H2020 5G Dive Project
Grant No. 859881

D1.1: 5G-DIVE architecture and detailed analysis of vertical use cases

Abstract

This document presents the first results from WP1 including: i) Targeted use cases and their technical and non-technical requirements; and ii) Baseline architecture including functional blocks and reference interfaces for the 5G-DIVE solution design to follow.

Document properties

Document number	D1.1
Document title	5G-DIVE architecture and detailed analysis of vertical use cases
Document responsible	III
Document editor	Tzu Ya Wang
Editorial team	All WP1
Authors	Alberto Solano, Luis M. Contreras, Alain Mourad, Carlos Guimarães, Milan Groshev, Chenguang Lu, Saptarshi Hazra, Chao Zhang, Angel Segovia, Samer Talat, ChenHao Chiu, YuChing Hsu, Osamah Ibrahiem, Timothy William and Muhammad Febrian Ardiansyah
Target dissemination level	Public
Status of the document	Final
Version	3.0

Production properties

Reviewers	Alain Mourad, Carlos Guimarães, Antonio de la Oliva

Document history

Revision	Date	Issued by	Description
1.0	02/03/2020	Tzu Ya Wang	First draft for first review round
2.0	16/03/2020	Tzu Ya Wang	Second draft for second review round
3.0	30/03/2020	Tzu Ya Wang	Final version
4.0	30/04/2021	Tzu Ya Wang	Updated version

Disclaimer

This document has been produced in the context of the 5GDIVE Project. The research leading to these results has received funding from the European Community's H2020 Programme under grant agreement Nº H2020-859881.

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List of Acronyms

3GPP	3rd Generation Partnership Project
5GC	5G Core network
5G NR	5G New Radio
5G-PPP	5G Private Public Partnership
ADS	Autonomous Drone Scout
AI	Artificial Intelligence
BASS	Business Automation Support Stratum
CD	Computing Device
DASS	Data Analytics Support Stratum
DC	Data Centre
DEEP	5G-DIVE Elastic Edge Platform
DL	Downlink
DNS	Drone Navigation Server
DSS	Decision Support System
EFS	Edge and Fog computing System
eMBB	Enhanced Mobile Broadband
eNA	enhancements on Network data Analytics
GPS	Global Positioning System
HD	High Definition
I4.0	Industry 4.0
IaaS	Infrastructure as a Service
IESS	Intelligence Engine Support Stratum
IoT	Internet of Things
KPI	Key Performance Indicator
NFV	Network Functions Virtualization
MEC	Multi-access Edge Computing
ML	Machine Learning
MTC	Machine Type Communications
OCS	Orchestration and Control System
PaaS	Platform as a Service
PMB	Progressive Map Building
PID	Person In Distress
RAT	Radio Access Technology
RIC	RAN Intelligent Controller
SAC	Standards Advisory Committee
WP	Work Package
UL	Uplink
URLLC	Ultra Reliability Low Latency
VIM	Virtualization Infrastructure Manager
ZDM	Zero Defect Manufacturing

Executive Summary

This deliverable reports the work carried in 5G-DIVE Work Package (WP) 1“Architecture and detailed analysis of vertical use cases”, and presents the first results on the targeted use cases, analysis of the business, functional and technical requirements, as well as the baseline architecture.

The following highlights the key achievements in this deliverable:

- A comprehensive description of targeted use cases including three for Industry 4.0, namely i) digital twinning, ii) connected worker augmented zero defect manufacturing (ZDM) decision support system (DSS), and iii) massive machine-type communications (MTC); and two for autonomous drone scout, namely i) drones fleet navigation and ii) intelligent image processing for drones.
- An initial identification of system requirements for the design of 5G-DIVE solution, the 5G End-to-End trial sites for Industry 4.0 and Autonomous Drone Scout (ADS) use cases. These are focused on business, functional and technical requirements.
- A baseline architecture detailing the internal elements and interfaces of each building block of the 5G-DIVE Elastic Edge Platform (DEEP) and describing how to integrate with Edge Computing Infrastructure and how the targeted use cases can be implemented following the baseline architecture.

All the findings in this deliverable have already been input to the ongoing design by other WPs. Future work is anticipated to expand and refine these results filling gaps identified and based on feedback received from the other WPs.

1. Introduction

5G-DIVE project targets end-to-end 5G trials aimed at proving the technical and business values of 5G-DIVE solution in two vertical pilots, namely Industry 4.0 and Autonomous Drone Scout. The 5G-DIVE solution is built on two main pillars, namely i) E2E 5G connectivity including 5G New Radio, Cross-haul transport and 5G Core, and ii) distributed edge and fog computing integrating intelligence closely to the user. The second pillar extends on the solution developed in the H2020 EU-Taiwan Phase I 5G-CORAL project, by adding support for automation, analytics and artificial intelligence. The targeted intelligent 5G-DIVE solution aims at achieving optimized end-to-end performance for each of the targeted vertical applications.

With the aim to help design targeted 5G-DIVE solution, Work Package 1 (WP1) has invested its efforts since the project kick-off in October 2019 on two fronts: i) Identifying the targeted use cases and detailing their technical and non-technical requirements; and ii) Developing a baseline architecture including functional blocks and reference interfaces for the solution design to follow.

This first deliverable from WP1 is therefore structured in two main sections presented in the sequel, i.e. Section 3 and Section 4, presented in the sequel after the risk assessment of COVID-19 impacts to WP1 is presented in Section 2:

- Section 3 gives a detailed view of the specifics of each use case considered in 5G-DIVE vertical pilots including the use case’s objectives, conditions, actors, execution flow, business requirements, and technical requirements.
- Section 4 is devoted next to the baseline architecture detailing the functional blocks and reference points and interfaces that the 5G-DIVE design will follow the outlines the next steps.

The Annex section is added to provide two reference use cases defined in NGMN, which are related to 5G-DIVE use cases.

2. COVID-19 Outbreak Risk Assessment

Owing to growing impact of COVID-19 outbreak, in this section, we evaluate the possible impact of following tasks and deliverables execution situation in WP1.

Task 1.2 focuses on the design and validation of the 5G-DIVE platform for the specific vertical use cases based on the results of the field trials. However, the development work will be slower since some countries are adopting a work-from-home policy or some companies even closed their office premises. The remote work will cause a slower interaction among partners and not all of the required actions for developing the use case can be done remotely.

For the next deliverables, planned for M12, it will be harder to gather the site survey data, because of the restriction for accessing the buildings, labs and campus. The site survey is assumed to measure some scenario parameters which will be taken as inputs into the techno-economic analysis, so these restrictions particularly will slow down the progress of the planned site measurements and demonstrator implementations.

WP1 is in charge of the overall validation of the vertical industry use cases, gathering the different inputs from the remaining technical WPs and providing an overall assessment of their outcomes in terms of business, functional and technical KPIs. General travel restrictions make face-to-face meetings currently impossible, which might have a further negative impact on the general progress. Thus, the whole project will be affected and may get delayed by a few months due to the current developments regarding the Covid-19-pandemic.

3. Specification of Targeted Use Cases

This section gives a detailed specification of each of the use cases targeted in 5G-DIVE vertical pilots including the use case's objectives, conditions, actors, execution flow, business requirements, and technical requirements, as briefly defined below:

- **Use Case Overview:** Statements written in natural language together with diagrams of the services provided by the 5G-DIVE solution and its operational constraints.
- **Use Case Objectives:** Objectives motivate the purpose and goals the use case aims at fulfilling.
- **Use Case Conditions:** Conditions that need to be met before the use case may proceed.
- **Actors Involved:** Person, other systems or machine using the solution to achieve a goal.
- **Use Case Flow:** A sequence of steps that represents a single use case execution.
- **Business Requirements:** A business requirement is not something a solution must do. It is something that the business needs to do or have in order to stay in business. For example, a business requirement may be a) a process they must complete; b) a piece of data they need to use for that process; or c) a business rule that governs that process and that data.
- **Functional Requirements:** The description of the solution's functions, services and operational constraints. Defines what should be implemented. Statements of services the solution should provide, how the solution should react to certain inputs and how the solution should behave in certain situations. May also state what the solution shall not do.
- **Technical Requirements:** Constraints on the services or functions offered by the solution such as timing constraints, constraints on the development process, standards, etc. Technical requirements are technical issues that must be considered to successfully complete a solution design. These are aspects such as performance, reliability, and availability that the solution must meet.

3.1. Industry 4.0 Use Cases

Industry 4.0 delivers the future of the manufacturing industry by combining smart objects and digital systems capable of autonomously exchanging information, triggering actions and controlling each other independently. The goal is to create flexible and resource efficient production systems in manufacturing and to integrate industry, business, and internal processes through computer-based systems [1].

Three Industry 4.0 use cases are targeted in 5G-DIVE, namely i) digital twinning application and ii) connected worker augmented zero defect manufacturing decision support system, and iii) massive MTC scaled for monitoring and predicative maintenance. An initial schema of the 5G-DIVE solution supporting these two use cases is depicted in Figure 3-3-1. More details will be described in the following subsections for three use cases, respectively.

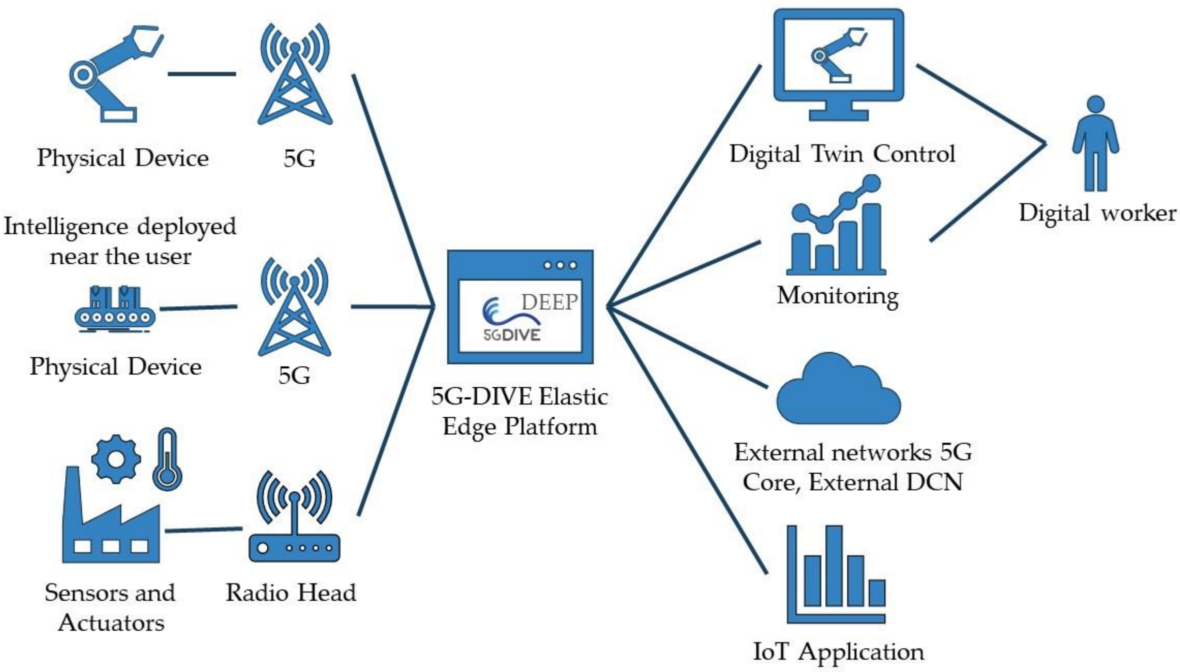

FIGURE 3-3-1: 5G-DIVE INDUSTRY 4.0 USE CASES.

3.1.1. Industry 4.0 Use Case #1 - Digital Twinning

3.1.1.1. Overview

Digital Twins are digital replicas of physical assets (see Figure 3-3-2), processes, and systems that also interact with the real system, where the digital replica reproduces 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.

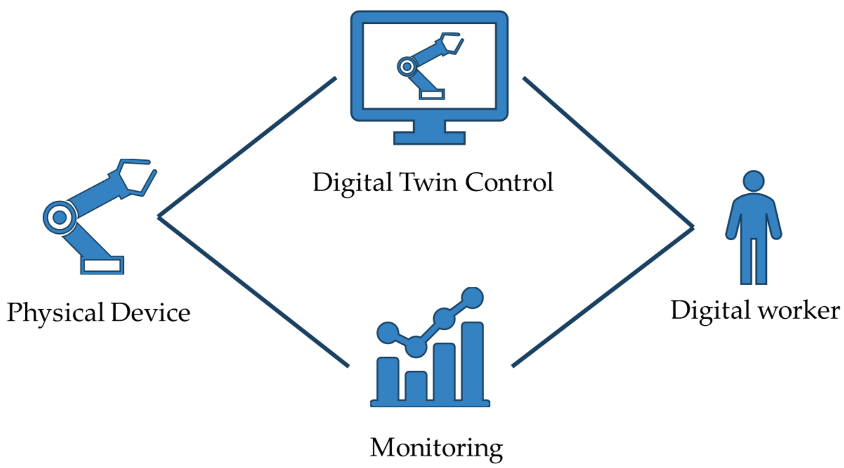

FIGURE 3-3-2: DIGITAL TWINNING USE CASE.

This use case will demonstrate End-to-End 5G performance for interconnecting a real robot to its digital twin, which will share the computing resources and the software with the real robot and will virtually replicate the same function. The robot will be controlled in real time, remotely by a virtual controller located either in a closer vicinity to remote worker or in the cloud or in a powerful dedicated resource. Also, if we want to target very low latencies, we may need to deploy things in the Edge. The robot will receive instructions about its position in a stepwise manner by the controller, while sensor data will be sent back to provide a real-time feedback to the remote controller. 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 a few milliseconds.

5G connectivity will guarantee the reliability and the low latency remote control and, at the same time, fully support the safety functions. In addition, the fixed connectivity with ultra-short delay will be provided between the Fog/Edge and Cloud, distributing the computational needs across the different tiers enabling a reduced reaction time of the digital twin.

Output

The digital twin use case will provide a virtual replica of a robot or of a part of a production line. The 5G network coverage will be deployed to enable real-time visibility and remote insights into robot status and performance without having to directly operate on the physical machine.

Benefit

Using a digital twin will facilitate, with respect to the real operating machines, assessing the concepts of remote control, monitoring for preventive maintenance, and safety that can be applied in a factory in large scale and with high density of devices.

3.1.1.2. Objectives

The objectives of this use case (I4.0-UC1) are listed below:

- To demonstrate 5G performance for interconnecting a real robot to its digital twin. For such a purpose, the digital twins, sharing the computing resources and the software, will virtually replicate the same function.
- To provide advanced network connectivity with low latency inside the Fog/Edge and Cloud, distributing the computational needs across the different tiers in order to reduce the reaction time of the digital twin.

- To monitor the operation of the physical robot in order to detect critical conditions and take adaptive measures to mitigate them.
- To mitigate latency variations in the remote control in order to correctly operate the physical device.
- To demonstrate automation capabilities for driving up the business value and reducing operational costs.

3.1.1.3. Conditions

The conditions for I4.0-UC1 are listed below:

- 5G radio must be available at the plant and must be able to collect data from many PLCs guaranteeing no perceived delay in the virtual representation.
- High bandwidth and low latency communications must be provided for the on-time delivery of the information of the sensors to the virtual twin and for the interaction with the digital model.
- Computing resources must be located both on premises and externally at the Fog/Edge for the correct operation of the use case.

3.1.1.4. Actors Involved

The actors involved in the I4.0-UC1 use case are identified below:

- **Plant Manager:** Person who uses monitoring application for updates about the status of each machinery in the production line, in case of problems, he/she may arrange maintenance activities in order to prevent stops. Plant Manager is the person who mainly uses this application to be updated about the current, past and future status of plant production lines and carry out actions to keep production rate optimised.
- **Digital Worker:** The operator who checks if his/her production is in line with the programmed one and participate in warding off bottlenecks or failure due to plant manager decisions.
- **Expert:** The expert is the person in charge of performing the calibration and configuration of the physical device.

3.1.1.5. Execution Flow

In the following, we present different execution flows using the abovementioned actors.

Flow 1 - Configure and calibrate Digitals Twins

1. The Digital worker will request the remote connection between digital replica and physical assets. The worker will easily plug the systems and configure the Digitals Twins.
2. The digital worker will choose the SLAs for the service.
3. The expert configures the machine and charges the measuring program prepared and simulated offline.

4. The physical assets perform an end-to-end 5G connectivity in accordance with the SLAs and will respond with a success message or connection failure message.
5. If it fails, a new connection must be requested.
6. If successful, the digital worker will request a test for adjustments. To perform the test, the digital worker will request predefined actions on the digital replica to be performed by the physical robot.
7. These movements will be captured by the sensors and verified by the digital worker. The two cameras show the movement to the worker as it happens.
8. If it fails, the faults found in this calibration process will be reported for adjustments. The IT department intervention may be required if it fails again.
9. If successful, the sensors will send a message to the Digital Controller and the digital twins will be ready to work. The Digital worker now can use the Digital Twin.

Flow 2 – Perform Action Replica with Twins Robots

1. The digital worker will request actions to be performed in real time on the twin robot through the controller. Real Robot will be controlled remotely by a virtual controller located on a Fog/Edge device or a virtual machine.
2. The robot will receive instructions about its position in a stepwise manner by the controller and will perform the exact requested actions in real time.
3. The robot may require changes in topology to perform the designated action and keep the SLAs. For this, an orchestrator monitors the behaviour performance that will predictively perform elasticity on slices, if necessary.
4. While performing the actions, sensors capture and report data about these actions, which are sent to the controller and datacentre. The actions generate sensitive information that will be processed locally and enhanced with context data to take action in real time, if necessary.
5. This data is processed by an AI tool to enhance the orchestration and control functions such as federation, orchestration, and enforcement of SLAs.

Flow 3 - Control Loop and Dashboard

1. The monitoring / telemetry app constantly monitors the real robot deployed on the production field and provides their status to the plant manager/digital worker through a dashboard. Sensors capture and report data about the robot which are sent to the controller and datacenter.
2. The actions generate sensitive information that will be processed locally and enhanced with context data to act in real time, if necessary. Control instructions and information from sensors will be used to update the virtual model in real-time. Meanwhile, sensor data will be sent back to provide real-time feedback to the remote controller.
3. The Controller will analyse the received data and turn it into information. Control instructions and information from sensors will update the virtual model in real-time. The tool collects data from the field as cycle time values and in case of deviations it performs calculations to predict if there will be bottlenecks or line stops. The Controller, through an AI tool, will evaluate and

suggest changes to be made. This data is processed by an AI tool to enhance the orchestration and control functions such as federation, orchestration, and enforcement of SLAs.

4. The virtual model will be used to highlight critical conditions inferred by sensors data and to provide alarms and preventive maintenance information to humans. The plant manager/digital worker uses the dashboard to monitor actual production and statistical data about historical data. Plant manager has access to a suggestion tool which can show some actions to avoid the problems detected. The digital workers and plant managers may request the execution of the suggested changes or define other actions from the obtained data.
5. The plant manager can monitor the effects of his decisions, they can monitor data coming from the field after the re-arrangement.

Flow 4 - Respond to Critical Behavior Detected

1. The sensitive information will be processed locally and enhanced with context data to act in real time, if necessary.
2. The Controller, through an AI tool, will evaluate and suggest changes to be made. This data is processed by an AI tool to enhance the orchestration and control functions such as federation, orchestration, and enforcement of SLAs.
3. In case of unexpected problems, the plant manager can change maintenance schedule in order to prevent machinery faults. The IT department must keep updated and maintained all the virtual machine in order to guarantee high availability and reliability.
4. In case that critical or dangerous situations are detected, the remote control will stop in real time the operations for safety reasons. 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 to few milliseconds.
5. In case of problems in a production plant where there is no maintenance operator, it is possible to call the right technician to drive step by step the maintenance task.
6. A message should be sent to digital worker and plant manager advising the actions taken and the reasons.

3.1.1.6. Business Requirements

Table 3-1 presents the business requirements for I4.0-UC1. These are performance improvements as desired by the business operator of the use case.

TABLE 3-1: BUSINESS REQUIREMENTS I4.0-UC1.

BR - ID	Description
BR-I4.0-UC1-01	Reduce technicians' travels by 30% by allowing them to remotely control the physical robot
BR-I4.0-UC1-02	Reduce failure rate at least of 20% with objective 90%
BR-I4.0-UC1-03	Improve service response time by 30%

3.1.1.7. Functional Requirements

Table 3-2 summarizes the functional requirements needed to meet the aforementioned business requirements.

TABLE 3-2: FUNCTIONAL REQUIREMENTS I4.0-UC1.

FR - ID	Description
FR-I4.0-UC1-01	Leverage AI to automate procedures, enable predictions and provide recommended actions accordingly
FR-I4.0-UC1-02	Provide E2E 5G connectivity inside the plant and to the outside public network
FR-I4.0-UC1-03	Guarantee information updates with unnoticeable delay
FR-I4.0-UC1-04	Support remote control protocols using wireless as an alternative to cable today

3.1.1.8. Technical Requirements

Table 3-3 gives the technical requirements in the form of target performance values to be met for the use case to operate seamlessly.

TABLE 3-3: TECHNICAL REQUIREMENTS I4.0-UC1.

TR - ID	Description	Value
TR-I4.0-UC1-01	Reference Availability [Table 7-1]	99.9999%
TR-I4.0-UC1-02	Reference Reliability [Table 7-1]	99.999%
TR-I4.0-UC1-03	Reference E2E Latency [Table 7-1]	20ms
TR-I4.0-UC1-04	Remote control bandwidth per instance (DL)	100Kbps
TR-I4.0-UC1-05	Video bandwidth per instance (UL)	5Mbps
TR-I4.0-UC1-06	Reference Connection density [Table 7-1]	<1000 device per Km^2
TR-I4.0-UC1-07	Reference Coverage [Table 7-1]	Local using one cell, no handover

3.1.2. Industry 4.0 Use Case #2 - Connected Worker Augmented Zero Defect Manufacturing for Decision Support System

3.1.2.1. Overview

This use case will investigate the capability of 5G including Fog/Edge to support real time analysis of HD/4K video of goods on a production line in order to detect possible defects. The set of equipment use in I4.0-UC2 is composed of a production line and a video camera that is used to monitor the production line. The video camera is continuously analysing the pieces in the production line and by using some algorithms deployed in the Fog/Edge devices. This is illustrated in Figure 3-3-3.

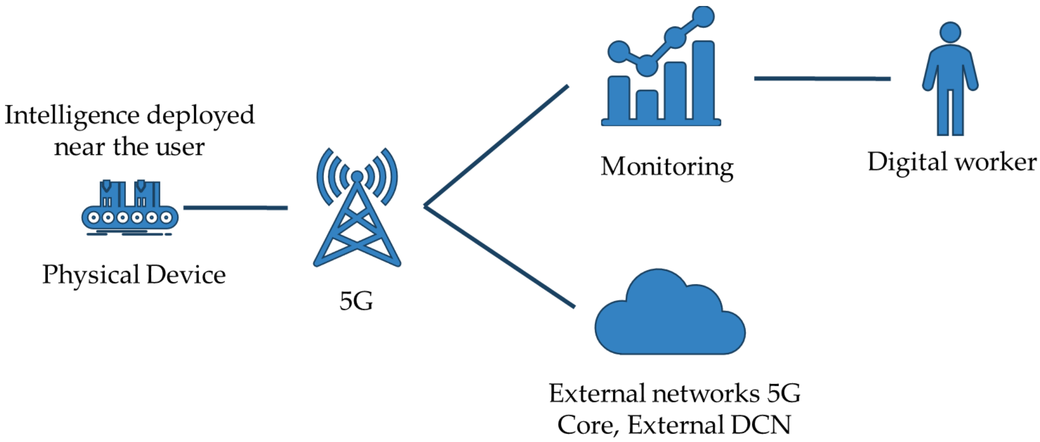

FIGURE 3-3-3: ZDM USE CASE.

Thanks to those devices and the intelligence deployed on them it is possible to detect characteristic patterns that allow the recognition of defects in the production line. In this sense, if a piece is detected as good, no action will be taken. However, when a piece is detected as defective, new mechanisms are triggered in order to take the piece out of the production line. This is achieved by using AI-based pattern/object recognition of the video feed. It can be said that the sooner a piece is detected as defective there is less scrap associated. The analysis of the video stream in the Fog/Edge will make cameras with pattern recognition simpler and cheaper. Due to the number of cameras and the bandwidth required by the videos, 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. Due to this reason, the information processing in Edge datacentres becomes mandatory for the operation of this use case.

5G connectivity arises as the solution able to provide the reliability and the low latency operation required by the previously described production line. In addition, a fast analysis of the video stream in the Edge and not in the device will require high bandwidth, low latency and high reliability enabled only by 5G, which will impact the number of piece analysis. The faster pieces are analysed, the more pieces can be produced in the same time.

Output

This use case will explore the capabilities of 5G connectivity extended with Fog/Edge to address the performance needs including real-time processing and visualization of geometric features for manufactured parts.

Benefit

The use of ZDM techniques may potentially reduce scrap by 100%, and predict form and/or welding errors, which will potentially increase the productivity of factories and quality of the goods.

3.1.2.2. Objectives

The objectives for this I4.0-UC2 use case are outlined below:

- To demonstrate 5G performance for delivering high-bandwidth traffic coming from the camera towards a monitoring application able to identify defective pieces.
- To demonstrate 5G and Edge capability to deliver low latency required to reduce reaction between the identification of the defective piece and its removal of the production line.
- To highlight critical conditions inferred by the camera data and provide alarms and preventive maintenance information.
- To provide plant managers with actual information about the status of the production lines, predicting future failures or bottlenecks, giving the opportunity to move up actions and prevent problems thanks to the monitoring process.

3.1.2.3. Conditions

The conditions for this I4.0-UC2 use case are listed below:

- 5G must be available at the plant facilities and must be able to interconnect all the different hardware in the production line (e.g., cameras, conveyor belt, removal tool, etc).
- High bandwidth and low latency communications must be provided for the on-time delivery of the information of the video camera to the monitoring application and, afterwards, its interaction with the removal tool.
- The video camera equipment shall be present in the conveyor belt installation in order to feed the monitoring platform with real time data.

3.1.2.4. Actors Involved

The actors involved in the execution of this I4.0-UC2 use case are listed hereafter:

- **Digital worker:** the operator who checks if his/her production is in line with the programmed one and participates in warding off bottlenecks or failure due to plant manager decisions.
- **Plant Manager:** the person who uses an application for updates about the current, past and future status of plant production lines and carries out actions to keep production rate optimised.
- **Maintenance operator:** the operator who adjusts and/or operates the equipment at the premises when there are malfunctioning situations with the aim of retrieving the normal flow of operation as soon as possible.

3.1.2.5. Execution Flows

Flow 1 - Configure and calibrate Video Cameras

1. The Digital worker will request the video camera connection to the command centre. The worker will easily plug the systems and configure the cameras.
2. The digital worker will choose the SLAs for the service.
3. The physical assets perform an End-to-End 5G connectivity in accordance with the SLAs and will respond with a success message or connection failure message.
4. If it fails, a new connection must be requested.

Flow 2 - Control Loop

1. The monitoring application constantly monitors the performance capabilities for supporting real time analysis of HD/4K video of goods being produced on a line, in order to detect possible defects.
2. The cameras collect different pieces of information about production that will be processed locally and enhanced with context data to act in real time, if necessary. But it also collects information about the operation of the application to monitor and control the performance of devices. Control instructions and information from cameras will be used to update the control model in real-time.
3. The AI algorithm uses this information to detect characteristic patterns for defects in the production, this is deployed in the Fog devices to a fast data analysis. Problems detected on the production line are reported and / or addressed in real time by an AI tool.

Problems about device performance will be addressed as follows:

1. The tool collects data from the field as cycle time values and in case of deviations performs calculations to predict if there will be bottlenecks or line stops.
2. The Controller, through an AI tool, will evaluate and suggest changes to be made. This data is processed by an AI tool to enhance the orchestration and control functions such as federation, orchestration, and enforcement of SLAs.

Flow 3 - Respond to Critical Behavior Detected

1. During monitoring, some behaviors can be observed. These will be processed locally and considered critical.
2. The sensitive information will be processed locally and enhanced with context data to act in real time, if necessary.
3. The Controller, through an AI, will evaluate and suggest changes to be made. This data is processed by an AI tool to enhance the orchestration and control functions such as federation, orchestration, and enforcement of SLAs.
4. In case of unexpected problems, the plant manager may change maintenance schedule in order to prevent machinery faults. The IT department keeps updated and maintained all the virtual machine in order to guarantee high availability and reliability.
5. In case that critical or dangerous situations are detected, the remote control will stop in real time the operations for safety reasons. In industrial applications, the overall end-to-end latency budget is spent for the processing time of the data received by sensors, the remaining part of the latency budget limits communication to few milliseconds.
6. In case of problems in a production plant where there is no maintenance operator it is possible to call the right technician to drive step by step the maintenance task.
7. A message should be sent to digital worker and plant manager advising the action taken and the reason.

Flow 4 - Augmented Zero Defect Manufacturing (ZDM) Decision Support System (DSS)

1. The monitoring application has an algorithm able to detect characteristic patterns for defects in the production. Data is collected in real time for this analysis. The sensitive information will be processed locally and enhanced with context data to act in real time, if necessary.
2. The algorithm uses this information to detect characteristic patterns for defects in the production, this is deployed in the Fog devices to a fast data analysis. Problems detected on the production line are reported and / or addressed in real time by an AI tool. This algorithm is responsible for centralizing the information received by various cameras. This requires 5G high bandwidth for the interaction with the platform for reinforced learning and 5G low latency for processing of results in the Fog devices.
3. Defective pieces are automatically removed from the production line.
4. When a problem is detected, some video cameras start broadcasting real-time video images (supporting real time analysis of HD/4K) start to be transmitted to control model.
5. The control model will be used to highlight critical conditions inferred by sensors data and to provide alarms and preventive maintenance information to humans. The plant manager / digital worker uses the dashboard to monitor actual production and statistical data about historical data. Plant manager has access to a suggestion tool which can show some actions to avoid the problems detected. The digital workers and plant managers may request the execution of the suggested changes or define other actions from the obtained data. The plant manager can monitor the effects of his decisions, they can monitor data coming from the field after the re-arrangement.
6. In case of unexpected problems, the plant manager may change maintenance schedule in order to prevent machinery faults. The IT department keeps updated and maintained all the virtual machine in order to guarantee high availability and reliability.
7. In case that critical or dangerous situations are detected, the remote control will stop in real time the operations for safety reasons. In industrial applications, the overall end-to-end latency budget is spent for the processing time of the data received by sensors, the remaining part of the latency budget limits communication to few milliseconds.
8. A message should be sent to digital worker and plant manager advising the action taken and the reason.

3.1.2.6. Business Requirements

Table 3-4 presents the business requirements for I4.0-UC2. These are performance improvements as desired by the business operator of the use case.

TABLE 3-4: BUSINESS REQUIREMENTS I4.0-UC2.

BR - ID	Description
BR-I4.0-UC2-01	Reduce cost of production by 10%
BR-I4.0-UC2-02	Increase the production throughput by 15% by improving the detection rate of defective pieces in production
BR-I4.0-UC2-03	Reduce customer visits by 40% by reducing the number of trips of the customer to the factory for quality assurance of the produced goods

BR-I4.0-UC2-04	Reduce scrap of at least 10% with an objective of achieving 0 scrap
BR-I4.0-UC2-05	Detect up to 30% of form and/or welding errors so anticipative measures may be deployed to mitigate these errors

3.1.2.7. Functional Requirements

Table 3-5 summarizes the functional requirements needed to meet the aforementioned business requirements.

TABLE 3-5: FUNCTIONAL REQUIREMENTS I4.0-UC2.

FR - ID	Description
FR-I4.0-UC2-01	Leverage AI to automate procedures, enable prediction and provide recommended actions accordingly
FR-I4.0-UC2-02	BASS will be able to scale up and down the system in order to guarantee SLAs
FR-I4.0-UC2-03	Provide E2E 5G connectivity inside the plant facilities and outside to the public network
FR-I4.0-UC2-04	Guarantee the delivery of information from the cameras to the monitoring application with minimal delay
FR-I4.0-UC2-05	Support remote control protocols using wireless as an alternative to cable today

3.1.2.8. Technical Requirements

Table 3-6 gives the technical requirements in the form of target performance values to be met for the use case to operate seamlessly.

TABLE 3-6: TECHNICAL REQUIREMENTS I4.0-UC2.

TR - ID	Description	Value
TR-I4.0-UC2-01	Availability [Table 7-2]	99.9999%
TR-I4.0-UC2-02	Expected Reliability [Table 7-2]	99.9999%
TR-I4.0-UC2-03	Reference E2E Latency [Table 7-2]	10ms
TR-I4.0-UC2-04	Remote control bandwidth per instance (DL)	100Kbps
TR-I4.0-UC2-05	Video bandwidth per instance (UL)	5Mbps (per camera)
TR-I4.0-UC2-06	Reference Connection density [Table 7-2]	<1000 device per Km^2
TR-I4.0-UC2-07	Reference Coverage [Table 7-2]	Local using one cell, no handover

3.1.3. Industry 4.0 Use Case #3 – Massive Machine-Type Communications

In this section, the 3rd I4.0 use case in 5G-DIVE is presented. Unlike the other 2 use cases where the focuses are on eMBB and URLLC types of applications, this use case focuses on the IoT applications based on massive machine-type communications (MTC), e.g. NB-IoT, CAT-M, LoRa, IEEE 802.15.4 etc., which is also a key pillar of the success of I4.0 for digitalized IoT factories, e.g. for process and assets monitoring and predicative maintenance.

3.1.3.1. Overview

Massive machine-type communications (MTC) enables connectivity for a massive number of small low-power low-cost sensor nodes. These aggregations of data from these sensor nodes provide insights into the industrial workflows and plant operations enabling closed-loop control. In the context of Industry 4.0, one example is process and asset monitoring [2] in the context of industrial production, which facilitates predicative maintenance with the monitored data available. Process monitoring connect critical industrial machinery with sensor nodes and actuators for providing insights into the current industrial workflows. These insights and analytics will be used for predictive maintenance using closed loop control. The current working environment inside a plant will be monitored through environmental monitoring which enables maintaining a productive work environment for the plant workers and preventing dangerous situations like fire hazards.

Traditionally in massive MTC network design, IoT stacks are implemented in HW ASIC chipsets in IoT gateways or base stations, which are deployed in the field. The amount of baseband resources (in HW) required equals to the number of gateways deployed. The total baseband resources don't scale with the actual traffic, which follows an over-dimensioning principle. When traffic is low, the resources are wasted. Further, the baseband capability and capacity are limited by the chipset capability, which is hard to upgrade once it is deployed. When more and more IoT devices are deployed, those gateways deployed need to be HW upgraded and replaced by new gateways with newer generation of HW with higher processing power to support more capacity and new features. Such an approach is not scalable and future proof to support ever-increasing number of IoT devices.

In this use case, the scalability and future proof are addressed by implement Cloud RAN for IoT. Instead of a fully functional gateway, a split architecture following Cloud RAN is adopted. The full gateway function is split into two part: radio heads and virtualized SW gateway at the Edge or Cloud, as illustrated in Figure 3-3-4. The radio heads perform mainly the radio functions and minor digital functions, while most baseband functions are implemented in the virtualized SW gateway. This use case will provide connectivity to dense deployments of IoT nodes across multiple IoT radio access technologies. As radio heads become simpler with minimum baseband functions, it can be designed to be more future proof, e.g. supporting more IoT carriers and bands. In this way, the lifetime of radio heads would be much longer than the traditional gateway. The virtualize SW gateway are deployed in a Cloud environment which could help achieve web-scale scalability and availability with orchestration features, like load balancing and auto-scaling. This would also provide resource pooling gain achieving better resource utilization scaling with IoT traffic load, along with flexibility. Automation will be also enabled, e.g. for automated life cycle management, to reduce the operational costs.

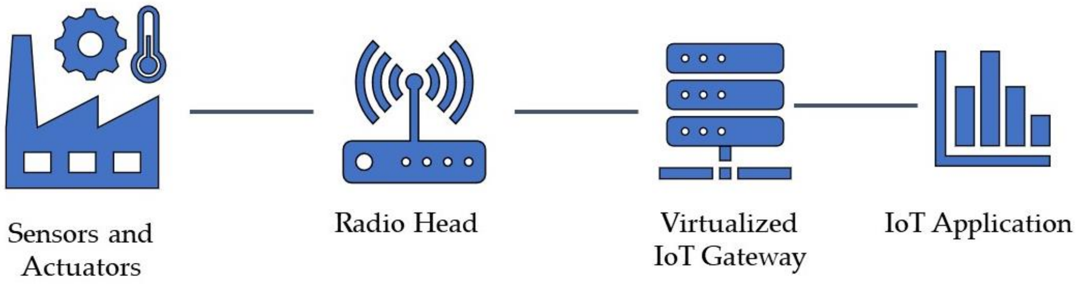

FIGURE 3-3-4: MASSIVE MTC USE CASE

Furthermore, the incorporation of softwarized approaches and integration of multiple radio access technologies allows us to enable AI/ML based intelligent services which address coordination across different RATs and security challenges for the massive number of IoT devices. Service-based data pipelines collect, store and organize the data gathered from the sensor nodes through the connectivity services. The IoT application accesses the data pipelines through well-defined procedures for visualizations and generating insights into the current industrial workflows and plant operations through data analytics. The data analytics can trigger actuation routines on certain pre-configured conditions through the connectivity services provided by the IoT gateway for closed-loop control e.g. actuation routines for predictive maintenance in the infrastructure monitoring case and maintaining productive working environment in the plant.

Output

The massive MTC will provide connectivity for dense heterogeneous (multiple RATs) deployments of IoT sensor nodes using intelligent and scalable connectivity services located at the edge of the network. The use case will also provide data pipelines supporting service-based architecture for the IoT sensor data including data visualization and data retrieval procedures.

Benefit

Our massive MTC use case focus on process and asset monitoring, e.g. infrastructure monitoring and environmental monitoring

Infrastructure monitoring: we connect the already available machinery with sensor nodes and collect data. This data can be used for gaining insights into the runtime operations of the industrial workflows and how they align with the business goals. Also, the health of the machinery can be tracked, which will allow us to do predictive maintenance if needed reducing downtime of these machineries.

Environmental monitoring: using environmental monitoring (e.g. temperature, humidity, noise etc.), we ensure the safety and security of the plant. The data from these can be useful in increasing the productivity of the workers with proper closed-loop control. These data can help in preventing dangerous situations in the plant like fire hazards saving critical industrial machinery, human cost and downtime.

3.1.3.2. Objectives

The objectives for this I4.0-UC3 use case are outlined below:

- To demonstrate connectivity performance of virtualized IoT gateways for supporting dense deployments of IoT sensors.
- To demonstrate the orchestration and automation features of the IoT connectivity services.
- To demonstrate the intelligence features of the virtualized IoT gateways
- To demonstrate a service-based data pipeline architecture for providing sensor data about the status of plant and workflows.

3.1.3.3. Conditions

The conditions for this I4.0-UC3 use case are listed below:

- Fixed or wireless network infrastructure are available to provide network connectivity between radio heads and virtualized IoT gateways at the Edge or in Cloud.
- Network bandwidth and latency fulfils the requirement of specific RATs used.
- Adequate computing, network and storage resources are available in the Edge and Cloud infrastructure for hosting virtualized IoT gateways and applications.
- Large number of wireless sensors and/or actuators with different RATs are deployed at the factory premises.
- Radio heads are deployed to provide coverage of the factory premises where wireless sensors and/or actuators are deployed.

3.1.3.4. Business requirements

Table 3-7 presents the business requirements for I4.0-UC3. These are performance improvements as desired by the business operator of the use case.

TABLE 3-7: BUSINESS REQUIREMENTS I4.0-UC3

BR - ID	Description
BR-I4.0-UC3-01	Reduce IoT network deployment cost by 25%
BR-I4.0-UC3-02	Reduce IoT network operational cost by 20%
BR-I4.0-UC3-03	Reduce mean time between failures by 50%

3.1.3.5. Functional requirements

Table 3-8 summarizes the functional requirements needed to meet the aforementioned business requirements.

TABLE 3-8: FUNCTIONAL REQUIREMENTS I4.0-UC3

FR – ID	Description
FR-I4.0-UC3-01	Orchestration with automated life cycle management
FR-I4.0-UC3-02	Orchestration with load balancing and auto-scaling
FR-I4.0-UC3-03	Virtualized IoT RAN supporting multiple RATs

FR-I4.0-UC3-04	Orchestration optimization with ML/AI

3.1.3.6. Technical requirements

TABLE 3-9 gives the technical requirements in the form of target performance values to be met for the use case to operate seamlessly.

TABLE 3-9: TECHNICAL REQUIREMENTS I4.0-UC2.

TR - ID	Description	Value
TR-I4.0-UC3-01	Application layer end-to-end latency	<10 s for cellular IoT (5G requirement) [3], < a few 100s ms for non-cellular IoT.
TR-I4.0-UC3-02	Air interface bit rate	a few 10s bps – a few100s kbps for cellular IoT [3], a few 100s kbps to 2 Mbps for non-cellular IoT.
TR-I4.0-UC3-03	Connection density	Up to 1 million devices/km2 for cellular IoT (5G requirement) [3].
TR-I4.0-UC3-04	Coverage	164 dB maximum coupling loss at a rate of 160 bps for cellular IoT (5G requirement) [3], 10-100 meters for non-cellular IoT.
TR-I4.0-UC3-05	Availability	99.99% [2]
TR-I4.0-UC3-06	Link reliability	High (exact value TBD, massive MTC requires lower reliability than eMBB and URLLC)

3.2. Autonomous Drone Scout Use Cases

In several recent reports [4], [5], [6], it is stated that commercial drones will deliver products and perform surveillance, disaster relief, and other duties. Indeed, drones have suffered an incredible transformation and increase of capabilities in recent years. Drone scouting has been used in the aftermath of many types of disasters such as the Tohoku earthquake, Tsunami and the Haiti earthquake in 2012. Obviously, Drones can be very useful for collecting sensor information or images to help in rescue operations. In addition, drone operation is characterized by the low-cost operation, safe access to dangerous areas and rapid, flexible, scalable deployments.

In 5G-DIVE, the focus is on a scenario where a Public Safety agency, such as the firefighter department, commissions a drone to scout a disaster area (see Figure 3-3-5). Fundamentally, the autonomous drones are utilized for efficient data collection and efficient transmission over 5G communication networks.

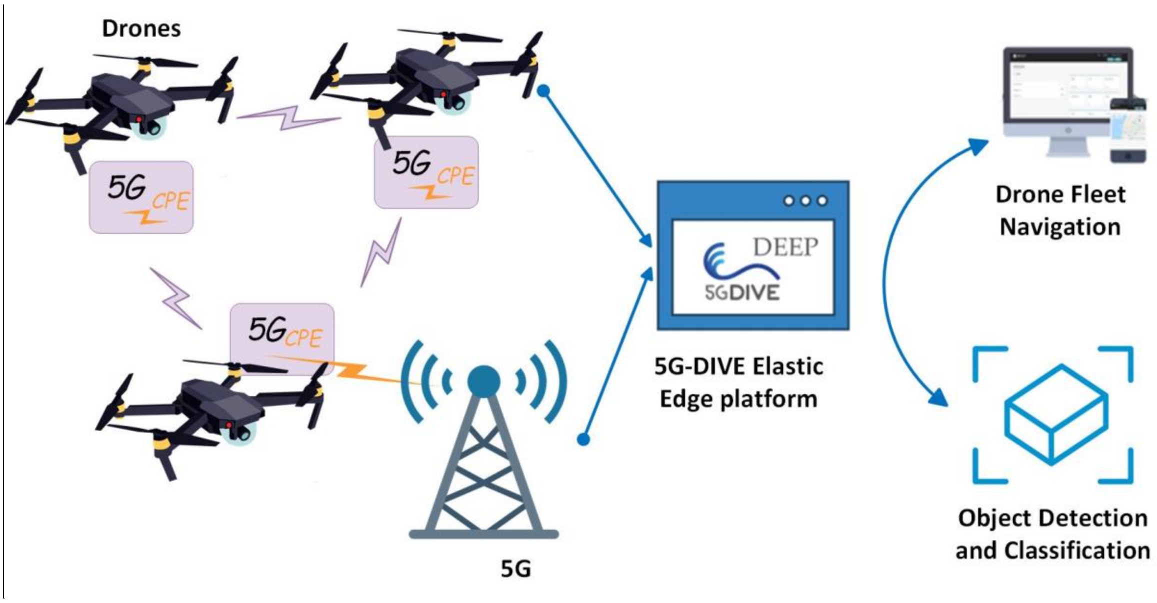

FIGURE 3-3-5: AUTONOMOUS DRONE SCOUT.

The collected data is then transmitted to the edge of the network for cognitive processing and decision making. Furthermore, the fleet control will be managed via drone fleet navigation software on the edge. Together, the communication and the computing capabilities of the platform facilitate the necessary means for low-cost and efficient rescue efforts. Besides, the facilitated drone navigation leverages drone-to-drone communication for drone's collision avoidance.

This scenario will be used to evaluate two use cases, namely i) Drones Fleet Navigation, and ii) Intelligent Image Processing for Drones. These are detailed in the sequel.

3.2.1. Autonomous Drone Scout Use Case #1 – Drones Fleet Navigation

3.2.1.1. Overview

Traditionally, drones are navigated through a set of GPS coordinates which are pre-loaded into the drone navigation software. This scheme, known as Way-point navigation, does not allow autonomous modification to the flight path.

To this end, Autonomous Drone Scout Use Case 1 (ADS-UC1) aims at enhancing the current navigation system to enable local and remote data processing as well as dynamic change to flight trajectory for the drone fleet. To accomplish this, a coordination mechanism among drones in the drone fleet is required. Each drone in the fleet captures and transmits image and GPS data to the edge datacenter through 5G. Next, edge applications process the received data in real-time to automate the fleet navigation.

With this use case, coordination mechanisms (centralized in regular flight mode or distributed if the collision avoidance system detects any collision possibility) among drones in the drone fleet will be required. Besides, the drone-to-drone direct link and Drone fleet relay will be developed and will be used to maintain the synchronization among various drones to cover more space and avoid any collision.

Output

ADS-UC1 will improve the state-of-the-art drone product portfolio through providing enhanced drone fleet coordination and piloting. Specifically, the coordination and the navigation of the drone fleet will be entirely autonomous through two main key technologies, 5G network and edge computing.

Benefit

Drone fleet navigation enhanced capabilities will enable new drone-based services such as drone delivery, drone inspection and monitoring, drone scouting, drone aerial imaging and large-scale precision agriculture.

3.2.1.2. Objectives

The objectives of the ADS-UC1 use case are summarized below:

- To demonstrate the performance of 5G system integrating intelligent edge in connecting and navigating a fleet of drones seamlessly. The collected data from drones is transmitted over 5G for processing at the edge.
- To provide low latency inter-server connectivity at the edge (e.g. using OPTUNS technology) for near real-time data processing and drones fleet navigation.
- To monitor drones flight status in order to detect and avoid collisions during rescue missions through intelligent drone-to-drone collaboration.
- To demonstrate the benefits of automation and scalability for drone fleet navigation.

3.2.1.3. Conditions

The conditions for ADS-UC1 use case are listed below:

- High bandwidth is required for on-time delivery of the information (sensing, imaging, and control) among drones and between drones and the edge.
- The weather condition shall satisfy the minimum requirement for safe drone piloting. This includes wind speed for drone handling and clear visibility.
- The edge computing resources shall always be available to ensure seamless operation and scalability.

3.2.1.4. Actors Involved

The actors involved in the execution of ADS-UC1 are listed below:

- **Mission Manager:** ground drone operator who continuously monitors the flight state of each deployed drone via a dashboard and remotely intervene with drone operations only when manual control is required.
- **Rescue Team:** personnel that may interact with the disaster site for emergency relief.

- **Aerial System Expert:** person who is responsible for configuring and calibrating the drones.

3.2.1.5. Execution Flows

Flow 1 - Drone fleet for disaster relief assisting ground rescuing mission control

1. The mission manager provides the plan for the rescue mission and monitors the status of each drone from a dashboard at ground control centre.
2. The aerial system expert configures and calibrates each drone in the fleet to perform the planned rescue mission.
3. Each drone in the fleet captures and transmits image and GPS data to the edge data centre (DC) over 5G.
4. The image and GPS data are processed in real-time using cognitive edge applications to detect emergency situation.
5. Based on the detected situation, an edge navigation application makes dynamic trajectory changes for each drone.
6. The rescue team utilizes the intelligence provided by the edge to promptly respond to the distress.

The drone navigation is facilitated by drone-to-drone communication for collision avoidance.

3.2.1.6. Business Requirements

Table 3-10 presents the business requirements for ADS-UC1. These are performance improvements as desired by the business operator of the use case.

TABLE 3-10: BUSINESS REQUIREMENTS ADS-UC1.

BR - ID	Description
BR-ADS-UC1-01	Reduce the data collection time by at least 50%
BR-ADS-UC1-02	Reduce the time of the staff hours by at least 50% to 90%
BR-ADS-UC1-03	Increase at 3X- 5X productivity
BR-ADS-UC1-04	Increase safety at 55% by using drones to inspect dangerous areas
BR-ADS-UC1-05	Decrease the time for the detection of risks to humans by 50%

3.2.1.7. Functional Requirements

Table 3-11 summarizes the functional requirements needed to meet the above business requirements.

TABLE 3-11: FUNCTIONAL REQUIREMENTS ADS-UC1.

FR - ID	Description
FR-ADS-UC1-01	High bandwidth and low latency through 5G are required for on-time delivery of the information (i.e. sensory data such as images, GPS location, etc) to the edge.
FR-ADS-UC1-02	High availability of the Drone connection including redundant connection to guarantee the communication in case of failure and Drone collision avoidance.

FR-ADS-UC1-03	Support programmability and virtualization (Native application if not possible) to enable flexible and dynamic reconfiguration
FR-ADS-UC1-04	Support flexible deployment options of the core network (remote, local)
FR-ADS-UC1-05	Support different levels of accuracy of image recognition of Drone to cater for the different factors of distance, height, and all environmental conditions.
FR-ADS-UC1-06	Support two-way communications between drones (Drone-to-Drone)

3.2.1.8. Technical Requirements

Table 3-12 gives the technical requirements in the form of target performance values to be met for the use case to operate seamlessly.

TABLE 3-12: TECHNICAL REQUIREMENTS ADS-UC1.

TR - ID	Description	Value
TR-ADS-UC1-01	Uplink data rate (Drone to Network)	50 Mbps
TR-ADS-UC1-02	Downlink data rate (Network Drone)	150 Mbps
TR-ADS-UC1-03	Uplink Latency (Drone to Network)	100ms
TR-ADS-UC1-04	Downlink latency (Network to Drone)	20ms
TR-ADS-UC1-05	Positioning accuracy	10m
TR-ADS-UC1-06	Altitude	15m to 100m
TR-ADS-UC1-07	UE speed	0 to 10m/s
TR-ADS-UC1-08	Number of UEs	3 to 5
TR-ADS-UC1-09	Image quality	1080p
TR-ADS-UC1-10	Service reliability	99.99%
TR-ADS-UC1-11	GPS 3D fix accuracy (see annex **¡Error! No se encuentra el origen de la referencia.** for details)	1.5m
TR-ADS-UC1-12	RTK float GPS (see annex **¡Error! No se encuentra el origen de la referencia.** for details)	<0.4m

3.2.2. Autonomous Drone Scout Use Case #2 - Intelligent Image Processing for Drones

3.2.2.1. Overview

5G-DIVE aims at integrating drone fleet as volatile moving resources in the platform. As such, drones will be able to benefit from data analytics and intelligence tools. The Autonomous Drone Scout Use Case 2 (ADS-UC2) aims to enable two potential applications, namely image processing and pattern recognition for drones. In particular, images from drones are processed in real-time edge applications for emergency detection and response. The result of the image processing and cognitive techniques is utilized to autonomously update the trajectory for each drone.

The ADS-UC2 relies on a joint operation of the resources deployed on the drone and in the ground fog, edge and cloud. Depending on the latency and computing requirements, the respective resource tier will be used to execute the designed algorithms to achieve the targeted result.

Output

This use case will enable the deployment of intelligent functions in the edge data center and its cooperation with other computing tiers in the fog, cloud and on the drone.

Benefit

This use case will open the door to more automation in the scouting processes, creating a new value chain of services which can be used to provide more services to the customers.

3.2.2.2. Objectives

The objectives of ADS-UC2 are the same as ADS-UC1 presented in section 3.2.1.2:

In addition, ADS-UC2 has the following objectives:

- To provide low latency inter-server connectivity at the edge (e.g. using OPTUNS technology) for intelligent image processing.
- To adjust drone trajectory based on the detected hazards
- To provide 2D-image stitching capabilities in order to provide more information to the relief team.

3.2.2.3. Conditions

The conditions for ADS-UC2 are the same as ADS-UC1 presented in section 3.2.1.3.

3.2.2.4. Actors Involved

The actors for ADS-UC2 are the same as ADS-UC1 presented in section 3.2.1.4.

3.2.2.5. Execution Flows

Flow 1 - Detection of Person in Distress (PID)

1. The mission manager provides the plan for the rescue mission and monitors the status of each drone from a dashboard at ground control centre.
2. The aerial system expert configures and calibrates each drone in the fleet to perform the planned rescue mission.
3. The drones transmit real-time aerial video stream and GPS data to the edge DC over 5G.
4. At the edge, the video stream is sliced into frames before being processed and the GPS data is registered.
5. The object detection and classification model process the video frames in parallel with multiple worker nodes.

6. The output of the detection and classification model are labelled image frames and GPS coordinates of persons in distress.
7. The rescue team utilizes this intelligence to promptly respond to the emergency situation.

Flow 2 - Autonomous Change of Drone Trajectory

1. All steps 1-2-3 from flow 1.
2. When an emergency situation is detected, GPS location will be provided to the drone navigation server via an API
3. The navigation server uses the GPS location to calculate waypoints and autonomously update each drone trajectory.

Flow 3 - Drone Collision Avoidance

1. To support collision avoidance between drones, each drone continuously broadcasts drone status, e.g., GPS location, during a drone mission.
2. Each drone analyzes the recorded information to detect possible collisions on the horizontal plane and vertical plane.
3. If a possible collision is detected, Drone Collision Avoidance will temporarily take control of the drone. The drones related to the collision will try to calculate possible solutions, e.g., calculate a new way point, or hover the drone.
4. After the collision risk is eliminated, the Drone Collision Avoidance program would release the control of the drone back to Drone Navigation Server (DNS).

Flow 4 - Drone Video Streaming Breakout

1. Applications, including A) Pattern recognition, B) Image stitching, C) Drone controller, and D) Image Storage are deployed at the Edge, together with 5G Core for local breakout.
2. Real-time aerial video stream is streamed from a drone via 5G to the Core hosted at the Edge.
3. The Core at the Edge will route the packets to Application A, Pattern recognition, according to the local breakout rules.
4. Part of the output of Application A will be the input of Application B, Image stitching.
5. The output of Application B will be the input of Application D, Image Storage, which will store images.
6. Part of the output of Application A will be the input of Application C, Drone controller.
7. Application C will send control signal to drones from the Edge through 5G.

Flow 5 - Progressive Map Building (PMB) of Disaster Site

1. Real-time aerial video stream is streamed to the edge over 5G.
2. At the edge, the video frames will be chopped into frames before being passed to the object detection and classification model. The chopped image frames will be passed into a Progressive Map Building (PMB) pipeline for stitching. Here, the stitching result will be outputted via a web API to show the real-time progress of the map building.

3.2.2.6. Business Requirements

The business requirements for ADS-UC2 are the same as for ADS-UC1 in Table 3-10.

3.2.2.7. Functional Requirements

The functional requirements for ADS-UC2 are the same as for ADS-UC1 in Table 3-11.

3.2.2.8. Technical Requirements

The technical requirements for ADS-UC2 are the same as for ADS-UC1 in Table 3-12.

4. Baseline Architecture

This section focuses on the baseline 5G-DIVE architecture, highlighting the internal elements of each building block of the 5G-DIVE Elastic Edge Platform (DEEP) and its internal and external interfaces. Furthermore, it describes the integration of DEEP with the Edge Computing Infrastructure from the phase 1 H2020 5G-PPP EU/TW joint action 5G-CORAL project [7], for each of the targeted use cases.

4.1. Architecture Overview

5G-DIVE functional architecture aims at providing a set of supporting strata to the verticals in order to support enhanced business automation and ease the provisioning of intelligence capabilities into the vertical services. 5G-DIVE solution is positioned on top of Edge Computing Infrastructures, allowing the shift from an Infrastructure-as-a-Service (IaaS) service model towards an end-to-end Platform-as-a-Service (PaaS) service model. Such approach allows customers to develop, run, and manage applications and services without the complexity of building and maintaining the infrastructure typically associated with the delivery of the application. This is particularly relevant given the heterogeneous and distributed nature of e.g. edge and fog environment, which can be perceived as a barrier for the adoption of the edge and fog paradigm by the vertical industries. It is therefore of paramount importance for the proposed platform to provide the necessary tools for a streamlined and flexible management, thus concealing the underlying complexity.

5G-DIVE solution introduces a new building block called DIVE Elastic Edge Platform (DEEP), which goal is to support vertical industries in day-by-day operations, management, and automation of businesses processes. Figure 4-4-1 shows the concept of DEEP as an add-on on-top of existing Edge Computing Infrastructures while underpinning vertical industries OSS/BSS systems.

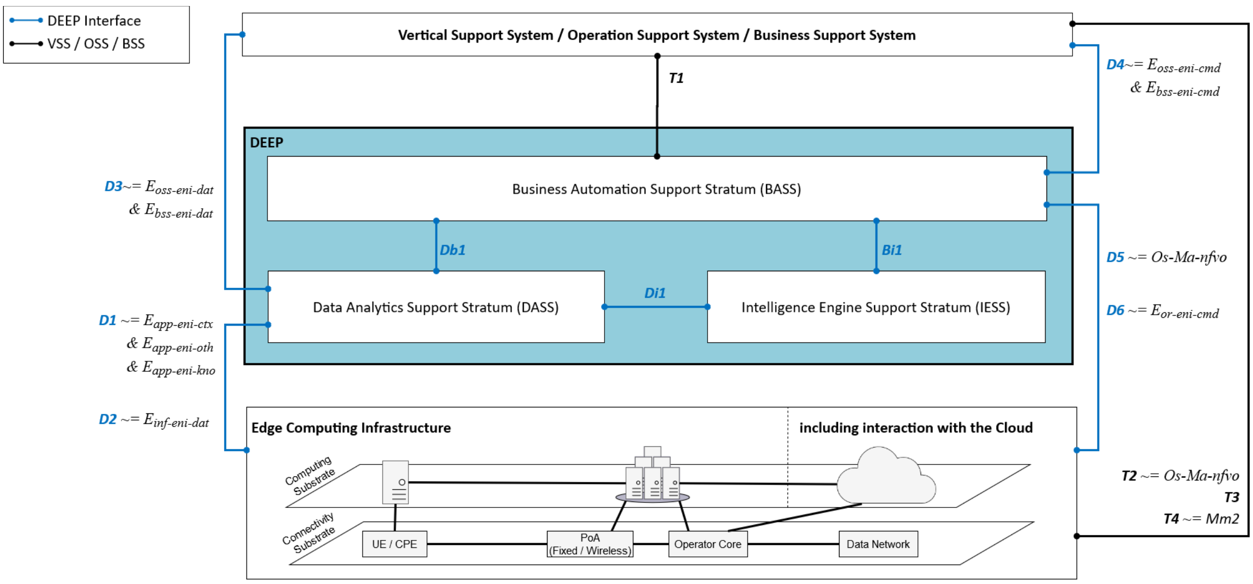

FIGURE 4-4-1: 5G-DIVE ELASTIC EDGE PLATFORM (DEEP).

DEEP is agnostic to the underlying Edge Computing Infrastructure, and hence flexible to be coupled with different edge solutions (e.g., 5G-CORAL, ETSI MEC, etc). In addition, as DEEP is envisioned as an add-on layer, vertical industries OSS/BSS systems may still interact directly with the underlying Edge Computing Infrastructures without going necessarily via DEEP.

Three strata are envisioned in DEEP to support the verticals in enhancing the operation and management of their business processes as follows:

- **Data Analytics Support Stratum (DASS):** this stratum offers the necessary support for pre-processing, storage and sharing of data generated from vertical services operation so they may be potentially enriched with a variegated set of context information, both from the local environment and the virtualization infrastructure. The locality offered by the edge infrastructure can be exploited to process and analyse sensitive data where they are generated, thus enabling strict privacy and low latency response for mission critical services.
- **Intelligence Engine Support Stratum (IESS):** this stratum offers the necessary support for an intelligence engine platform encompassing heterogeneous resources including terminal devices. This allows vertical industries to augment their vertical services with applications and operations assisted by AI techniques for dynamic and mobile environments. This includes machine learning for supporting complex systems and applications, events predictions, forecast demands, find patterns and anomalies in data as well as raise alerts if need be. The IESS is assumed not to require a direct interface to the edge infrastructure, rather where needed, it may rely on the DASS and/or BASS to interact with the edge infrastructure.
- **Business Automation Support Stratum (BASS):** this stratum offers the necessary support to the vertical industries to achieve automation of their business processes by allowing to plug their OSS/BSS systems into DEEP. It allows to verify that a set of end-to-end business processes work as intended by identifying anomalies early to minimize the business impact. Indeed, if there are problems in one or more applications that support a business process, or in the integration or configuration of those systems, then the consequences of disruption to the business may be serious. To this end, this stratum helps at ensuring that vertical business processes continue to work, even when mission critical services change.

4.2. DEEP Platform

The internal architecture of DEEP including its three supporting strata (DASS, IESS, and BASS) is depicted in Figure 4-4-2.

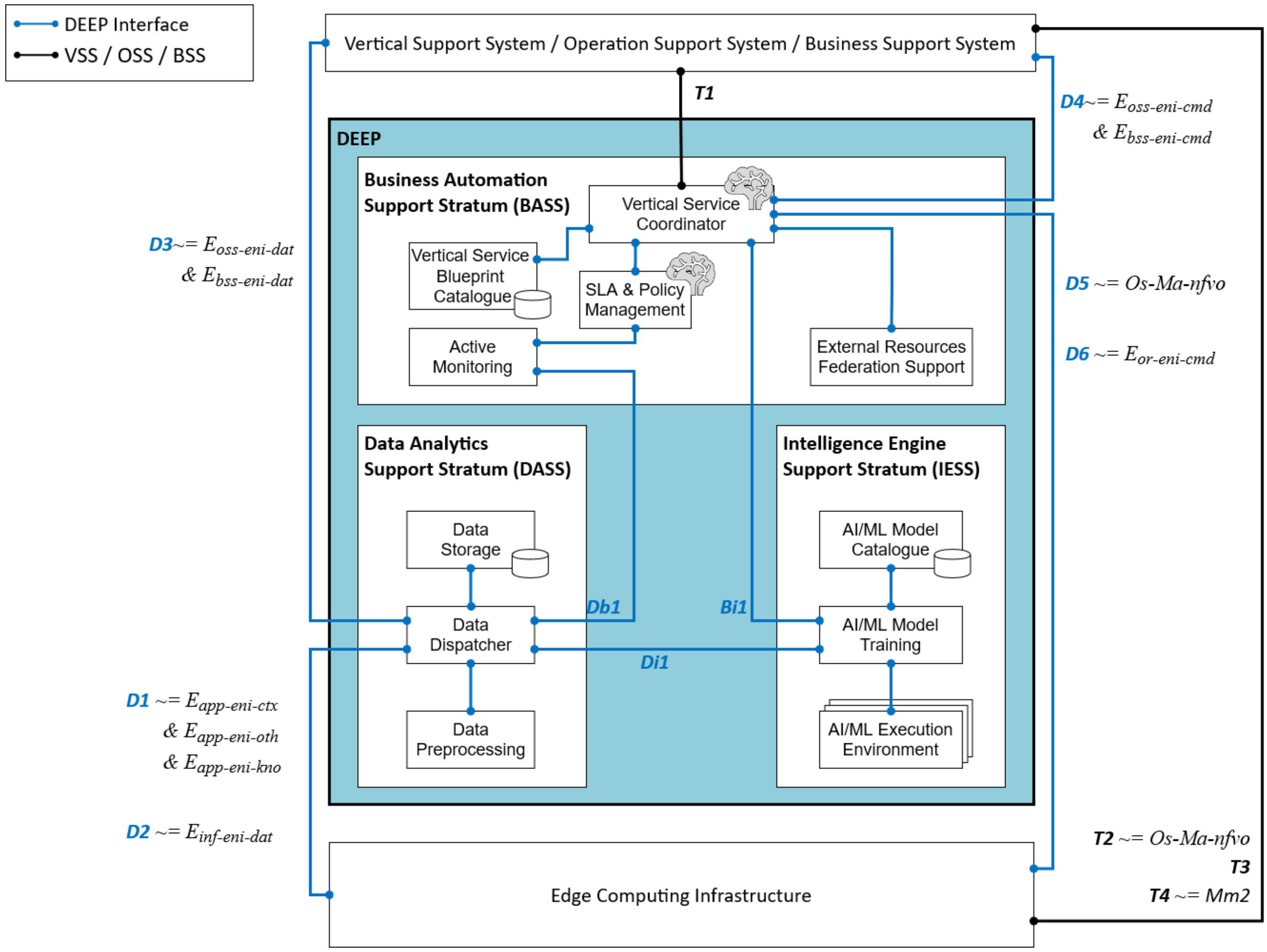

FIGURE 4-4-2: DEEP INTERNAL ARCHITECTURE.

4.2.1. Data Analytics Support Stratum (DASS)

DASS comprises three main functionalities:

- **Data Dispatcher:** the data dispatcher is responsible for gathering information from the different sources, including from both the OSS/BSS and the Edge Computing Infrastructure, and delivering the information to all the interested entities. This functionality is responsible for enforcing authorization mechanisms in order ensure that the data is sent only to the permitted recipients.
- **Data Pre-processing:** the data pre-processing comprises the different tasks required to transform raw data into a proper, understandable and common format. This transformation of the data is an essential step when the purpose of the data is to feed into AI/ML algorithms. As such, among others, this includes data cleaning, data filtering, data grouping, data normalization, data anonymization, data transformation and data compression.
- **Data Storage:** the data storage, as its name implies, is responsible to keep the collected information provided by the different sources, including from the vertical's OSS/BSS and the Edge Computing Infrastructure (both the information exposed by the VNFs that compose a

given vertical service and the virtualization infrastructure). The decision with respect to whether to store the data is up to the publisher of the information, which not only flags the information but, optionally, provides its lifespan too.

4.2.2. Intelligence Engine Support Stratum (IESS)

IESS comprises three main functionalities:

- **AI/ML Model Catalogue:** this functionality consists in a repository where AI/ML algorithm implementations and AI/ML trained models are stored. Regarding the former, it consists in a local or remote code repository mapped to the supported platform and to the applications that each algorithm is suitable to. Regarding the latter, it consists in a database or repository where the trained models are saved in a certain format (e.g., binary files, HDF5 [8], ONNX [9], YAML [10], etc) along with metadata characterizing the model (e.g., purpose, accuracy, loss, etc).
- **AI/ML Model Training:** this functionality comprises all the procedures required for training a given AI/ML application. It includes (i) the selection of the most appropriate or a set of AI/ML algorithms according to the intent-based automation purpose as well as the relevant features for training the selected intelligence; (ii) the AI/ML runtime environment including the required AI/ML platform (e.g., Keras [11], TensorFlow [12], etc) to train the selected model(s); and (iii) cross validation of the trained model to assess the accuracy of the trained model.
- **AI/ML Execution Environment:** this functionality comprises the runtime environment for the execution of an AI/ML application instance, depending on its purpose such as prediction, forecasting, classification, decision inference, among others.

4.2.3. Business Automation Support Stratum (BASS)

BASS comprises the following functionalities:

- **Vertical Service Coordinator:** this is the entry point for requests of new vertical services and it coordinates all the logic associated with their provisioning and their lifecycle management. As part of its responsibilities, the Vertical Service Coordinator is responsible for (i) translating the received vertical service blueprints into network service descriptors; (ii) requesting the deployment of the vertical service; and (iii) automating and managing the lifecycle of the vertical services ideally in an intelligent manner through the support of IESS.
- **Vertical Service Blueprint Catalogue:** this consists in a repository containing vertical services blueprints, which provides the vertical template with the service-specific parameters.
- **SLA & Policy Management:** this ensures that the SLAs and policies associated with a given vertical service are fulfilled and, in case of a violation, triggers an event towards the Vertical Service Coordinator. The operation of this functionality may be enhanced with intelligence and forecasting capabilities using IESS, so that violations of an SLA or policy are predicted and dealt with before they occur.

- **Active Monitoring:** this is responsible for identifying the relevant information to assess the performance associated with a given vertical service, as well as for actively retrieving the identified information from DASS.
- **External Resource Federation Support:** this is responsible for supporting and facilitating the alienation of external resources (e.g., resources owned by the vertical) that should have priority for the deployment of (or part of) the requested vertical service. The usage of these resources may have relevance when the vertical aims to reduce the cost of deployment for a given vertical service using its own computing infrastructure.

4.3. DEEP Interfaces

Table 4-1 gives an overview and description of DEEP internal and external interfaces illustrated in Figure 4-4-1 and their relevance to ETSI ENI and ETSI NFV reference points.

TABLE 4-1: DEEP INTERFACES.

ID	ETSI ENI /ETSI NFV ref. point	Description
D1	ETSI ENI: • $E_{app\text{-}eni\text{-}ctx}$ • $E_{app\text{-}eni\text{-}oth}$ • $E_{app\text{-}eni\text{-}kno}$	This interface is used for exchange between the VNFs of a given vertical service and DASS, and supports the following: • Sharing information exposed by each VNF • Defining the situation- and context-aware of the exposed information • Defining model and knowledge information with respect to the exposed information The actual information models exchanged through the relevant ETSI ENI reference points are not yet defined and, therefore, a comparison is planned in a future deliverable D1.3.
D2	ETSI ENI: • $E_{inf\text{-}eni\text{-}dat}$	This interface is used for exchange between the virtualization infrastructure and DASS, and supports the following: • Fetching (abstracted) monitoring information regarding the different resources comprising the virtualization infrastructure The actual information models exchanged through the relevant ETSI ENI reference points are not yet defined and, therefore, a comparison is planned in a future deliverable D1.3.
D3	ETSI ENI: • $E_{oss\text{-}eni\text{-}dat}$ • $E_{bss\text{-}eni\text{-}dat}$	This interface is used for exchange between VSS/OSS/BSS and DASS, and supports the following: • Sharing of context data related to the requested vertical services, which may be relevant for training AI/ML applications with the purpose of fulfilling the vertical service intent-based AI capabilities

		The actual information models exchanged through the relevant ETSI ENI reference points are not yet defined and, therefore, a comparison is planned in a future deliverable D1.3.
D4	ETSI ENI: • $E_{oss\text{-}eni\text{-}cmd}$ • $E_{bss\text{-}eni\text{-}cmd}$	This interface is used for exchange between BASS and VSS/OSS/BSS, and supports the following: • Provide notifications about SLAs and policy conflicts • Providing notifications regarding the automated decisions that were enforced by the BASS regarding the operation and management of a running vertical services • Providing notifications in case the BASS becomes unable to comply with the required actions and, therefore, requires assistance from the VSS/OSS/BSS The actual information models exchanged through the relevant ETSI ENI reference points are not yet defined and, therefore, a comparison is planned in a future deliverable D1.3.
D5	ETSI NFV: • Os-Ma-nfvo	This interface is used for exchange between BASS and Orchestrator, and supports the following: • Edge computing infrastructure Stack Descriptor and Stack lifecycle management, including Stack instantiation, update, scaling, migration, termination, and query (e.g., retrieving summarised information about edge and fog resources associated to the Edge stack instance); • Policy management and or enforcement for Edge stack instances, function and application instances, and edge and fog resources (e.g., authorisation, access control, resource reservation, placement, allocation, etc.); • Forwarding of events, accounting and usage records and performance measurement results regarding Edge stack instances, application and function instances, and edge/fog resources to OSS/BSS, as well as and information about the associations between those instances and edge/fog resources; • Integrating and releasing of resources into/from the target Edge including third-party information and SLAs. Compared to ETSI NFV environment, such interface also needs to support federation and privacy of multiple administrative domains coexisting in the same environment.
D6	ETSI ENI: • $E_{or\text{-}eni\text{-}cmd}$	This interface is used for exchange between BASS and Orchestrator, and supports the following: • Relaying all the information required for the establishment of an open federation with the provider of external resources. The actual information models exchanged through the relevant ETSI ENI reference points are not yet defined and, therefore, a comparison is planned in a future deliverable D1.3.

T1	Not Applicable	This interface is used for exchange between OSS/BSS and BASS, and supports the following: • Allowing the vertical to retrieve vertical services blueprints, to manage vertical service descriptors and to request operational actions on vertical service instances (i.e., instantiation, modification, termination and monitoring of instantiated vertical services). • Enable SLAs and policy management functionalities, such as transfer, delete, activate, deactivate, associate, disassociate policies.

4.4. Architecture Mapping to Existing Industry Frameworks

5G-DIVE concept and DEEP internal architecture was inspired from existing industry frameworks such as, ETSI ENI [13], 3GPP eNA [14], ITU-T ML5G [15] and O-RAN [16] which target the application of AI/ML procedures towards intelligent automation of communication networks. An initial mapping between DEEP functionalities and these industry frameworks and standards is presented in Table 4-2. This is not a one-to-one mapping but rather to highlight the overlap in scope of the functionalities defined in DEEP and similar ones defined in these standards.

TABLE 4-2: DEEP FUNCTIONAL BLOCK MAPPING TO EXISTING INDUSTRY FRAMEWORKS.

ETSI ENI	**DEEP Functionality**
Data ingestion and Data Normalization	Data Pre-processing @ DASS
Knowledge Management and Processing	AI/ML Execution Environment @ IESS / Vertical Service Coordinator @ DASS
Situation-based Policy Generation	AI/ML Execution Environment @ IESS / Vertical Service Coordinator @ DASS
De-normalization and Output Generation	Vertical Service Coordinator @ BASS
3GPP eNA	
NWDAF	The NWDAF is currently evolving from simple data collection to include more sophisticated analytics features. The mapping will be updated when it is clear which features are included.
NEF	Exposure of monitoring, provisioning, policy/charging and analytics reporting capabilities of 3GPP NFs to 5G-DIVE
ITU-T ML5G	
MLFO	AI/ML Model Training (Model selection) @ IESS
ML Sandbox	AI/ML Model Training (Training and Cross validation) @ IESS
ML Pipeline (Collector) ML Pipeline (Pre-processor) ML Pipeline (Model) ML Pipeline (Policy) ML Pipeline (Distributor)	Data Dispatcher @ DASS Data Pre-processing @ DASS AI/ML Execution Environment @ IESS SLA and Policy Management @ BASS Vertical Service Coordinator @ BASS
ML Marketplace	AI/ML Model Catalogue @ IESS

O-RAN	
RAN Intelligent Controller (RIC) non-Real Time (non-RT): • Service and policy management • RAN analytics • Model Training	SLA and Policy Management @ BASS AI/ML Execution Environment @ IESS AI/ML Model Training (Model selection) @ IESS
RAN Intelligent Controller (RIC) near-Real Time (near-RT) • Inference Management • Trained models	Vertical Service Coordinator @ BASS AI/ML Execution Environment @ IESS

This initial mapping is preliminary and further details are planned in collaboration with 5G-Dive Standards Advisory Committee (SAC). As an example, regarding 3GPP System Architecture study item, enhancements on network data analytics (eNA) are already identified as one mapping to the 5G-Dive project, but it is left for future study the use of data analytics beyond data collection and exposure and the mapping of 3GPP release 17 components to 5G-DIVE.

4.5. 5G-DIVE applied to the 5G-CORAL Edge Computing Platform

4.5.1. 5G-CORAL Overview

5G-CORAL architecture [17] (Figure 4-4-3) follows a hierarchical and integrated computing infrastructure spanning across multiple tiers comprising clouds and central data centres on top, Edge data centres in the middle, and Fog computing devices that are available locally in the access area. The focus of 5G-CORAL is on the Edge/Fog tiers of the distributed computing infrastructure, along with their interaction with the distant tiers (e.g., cloud data centres). The Edge and Fog tiers are therefore merged into a single computation platform, dubbed as Edge and Fog computing System (EFS), which serves as the environment for hosting virtualized functions, services, and applications. Therefore, EFS is a logical system subsuming Edge and Fog resources in the Edge and Fog domains, and the networking substrate which may span from end user devices and things, to access nodes belonging to different RATs, further up to transport (fronthaul and backhaul) switches at the Edge.

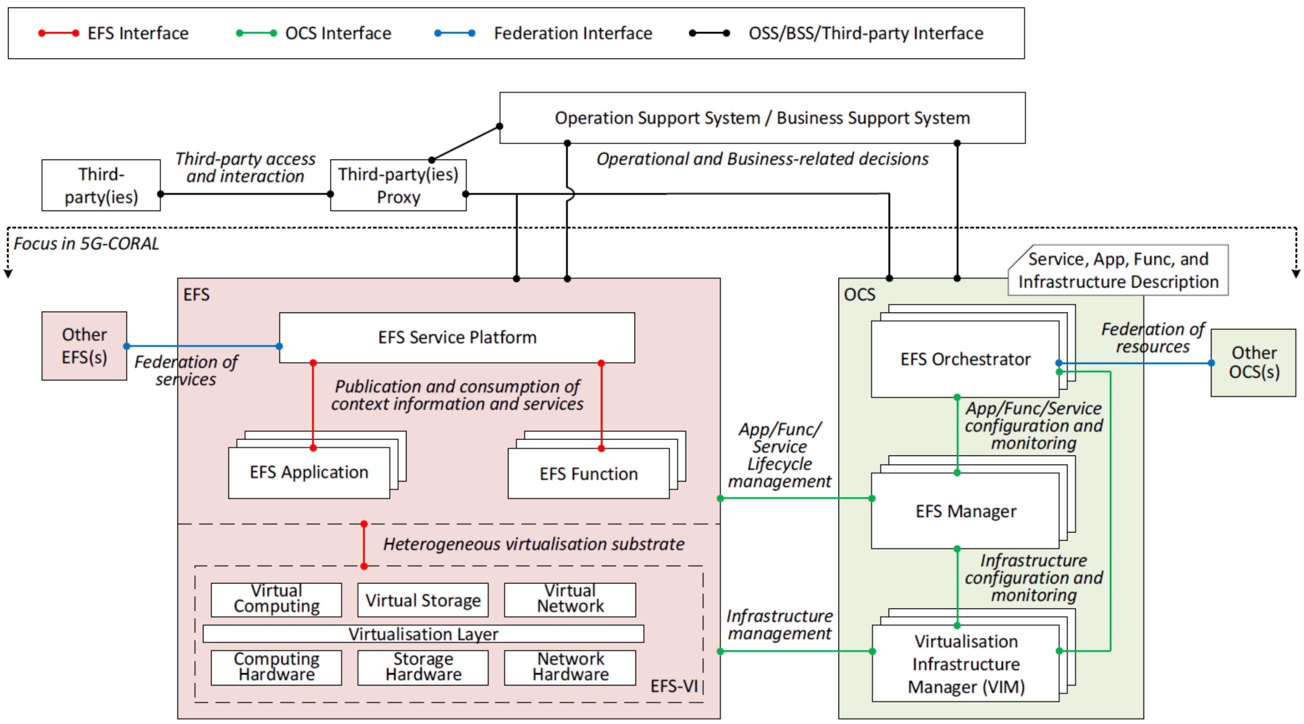

FIGURE 4-4-3: 5G-CORAL BASELINE ARCHITECTURE

As shown in Figure 4-4-3, the EFS mainly hosts three types of components, namely EFS service platforms, EFS applications, and EFS functions:

- **EFS Service Platform:** a logical data services exchange platform within EFS consisting of (i) data storage to keep the collected information from EFS applications/functions and Edge/Fog resources, and (ii) communication protocol to gather/provide information from/to EFS applications/functions and Edge/Fog resources.
- **EFS Function**: an EFS function is a computing task comprised by at least one atomic entity deployed in EFS for networking purposes. An atomic entity is defined as an unpartitionable computing task executed in the EFS.
- **EFS Application**: an EFS application is a computing task comprised by at least one atomic entity deployed in EFS for consumption by end users and third parties.

On the other hand, to manage, control, and federate resources for the EFS and its interaction with any other tiers, 5G-CORAL envisions an Orchestration and Control System (OCS) as another pillar component. The OCS is a logical system in charge of composing, controlling, managing, orchestrating, and federating one or more Edge and Fog computing Systems. Therefore, it has the mission to deliver a flexible management and control capable of coping with the dynamicity and heterogeneity of the EFS (as user conditions change, network conditions vary, and part of the involved resources might become unavailable or even move). As shown in Figure 4-4-3, three main logical entities compose the OCS, namely, (i) the EFS orchestrator, (ii) the EFS manager, and (iii) the Virtualization Infrastructure Manager (VIM):

- **EFS orchestrator:** responsible for the orchestration and management of Edge and Fog resources and composing the EFS. An EFS orchestrator supports accessing the Edge and Fog resources in an abstracted manner independently of any VIM, as well as governance of the EFS Service Platform, EFS function, and EFS application instances sharing resources in the EFS.
- **EFS manager:** responsible for the life cycle management (i.e., updating, scaling) of the distinct components of the EFS (i.e., EFS Service Platforms, EFS functions, and EFS applications) as detailed in Figure 3-2. As a result, multiple EFS managers coexist in the same OCS and each of them manages a single EFS Service Platform, EFS function, EFS application, or a pool of them.
- **VIM**: comprises the functionalities that are used to control and manage the interaction of the EFS Service Platforms, EFS functions, and EFS applications with the Edge and Fog resources under its authority, as well as their virtualization. Multiple VIMs may be deployed to control and manage distinct virtualization substrates or administrative domains so as to offer a unified virtualized execution environment view. Distinct execution environments are expected to coexist, such as hypervisors for virtual machines, containers, as well as native applications on resource-constrained devices.

4.5.2. Integration of DEEP with 5G-CORAL

Figure 4-4-4 presents the integration of DEEP with 5G-CORAL platform. DEEP stands between 5G-CORAL building blocks (i.e., the EFS and OCS) and the VSS/OSS/BSS providing not only a higher-layer of abstraction of the underlying 5G-CORAL platform but also a set of automation and intelligence capabilities to the VSS/OSS/BSS.

The flexibility of the 5G-DIVE DEEP building block, being provided as an add-on that can be placed on top of different edge computing platforms, allows its integration with 5G-CORAL without requiring any change in the latter regarding their basic functionalities. In addition, direct interactions between the VSS/OSS/BSS and 5G-CORAL platform are still available but, since they are out of the scope of this project, they are not going to be discussed in this deliverable.

There are two main interactions between DEEP and 5G-CORAL EFS and OCS, respectively:

1. **with the EFS** for the acquisition of information from the different EFS entities (i.e., EFS applications, EFS functions and EFS Service Platform) as well as from the EFS Virtualization Infrastructure (EFS-VI)
2. **with the OCS** for requesting handling all the aspects of the lifecycle management of vertical services (i.e., instantiate, terminate, query, and reconfigure) as well as for exchanging information with respect to federation of external resources belonging to the vertical.

Regarding the first interaction (i.e., with the EFS), information of any EFS entity or EFS-VI can be shared with other entities using the EFS Service Platform. In doing so, the DASS is able to collect context information by interfacing only with the EFS Service Platform. However, if EFS applications, EFS functions or EFS-VI implements other mechanisms for exposing the information (i.e., not relaying on the EFS Service Platform), these can be exploited by the DASS for a direct access to the information.

Regarding the second interaction (i.e., with the OCS), the incumbency of handling the aspects of the lifecycle management of vertical services has been moved from the VSS/OSS/BSS (as it was in vanilla 5G-CORAL) to the BASS, on which is delegated the its business automation. The BASS interacts with the EFS Orchestrator using already supported reference points (such as, ETSI NFV Os-Ma-nfvo). Additionally, the BASS may request the EFS Orchestrator to take into consideration the federation of external resources belonging to the vertical (e.g., for lowering the costs of deploying the vertical service or for guaranteeing the locality of key parts of the vertical service in the vertical premises). For that, the EFS Orchestrator needs to be enhanced in order to support open federation (i.e., dynamic and on-demand federation), so that it can connect to the network and communicate with the target EFS and OCS and, ultimately, use federated resources from the vertical domain.

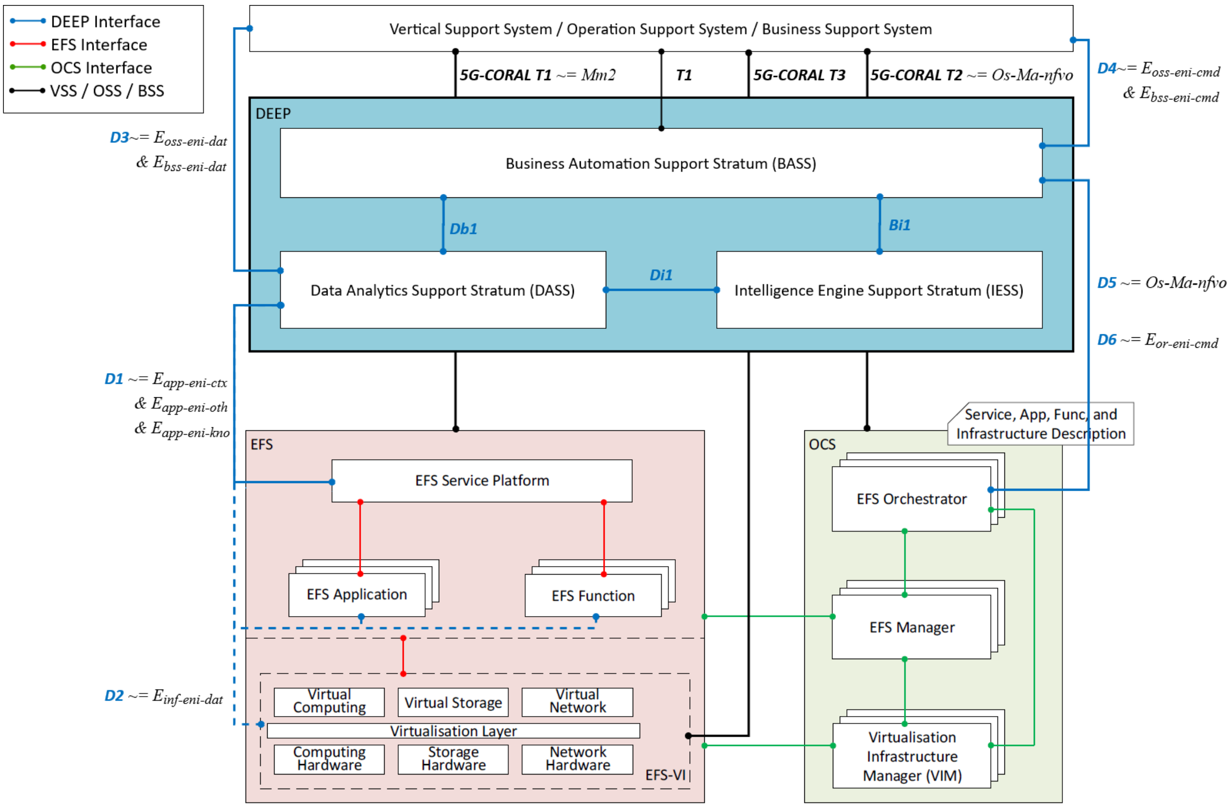

FIGURE 4-4-4: INTEGRATION OF 5G-DIVE WITH 5G-CORAL.

4.6. Use Case Mapping to 5G-DIVE Baseline Architecture

The goal of the 5G-DIVE architecture design is to have a flexible system architecture to support different use cases. This section shows how the 5G-DIVE baseline architecture integrated with 5G-CORAL can fit to the solution design targeted for the different use cases.

4.6.1. Mapping to I4.0 Use Cases

4.6.1.1. Mapping of I4.0-UC1

Figure 4-4-5 presents the Digital Twinning use case as enabled by 5G-DIVE solution. The OCS, EFS and DEEP components are fully distributed between the robots in the factory floor and the infrastructure EFS resources (Cloud and Edge DC).

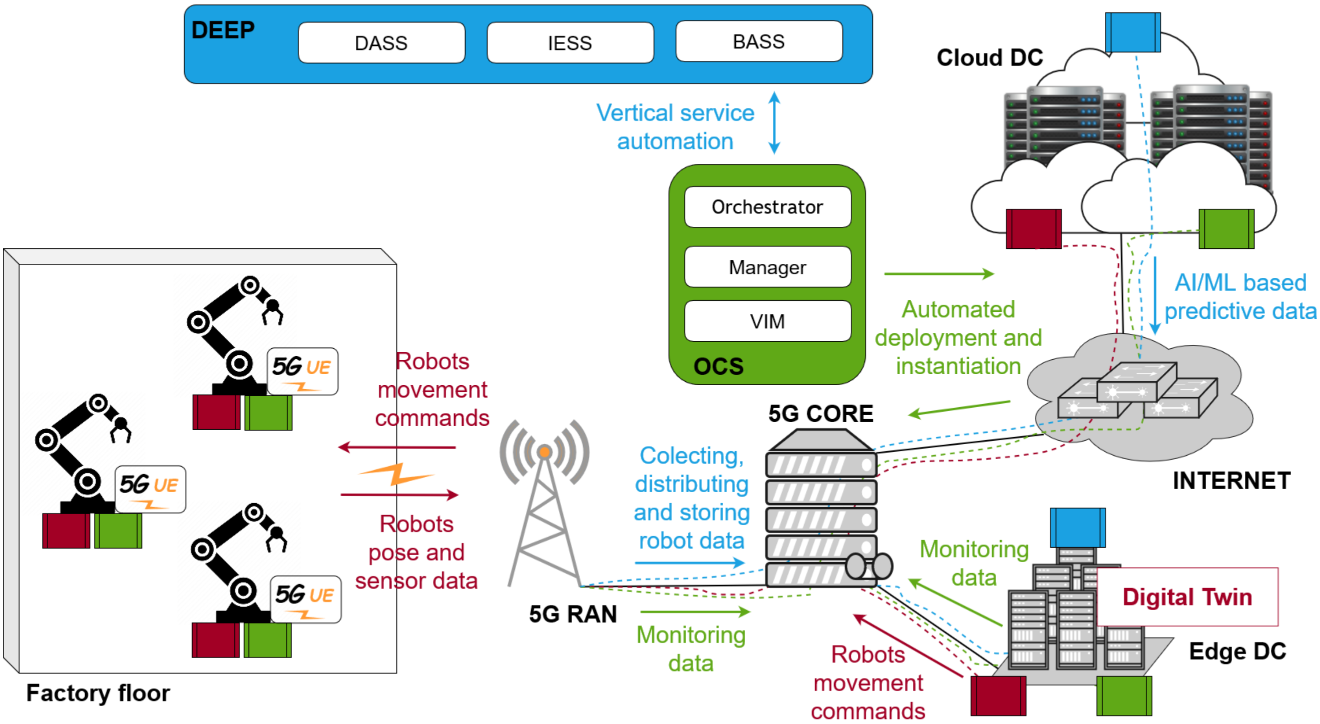

FIGURE 4-4-5: MAPPING OF I4.0-UC1 TO 5G-DIVE SOLUTION.

The OCS oversees the deployment and instantiation of the Digital Twin service. First, it decides in which location the Digital Twin should be placed. In order to do that, the OCS considers the availability of the resources and the status of the network connections available to the factory floor. Once the OCS decides the location of the Digital Twin, it also instantiate and deploys the robot drivers on the factory floor robot.

The Digital Twin continuously consumes the factory floor robot pose and other sensor related data in order to update the view of the digital replica. Moreover, the Digital Twin can command the robot to perform desired actions. Any action that is performed on the digital twin is translated into robot movement commands and is executed on the physical robot.

The Digital Twin can be enchanted with AI/ML based applications that are part of IESS component of DEEP. Robot movement predictions or autonomous task execution are just couple of examples for such applications. These types of application usually require data in order to be trained. DEEP offers collection and distribution of data to different interested parties via DASS component. This data can come from different sources (factory floor robots, Edge/Cloud resources) and can be used for real-time decision making, predictive maintenance and automation. DASS includes features like storing and pre-processing. Finally, BASS can also be enhanced with AI/ML applications in order to enhance the life cycle automation for the vertical service (e.g. SLA enforcer or smart priority queuing).

4.6.1.2. Mapping of I4.0-UC2

Figure 4-4-6 presents the ZDM use case as enabled by 5G-DIVE solution. The OCS, EFS and DEEP components are fully distributed between the resources in the factory floor and the infrastructure EFS resources (Cloud and Edge DC).

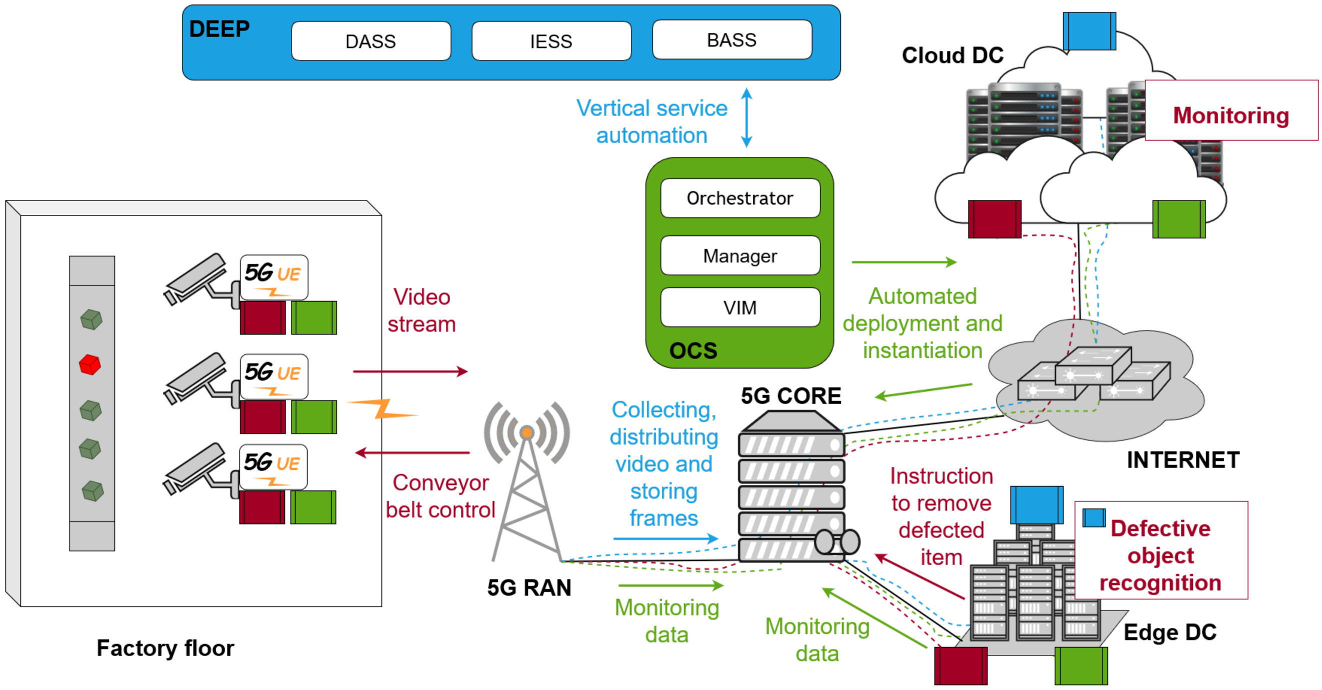

FIGURE 4-4-6: MAPPING OF I4.0-UC2 TO 5G-DIVE SOLUTION.

The OCS oversees the deployment and instantiation of the ZDM service. First, it decides in which location the defected object recognition and the monitoring should be placed. In order to do that, the OCS considers the availability of the resources and the specific applications requirements for different KPIs. Once the OCS decides the location of all the infrastructure modules of the ZDM service, it also instantiate and deploys the cameras on the factory floor robot.

The cameras that are available on the factory floor are used to provide continues video stream of different parts of the production line. The monitoring application consumes the video stream from the camera and offers web based remote view of the production line for the connected worker. The same video stream is consumed also by the defective object recognition application. The IESS component of DEEP provides AI/ML capabilities to this application. By analysing the video stream in real-time, the defective object recognition application detects defective item on the production line. Once the defective item is identified, the defective object recognition application coordinates the factory floor in order to remove the targeted item from the production line.

The defective object recognition application requires item related data in order the AI/ML model to be trained. DASS offers distributed collection and distribution of data to different interested parties. This data can come from a variety of sources and DASS includes features like storing and pre-processing. Finally, BASS offers life cycle automation for the relevant vertical service. This type of automation can be also enhanced by AI/ML applications offered by the IESS. An example of this kind of automation for this use case is SLA enforcement and smart priority queuing for different factory floors cameras.

4.6.1.3. Mapping of I4.0-UC3

Figure 4-4-7 presents the Massive MTC use case as enabled by the 5G-Dive solution. OCS, EFS and DEEP components are distributed between the radio heads on the factory floor and the infrastructure EFS resources (Cloud and Edge DC).

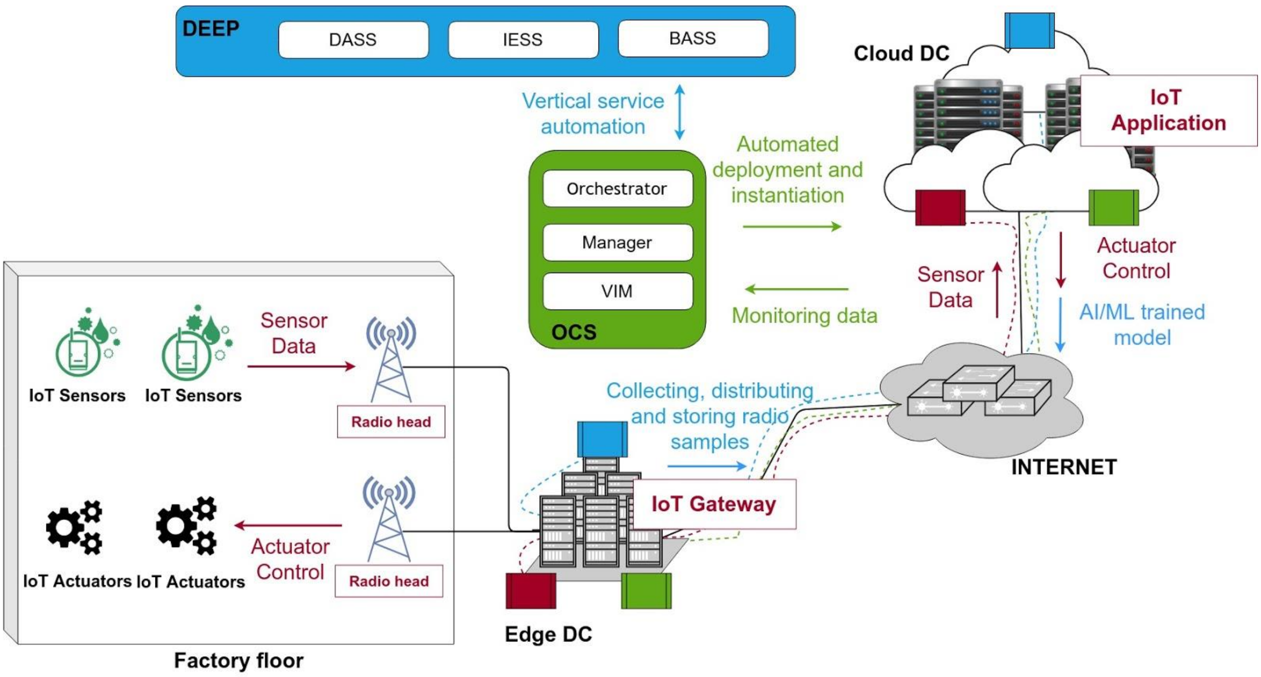

FIGURE 4-4-7: MAPPING OF I4.0-UC3 TO 5G-DIVE SOLUTION.

The OCS oversees the deployment and instantiation of the IoT Gateway service. First, it decides in which location the IoT Gateway service should be placed. In order to do that, the OCS considers the availability of the resources and the status of the network connections available to the factory floor. Once the OCS decides the location of the IoT gateway service, it instantiates and deploys the IoT Gateway services and connect them to the corresponding radio heads.

The IoT Gateway continuously consumes the radio samples to/from the radio heads in order to provide connectivity to the IoT sensors and actuators. The IoT Gateway service connects to the IoT Application service which can be hosted on either the cloud DC or the Edge DC or distributed in both. The IoT Gateway service forwards the IoT sensor data to the IoT Application services and IoT actuator control is forwarded to the IoT actuator nodes through the IoT Gateway service. IoT Application service consumes the IoT sensor data from the IoT Gateway service and allows for visualization and closed-loop control using pre-configured conditional triggers.

The IoT Gateway service also collects, distributes and stores the radio samples via EFS service platform and DASS. The IESS component of DEEP provides AI/ML capabilities to the IoT Gateway service. By analysing the radio sample data, the IoT Gateway service provides a RAN controller that manages the RAN parameters as well as the coordination between multiple RATs. This improves the connectivity service provided by improving latency and throughput to the IoT sensors. The AI/ML model is trained on the cloud DC and then the inference engine is placed on the edge DC in order to improve the AI/ML inference response time to current radio conditions.

The intelligent IoT Gateway service requires radio-sample data in order for the AI/ML model to be trained. DASS offers distributed collection and distribution of data to different interested parties. These data can come from a variety of sources and DASS includes features like storing and pre-processing. Finally, BASS offers life cycle automation for the relevant vertical service. This type of automation can be also enhanced by AI/ML applications offered by the IESS.

4.6.2. Mapping to ADS Use Cases

4.6.2.1. Mapping of ADS-UC1

Figure 4-4-8 illustrates the mapping of the drone fleet navigation use case to 5G-DIVE solution. Here, the EFS, OCS and DEEP components are distributed among the infrastructure resources including drones, edge DC and cloud DC. In this mapping, as part of the DEEP, BASS specifies the drone navigation service blueprint to be deployed in the infrastructure. Next, the OCS oversees the automated deployment and instantiation of the services at EFS resources. The OCS considers the availability of the resources and the status of the network available to the drone navigation service. Once the applications, functions, and their requirements are specified, the OCS instantiates them in the appropriate resource tier. For example, drone navigation server is deployed at edge DC for its low latency requirement, while the drone control application is deployed at the cloud DC.

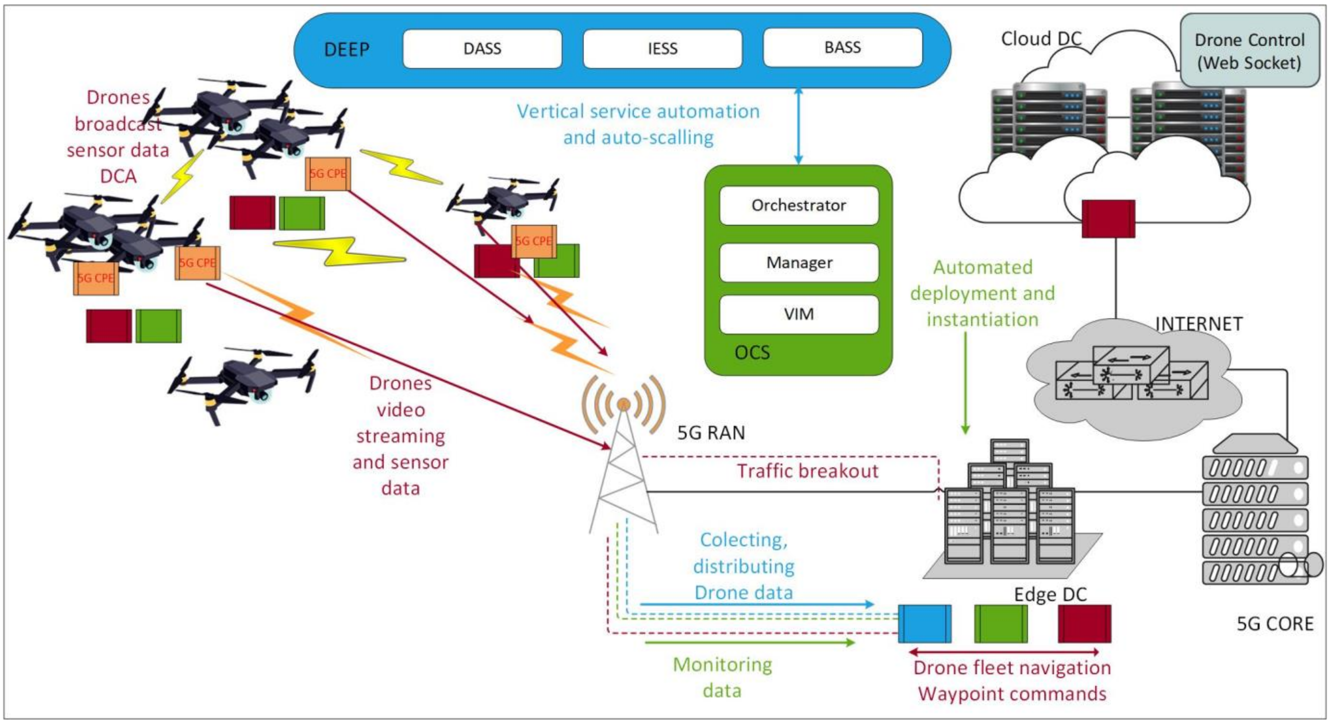

FIGURE 4-4-8: MAPPING OF ADS-UC1 TO 5G-DIVE SOLUTION.

For navigation, drones will continuously transmit video streaming and sensory data to the edge DC in which these data will be consumed by the drone fleet navigation EFS application. The captured data will be used in IESS subsystem to autonomously update the drone trajectory. In addition, the drone control application provides an interface that enables the control of the drone navigation via waypoints. Equally important, the edge navigation system collaborates with in-drone EFS application for collision avoidance. Drones broadcast their sensory data through drone-to-drone communication. Then the in-drone OCS detects the possibility of collision and update the waypoint of drones.

Finally, to avoid backhaul latency when transmitting drone data, the drone navigation employs a traffic breakout function which enables transmitting sensory data directly the edge DC instead of going through the core network.

4.6.2.2. Mapping of ADS-UC2

Figure 4-4-9 shows the mapping of intelligent processing of images for the drones use case to 5G-DIVE solution. Similar to the mapping of ADS-UC1, the EFS, OCS and DEEP subsystems are distributed among the infrastructure resources including drones, edge DC and cloud DC. The main focus in this use case is to provide an aerial emergency relief response service. To this end, an object detection and classification technique, as part of the IESS component of the DEEP, is utilized to identify and locate a person-in-distress (PID) situation. In particular, the drones' video and GPS data are utilized to train an intelligent engine to be deployed as an EFS application for PID real-time detection.

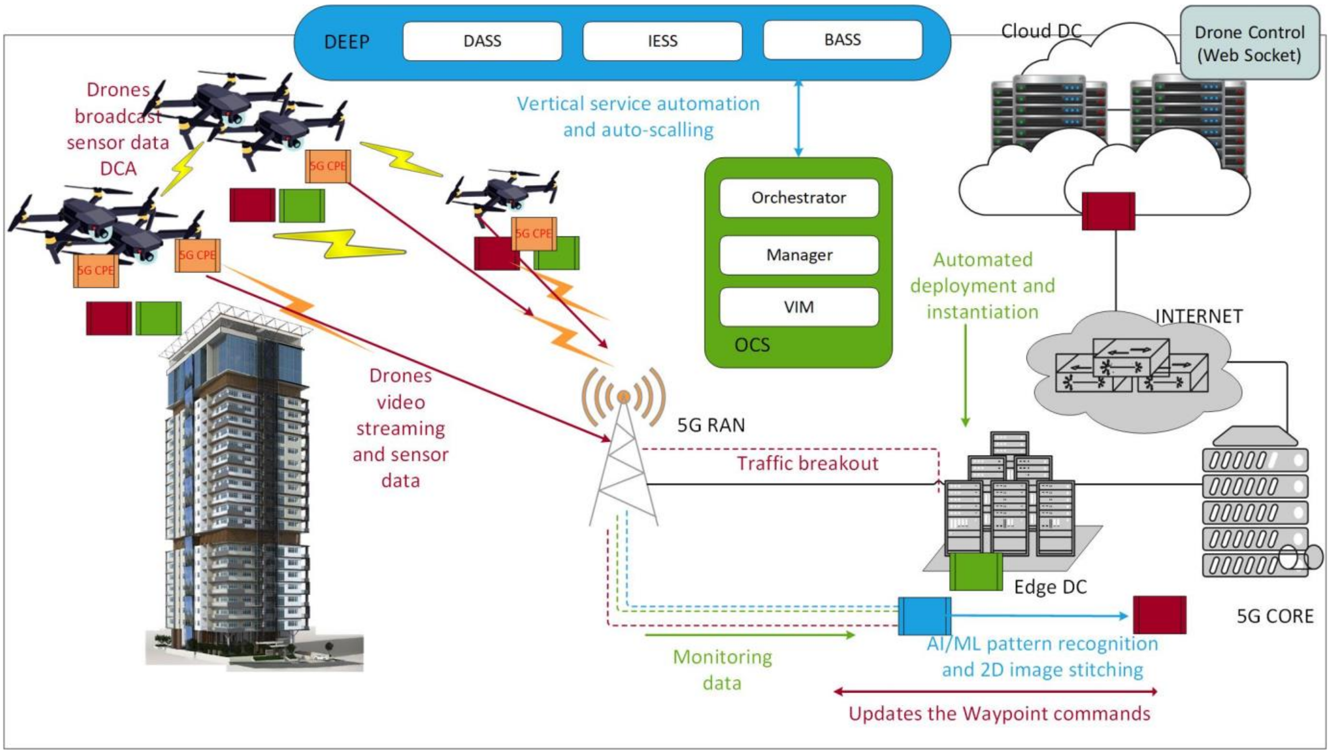

FIGURE 4-4-9: MAPPING OF ADS-UC2 TO 5G-DIVE SOLUTION.

Furthermore, a 2D image stitching application, as part of DASS, exploits image pre-processing and analytics techniques to provide a total panoramic view of the disaster-impacted areas. The overlap area between video frames and the GPS will be utilized in the construction of the stitched image.

5. Conclusions

This deliverable presented a detailed analysis of the vertical use cases targeted in 5G-DIVE. This includes the definition of targeted use cases in I4.0 and ADS verticals and an initial list of their respective business, functional and technical requirements. A baseline system architecture of 5G-DIVE is also provided together with initial deployment of 5G-DIVE solution to support the use cases.

In section 3, two different 5G end-to-end scenarios for I4.0 and ADS have been defined with detailed specification of each of the use cases targeted in 5G-DIVE vertical pilots including the use case's objectives, conditions, actors, execution flow, business requirements, functional requirements, and technical requirements.

For I4.0, the main goal of the defined three use cases is to create flexible and resource efficient production systems and demonstrate the values of 5G technologies (e.g. eMBB, low latency, massive MTC) to potentially increase the productivity of factories and quality in manufacturing. For ADS, the two use cases target public safety agency, such as the firefighter department, for commissioning a drone to scout a disaster area, and show the values of 5G integrating intelligent edge for connecting and navigating a fleet of drones seamlessly.

In section 4, the baseline architecture is detailed with focus on the DEEP system and its three supporting strata DASS, IESS, and BASS. DEEP is positioned over the top of Edge Computing Infrastructure, allowing the shift from an Infrastructure-as-a-Service (IaaS) service model towards an end-to-end Platform-as-a-Service (PaaS) service model. The goal of DEEP is to support vertical industries in day-by-day operations, management, and automation of businesses processes. An initial deployment of DEEP in the targeted I4.0 and ADS use cases has been provided.

As the first deliverable of WP1, the findings and plans presented are provided as key inputs to ongoing developments in other work packages, namely WP2 and WP3.

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7. Annexes

7.1. NGMN references for 5G-DIVE use cases

In this annex we provide two copied/pasted from the document *NGMN Verticals 5G low latency Use Cases and Requirements* [https://www.ngmn.org/publications/5g-e2e-technology-to-support-verticals-urllc-requirements.html] for being used as a reference for I4.0 UC1&2 of the 5G-DIVE project:

TABLE 7-1: NGMN REFERENCE FOR DIGITAL TWIN

Technical requirements (KPIs)	NGMN Verticals 5G low latency Use Cases and Requirements (RMG crane use case)	NGMN Verticals 5G low latency Use Cases and Requirements (Augmented worker use case)	NGMN Verticals 5G low latency Use Cases and Requirements (Control the journey of automated guided vehicles)
End to end latency	20 ms	10ms	5ms
High reliability for remote control information	99,999%	99.9999%	99.999%
Remote control bit rate	100 Kbps (down link)	N/A	100Kbps
Real time video(1080P) for human control	40Mbps in UL 120Mbps in UL for a cell	N/A	3 to 8Mbps in UL
Need for real time data processing	Yes	Yes	Yes
Mobility	N/A	Yes	Yes
Connection Density	N/A	N/A	N/A
Wide Area Coverage	N/A	N/A	N/A
Access to context information	N/A	Yes	N/A

TABLE 7-2: NGMN REFERENCE FOR ZDM

Technical requirements (KPIs)	NGMN Verticals 5G low latency Use Cases and Requirements (Production line enhancement –robot tooling in the factory)
End to end latency	1 to 10ms for machine control
High reliability for remote control information	99,9999 %
Remote control bit rate	N/A
Real time video (1080P) for human control	N/A
Need for real time data processing	N/A
Mobility	N/A
Connection Density	N/A
Wide Area Coverage	N/A
Jitter	< 50% of cycle time

7.2. GPS analysis for ADS pilot

Traditional, Drone navigation relies on satellites such as the Global Position System (GPS). In ADS, initially, GPS is adopted to support the drone flight mission using GPS 3D fix[1]. The GPS accuracy is measured for 20 minutes flight of a drone in an open area as shown in **¡Error! No se encuentra el origen de la referencia.**. Two main GPS accuracy measurements are obtained. The first is Horizontal Accuracy (HAcc). The average value of HAcc is 0.62 meters. The second is Vertical Accuracy (VAcc). The average value of VAcc is 1.6 meters. This value is acceptable in open area space. However, in a disaster mission, the drone flight is vulnerable to disruption of satellite signals e.g., blockage by high buildings or bad weather conditions. Hence, we adopt Real-Time Kinematic (RTK) reference point especially if the mission is located near a blocking building.

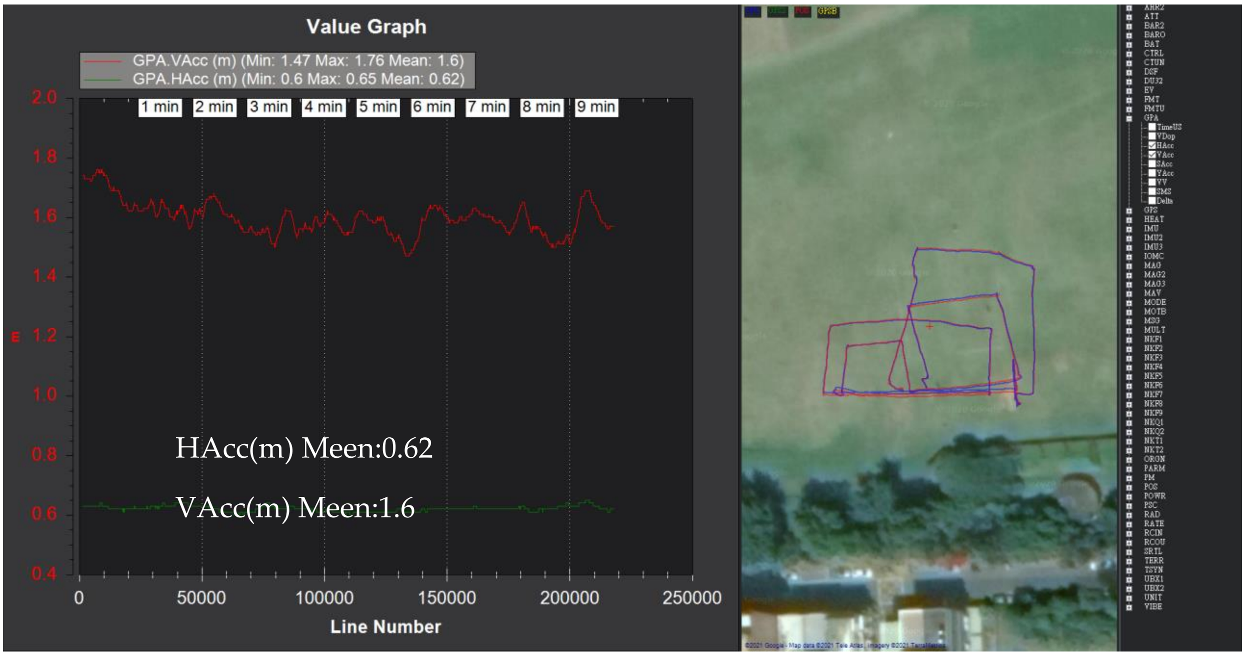

FIGURE 7-1: GPS ACCURACY USING 3D FIX

It is important to place the RTK Antenna correctly to get a precise RTK positioning. In particular, the RTK working condition has special requirements rather than the regular GPS. For instance, the best environment requires the base and rover antenna of RTK to have a clear view of the sky (i.e. 30 degrees above the horizon). In addition, the RTK antenna shall be elevated with no obstacles around, such as buildings, trees, cars, etc.

[1] This is most commonly done by combining distance measurements to 4 or more GPS satellites, which orbit the earth along known paths, 3D trilateration is used by GPS receivers to determine their position on the earth's surface. A minimum of four satellites are required to achieve this, as using any fewer satellites will result in multiple solutions

It is recommended to avoid interfering environments such as indoors, urban areas, and forest, near the ground. Do not place the RTK antenna near electronic devices, as high-power electronic devices nearby may affect the radio frequency noise of the GPS signal. For example, mobile phone base stations, high voltage transformers, etc. Also, it is recommended to set up an RTK base station in a good environment such as open spaces, the peak of the mountains, and the roof of the buildings. The setup for the RTK base station is used the open space of NCTU athletic field as shown in Figure 7-2.

FIGURE 7-2 RTK BASE STATION SETUP

We run two experiments for 2 minutes flight using the same environment, the first is using the GPS 3D fix. While the second is using the RTK float method. We obtain the results shown in Figure 7-3. Also, we run the same experiment for GPS accuracy on top of the roof building close to the field trial location as shown in Figure 7-4. The GPS accuracy for both HAcc and VAcc is less than 0.4 meters for the RTK system in a different environment. The results of RTK GPS accuracy are suitable for drone navigation during disaster mission relief. It provides a stable GPS signal which will prevent the drone from flying into the wrong location. Where, if the horizontal accuracy error is more than 1 meter, it may result in the drone hitting the building under rescue effort. If the vertical accuracy error is 1 meter, the drone is targeting the third floor, but Drone will fly to the second or fourth floor.

GPS 3D Fix RTK Float

FIGURE 7-3 GPS ACCURACY USING 3D FIX VS RTK FLOAT IN OPEN SPACE

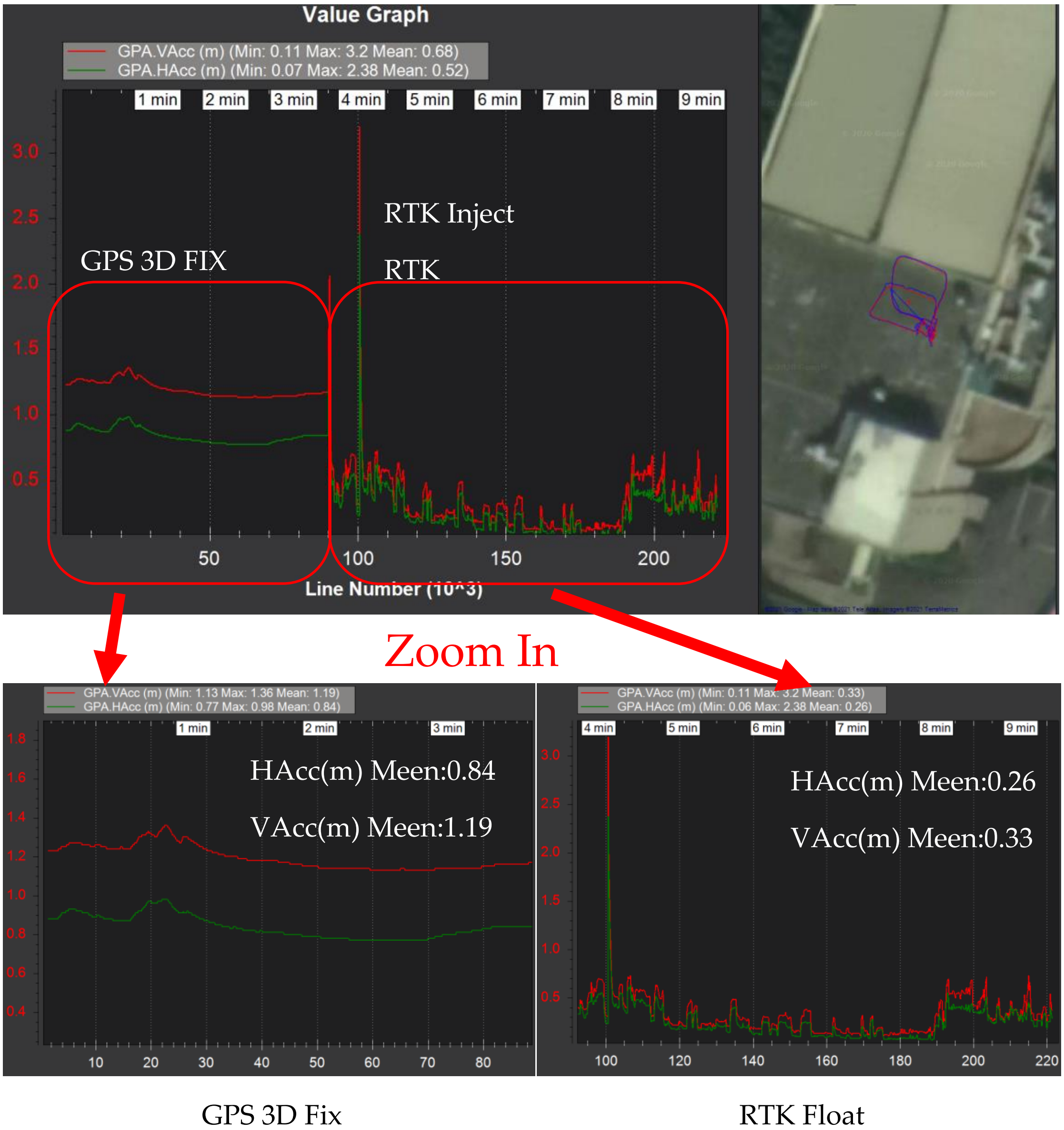

FIGURE 7-4 GPS ACCURACY USING 3D FIX VS RTK FLOAT ON ROOFTOP