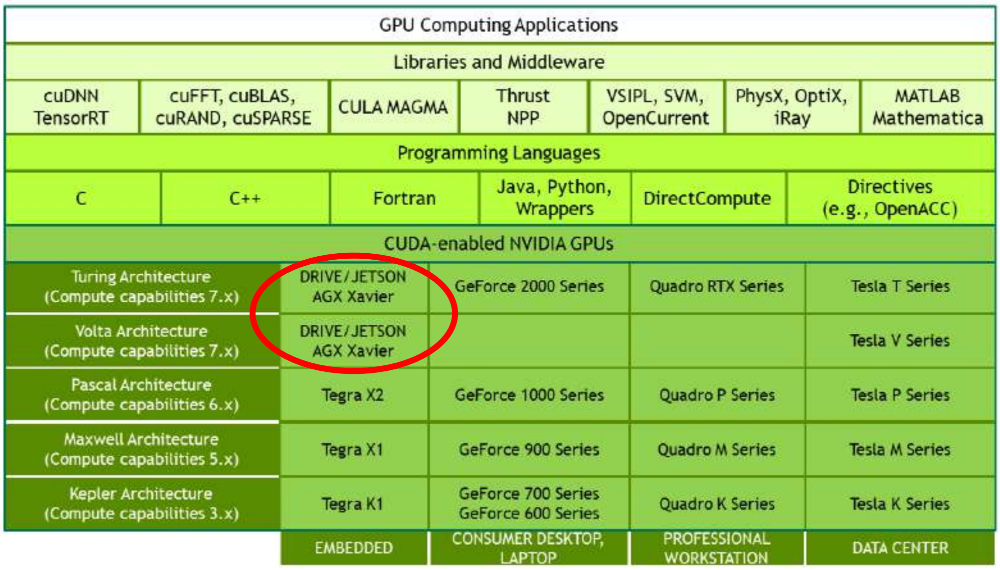

FIGURE 7-3: GPU COMPUTING APPLICATIONS. CUDA IS DESIGNED TO SUPPORT VARIOUS LANGUAGES AND APPLICATION PROGRAMMING INTERFACES

Figure 7-4 shows the SW pipeline employed to implement object detection. The video feed originated from the camera sensors is processed by using a specific OpenNI camera library, which is a dependency of OpenCV. Next, OpenCV is used to produce RGB-depth (RGBD) images, which are sent to the CUDA platform running the YOLO model. Finally, the object detection algorithm returns an output consisting of the detected object with a given probability of correct prediction.

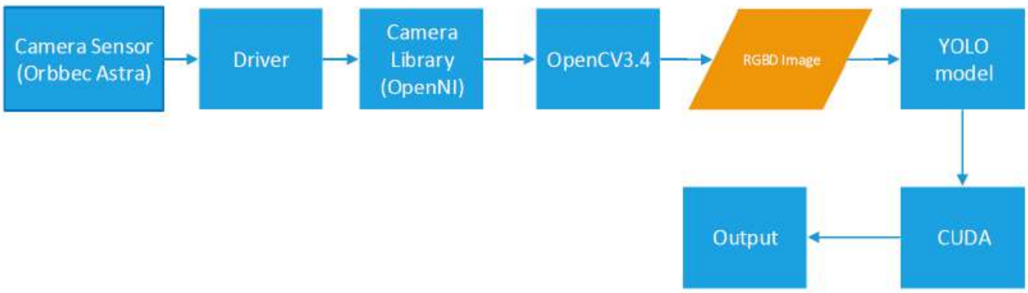

FIGURE 7-4: OBJECT DETECTION PIPELINE IN 5G-DIVE PROJECT

We also list SW libraries and components employed:

- OpenCV3.4 – open-source reference library containing hundreds of computer vision algorithms
- CUDA Toolkit 9.0 - development environment for creating high-performance GPU-accelerated application, including GPU-accelerated libraries, debugging and optimization tools, etc.

- OpenNI 2 – open-source framework for "natural interaction"
- CMAKE 3.16 - open-source, cross-platform family of tools designed to build, test and package software
- BOOST 1.72 - set of libraries for the C++ programming language that provides support for tasks and structures such as linear algebra, pseudorandom number generation, multithreading, image processing, etc.

7.1.4. Software Modules for the I4.0 Use Cases

In Table 7-1are listed the software modules used in the Industry 4.0 vertical trials

TABLE 7-1: INDUSTRY 4.0 TRIALS SOFTWARE COMPONENTS

SW Component	Description	Usage
ROS	Set of frameworks to develop robot applications	• Send commands from the Digital Twin GUI to the Robot arm • Receive feedback on the actual pose of the robot arm
Coppelia Sim	Robot simulation platform	• Create the Digital Twin application
Tensorflow	Opensource software library optimized to develop and train AI/ML models.	• Develop and train AI/ML algorithm for image/video recognition • Implement an Imitation Learning algorithm for the robot arm
OpenCV	Multi-platform software library for real-time computer vision.	• Used to access and use the video stream of a camera.
MQTT	Lightweight messaging protocol which uses the publish/subscribe pattern.	• Used as an EFS Service Platform to provide API to access services in a publish/subscribe fashion.
FOG05	Decentralized virtual infrastructure manager.	• As a decentralized VIM to manage and provide required resources to the EFS entities, functions and applications
F0rce	Orchestrator.	• Orchestrate EFS resources in an abstracted manner

7.1.5. Software Modules for the ADS Use Cases

In Table 7-2 are listed the software modules used in the ADS vertical trials

TABLE 7-2 ADS TRIALS SOFTWARE COMPONENTS

SW Component	Description	Usage
Drone Collision Avoidance	Installed on drones to co-operative sharing information in timely manner to detect and avoid collisions between drones (Automatic Mode)	• Used to detect collisions between drones during the flight. • Perform collision avoidance (e.g., stop or figure out a new way-point) when a potential collision is detected.

OpenCV	Multi-platform software library for real-time computer vision.	• Used to access and use the video stream of the drone camera. • Extract each frame and feed them into object detection algorithm
YOLOv3	Open Source library of an object detection algorithm based on convolutional neural network.	• As the core algorithm to develop and detect person in distress.
PyTorch	Python-based open source machine learning library based on the Torch library.	• Used by YOLOv3 to send the extracted frame information into the network and perform real-time object detection.
FFServer	Open source streaming server platform.	• Stream the results of object detection into a video with an HTTP/RTSP protocol.
Redis Database	In-memory key-value database with publish-subscribe feature.	• Store GPS information from the drone. • Store extracted video information from the drone. • Perform Publish and Subscribe information in within Real-time Pattern Recognition and Progressive Map Building applications.
Merged Object Detection	A python library to merge two bounding boxes generated by object detection algorithm.	• Create pairs of merged bounding boxes and draw the boxes into the respective image.
FOG05	Decentralized virtual infrastructure manager.	• As a decentralized VIM to manage and provide required resources to the EFS entities, functions and applications
F0rce	Orchestrator.	• Orchestrate EFS resources in an abstracted manner

7.1.6. Support letter from 5TONIC (ICT-17 hub) to 5G-DIVE

5TONIC

Leganés, January 10th, 2019

Ref.: Support of the ICT-23-2019 project proposal eDge Intelligence for Vertical Experimentation

To whom it may concern:

I, the undersigned Ignacio Berberana, acting as TECHNICAL COORDINATOR of the 5TONIC Open 5G Lab, hereby confirm the compromise to make available the facilities of the 5TONIC site for the development of the technical activities of the 5eDge Intelligence for Vertical Experimentation project.

5TONIC Open 5G Lab is one the key platform hubs for the 5G EVE and 5G-VINNI ICT-17 platforms. If the eDge Intelligence for Vertical Experimentation project proposal is approved for funding by the EC, 5TONIC will provide access to the 5G infrastructure deployed to the project members under the conditions that will be agreed by both parties for the vertical trials the project is intended to support.

Yours sincerely,

I. Berbe—

Ignacio Berberana
Senior Research Engineer

5TONIC Open 5G Lab
IMDEA Networks Institute
Avda. del Mar Mediterráneo 22
28918 Leganés (Madrid) - SPAIN
phone: +34 91 481 6928
mobile: +34 649 398308
e-mail: ignacio.berberana@imdea.org