

D6.2 - Trial demonstration & evaluation results

ZERO-enabling Smart networked control framework for Agile cyber physical production systems of systems

Topic	HORIZON-CL4-2021-TWIN-TRANSITION-01-08
Project Title	ZERO-enabling Smart networked control framework for Agile cyber physical production systems of systems
Project Number	101057083
Project Acronym	Zero-SWARM
Contractual Delivery Date	M15
Actual Delivery Date	M17
Contributing WP	WP6
Project Start Date	01/06/2022
Project Duration	30 Months
Dissemination Level	Public
Editor	NX-SE, SICK
Contributors	all

Author List

Leading Author (Editor)			
Surname	Initials	Beneficiary Name	Contact email
Fritz	AF	NX-SE	artur.fritz@se.com
Co-authors (in alphabetic order)			
Surname	Initials	Beneficiary Name	Contact email
Khodashenas	PK	HWE	pouria.khodashenas@huawei.com
Krzikalla	RK	SICK	roland.krzikalla@sick.de
Mendez Rial	RM	AIM	roi.mendez@aimen.es
Contributors (in alphabetic order)			
Surname	Initials	Beneficiary Name	Contact email
Atmojo	UA	AALTO	udayanto.atmojo@aalto.fi
Deshmukh	SD	NX-SE	shreya.deshmukh@se.com
Drosou	AD	CERTH	drosou@iti.gr
Maccioni	RM	RWG	raffaele.maccioni@rwings.tech
Pagliarini	GP	PERK	GianPietro.Pagliarini@promachbuilt.com
Zubia	JEZ	S21	jegana@s21sec.com

Reviewers List

List of reviewers (in alphabetic order)			
Surname	Initials	Beneficiary Name	Contact email
Bastidas-Cruz	AB	FhG	arturo.bastidas-cruz@ipk.fraunhofer.de
Lazaridis	GL	CERTH	glazaridis@iti.gr
Maccioni	RM	RWG	raffaele.maccioni@rwings.tech
Pagliarini	GP	PERK	GianPietro.Pagliarini@promachbuilt.com
Khodashenas	PK	HWE	pouria.khodashenas@huawei.com

Document History

Document History			
Version	Date	Author	Remarks
0.1	01/06/2023	Fritz Artur	Table of Content
0.2	07/06/2023	Fritz Artur	Detailed structure with comments of kickoff
0.3	26/07/2023	Fritz Artur	Changes after review of D6.1 templates
0.4	04/08/2023	Fritz Artur	Functional Test-cases for WP5 and template trial results review of D6.1
0.5	10/08/2023	Zubia Jon Egaña	T6.3: Added functional tests for cybersecurity of S21 (T5.4, T5.5)
0.6	17/08/2023	Fritz Artur	T6.3: Input of NX-SE (T5.1 and T5.3)
0.7	18/08/2023	Fritz Artur	T6.3: Input of NX-SE (T5.1 and T5.3)
0.71	28/08/2023	Pagliarini Gian Pietro	T6.3: Input of PERK (T5.1)
0.72	29/08/2023	Anastasios Drosou	T6.3: Input of CERTH (T5.4, T5.5)
0.73	30/08/2023	Krzikalla Roland	T6.2: Micro services in chapter 6
0.74	01/09/2023	Fritz Artur	Chapter 1, 2 and 7
0.75	07/09/2023	Fritz Artur	Integration of inputs in WP5 Test-cases and Chapter 2, 6 and 7 from SICK, RWG, FHG, LTU.
0.76	08/09/2023	Krzikalla Roland	Chapter 1, 7
0.77	11/09/2023	WP3 and WP4	Integration of all inputs of WP3 and WP4
0.78	12/09/2023	Atmojo Udayanto	WP5 for NN and SN
0.79	13/09/2023	Dal Maso	DigitalTwin
0.79	16/09/2023	Pagliarini Gian Pietro	Revision
0.80	19/09/2023	Fritz Artur	Rework after review
0.81	20/09/2023	Fritz Artur	Rework after review
1.0	20/09/2023	Anastasios Drosou	Check for final submission
1.01	09/10/2023	Fritz Artur	Update and TechComponent synchronisation
1.02	16/10/2023	Fritz Artur	Finale update and TechComponent synchroni- sation

DISCLAIMER OF WARRANTIES

This document has been prepared by Zero-SWARM project partners as an account of work carried out within the framework of the contract no 101057083.

Neither Project Coordinator, nor any signatory party of Zero-SWARM Project Consortium Agreement, nor any person acting on behalf of any of them:

- makes any warranty or representation whatsoever, express or implied,
 - with respect to the use of any information, apparatus, method, process, or similar item disclosed in this document, including merchantability and fitness for a particular purpose, or
 - that such use does not infringe on or interfere with privately owned rights, including any party's intellectual property, or
- that this document is suitable to any particular user's circumstance; or
- assumes responsibility for any damages or other liability whatsoever (including any consequential damages, even if Project Coordinator or any representative of a signatory party of the Zero-SWARM Project Consortium Agreement, has been advised of the possibility of such damages) resulting from your selection or use of this document or any information, apparatus, method, process, or similar item disclosed in this document.

Zero-SWARM has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101057083. The content of this deliverable does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the deliverable lies entirely with the author(s).

Executive Summary

Deliverable D6.2 has a dual focus, addressing two key aspects. Firstly, it involves Task 6.3, which aims to verify and demonstrate the feasibility of the technologies within WP3, WP4, and WP5 of the project. Initially, this entails defining smaller test cases as part of the proof of concepts. These preliminary test cases are a crucial part of the initial version of this deliverable. It's important to note that the technical components will be implemented individually before their integration can take place.

In the subsequent version of this deliverable (Version 2), the emphasis will shift towards testing the technologies within WP3, WP4, and WP5 within the context of the final testbed and trial. In this phase, we anticipate expanding the structure of the deliverable to include additional integration test cases and scenarios. These tests will serve as further proof of concept assessments within the demonstrator. Additionally, the deliverable will involve demonstrating and testing the final solution in interaction with various technologies of all technical work packages used in dedicated trials.

The second focus is the task 6.2 where the main goal is to show the benefits of the use of 5G communication in industrial applications to follow the goal of zero emissions in industrial environment. For this the document begins with the description of the used test approach. It follows the descriptions about the tests regarding connectivity, data aggregation and processing and results in the description of the tests for the industrial automation. Finally additional micro services will be described that benefits significantly from the new developed 5G capabilities in industrial applications.

Table of Contents

Executive Summary	6
Table of Contents	7
List of Figures.....	9
List of Tables.....	9
List of Acronyms	11
1 Introduction	13
1.1 Purpose of the document.....	13
1.2 Structure of the document	13
2 Testing approach of Zero-SWARM technological components	14
2.1 Proof-of-concept verification approach	15
2.2 Trial testing validation approach	15
2.3 Test-Template.....	16
3 Functional tests concerning the 5G Connectivity	16
3.1 Service and Network orchestrator in cloud/edge continuum	16
3.2 Standalone non-public 5G stack & End to end layer 2 connectivity service.....	17
3.2.1 Preliminary performance of the 5G stack	17
3.2.2 Connectivity service validations	21
3.3 5G capable edge computing device.....	22
3.4 Integration of 5G & industrial wired networks [Inno, UMH]	23
4 Functional tests concerning data aggregation & processing	24
4.1 Digital twin configuration, edge AI and deep learning	24
4.2 Distributed stream computing for continuous gathering and learning of data within the Edge-Cloud continuum	26
4.2.1 IEC61499 and MQTT and KAFKA	26
4.2.2 IEC61499 and OPC UA and KAFKA.....	27
4.3 Digital twin configuration, edge AI and deep learning	28
4.4 Federated transparent, flexible, and trustable data infrastructure and DevOps tools for continuous data-driven models	32
5 Functional tests concerning the Industrial Automation Platform with their applications and interfaces.....	35
5.1 Distributed automation to sustain deployment of real-time and anytime applications in the Edge..	35
5.1.1 South to North Bound Communication in the IEC61499 automation platform.....	35
5.1.2 South to North Bound Communication in the IceBlock Edge-Device	36
5.1.3 South to North Bound Communication for the DigitalTwin.....	37
5.2 Extension of the IEC-61499 platform to support dynamic setup and reconfiguration of agents.....	39
5.2.1 Edge-Device Layer	39
5.2.2 Edge-Gateway Layer.....	40
5.3 Validation and Adaptation of IEC-61499 formalism and compile time to ease embedding of AI-focused applications.....	43

5.3.1	AI Edge Gateway Platform	43
5.3.2	AI Plugin for the IEC61499 platform and Edge-Gateway functionality	44
5.4	Ad-Hoc penetration and hypothesis testing plugins	45
5.4.1	Functional tests and integration steps for the IEC61499 test application with KPI measurement.	45
5.4.2	Penetration and Hypothesis Testing	46
5.4.3	Penetration test module for OPC-UA.....	50
5.5	Anomaly detection and countermeasure selection modules.....	51
5.5.1	Cybersecurity event detection and response scenario	51
5.5.2	Anomaly Detection and Counter Measure Selection Module	53
6	Micro services in secure 5G edge cloud continuum	57
6.1	Micro services on the edge with 5G benefits	57
6.1.1	Architecture of micro services on edge devices.....	58
6.1.2	Localization and mapping service	58
6.1.3	Environment perception service	59
6.1.4	Sensor data fusion service.....	60
6.1.5	Test-cases	61
7	Conclusions & next steps	62
	References.....	64

List of Figures

Figure 1: 5G private network elements and network topology.	19
Figure 2: RTT for each considered end to end link	20
Figure 3: RTT values on the Machine to Core execution	20
Figure 4: Throughput from the machine to the core using iperf tool	21
Figure 5: Mockup of the 5G capable edge computing device	23
Figure 6: Physical architectural diagram of simulated testbed	46
Figure 7: Penetration testing module	46
Figure 8: Interconnection of modules from T5.4 & T5.5	47
Figure 9 functional architecture view for the hypothesis testing module.	49
Figure 10: Penetration Test Schema	50
Figure 11: Penetration Test Module	50
Figure 12 Cybersecurity event detection and response scenario	52
Figure 13 Functional architecture view for the Anomaly detection and countermeasure selection modules.	57
Figure 14: General structure of for micro services on the 5G capable edge computing device “TDC”	58
Figure 15: General structure of the data processing pipeline of lidar based environment perception service.	59
Figure 16: Fusion of onboard sensor SRS1 and infrastructure sensor SRS2; Example from ISO 62998-1:2019 (page 86) [3]	60
Figure 17: Benefit of 5G capable perception services to close efficiency gaps at intersections with AGVs	60
Figure 18: General structure of the planned fusion service	61

List of Tables

Table 1: Test Template	16
Table 2: Test-cases of Tech. Comp. “Service and Network orchestrator in cloud/edge continuum” of WP3	16
Table 3: Test-cases of Tech. Comp. “5G_NPN_SA” of WP3	17
Table 4: Summary of the network topology and characteristics of the devices.	19
Table 5: Test-cases of Tech. Comp. “E2E_L2_CONNECTIVITY_SERVICE” of WP3	21
Table 6: Test-cases of Tech. Comp. “5G-EDGE-DEVICE-TDC” of WP3	23
Table 7: Test-cases of Tech. Comp. “AAS_editor” of WP4	24
Table 8: Test-cases of Tech. Comp. “AAS_edge_computing_framework” of WP4	25
Table 9: Test-cases of Tech. Comp. “IEC61499_MQTT_PS” of WP4	26
Table 10: Test-cases of Tech. Comp. “MQTT_to_KAFKA_service” of WP4	26
Table 11: Test-cases of Tech. Comp. “IEC61499 OPCUA_SC” of WP4	27
Table 12: Test-cases of Tech. Comp. “IEC61499_HTTP_to_cloud” of WP4	27
Table 13: Test-cases of Tech. Comp. “RWG_MISSIONS_TO_JOBS” of WP4	28
Table 14: Test-cases of Tech. Comp. “RWG_AMR_STATUS_UPDATE” of WP4	28
Table 15: Test-cases of Tech. Comp. “RWG_LAYOUT_TWIN” of WP4	29
Table 16: Test-cases of Tech. Comp. “RWG_RESOURCE_TWIN” of WP4	29

Table 17: Test-cases of Tech. Comp. “RWG_RESOURCES_SET_TWING” of WP4	29
Table 18: Test-cases of Tech. Comp. “RWG_AMR_RE-SCHEDUING_TRIGGER” of WP4	30
Table 19: Test-cases of Tech. Comp. “RWG_AMR_FLEET_SCHEDULER” of WP4	30
Table 20: Test-cases of Tech. Comp. “RWG_AMR_BATTERY_LEVEL_PREDICTION” of WP4	30
Table 21: Test-cases of Tech. Comp. “Federated Learning (Server Module)” of WP4	31
Table 22 Test-cases of Tech. Comp. “Federated_Learning_Client” of WP4	32
Table 23: Test-cases of Tech. Comp. “Collection Platform” of WP3	33
Table 24: Test-cases of Tech. Comp. “MLOPs_framework” of WP3	33
Table 25: Test-cases of Tech. Comp. “Data_auditing” of WP4	34
Table 26: Test-cases of Tech. Comp. “IEC61499_OPCUA_SC” and “IEC61499_MQTT_PS” of WP5	35
Table 27: Test-cases of Tech. Comp. “IEC61499_MQTT_PS” in IceBlock Edge-Device of WP5	36
Table 28: Test-cases of Tech. Comp. “AMR_Simulator” of WP5	37
Table 29: Test-cases of Tech. Comp. “VirtualComissioing_Runtime_Engine”	37
Table 30: Test-cases of Tech. Comp. “AFOF_WEB_VC_Core” of WP5	38
Table 31: Test-cases of Tech. Comp. “AFOF_WEB_VC_Extensions” of WP5	38
Table 32: Test-cases of Tech. Comp. “AFOF_WEB_VC_SIMULATOR” of WP5	38
Table 33: Test-cases of Tech. Comp. “AFOF_WEB_VC_AGENT” of WP5	39
Table 34: Test-cases of Tech. Comp. “IEC61499_ROS2” of WP5	39
Table 35: Test-cases of Tech. Comp. “IEC61499_DynamicConnector” of WP5	40
Table 36: Test-cases of Tech. Comp. “REENEXT_ARM Module_Scheduling” and “REENEXT_AMR Module_Monitoring” of WP5	40
Table 37: Test-cases of Tech. Comp. “RWG_AMR_DYNAMIC_DISCOVERY_RECONFIGURATION” of WP5	41
Table 38: Test-cases of Tech. Comp. “IEC61499_Scheduler” of WP5	42
Table 39: Test-cases of Tech. Comp. “IEC61499_RecipeManager” of WP5	42
Table 40: Test-cases of Tech. Comp. “IEC61499_GraphDB_Monitoring_Interface” of WP5	43
Table 41: Test-cases of Tech. Comp. “FBME_Reconfigurability_Plugin” of WP5	43
Table 42: Test-cases of Tech. Comp. “IEC61499_Edge” of WP5	43
Table 43: Test-cases of Tech. Comp. “IEC61499_AI_plugin” of WP5	44
Table 44: Test-cases of Tech. Comp. “Embedded_AI_Prediction_in_IEC61499” of WP5	44
Table 45: Test-cases of Tech. Comp. “IEC61499_testapp” of WP5	45
Table 46 Test-cases and KPIs for the Anomaly detection and Countermeasure selection modules of WP5	47
Table 47: Test-cases of Tech. Comp. “OPC-UA penetration test” of WP5	50
Table 48: Test-cases of Tech. Comp. “Cybersecurity detection module” of WP5	52
Table 49 Test-cases and KPIs for the Anomaly detection and Countermeasure selection modules of WP5	53
Table 50: Test-cases of developed micro-services	61

List of Acronyms

Acronym	Description
5G	Fifth-Generation Wireless Communications
AE	Alarm And Events
AFoF	AALTO Factory of the Future
AGV	Autonomous Guided Vehicles
AI	Artificial Intelligence
AIC	Automotive Intelligence Centre
AIIC	AALTO Industrial Internet Campus
AR	Augmented Reality
CAT	Composite Automation Type
CPSoS	Cyber-Physical System of Systems
CUC	Centralized User Configuration
DA	Data Access
DFA	Demonstration Factory Aachen (DFA)
DLFi	Distributed Learning Framework
DSS	Dss Dynamic Spectrum Allocation
E2E	End-To-End
eMBB	Enhanced Mobile Broadband
gPTP	Generalized Precision Time Protocol
HDA	Historical Data Access
ICT	Information Communication Technologies
IDS	International Data Spaces
IICF	Industrial Internet Connectivity Framework
IIoT	Industrial Internet Of Things
IIRA	Industrial Internet Reference Architecture
IMC	Intelligent Mechatronic Components
ITU	International Telecommunication Union
LBO	And Local Breakout
MAS	Multi-Agent Systems
MES	Manufacturing Execution Systems
mIoT	Massive Internet of Things
mMTC	Massive Machine Type Communication
MR	Mixed Reality
NASA	National Aeronautics and Space Administration NASA
NASA	Telematic Data Collector
NPN	Non-Public Networks
OLE	Object Linking and Embedding
OPC	Open Platform Communication
OPC-UA	Opc Unified Architecture

PLC	Programmable Logic Controllers
PTZ	Production Technology Center (PTZ)
ROS	Robot Operating System
SLAM	Simultaneous Localization and Mapping
SNPNs	Stand-Alone Npns
SOAP	Simple Object Access Protocol
SoS	Systems Of Systems
TSN	Time Sensitive Networking
UA	Unified Architecture
UACP	Unified Architecture Connection Protocol
UES	User Equipment
UPF	User Plane Function
uRLLC	Ultra-Reliable Low Latency Communication
VR	Virtual Reality

1 Introduction

The purpose of this deliverable (D6.2 Trial demonstration and evaluation results V1) is on one side task 6.2 to show the benefits of the use of 5G communication in industrial applications to follow the goal of zero emissions in industrial environment. For that in Zero-SWARM are a lot of developments planned to improve the capability and the usability of 5G networks.

Task 6.3 is to start with the basic functional tests of new developed software modules and configurations of the technical work packages (WP3, WP4, WP5), before they are going to be integrated in the trials, which is necessary for achieving a good functional quality, which can be used in the trials, with the following objectives in this and in the next version of this deliverable:

- Verify and demonstrate the feasibility of the project methodology and the technologies
- Validate the technologies and then verify the trials selected for this technology
- Evaluate and assess the results of the validation and demonstration

This document will show the used test approach and the obtained results. The outcomes of this deliverable will provide feedback to the technical work packages for further development as well as to WP2 to refine the architecture and the requirements of the project, and to demonstrate the new benefits various industry typical trials and demonstrations have defined and prepared.

This deliverable was delayed about 3 weeks, because of additional synchronisation needs with D6.1 for the completeness of the technical components, and for the completeness of chapter 6 and because of the synchronisation of all partner inputs, which was a lot of effort, also from the timing point of view.

1.1 Purpose of the document

The task 6.3 has different focuses. Firstly, it centres on the various testing approaches. One aspect involves assessing the technical components, which have either been adapted for or newly developed for the trials. This adaptation aligns with the technical task requirements. Secondly, it deals with the approach for verifying the functionality of these technical components within the trial environments where they are utilized.

It's worth noting that not all components may be integrated into the trials. Some may be deployed in alternative scenarios to evaluate specific cybersecurity aspects or to conduct system penetration tests. This divergence is essential to avoid potential damage to components in the trials itself.

Chapters 3, 4, and 5, serving as placeholders for the functional test cases of WP3, WP4, and WP5, respectively, and are linked to the technical components identified in D6.1. These components are primarily newly configured or adapted and newly developed. The primary focus in these chapters is on the fundamental functional test cases for proof-of-concept testing in the initial stage.

In addition, Chapter 6 describes the development of new micro-services that will benefit from the new 5G technology. These micro-services are examples of extending the capabilities in current industrial automation processes by leveraging the developed 5G functionalities.

1.2 Structure of the document

The document is structured as follows:

- **Chapter 1** is an introduction to the whole document, describes its scope and purpose, as well as its structure.

- **Chapter 2** provides the different testing technologies for task 6.3.
- **Chapter 3** formulates the functional tests for the 5G related technical components developed in WP3, as they were presented in D6.1. These works are related to task 6.2.
- **Chapter 4** formulates the functional tests for data aggregation and processing related technical components developed in WP4, as they were presented in the D4.x deliverables. These works are related to task 6.2.
- **Chapter 5** formulates the functional tests industrial automation technical components developed in WP5, as they were presented in D6.1. These works are related to task 6.2.
- **Chapter 6** describes the development of new micro-services for industrial automation on edge devices, that benefit from the new 5G technology. These works are related to task 6.2.
- **Chapter 7** makes a conclusion and an outlook about the next steps.

2 Testing approach of Zero-SWARM technological components

In the forthcoming chapters, we delve deeper into the intricacies of our project, specifically focusing on the **technical components** developed for Work Packages 3, 4, and 5 and described and summarized in D6.1. These technical components play a pivotal role in the testing scenarios we are about to explore. Our primary aim at this juncture is to conduct small-scale proof-of-concept tests, and this constitutes the essence of this deliverable.

As we progress, it's important to note that the subsequent version of this deliverable, D6.2 scheduled for M30, will shift its focus towards integration testing within the trials themselves, while placing a more concentrated emphasis on the practical use case scenarios. The rationale behind this division lies in the necessity to rigorously verify the newly developed software components within the controlled laboratory environment of our technological partners. After this meticulous verification process will these components be deemed ready for integration into a selected trial.

It's worth mentioning that not every technical component will ultimately find its way into a trial setting of a demonstrator. Some of these components will undergo thorough scrutiny exclusively within the proof-of-concept test environment. This phased approach ensures that.

During the phases when our primary emphasis was not on the software development methodology but rather on the rigorous test and implementation work, we recognized the importance of granting each partner the autonomy to choose their own approach. This flexibility allowed our project to flourish in a diverse and dynamic environment, harnessing the unique strengths and expertise of each team member. In this collaborative endeavour, we understood that there is no one-size-fits-all solution when it comes to implementing and testing complex technical components. Acknowledging this, we encouraged partners to leverage their individual methodologies, experiences, and insights to tackle the challenges at hand. This approach not only fostered a culture of innovation but also promoted a rich exchange of ideas and best practices among the project contributors. It allowed us to tap into a wealth of diverse knowledge and strategies, ultimately leading to a more comprehensive and robust project outcome.

As a result, our project benefited from the collective wisdom of our partners, who, by following their own paths in test and implementation, contributed to a holistic and resilient solution that stands as a

testament to the power of collaboration and the synergy that arises when individuals are empowered to make choices aligned with their expertise and vision.

2.1 Proof-of-concept verification approach

Proof of concept (PoC) verification is a crucial process used to evaluate the feasibility and functionality of a new or innovative idea, concept, or technology in a practical environment. It helps determine whether the proposed concept can work as intended and whether it is worth pursuing further development or investment.

The proof-of-concept testing verification approach is used in this project as following:

- Before starting with the development of a prototype, **check the specification** of the related technical components (in D6.1) and linked requirements (technical deliverables of WP3, WP4, WP5), identify the functional and object-oriented structure and the dedicated development environment and programming language which will be used.
- **Develop the prototype** or a minimal viable version of the architectural concept. This prototype is a simplified but functional representation of a future product or solution.
- For this prototype a **laboratory testing environment** is setup, to test the pure functional cases. This may involve setting up hardware, software, and any other necessary infrastructure.
- **Conduct the actual tests described in the test-template**, using the prototype. Collect data and information on how the concept performs under different conditions/configurations and check the result in relation to the expected ones.
- When there are KPIs or metrics defined, **analyse the collected data** against this predefined metrics. Evaluate the prototype's performance, identify strengths, weaknesses, and areas for improvement.
- If the proof-of-concept verification is successful, go to the next step for the integration and validation in a selected **trial**.

2.2 Trial testing validation approach

The trial testing validation approach is a structured approach for evaluating the performance, functionality, and feasibility of the demonstrator with its proof-of-concept technical components and all other components, necessary for it. The demonstrator is a working model or a partial representation of a product, system, or concept that is used to showcase its capabilities or prove its viability.

Here's more about the used steps of the trial validation approach:

- Develop the demonstrator with the **trial laboratory setup**, which will involve all available and ready technical components (hardware and software).
- Determine the scope and features of the demonstrator. Decide which functionalities or components will be included in the demonstrator and which may be omitted for the first testing phase and start with first pre-evaluations of basic functions, based on the functional requirements of a trial.
- Use the integration plan of D6.1 and check the status of the new or adapted technical component. **When the technical component is ready** start with the integration in your trial setup.
- **Conduct the actual tests described in the test-template**, for the NN, CN and SN trials. Interact with different technical work-packages WP3, WP4 and WP5, in case of problem analyse.

- When there are KPIs or metrics defined, **analyse the collected data** against this predefined metrics. Evaluate the prototype's performance, identify strengths, weaknesses, and areas for improvement.

Along with the demonstration of the trial, the evaluated results will be used to draw conclusions and recommendations to improve the applicability, to guide future R&D improvements, to overcome technological barriers and to build practical knowledge on how to potentially deploy this solution to Industry Customer networks and early adopters as well.

2.3 Test-Template

To simplify the testing process, a straightforward test template is employed. This template concentrates on the core functional tests or test settings for a specific component. It has been designed to be user-friendly for all project partners, including those not necessarily from an industrial background. This approach differs from the varied and often extensive test objectives commonly found in different test teams during product development in the industry, but it is adapted to the constraints of a research project context. The test template is applied in the subsequent chapters to establish test cases for technical prototypes and for conducting tests within the integrated trial, and is self-explanatory, see Table 1:

Table 1: Test Template

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_AI_plugin	import	< 1sec		Python Function

3 Functional tests concerning the 5G Connectivity

3.1 Service and Network orchestrator in cloud/edge continuum

This component is a Network slice solution for the zero-touch management of the network. For evaluating this component, a series of tests are listed in the table below.

Table 2: Test-cases of Tech. Comp. "Service and Network orchestrator in cloud/edge continuum" of WP3

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Service and Network orchestrator in cloud/edge continuum "SN_Orch_Ed_Clo", "Col_Plat", "MLO_Fram"	Onboarding: Demonstration of receiving a VSB from an AI/ML model or from a Vertical and translate it to one or more VSDs that assign specific value to the	The VSB is received on the NBI of the component and is translated to one or more VSDs		

	parameters contained in the VSB			
	Instantiation: Demonstration of receiving an instantiation request from an AI/ML model or from a Vertical, selecting one of the VSD created previously. The VSMF handles the Vertical Service provisioning, first by triggering the mapping/translation sub-procedure to determine the most suitable NST to fulfil the instantiation request, and then propagating the instantiation request to the NSMF. The NST received by the VSMF is used by the NSMF for the deployment of the network slice.	The NST is created and is sent to the NSMF.		
	NSMF CRUD: The NSMF breaks down network slices into Network Services and requests the NFV orchestrator (OSM is one of the supported NFV orchestrators) to create, update, and terminate them.	The NSMF create/update/terminate the network slice.		

3.2 Standalone non-public 5G stack & End to end layer 2 connectivity service

3.2.1 Preliminary performance of the 5G stack

This subsection presents a preliminary performance test for the private 5G stack that has been considered in the AIMEN trial. It is worth explaining that the firmware of the 5G indoor cell can be improved during the evolution of the project toward the final release of the product. Hence, the network performance.

A summary test table is provided below, and thorough explanations are given next.

Table 3: Test-cases of Tech. Comp. "5G_NPN_SA" of WP3

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
5G_NPN_SA	Configuration of control and user plane functions and 5G RAN (central unit and distributed unit)	Connectivity is achieved yes/no (C)	OK - additional validations are needed	Connectivity should be achieved after configurations are performed
	CPE to core round trip time (RTT)	No specific requirement. Aim to achieve less than	OK - additional on-site validations	Measured average RTT is less than 50

		50 ms to support 20 Hz transmission frequency	are needed	ms
	Machine (M) to core RTT	No specific requirement. Aim to achieve less than 50 ms to support 20 Hz transmission frequency	OK - additional on-site validations are needed	Measured average RTT is less than 50 ms
	Machine to DNS RTT	No specific requirement. Aim to achieve less than 50 ms to support 20 Hz transmission frequency	OK - additional on-site validations are needed	Average RTT is less than 50 ms
	Machine to core throughput UDP downlink	No specific requirements, but it will be tested	OK - additional on-site validations are needed	Iperf tool Initial test yields average > 200 Mbps
	Machine to core throughput UDP uplink	> 2 Mbps per each cell (C)	OK - additional on-site validations are needed	Iperf tool Initial test yields average > 100 Mbps
	Machine to core throughput TCP downlink	No specific requirements, but it will be tested		Initial test yields average > 80 Mbps
	Machine to core throughput TCP uplink	> 2 Mbps per each cell (C)	OK - additional validations are needed	Iperf tool Initial test yields average > 20 Mbps

Network Topology:

Figure 1 shows the network architecture that has been considered to test the performance of the proposed private 5G network. The 5G core is an Open5gs, which is installed in bare metal. The 5G cell is a Node-H RAN which also hosts T&W as the RU. The CPE is a Milesight UR75 and the smartphone is a Huawei P40 pro. Additional details are provided by Table 4, where the main characteristics of the considered devices are summarized. Node-H and T&W operating at N78 band were considered to have a preliminary estimation of the performance. However, the final version of the vRAN is Node-H and As-key radio operating at N77 band, in order to satisfy the European regulations. This modification may result in a slight deviation of the network performance. For this reason, we are currently working on the integration and testing of the final version of the 5G stack.

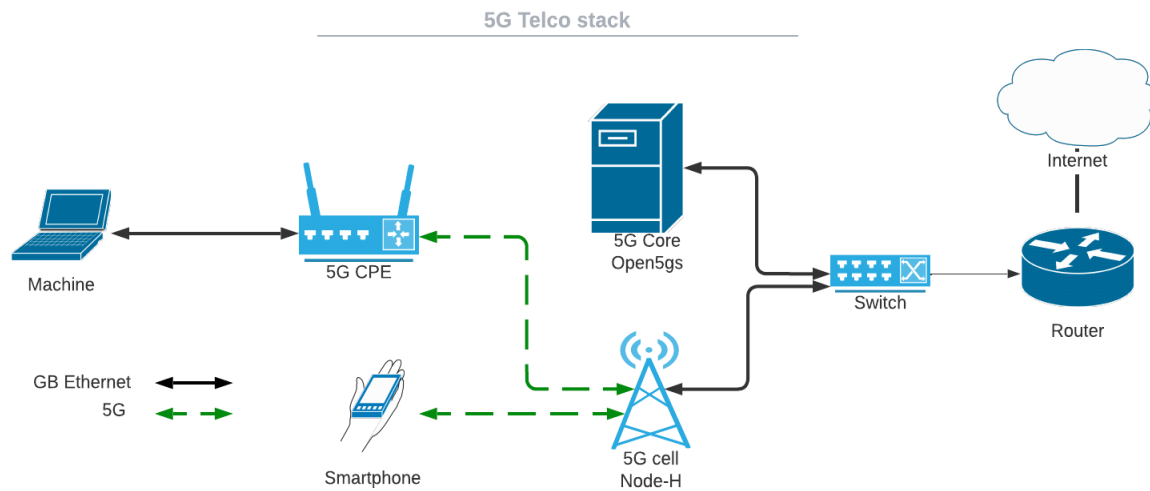


Figure 1: 5G private network elements and network topology.

Table 4: Summary of the network topology and characteristics of the devices.

Parameters/Elements	Specification
5G Core	Open5GS
vRAN	Node-B + T&W
RU antenna configuration	2*2 MIMO
Band	N78
Bandwidth	40 MHz
SCS	30 kHz
TDD subframe structure	(Period, DL, UL) -> (10, 7, 2) ms
Core Slice configuration	Default (1Gbps UL/DL)
UEs	1- Milesight UR75 CPE 2- Huawei P40 Plus cell phone

Preliminary results

This subsection presents the performance results of the proposed 5G stack based on latency and throughput. It is worth mentioning that these results are based on a preliminary analysis and configuration of the network elements. For this reason, results can be different during the trial execution when parameters will be adapted to the trial requirements.

Based on Figure 1, it is possible to see that we have multiple connections to measure the network performance. This analysis focuses on four end to end connections: Machine to Core, Smartphone to Core, Machine to Internet and Smartphone to Internet.

The latency can be estimated as the round-trip time (RTT) divided by 2. This measurement was executed as an initial step using the ping tool. Figure 2 shows the obtained RTT, where the scale of the y-axis has been modified to improve the bars visualization.

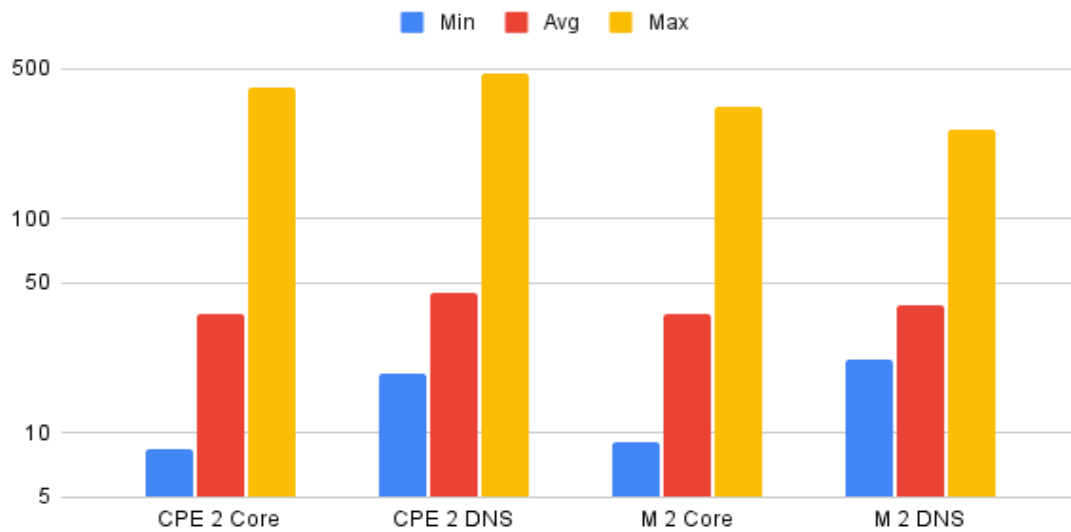


Figure 2: RTT for each considered end to end link

Figure 2 shows that the latency, under certain conditions, experiences extremely high values. However, it is not possible to see on this graph the distribution of the values. For this reason, Figure 3 exhibits an example of the latency values in milliseconds, particularly in the machine/CPE to core link.

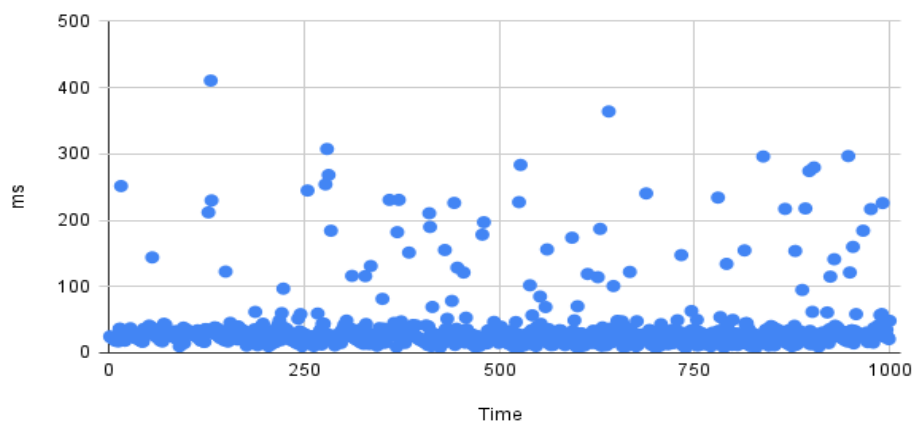


Figure 3: RTT values on the Machine to Core execution

The average RTT is always below 50ms under the considered situations. As the presented measurements consider the RTT, it is possible to estimate values of latency around 20ms to the internet and less than 20ms to the core. There are high peaks in the latency and their distribution can be appreciated in Figure 3.

Regarding the throughput, the analysis has been performed using the same reference links but using UDP and TCP as transport protocols. However, only results from the CPE perspective will be presented due to it is the case that will be used in the AIMEN trial.

Figure 4 shows the throughput obtained from the CPE. Iperf tool with 10 parallel threads running as client in the machine, while the server was in the core, was considered to execute these tests.

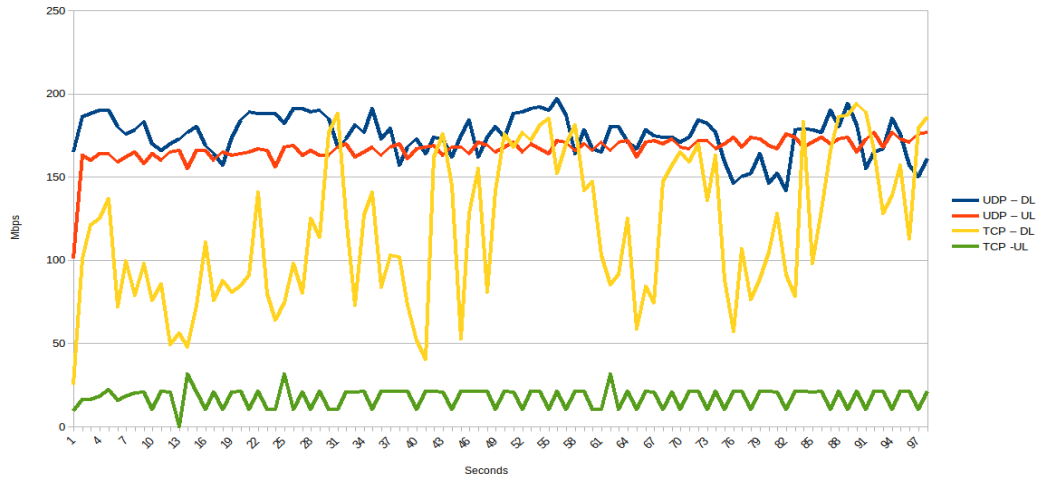


Figure 4: Throughput from the machine to the core using iperf tool

As we have previously mentioned, these tests will be repeated during the evolution of the project using different firmware versions of the radio unit.

3.2.2 Connectivity service validations

As part of the AIMEN validations in the Spanish trials, the CPE with support for L2 services over 5G developed by i2CAT in WP3, is to be integrated with the NEUTROON private 5G network. This involves validations of components developed in T3.2 and T3.4, which are to be performed jointly.

Table 5: Test-cases of Tech. Comp. "E2E_L2_CONNECTIVITY_SERVICE" of WP3

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
E2E_L2_CONNECTIVITY_SERVICE	Validate performance over 5G without end-to-end layer 2 (L2) connectivity	Round trip latency (C)		To be measured with lag scope and PING This will serve as a baseline KPI for round trip latency achieved with end-to-end L2 connectivity over 5G
	Validate performance over 5G without end-to-end layer 2 (L2) connectivity	Throughput (C)		This will serve as a baseline KPI for round trip throughput achieved with end-to-end L2 connectivity over 5G
	Validate end-to-end L2 connectivity over 5G	Round trip latency (C)		Baseline value from round trip latency achieved without end-to-end L2 connectivity

	Validate end-to-end L2 connectivity over 5G	Throughput (C)		Baseline value from throughput achieved without end-to-end L2 connectivity
	IP addressed is acquired from DHCP behind edge server	IP address acquired yes/no (C)		
	Validate multiplexing of two VLANs over the same private 5G infrastructure	Each DHCP server provides IP addresses per each VLAN (yes/no)		The end device should acquire one IP address from each DHCP server on each VLAN
	Validate multiplexing of two VLANs over the same private 5G infrastructure	End-to-end latency (C)		Baseline KPI from test performed with a unique VLAN (section 3.2.2)
	Validate multiplexing of two VLANs over the same private 5G infrastructure	Parallel throughput from the two VLANs (C)		Baseline KPI from test performed with a unique VLAN (section 3.2.2)
	Validate deployment of two VLANs connected to different 5G APNs	Each DHCP server provides IP addresses per each DHCP (yes/no)		The end device should acquire one IP address from each DHCP server on each APN
	Validate deployment of two VLANs connected to different 5G APNs	End-to-end latency (C)		Baseline KPI from test performed with two VLANs over the same private infrastructure
	Validate deployment of two VLANs connected to different 5G APNs	Parallel throughput from the two VLANs (C)		Baseline KPI from test performed with two VLANs over the same private infrastructure

3.3 5G capable edge computing device

This section describes the tests regarding the provided 5G capable edge computing device for future industrial applications using 5G communication. The main tests are about the tests of the connectivity to the 5G- and the ethernet network, the tests about the deployment of micro-services and the tests regarding the computational power of the device.



Figure 5: Mockup of the 5G capable edge computing device

Table 6: Test-cases of Tech. Comp. “5G-EDGE-DEVICE-TDC” of WP3

Tech. Component ID “empty” = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI “C” = Critical “empty” = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result “OK” “NOK” “empty” = not validated	Comment
5G-EDGE-DEVICE-TDC	Validate 5G connection	Connectivity and throughput (C)		The device should establish connections to the provided 5G network and a data transmission with a given throughput and latency should be possible.
	Validate ethernet interface	Connectivity and throughput (C)		The device should establish connections via ethernet to other networks or sensors and a data transmission with a given throughput and latency should be possible.
	Validate the deployment of micro-services	Deployment process (C)		Micro-services should be deployable on the device.
	Validate the processing power of the device			The device should provide sufficient processing power for various micro-services, especially a lidar-based self-localization service and an environment perception service for intra logistic applications.

3.4 Integration of 5G & industrial wired networks [Inno, UMH]

This subsection presents Test-cases that are planned to test and validate the management techniques implemented to ensure an effective integration and interworking of industrial wired networks and 5G to guarantee the end-to-end QoS requirements for the data flows in integrated 5G+industrial networks. This software will be implemented in the SN03 trial. Particularly, it will be implemented in the industrial network deployed in the Innovalia’s premises. This component will manage traffic in the

industrial wired network to guarantee the QoS demanded by the application and that critical traffic is prioritized ensuring that its performance is not affected when other traffic is present in the network. The component will interact with the 5G network that provides connectivity with a remote control centre to guarantee the required end-to-end performance. We show a preliminary test planning that can be subject to changes as the trial evolved.

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Integration of 5G-industrial networks	Management and prioritization of critical traffic in the wired network.	Number of packets satisfactorily received for critical traffic >99.99 %		A packet is satisfactorily received if it arrives before a maximum latency.
		Throughput for non-critical traffic.		
	Evaluation of the latency and reliability performance in the integrated 5G + industrial wired network.	Latency < 4 ms (highly dependent of the 5G network configuration) Reliability > 99.99% at the application level		

4 Functional tests concerning data aggregation & processing

4.1 Digital twin configuration, edge AI and deep learning

AAS editor

The AAS editor will be used for modelling several manufacturing assets in the trials (mainly SN03). The AAS model will be serialized as an OPC-UA information model in xml file. Compatibility of the model with third party AAS editors and OPC-UA stacks will be tested.

Table 7: Test-cases of Tech. Comp. "AAS_editor" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
AAS_editor	Serialization of AAS model in OPC-UA a valid nodeset XML. Check compatibility with AAS editors (e.g., AASX Package Explorer) and OPC-UA stacks	[C]		
	Import .aasx files with OPC-			

	UA submodels. From the AAS file format obtain the corresponding OPC-UA specification of each sub-model.			
--	--	--	--	--

AAS edge computing framework

Table 8: Test-cases of Tech. Comp. "AAS_edge_computing_framework" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
AAS_edge_computing_framework	Generation of embedded OPC-UA servers from standard XML definition, including AAS OPC-UA APIs. Check compatibility of the OPC-UA API with other AAS frameworks following IEC 63278-1	[C]		
	Data aggregation from multiple sources. Verify the AAS can collect data correctly and synchronized. Data collection from GigE Camera, TCP socket (robot) and analog digital I/O module, and storage in a local file.	Collected data rates > 1Gbps No image frames or data packages lost.		
	Data aggregation from multiple sources. Verify AAS can collect data correctly and synchronized. Data collection from GigE Camera, TCP socket (robot) and analog digital I/O module, and publication in the embedded OPC-UA server.	Refresh data rates > 10Hz. CPU load <50%		
	Near real-time data processing capabilities. Image processing module extracts image features (meltpool width) from a VGA camera at video rate.	feature extraction rate > 25 FPS		
	TensorRT inference module. Import tensorRT engine and perform inference online Load a pre-trained deep learning segmentation model and do online inference on VGA camera images.	DL image segmentation rate > 5 FPS		
	ONNX Inference module. Import an ONNX AI model and perform inference online. Load a pre-trained deep learning segmentation model and do online inference on VGA camera images.	DL image segmentation rate > 5 FPS		
	Online control of pipeline modules through AAS API. Modification of camera exposure time and loading a new deep learning			

	model at runtime through OPC-UA.			
	Support the creation of edge AAS with AI capabilities based on a library of modules without coding. Automatic generation of an embedded AAS server including a processing pipeline combining data sources (Camera, TCP socket), AI inference module, and data sinks (OPC-UA server and File sink) based on config text file yaml.	Time to create an AAS		

4.2 Distributed stream computing for continuous gathering and learning of data within the Edge-Cloud continuum

4.2.1 IEC61499 and MQTT and KAFKA

A synthetical test application is going to be developed, able to test south to north bound communication for MQTT basic interface in the IEC61499 runtime, and able to test with different loads, and KPI measurements for CPU, Memory, event latency and partly delay.

Table 9: Test-cases of Tech. Comp. "IEC61499_MQTT_PS" of WP4

Tech. Component ID "empty" = same as row before Use unique component/interface Identifier from D6.1	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical Use KPI of D6.1, or define new	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_MQTT	publish	CPU<50%[C]		[ST]
	subscribe	CPU<50%[C]		[ST]
	connect	CPU<50%[C]		[ST]
	anonymous			Setting for testcase
	user			Setting for testcase
	Text message			Setting for testcase
	Encrypted message			Setting for testcase
	OoS (quality of Service)			Setting for testcase Check if supported.
	Wireless			Setting for testcase
	Wired			Setting for testcase
	SoftPLC and Edge Gateway (Harmony P6)			Setting for testcase
	External MQTT Broker			Setting for testcase

Table 10: Test-cases of Tech. Comp. "MQTT_to_KAFKA_service" of WP4

Tech. Component ID "empty" = same as row before Use unique component/interface	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical	Test-Analysis-Result "OK" "NOK"	Comment
--	--	---	---------------------------------------	---------

Identifier from D6.1		Use KPI of D6.1, or define new	"empty" = not validated	
MQTT_to_KAFKA_service	Service is capable to read assigned data from MQTT topics and publish in Kafka topics			
	Service is capable to read assigned data from Kafka topics and publish it in MQTT			

4.2.2 IEC61499 and OPC UA and KAFKA

A synthetical test application is going to be developed, able to test south to north bound communication for OPC UA basic interface in the IEC61499 runtime, and able to test with different loads, and KPI measurements for CPU, Memory, event latency and partly delay.

Table 11: Test-cases of Tech. Comp. "IEC61499_OPCTUA_SC" of WP4

Tech. Component ID "empty" = same as row before Use unique component/interface Identifier from D6.1	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical Use KPI of D6.1, or define new	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_OPCTUA_SC	Server read	CPU<50%[C]		Synthetical testapplication [ST]
	Server write	CPU<50%[C]		[ST]
	Client read	CPU<50%[C]		[ST]
	Client write	CPU<50%[C]		[ST]
	Client connect	CPU<50%[]		[ST]
	anonymous			Setting for testcase
	user			Setting for testcase
	Text message			Setting for testcase
	Encrypted message			Setting for testcase
	Wireless			Setting for testcase
	Wired			Setting for testcase
	SoftPLC and Edge Gateway (Harmony P6)			Setting for testcase
	External OPC UA Client			Setting for testcase

Table 12: Test-cases of Tech. Comp. "IEC61499_HTTP_to_cloud" of WP4

Tech. Component ID "empty" = same as row before Use unique component/interface Identifier from D6.1	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical Use KPI of D6.1, or define new	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
---	--	---	--	---------

IEC61499_HTTP_to_cloud	Communicate the data assigned over the network	CPU<50%		IEC 61499 function block. Setting for testcase
------------------------	--	---------	--	--

4.3 Digital twin configuration, edge AI and deep learning

A series of tests will verify the software components' functionalities representing the intelligent agents used in the Reepack use case. In particular, for the AMR jobs Scheduling algorithm and for the machine learning-based predictive model used to predict the battery level of the single AMR.

The tests will focus on the following different aspects:

- testing the auxiliary components constituting the interconnectivity layer with other (/external) software components, such as the production line software or the AMR on-board software.
- testing of auxiliary components able to handle the data to/from the algorithms.
- testing the algorithm's functionalities.

Table 13: Test-cases of Tech. Comp. "RWG_MISSIONS_TO_JOBS" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
RWG_MISSIONS_TO_JOBS	Mission List Reading			Python
	Jobs list Creation			Python
	Jobs lists Publication			Python/MQTT/ OPC-UA

Table 14: Test-cases of Tech. Comp. "RWG_AMR_STATUS_UPDATE" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
RWG_AMR_STATUS_UPDATE	Status update Request			Python
	Status update			Python – Alerts included
	Status Publication			Python/MQTT/ Alerts published separately

Table 15: Test-cases of Tech. Comp. "RWG_LAYOUT_TWIN" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
RWG_LAYOUT_TWIN	Layout Master Records initialization	< 1sec		Python – reading from csv files
	Layout status updates			Alerts are also generated
	Layout status publication			Phyton/ MQTT - Alerts are published separately

Table 16: Test-cases of Tech. Comp. "RWG_RESOURCE_TWIN" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or test-case]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
RWG_RESOURCE_TWIN	Resources Master Record initialization			Python – reading from csv files Activation via RWG_AMR_DYNAMIC_DISCOVERY_RECONFIGURATION
	Resources Status Update			Python, linked via components - RWG_AMR_STATUS_UPDATE
	Status & Alerts Publishing			Phyton/ MQTT

Table 17: Test-cases of Tech. Comp. "RWG_RESOURCES_SET_TWIN" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or test-case]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
RWG_RESOURCES_SET_TWIN	Fleet(s) Master Record initialization			Python Function
	Fleet Dynamic Update			Python, MQTT linked via components - RWG_AMR_STATUS_UPDATE
	Fleet Composition Publishing			Phyton, MQTT

Table 18: Test-cases of Tech. Comp. “RWG_AMR_RE-SCHEDULING_TRIGGER” of WP4

Tech. Component ID “empty” = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI “C” = Critical “empty” = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result “OK” “NOK” “empty” = not validated	Comment
RWG_AMR_RE-SCHEDULING_TRIGGER	Initialization			Python Function
	Scheduler launch/ call			Phyton / MQTT
	Scheduler Responses Monitoring & Alerting			Phyton / MQTT The trigger monitors the Scheduler responses and generate alert

Table 19: Test-cases of Tech. Comp. “RWG_AMR_FLEET_SCHEDULER” of WP4

Tech. Component ID “empty” = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI “C” = Critical “empty” = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result “OK” “NOK” “empty” = not validated	Comment
RWG_AMR_FLEET_SCHEDULER	Input Data Loading			Python function / Restful API / MQTT /
	Schedule Generation & Schedules update /	Coherence of the output Computational load & time adequate		Python function – assignment of jobs to AMR
	Schedule Publishing			Python / MQTT
	Alerts Generation & Publishing			Python / MQTT

Table 20: Test-cases of Tech. Comp. “RWG_AMR_BATTERY_LEVEL_PREDICTION” of WP4

Tech. Component ID “empty” = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI “C” = Critical “empty” = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result “OK” “NOK” “empty” = not validated	Comment
RWG_AMR_BATTERY_LEVEL_PREDICTION	Historical dataset loading	< 1sec		Python Function /MQTT / RESTful API OPC-UA
	Training Process /Model performance			Phyton function
	Model Saving			Python function

	Prediction Generation			Phyton function
	Forecast Publishing			

FEDERATED LEARNING MODULE (Server & Client)

Table 21: Test-cases of Tech. Comp. "Federated Learning (Server Module)" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Federated Learning Server Module Federated Learning module (Server & Client)	To test Federated Learning server and client modules, a model will be trained over on several clients and results as well as metrics will be evaluated.	Communication efficiency		The amount of data transferred from the server to the client in each communication round. Minimizing communication overhead is important.
		Model convergence (C)		The number of communication rounds required for the federated model to converge or reach a satisfactory performance level. Faster convergence is desirable.
		Shared Model performance improvement (C)		Measure the improvement in model accuracy over rounds of training. The goal is to see consistent improvement
		Server Computational Resources Consumption		Resource usage (CPU, memory, etc.) will be monitored during the federated learning process to ensure efficient usage.
		Federated vs central model performance		The performance of the shared model will be evaluated against the performance of an equivalent model trained centrally.

Table 22 Test-cases of Tech. Comp. “Federated_Learning_Client” of WP4

Tech. Component ID “empty” = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI “C” = Critical “empty” = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result “OK” “NOK” “empty” = not validated	Comment
Federated_Learning_Client	To test Federated Learning server and client modules, a model will be trained over on several clients and results as well as metrics will be evaluated.	Communication efficiency		The amount of data transferred from the client to the server during each communication round. Minimizing communication overhead is important.
		Data privacy (C)		Assess the effectiveness of privacy-preserving techniques employed to ensure that individual device data remains protected.
		Model Update Efficiency		Track the time taken by the client to process updates from the server and apply them to the local model. Faster updates improve responsiveness.
		Local Model Performance		Evaluate the local model's accuracy, precision, recall, or any other relevant metrics after each FL round. Ensure that the model is improving.
		Computational Resources Consumption		Resource usage (CPU, memory, etc.) will be monitored during the federated learning process to ensure efficient usage.

4.4 Federated transparent, flexible, and trustable data infrastructure and DevOps tools for continuous data-driven models

Collection Platform

The concept behind the Collecting Platform is to retrieve different types of data in the shop floor and route them to specific targets. The goal of this platform is to facilitate the integration between the industry 4.0 domain with their own formats, data types and protocols, and the IT/OT domain that has other types of information. The testing of this component resides on the capability to gather the data from the shop floor, clean/aggregate them and store them inside the databases/repositories used.

Table 23: Test-cases of Tech. Comp. "Collection Platform" of WP3

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Collection Platform	Demonstrate that the Zero SWARM Collection platform can collect, store and aggregate/clean data from different sources (physical network infrastructure, NFs, AFs, services, external data repositories)	Data are stored correctly on the databases/repositories used		The validation will be done by viewing the log of the collection platform and querying it
	Demonstrate that the Zero SWARM Collection Platform offers a query and subscribe/notify interfaces to access these monitoring data from external functions.	Data are retrieved using the Collection platform interfaces.		The validation will be done by viewing the log of the collection platform and querying it

MLOps Framework

The MLOps framework aims to decentralize the learning process with the objective to not move sensible data across the network. The data that resides in the Collection platform are used to train federated models without the overhead of moving them. The following testing table describe the test phase to accomplish in order to validate the whole framework.

Table 24: Test-cases of Tech. Comp. "MLOPs_framework" of WP3

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
MLOPs_framework	Demonstrate that the MLOps Framework can gather the data from the collection platform via API.	Retrieve of data		The validation of all the testcase will be done viewing the log of the MLOps framework.
	Demonstrate that the MLOps Framework can train a model with the data gathered from the edge.	Train successful		The validation of all the testcase will be done viewing the log of the MLOps framework.

	Demonstrate that the Gitlab platform can trigger the MLOps pipeline	Pipeline successfully triggered and correctly executed		The validation of all the testcase will be done viewing the log of the MLOps framework.
	Demonstrate that the data aggregation and processing layer of the MLOps framework aggregates correctly the model trained on the edges.	Model aggregated correctly		The validation of all the testcase will be done viewing the log of the MLOps framework.
	Demonstrate that the whole trained model is deployed on each edge and infers the right results.	Deploy done		The validation of all the testcase will be done viewing the log of the MLOps framework.

Data Auditing Module

The data auditing module handles the audit of collected data and actions needed to improve the performance of the federated model trained. The tests will evaluate the impact of the auditing module on the model performance.

Table 25: Test-cases of Tech. Comp. "Data_auditing" of WP4

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Data_auditing	To test the Data Auditing module client datasets will be audited and then Federated training a python script simulating federated training will be used to evaluate the benefits of data auditing.	Model performance improvement (C)		The performance of the federated model after training will be evaluated before and after data auditing to measure the effectiveness of Data auditing module
		Data Loss		The percentage of data lost or discarded during auditing will be measured.
		Audit coverage		Percentage of data used during the audit.

5 Functional tests concerning the Industrial Automation Platform with their applications and interfaces

5.1 Distributed automation to sustain deployment of real-time and anytime applications in the Edge

5.1.1 South to North Bound Communication in the IEC61499 automation platform

A synthetic test application is going to be developed, able to test south to north bound communication for OPC UA [5] and MQTT [4] basic interface in the IEC61499 runtime [9], and able to test with different loads, and KPI measurements for CPU, Memory, event latency and partly delay.

During the continuous development of the IEC61499 automation platform by SE/NX-SE [7] [8] it is needed to extend this platform with additional Service Function Blocks e.g. for MQTT services, which needs to be rebuilt and test the platform, before using it in the trials.

The semantic for OPC UA and MQTT messages is built by the real IEC61499 application [6] in the trials once the FB structure is built for the different services, by the IEC61499 application of the trial.

The tests run on selected hardware edge devices (e.g. SE M262dPac) and on an edge gateway (e.g. SE Harmony P6 [11]) with different cyber security settings.

Table 26: Test-cases of Tech. Comp. "IEC61499_OPCUA_SC" and "IEC61499_MQTT_PS" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_OPCUA	Server read	CPU<50%[C]		Synthetical testapplication [ST]
	Server write	CPU<50%[C]		[ST]
	Client read	CPU<50%[C]		[ST]
	Client write	CPU<50%[C]		[ST]
	Client connect	CPU<50%[C]		[ST]
	anonymous			Setting for testcase
	user			Setting for testcase
	Text message			Setting for testcase
	Encrypted message			Setting for testcase
	Wireless			Setting for testcase
	Wired			Setting for testcase
	Edge Device (M262)			Setting for testcase
	SoftPLC and Edge Gateway (Harmony P6)			Setting for testcase
	External OPC UA Client			Setting for testcase

	AI RT system with OPC UA Client			Setting for testcase
IEC61499_MQTT	publish	CPU<50%[C]		[ST]
	subscribe	CPU<50%[C]		[ST]
	connect	CPU<50%[C]		[ST]
	anonymous			Setting for testcase
	user			Setting for testcase
	Text message			Setting for testcase
	Encrypted message			Setting for testcase
	OoS (quality of Service)			Setting for testcase
	Wireless			Setting for testcase
	Wired			Setting for testcase
	Edge Device (M262)			Setting for testcase
	SoftPLC and Edge Gateway (Harmony P6)			Setting for testcase
	External MQTT Broker			Setting for testcase
	Internal MQTT Broker			Setting for testcase

5.1.2 South to North Bound Communication in the IceBlock Edge-Device

A synthetic test application from D5.4, able to test south to north bound communication for OPC UA and MQTT basic interface in the IEC61499 runtime, and able to test with different loads, and KPI measurements for CPU, Memory, event latency and partly delay.

Table 27: Test-cases of Tech. Comp. "IEC61499_MQTT_PS" in IceBlock Edge-Device of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_MQTT_PS	publish	CPU<50%[C]		[ST]
	subscribe	CPU<50%[C]		[ST]
	connect	CPU<50%[C]		[ST]
	anonymous			Setting for testcase
	user			Setting for testcase
	Text message			Setting for testcase
	Encrypted message			Setting for testcase
	OoS (quality of Service)			Setting for testcase
	Wireless			Setting for testcase
	Wired			Setting for testcase
	Edge Device (M262)			Setting for testcase

	SoftPLC and Edge Gateway (Harmony P6)			Setting for testcase
	External MQTT Broker			Setting for testcase
	Internal MQTT Broker			Setting for testcase

5.1.3 South to North Bound Communication for the DigitalTwin

Utilizing the MQTT protocol, the Digital Twin has the capability to engage with both the IEC61499 SoftPLC entities stationed within the Edge Gateway for the integration of the AMR simulation and with the IEC61499 hardware PLC independently for the integration of the virtual commissioning functionality. For both integrations different services are used. Notably, there exists no direct linkage between the Digital Twin and the physical AMR (Autonomous Mobile Robot) device, so for that no testcase must be developed.

Table 28: Test-cases of Tech. Comp. "AMR_Simulator" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
AMR_Simulator	command	<10ms delay		start, stop, pause, resume, move to a destination
	status	<10ms delay		
	action	<500 ms		create, delete, modify

Table 29: Test-cases of Tech. Comp. "VirtualComissioing_Runtime_Engine"

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
VirtualComissioing_Runtime_Engine	3D visualization model	Adequate visual identity (subjective)		The 3D representation of the assets must be created based on end user data (possibly CAD models).
	Kinematics model	Kinematics movement approximation: From 0.5 mm to 1 mm for location precision From 1% to 3% for timing		The kinematics description of the relevant assets must be created based on end user data. Acceptable error depends on the system dynamics.

	Behavioral model	100% accurate approximation of deterministic rules. Statistical approximation of events.		The behavior of the active assets must be modelled based on end user description.
	Simulation model	Process replication error (fully automated): < 5% productivity < 10% timing		The overall simulation model is composed of the assets and their relationships. If human operators are presents, it should be possible to model a statistical approximation of their behavior otherwise the overall system performance is unpredictable.

Table 30: Test-cases of Tech. Comp. "AFOF_WEB_VC_Core" of WP5

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
"empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	[description of the function and/or testcase]	"C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	"OK" "NOK" "empty" = not validated	
AFOF_WEB_VC_Core	Browsing via web browsers	All web page pages, sections, and interfaces are displayed in browser correctly[C]	OK	
	Send data from websocket client to server	Data loss < 5% [C]		Setting for testcase

Table 31: Test-cases of Tech. Comp. "AFOF_WEB_VC_Extensions" of WP5

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
"empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	[description of the function and/or testcase]	"C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	"OK" "NOK" "empty" = not validated	
AFOF_WEB_VC_Extensions	Testing data visualization	Testing dataset is visualized 100% correctly [C]		Setting for testcase
	CRUD (create, read, update, and delete) with the database	Operations executed > 95% [C]		Setting for testcase
	Export report	Exporting report time < 5 min		Setting for testcase

Table 32: Test-cases of Tech. Comp. "AFOF_WEB_VC_SIMULATOR" of WP5

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
"empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	[description of the function and/or testcase]	"C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	"OK" "NOK" "empty" = not validated	
AFOF_WEB_VC_SIMULATOR	Visualizing simulators	Latency < 300ms [C]		Setting for testcase

Table 33: Test-cases of Tech. Comp. "AFOF_WEB_VC_AGENT" of WP5

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
"empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	[description of the function and/or testcase]	"C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	"OK" "NOK" "empty" = not validated	
AFOF_WEB_VC_AGENT	Deploy	Deployment success 95% [C]		Setting for testcase
	Send monitored data to server	Data loss < 5%		Setting for testcase

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
"empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	[description of the function and/or testcase]	"C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	"OK" "NOK" "empty" = not validated	
IEC61499_Manipulator_PID_Control	Control	Least mean square with trajectory < 3 [C]		Setting for testcase
	Connection	Connection loss < 5% [C]		Setting for testcase

5.2 Extension of the IEC-61499 platform to support dynamic setup and reconfiguration of agents

5.2.1 Edge-Device Layer

The edge device layer consists of two main types of technical computing modules, one for interfacing with the ROS2 assets of the existing production cells with the IEC61499 automation platform, and the other one for connecting such assets dynamically to the edge-gateway layer to reschedule the tasks in a reconfigurable manner, which is the main part of D5.3. To connect ROS2 with function blocks in IEC61499, the trial CN2 will integrate and test a ROS2-MQTT Bridge and corresponding MQTT-IEC 61499 interface.

Table 34: Test-cases of Tech. Comp. "IEC61499_ROS2" of WP5

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
"empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	[description of the function and/or testcase]	"C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	"OK" "NOK" "empty" = not validated	
ROS2-IEC61499 Gateway	ROS2 to MQTT message structure and encoding			Human readable message in MQTT received from ROS2 is desired for debugging
	ROS2 to IEC61499 Eco Structure over MQTT message structure and encoding			Messages received in IEC61499 should show interpretable structure and values
	ROS2 to IEC61499 Eco Structure over MQTT and back to ROS2 message structure and	C		[C] Should generate the same message as

	encoding			send
	latency			Low latency to avoid undesired lags during production sequence is desired; Rough estimation is interesting for future research
	Number of subscribers			Additional subscribers will be virtually created; Rough estimation is interesting for future research
	Sampling time, frequency			Rough estimation is interesting for future research

Table 35: Test-cases of Tech. Comp. "IEC61499_DynamicConnector" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_DynamicConnector	Connecting to any available AGV	Creating connections to AGVs with delay < 1s		Setting for testcase
	Dynamic configuration	Being dynamically configured with delay < 500ms		Setting for testcase
	Sending control request	Delay << 200ms		Setting for testcase

5.2.2 Edge-Gateway Layer

In the Edge-Gateway layer are the main technical components, which are responsible for data analytics to reschedule tasks and to organize the dynamic reconfigurability of the production line, as well as the interface and modules for monitoring and supervisory. The trial CN2 will identify the relevant information needed to control a production sequence on a high abstraction level (Recipe Manager) and tests these functionalities by directly calling the ROS2-services from a python script.

Table 36: Test-cases of Tech. Comp. "REENEXT_ARM Module_Scheduling" and "REENEXT_AMR Module_Monitoring" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
---	---	---	---	----------------

REENEXT_ARM Module_Scheduling	By means ReeNEXT ARM Module Interface integrated with ReeNEXT Production Planning Module [10] the Production Manager of Food-Packaging Line fills and manages ARM Missions according to New Production Orders and relative Machine Recipes. The AMR Missions are defined as an Input of ARM Algorithm which return a List of AMR Task with relative priorities.	SN-TB-RPKL-2d1 – not critical		The Validation Activities will impact mainly on: - 5G/WLAN Network Protocol; - OPC-UA Communication Protocol through Machine PLC based on IEC61499; - ReeNEXT DataBase and WebBased Interface for New AMR Module vs. AI Algorithms.
REENEXT_AMR Module_Monitoring	By means ReeNEXT ARM Module Interface integrated with ReeNEXT Live Data Dashboard the Production Manager of Food-Packaging Line monitors ARM Status and Tasks Execution. The AMR Tasks and relative Priority, as Output of AI Algorithm, changes according to AMR Status and Production Orders Scheduling and Re-Scheduling according to AI Algorithms Output Scheduling and Re-Scheduling.	SN-TB-RPKL-2d2 – not critical		The Validation Activities will impact mainly on: - 5G/WLAN Network Protocol; - OPC-UA Communication Protocol through Machine PLC based on IEC61499; - ReeNEXT DataBase and WebBased Interface for New AMR Module vs. AI Algorithms AND IceBlock Device on board to AMR Device.

Table 37: Test-cases of Tech. Comp. “RWG_AMR_DYNAMIC_DISCOVERY_RECONFIGURATION” of WP5

Tech. Component ID “empty” = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI “C” = Critical “empty” = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result “OK” “NOK” “empty” = not validated	Comment
RWG_AMR_DYNAMIC_DISCOVERY_RECONFIGURATION	Initialization			Python Function
	Resource TWING instance creation and initialization			/MQTT / RESTful API via component RWG_RESOURCE_TWING
	Action Publishing			MQTT

Table 38: Test-cases of Tech. Comp. "IEC61499_Scheduler" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_Scheduler	start	C		The execution of a demo program can be started
	Pause			Program sections are allowed to be atomic and still be finished before the pause
	resume			Continue the demo after pause
	cancel	C		Stop immediately
	reset			Enable the execution of the same or a different demo after cancellation (e.g. reset the environment)

Table 39: Test-cases of Tech. Comp. "IEC61499_RecipeManager" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_RecipeManager	Creation of a demo program			
	Loading of a demo program	C		
	Reading of different parameter files ("ingredients")			
	Functionality of FB for AMR driving	C		See D5.1 Section 3.2.3
	Functionality of FB for robotic arm			See D5.1 Section 3.2.3
	Functionality of FB for Assembly Station			See D5.1 Section 3.2.5
	Functionality of FB for Storage Rack			See D5.1 Section 3.2.4

Table 40: Test-cases of Tech. Comp. "IEC61499_GraphDB_Monitoring_Interface" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_GraphDB_Monitoring_Interface	Connect Disconnect Add agent Remove agent Rconfigure agent Retrieve skills Execute SPARQL			Setting for test-case Setting for test-case Setting for test-case Setting for test-case Setting for test-case Setting for test-case

Table 41: Test-cases of Tech. Comp. "FBME_Reconfigurability_Plugin" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
FBME_Reconfigurability_Plugin	Agent connected Agent disconnected Get agent's Skills			Setting for testcase Setting for testcase Setting for testcase

5.3 Validation and Adaptation of IEC-61499 formalism and compile time to ease embedding of AI-focused applications

5.3.1 AI Edge Gateway Platform

There are more edge gateways going to be used in selected trials, where the installation, configuration and selected tests have to be done, before the integration into the trial:

Table 42: Test-cases of Tech. Comp. "IEC61499_Edge" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_Edge_Gateway	Dockerized IEC61499 platform			Selected load test and KPI measurement with the synthetical test application

	AI-runtime with Python-Model			Successful Generation of the AI runtime
--	------------------------------	--	--	---

5.3.2 AI Plugin for the IEC61499 platform and Edge-Gateway functionality

The goal is to test with a simple model and Python algorithm the whole loop between AI modelling and IEC61499 runtime interaction, by following the 4 steps of integration with the IEC61499 runtime:

Table 43: Test-cases of Tech. Comp. "IEC61499_AI_plugin" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
AI_plugin_IEC61499_IDE	Import [12] [13]	< 1sec		Python Function to select
	generate	< 1sec		FB template with OPC UA
	integrate	manual		CAT in CAT
	communication	CPU<50%[C]		Between FB and AI

Table 44: Test-cases of Tech. Comp. "Embedded_AI_Prediction_in_IEC61499" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Embedded_AI_Prediction_in_IEC61499	Call the interface function from the AI-Scheduler TechComponent RWG_AMR_BATTERY_LEVEL_PREDICTION (in WP4) in a dedicated interval for Battery prediction with the Voltage Input from the AMR in TechComponent IEC61499_AMR_Navigation_SN, e.g. each 30 sec and retrieve the indication for the operator			This is a Template FB to test the basic functionality
	Sending Battery Values to AI Model			getting value from AMR or simulation
	Getting Battery Status from AI model			Display for operator

5.4 Ad-Hoc penetration and hypothesis testing plugins

5.4.1 Functional tests and integration steps for the IEC61499 test application with KPI measurement

The test application is going to be developed and tested in a stepwise approach to add more functionality starting with the IEC61499 cross-communication with a synthetic load for the penetration tests. After this is fine, the functionality will be extended with other communication possibilities used in the trials later.

Table 45: Test-cases of Tech. Comp. "IEC61499_testapp" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
IEC61499_test_application	Scalable Value-Simulation and more FB-instances with IEC61499 and mirroring			CATInCAT 4xDO/DI
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	Scalable Value-Simulation with MQTT			4xDI/DO are subscribed my MQTT-Explorer
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	Scalable Value-Simulation with MQTT and IEC61499 mirroring			
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	Scalable Value-Simulation with OPCUA			4xDI/DO are subscribed my OPC UA Expert
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	Scalable Value-Simulation with OPCUA and IEC61499 mirroring			
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	HMI value changes test			4xDO/DI, check changes in the HMI visually

	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	Archiving test			4xDO/DI, check changes in the archive by trends
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			
	Add Algorithm for each DO/DI value change			
	KPI-Measurements for CPU/MEM/Event-Latency for 1/10/100/100			

5.4.2 Penetration and Hypothesis Testing

In the scope of T5.4, CERTH has developed an early-stage laboratory testbed using several tools, in order to simulate the industrial Modbus communication of a CPS (PLC) and start developing and testing both modules. The following figure presents the high-level architecture of the aforementioned industrial testbed, showcasing the used software for simulating particular industrial components. More details about this testbed will be presented in D5.4.

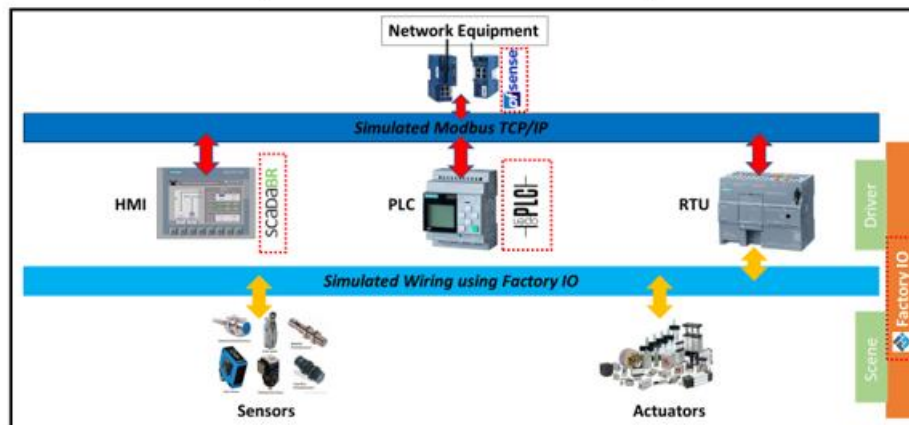


Figure 6: Physical architectural diagram of simulated testbed

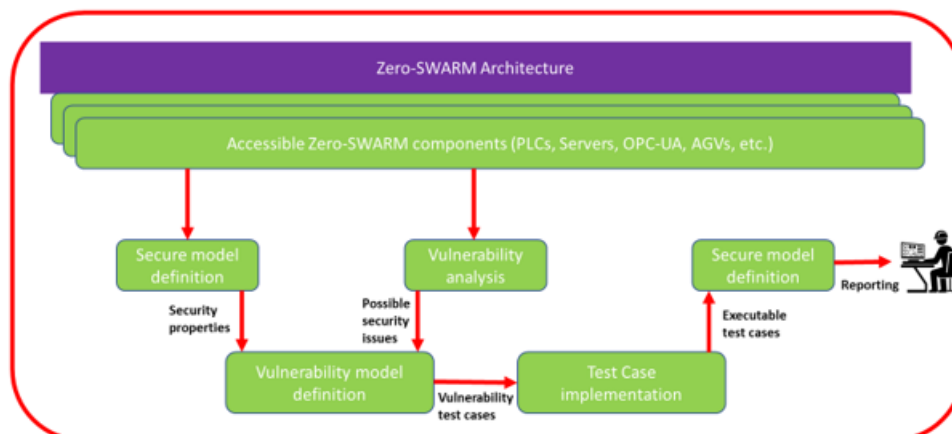


Figure 7: Penetration testing module

As it will be explained thoroughly in D5.4, the Penetration testing module and the Hypothesis testing module are not connected straightforwardly. As depicted in the Figure 8 below, the Penetration testing module (T5.4) informs the Anomaly detection module (T5.5) about possible attack types and vulnerabilities. Then, the Anomaly detection module gives input to the Countermeasure selection module (T5.5) regarding the ongoing attacks and anomalies found in the industrial system. Finally, the Countermeasure selection module informs the Hypothesis testing module (T5.4) about the decided strategy and a predefined list of actions based on the components attacked. This workflow demonstrates the flow of the modules developed in tasks T5.4 and T5.5 and the interaction between them.

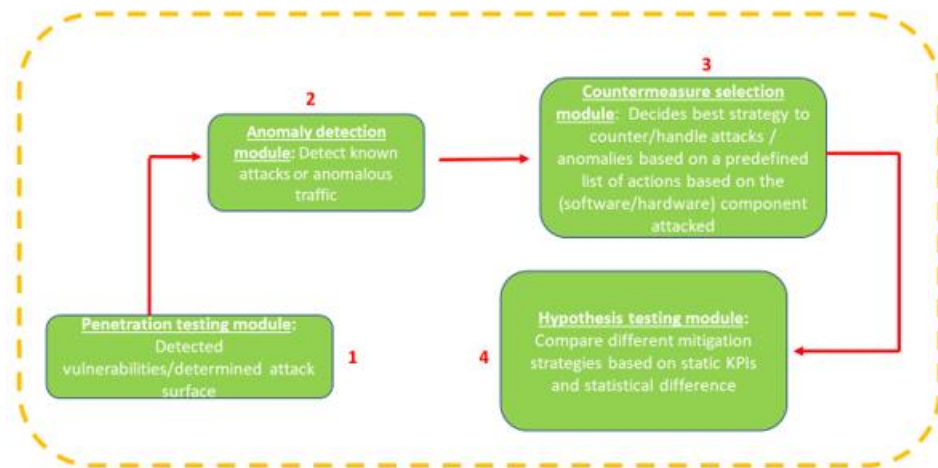


Figure 8: Interconnection of modules from T5.4 & T5.5

The following table presents the Test-cases and KPIs for the 5.4.2 Penetration and Hypothesis Testing modules.

Table 46 Test-cases and KPIs for the Anomaly detection and Countermeasure selection modules of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Penetration Testing Module	In order to examine the vulnerabilities of the industrial automation and control systems, the penetration testing module will be developed firstly being tested with the IEC61499 automation platform simulating a real industrial environment (test application) and in a later stage will be tested securely in the Nodes. Details will be available in D5.4.	Penetration testing time		This KPI will measure the average time needed by the penetration testing.

		Regulatory Compliance (C)		This KPI will measure the compliance of the different automation components with several industrial based regulations.
		Number and severity of vulnerabilities (C)		This KPI will measure the number of risks opposed towards an automation system and will sort the risks based on a scoring system (e.g CVSS)
		Remediation time (C)		This KPI will measure the amount of time to fix the issues found during a penetration test.
		Impact on customers/end Users (C)		This KPI will be measure the impact of any vulnerability found in the automation system, ensuring that the customers or end-users should be affected as little as possible
Hypothesis testing module	The Hypothesis Testing tool will allow the system operator to examine how the application of different countermeasures will affect the CPSoS. This is achieved by comparing the effect of different mitigation strategies based on the static KPIs values and their statistical difference. Since the hypothesis testing module is interconnected to the countermeasure selection module, the Test-cases are fully aligned with those described in the aforementioned tool. Details will be available in D5.4.	Mean Time for countermeasure deployment (C)		This KPI will measure the elapsed time in which the countermeasure will be deployed.

		Mitigation deployment cost (C)		This KPI evaluates the deployment costs of the mitigation actions by considering deployment time, consumed resources and the importance of the device that is affected by the countermeasure as assessed by the network security operator.
		Mean Vulnerability Surface Coverage (VSC) (C)		VSC of a countermeasure is the number of vulnerabilities it covers.
		Mean Common Vulnerability Scoring System (CVSS) (C)		CVSS is an open Industrial standard for assessing the severity of a cybersecurity vulnerability. It will evaluate sort the vulnerabilities based on a 1 to 10 scoring system.
		Runtime latency (C)		This KPI will measure the amount of time the hypothesis testing module takes to process a request.

The Figure 9 below showcases the functional architecture view for the Hypothesis testing module.

Hypothesis testing module architecture

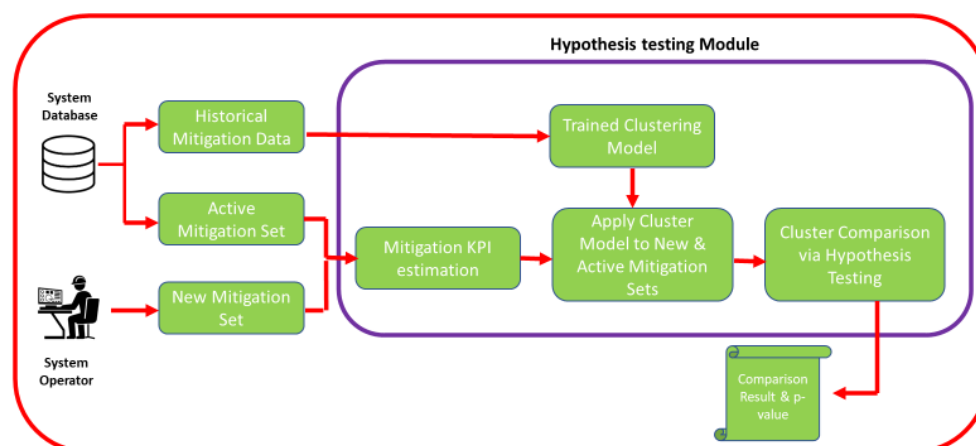


Figure 9 functional architecture view for the hypothesis testing module.

5.4.3 Penetration test module for OPC-UA

S21Sec has implemented a laboratory to validate the OPC-UA penetration test developed in task T5.4. In particular, it has been decided to perform the penetration test on an Open62541 server (which is implemented as an OPC-UA server).

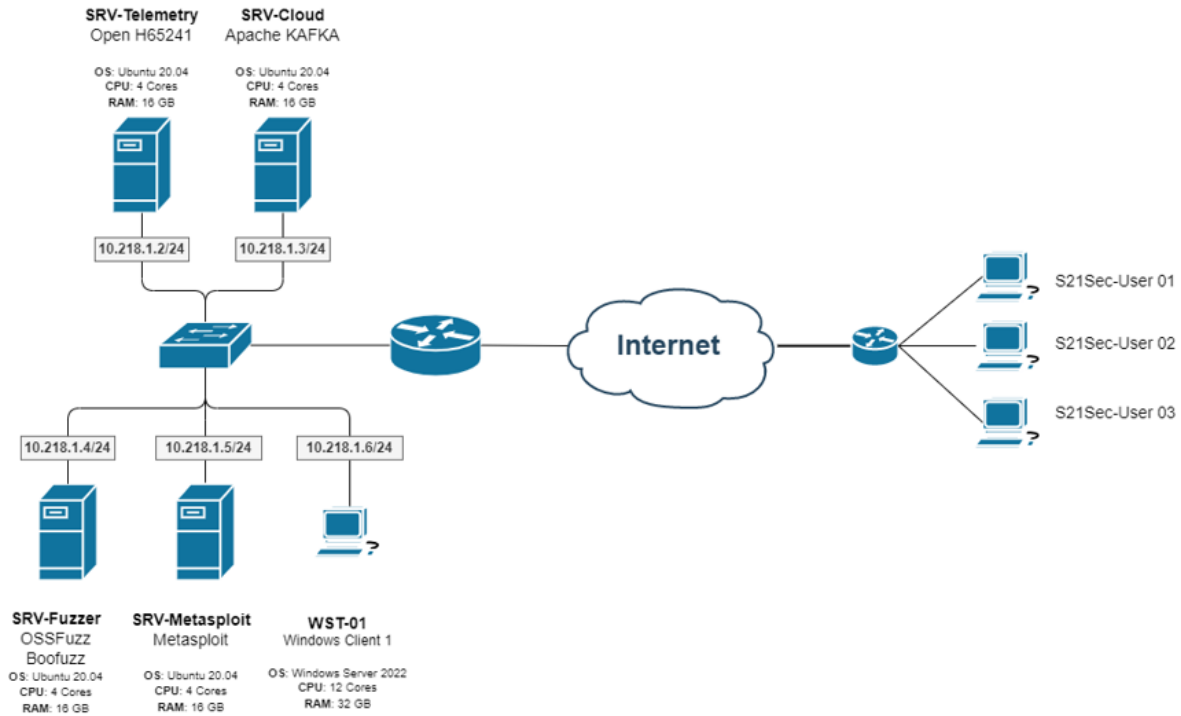


Figure 10: Penetration Test Schema

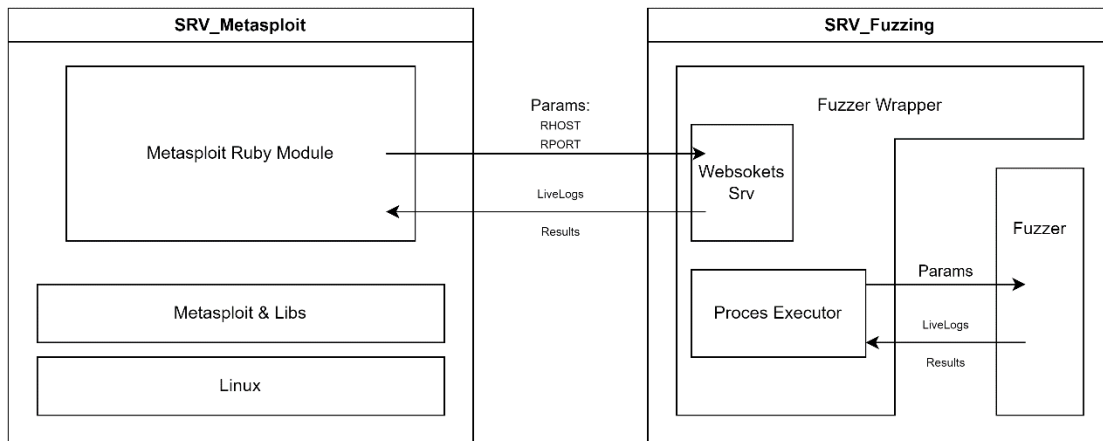


Figure 11: Penetration Test Module

Table 47: Test-cases of Tech. Comp. “OPC-UA penetration test” of WP5

Tech. Component ID	Function/Testcase	KPI	Test-Analysis-Result	Comment
“empty” = same as row before	[description of the function and/or testcase]	“C” = Critical “empty” = not critical Use KPI of D6.1, or define new	“OK” “NOK” “empty” = not validated	
Use unique component/interface Identifier from D6.1				

OPC-UA penetration test	Metasploit extension for OPC-UA penetration test	Number of Metasploit extensions developed and used		It is an extension developed specifically to test for known OPC-UA vulnerabilities. Setting for test-case
	Metasploit extension for OPC-UA penetration by fuzzing	Number of anomalies or vulnerabilities detected by the Metasploit extensions fuzzer		Fuzzing is an automatic testing technique that consists of generating various inputs with the intention of breaking the system. This technique is very popular for finding 0-days (unknown attacks), as it allows detecting previously undetected errors without influencing the system or knowing how it works in depth. Setting for testcase
	Websocket	Time needed to launch the Fuzzer		It oversees making the connection from the Pen tester module to be able to launch the Fuzzer using the necessary parameters. Setting for testcase
	Fuzzer wrapper	Response time from the Fuzzer		The wrapper is the program that allows direct control of the fuzzer via a websockets server. The necessary parameters are received from the client (which would be the metasploit module). Setting for test-case

5.5 Anomaly detection and countermeasure selection modules

5.5.1 Cybersecurity event detection and response scenario

The Figure 12 presents the scenario for the detection of cybersecurity events and the response to the alerts generated from the incident detection system. The scenario is divided in 3 steps:

- 1) Monitored endpoint: An agent installed in the endpoint will be in charge of read different logs from the monitored system or applications running on it (which also can be considered as an input an IDS connected to mentioned monitoring agent). This agent detects different security events (for example: authentication errors, software/malware installation, unwanted file changes or networks attacks) from the sources we have explained.

- 2) Incident detection system (SIEM): A different device will consolidate in the Incident detection system, collecting the events from different sources considering as monitored endpoints, feed from different sources via agents, syslog or others. The SIEM system correlates data to detect and respond to security incidents in real-time.
- 3) Incident response system (SOAR): In a third device the incident response system, will gets all the alerts generated by the SIEM. Incident response plan outlines procedures for detecting, reporting, and mitigating security incidents. Concrete parts of the incident response procedures will include incident triage, containment, eradication, and recovery steps.

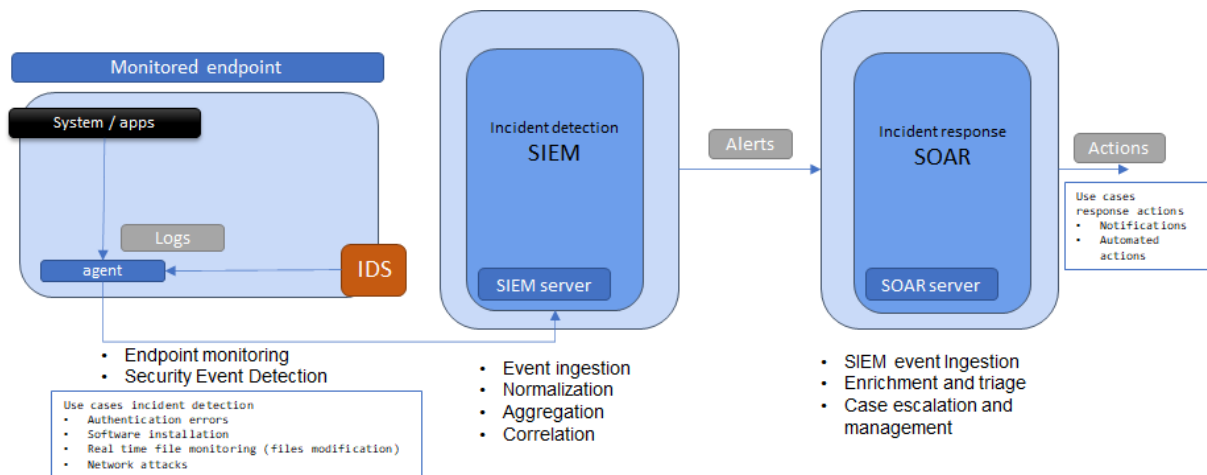


Figure 12 Cybersecurity event detection and response scenario

Table 48: Test-cases of Tech. Comp. "Cybersecurity detection module" of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Cybersecurity detection module	SIEM	Number of cybersecurity events detected per day (C)		This component is responsible for collecting, normalising, aggregating and correlating events collected from different agents. It also has a dashboard where the cybersecurity status of the monitored components can be analysed in real time. Setting for testcase
	SIEM Agent	Number of alerts generated per alert, per day		This agent is installed on all systems to be monitored. It is connected to system logs and an IDS installed on the same equipment and is responsible for collecting cybersecurity events and sending them to the SIEM. Setting for testcase

	IDS	Number of intrusions detected per day (C)		This component is responsible for detecting possible cybersecurity intrusions in the monitored unit. Setting for testcase
Cybersecurity response module	SOAR	Number of cybersecurity responses implemented per day (C)		This component receives the consolidated alerts from the SIEM, enriches and triages them and presents them in a cybersecurity case management environment. Through this environment, the cybersecurity operator can launch the necessary responses to mitigate the detected alert. Setting for testcase

5.5.2 Anomaly Detection and Counter Measure Selection Module

The anomaly detection tool will monitor and analyse cross layer and machine-to-X communications to detect anomalous traffic that might indicate adverse actions against the system, by behavioural analysis of the data flows. The tool will utilize deep learning AI and it will perform near-real time. Additionally, suspicious traffic will be further analysed in order to try and classify it to a specific attack type. The following table presents the Test-cases and KPIs for the Anomaly detection and Countermeasure selection modules.

Table 49 Test-cases and KPIs for the Anomaly detection and Countermeasure selection modules of WP5

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or testcase]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment
Anomaly_Detection_Module (Anomaly_Detection_Agent and Anomaly_Detection_Core)	To test the Anomaly Detection Module a python script launching multiple attacks against the system components will be used. Details will be available in D5.5.	Anomalous traffic detection Accuracy (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Mean Time to detect anomalous traffic (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Area Under the Curve (AUC) for Anomalous traffic detection		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.

		Attack type classification Accuracy (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Mean Time for Attack type classification (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		AUC for Attack type classification		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Deep Packet analysis classification Accuracy (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Mean Time for Deep Packet analysis classification (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		AUC for Deep Packet analysis classification		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Throughput consumption		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Power consumption		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.

		Computational Resources Consumption		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
Counter_Measure_Selection_Module _Module (Counter_Measure_Selection_Module _Agent and Counter_Measure_Selection_Module _Core)	To test the Counter measure selection Module, a python script simulating multiple attacks detected against the system components will be used. The number of the attacks detected will be scaled up to evaluate the behavior and results of the module. Details will be available in D5.5.	Mean Time for countermeasure deployment (C)		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Mitigation deployment cost (C)		This KPI evaluates the deployment costs of the mitigation actions by considering deployment time, consumed resources and the importance of the device that is affected by the countermeasure as assessed by the network security operator. It will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Mean Vulnerability Surface Coverage (VSC) (C)		VSC of a countermeasure is the number of vulnerabilities it covers. It will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.

		Mean Common Vulnerability Scoring System (CVSS) (C)		CVSS is an open Industry standard for assessing the severity of a cybersecurity vulnerability. It will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Throughput consumption		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Power consumption		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.
		Computational Resources Consumption		This KPI will be measured both in the Agents and in the Core to evaluate the most efficient place to deploy said functionality.

Figure 13 contains the functional architecture view for the Anomaly detection and countermeasure selection modules.

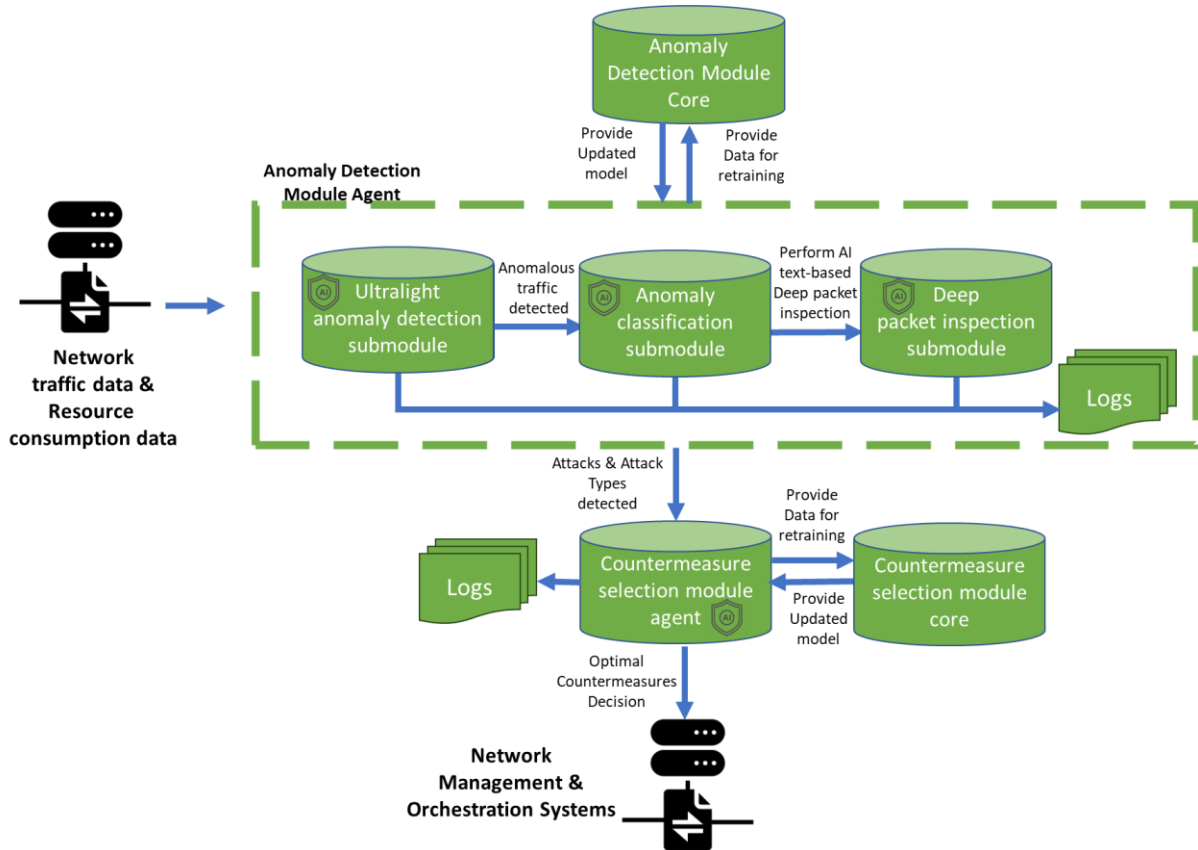


Figure 13 Functional architecture view for the Anomaly detection and countermeasure selection modules.

6 Micro services in secure 5G edge cloud continuum

The 5G edge cloud continuum provides possibilities that other wireless communication technologies are not providing. Thereby micro services on edge devices will become possible which were previously not possible or only possible with great effort. This section describes the development of new micro services that benefit from the new 5G technology.

As one of the micro services an enhanced environment perception service is planned in this task, which determines persons or objects in automated areas as a base for future functional safety approaches. Therefore, different sensors (e.g. Lidar, ToF, and Radar or 2D/3D cameras) will be combined with the newly developed 5G edge computing device, where newly developed algorithms will determine relevant objects in the detection area on the edge. The perception results will be transmitted via 5G to e.g. an AGV that could adjust its behaviour. Another micro service will be a map update service for Lidar-based localization systems. Typically, a Lidar localization system is based on an initially provided map with which the system is able to localise. Changes in the environment will be either ignored or only be used in the local localization system. With 5G a new map update service will be enabled to share changes in the environment over the local Lidar localization systems.

6.1 Micro services on the edge with 5G benefits

5G provides possibilities that are not available or very hard to provide in other wireless technologies. These are for example high data rates, high availability, or low latency. Especially applications in the field of automated guided vehicles (AGVs) benefit from these properties.

The following section describes the architecture of micro services on the planned 5G capable edge

computing device “TDC” that will be introduced in Zero-SWARM. This architecture enables a wide spectrum of possible micro services that can benefit from the 5G network, that will be introduced in Zero-SWARM.

Furthermore, some micro services are described that benefits from the 5G network capabilities.

6.1.1 Architecture of micro services on edge devices

The general architecture for micro services on the 5G capable edge computing device “TDC” is shown in Figure 14. The device is running a customized Linux operating system. On top of that Docker is used for the micro service orchestration. Docker is widely used and strongly accepted in industrial applications [1]. Furthermore, Figure 14 shows some of the micro services that will be used for an AGV trial of the Central Node within Zero-SWARM, that will be described in the following section.

6.1.2 Localization and mapping service

AGVs (and generally AMR) have the task to transport goods within a factory or warehouse from one point to another. Therefore, an AGV must be able to communicate wirelessly with a superordinate central to receive new or changed orders. Typically, this will be realized by a wireless router directly on the AGV. Currently, AGVs can only drive on fixed lanes due to safety issues. To enhance the flexibility of an AGV new systems allow a free navigation of the AGV within a factory or warehouse without fixed lanes. This requires a permanent self-localization of the AGV in the factory or warehouse also in changing environment. Lidar-based self-localization systems are very often used in this context. [2] shows one available product on the market that provides the AGV position within a warehouse using lidar sensors.

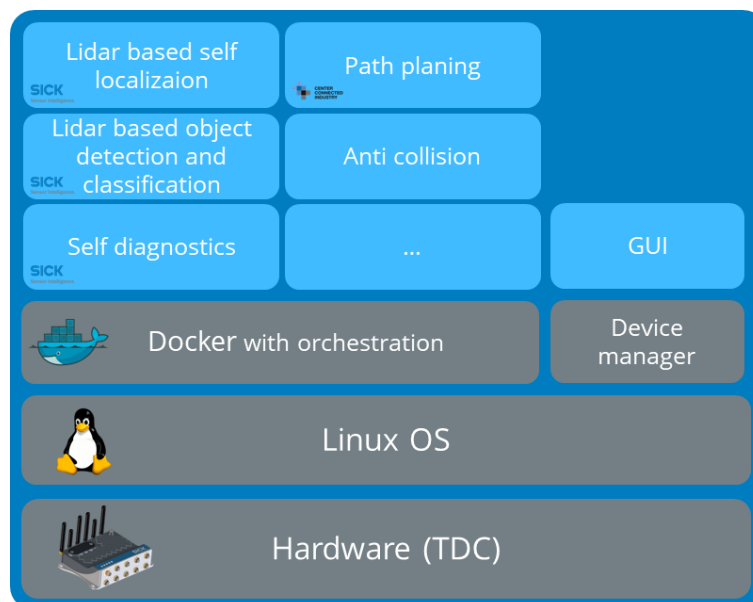


Figure 14: General structure of for micro services on the 5G capable edge computing device “TDC”

Lidar-based self-localization systems works in this way that the current data of a 2D lidar sensor will be compared with a static 2D map. For that comparison typically a nearest-neighbour approach will be used to calculate the lidar sensor position relative to the given map.

This service here will provide both, on the one hand side the generation of the 2D map of the localization area, and on the other side the calculation of the pose estimation within the given map. The results will be provided via the 5G network either with a needed data rate or with a needed latency or with 5G positioning and localization services¹ which are already specified in the 3GPP specifications. For the latter, the availability of the feature on the actual products in the market should be examined, since there is always a delay between the specification at the standard level and the feature deployment in the product.

6.1.3 Environment perception service

An environment perception service is of high importance of flexible AGVs. Typically, AGVs are equipped with safety sensor to avoid collisions especially with persons. If an object is detected in the protection area of the sensors the AGV stops. This leads to a low performance of the overall process of the AGV. A more intelligent environment perception system could increase the performance of the overall transport process of the AGV significantly.

For example, if a person or an object is detected in the path of the AGV, the AGV could do a re-routing of the path to its destination. Furthermore, if the object is moving away from the AGV no safety break must be initiated.

An additional advantage for a local environment perception service in combination with 5G communication is the possibility to transmit the results of the environment perception service to other AGVs and extends so their own field of view. The previously described self-localization service is an essential part of that to transform coordinates of the local AGV system to the superordinate coordinate system of the factory or warehouse.

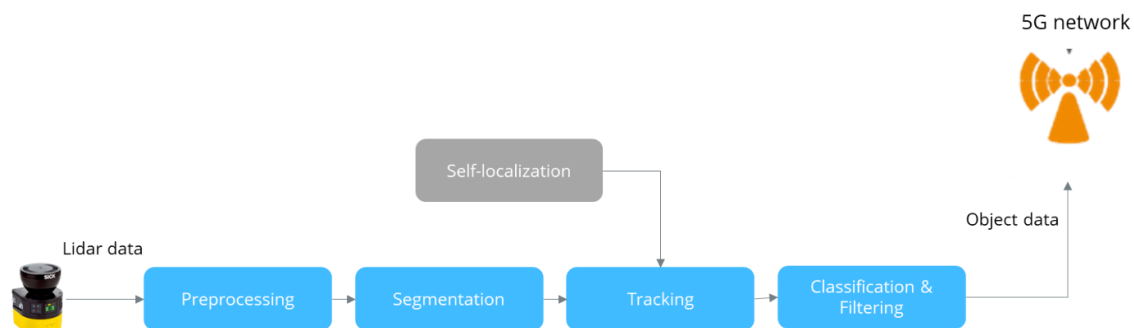


Figure 15: General structure of the data processing pipeline of lidar based environment perception service.

In Zero-SWARM different possibilities of environment perception services are in planning. In the first stage the data of a 2D or a 3D lidar sensor will be used determine objects in the near surrounding of the AGV. Figure 15 shows the general structure of the data processing pipeline of lidar based environment perception service. In the first step the data from the lidar sensor will be pre-processed by removing ground noise or background data. In the next step the remaining data will be combined to so called segments. Segments combines lidar data that are close to each other and might belong to the same real object. In the Tracking-step new segments will be compared and associated to previously determined segments. By comparing selected characteristics of the segments (e.g. centre of gravity) a velocity and an orientation of the object can be calculated. With the absolute position from the self-

¹ <https://www.3gpp.org/technologies/location-and-positioning>

localization service of the AGV the objects can also be transform to the superordinate coordinate system of the factory or the warehouse. A final classification and filtering step provided a classification of the objects (e.g., pedestrian, AGV, unknown object type) and a selection of the final object list. Finally, the calculated object list will be provided via the 5G network, for example via MQTT or a REST API.

6.1.4 Sensor data fusion service

The fusion of distributed sensor data provides a lot of advantages. For example, a data fusion can extend the field of view of an AGV significantly. Figure 16 shows the outline of a data fusion of AGV local environment perception systems an infrastructure-based environment perception systems at intersections. While a vehicle cannot look around the corner and may slow down its velocity for safety reasons an infrastructure-based environment perception system can determine objects in areas that are not visible for the AGV.

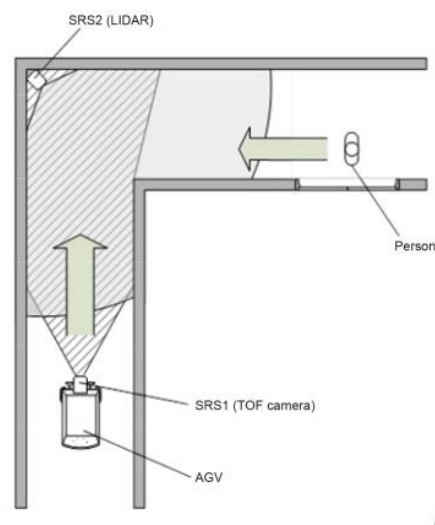


Figure 16: Fusion of onboard sensor SRS1 and infrastructure sensor SRS2; Example from ISO 62998-1:2019 (page 86) [3]

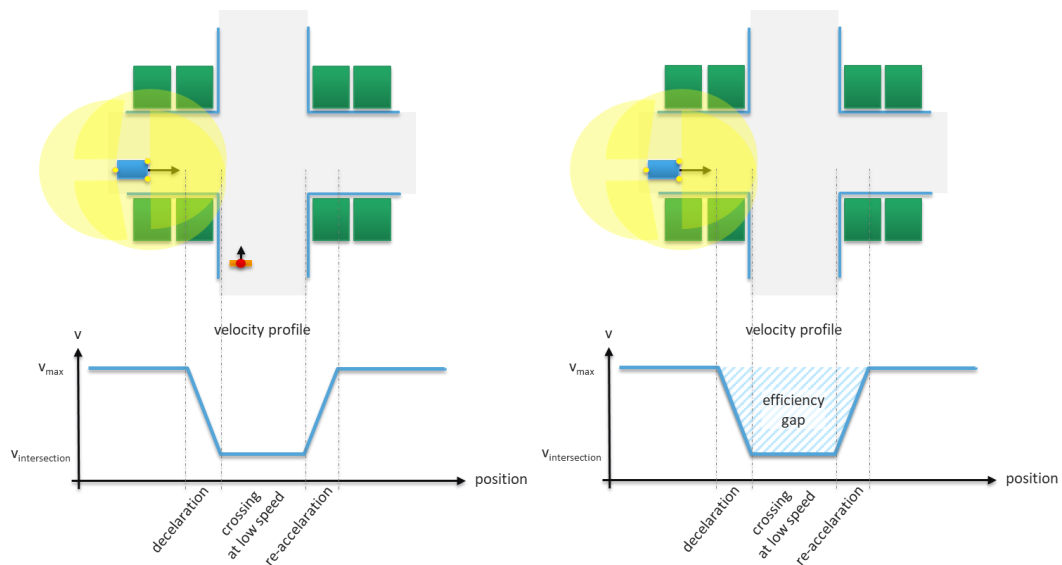


Figure 17: Benefit of 5G capable perception services to close efficiency gaps at intersections with AGVs

This approach is also in planning for future safety considerations and the implementation of risk-re-

ducing measures. The advantage of this approach is shown in Figure 17. If an AGV comes to an intersection, it must slow down because around the corner a person could appear and the AGV must stop in time. But if the intersection is free the AGV must break and accelerate again unnecessarily. An efficiency gap that could be avoided.

The prerequisites for this are on the one hand side the same coordinate system of the data to be merged and on the other side the same time information of the provided data. The goal of the fusion service is to provide a merged and consistent object list based on object lists of distributed perception systems. Figure 18 shows the general structure of the planned fusion service. At first the time information of the received object list must be synchronized. To predict the positions of the received objects to a given time of the fusion service a Kalman filter-based approach will be used in the first step. If all received object lists are synchronized to one time base an object association step will be performed. Characteristics of objects from different perception systems can be combined here together.

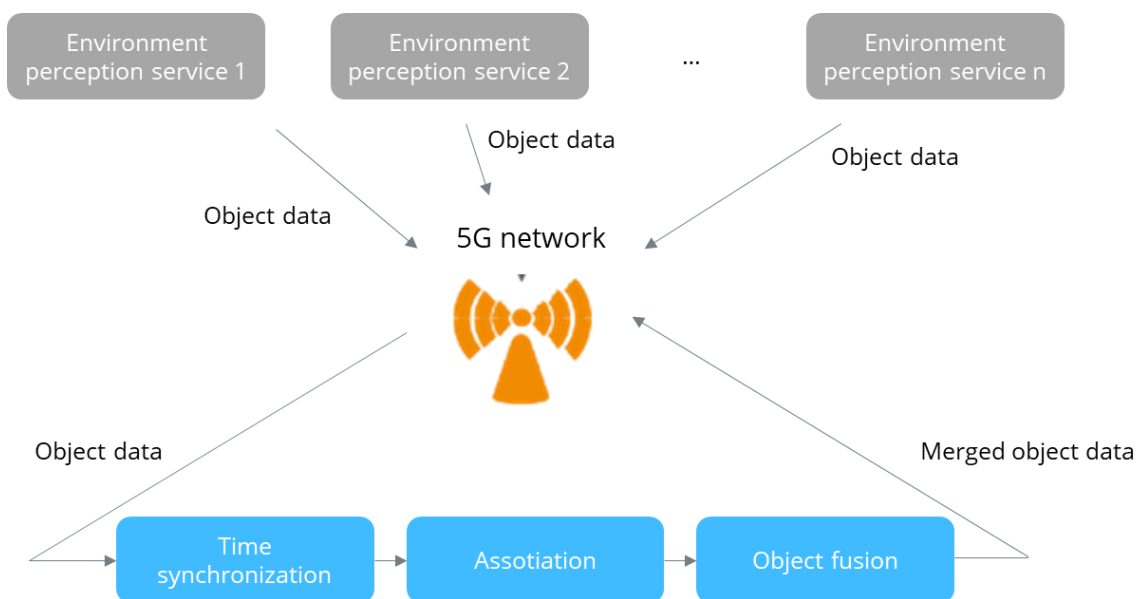


Figure 18: General structure of the planned fusion service

6.1.5 Test-cases

The main Test-cases for the micro-services are summarized in the following table:

Table 50: Test-cases of developed micro-services

Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>	Function/Testcase [description of the function and/or test-case]	KPI "C" = Critical "empty" = not critical <i>Use KPI of D6.1, or define new</i>	Test-Analysis-Result "OK" "NOK" "empty" = not validated	Comment	Tech. Component ID "empty" = same as row before <i>Use unique component/interface Identifier from D6.1</i>
AMR_SELF_LOC	Lidar-based self-localization algorithm			MQTT Message that contains the position of the AGV in the given digital map	

AMR_ENV_PER	Environment perception algorithm on the AGV using 2D or 3D lidar sensor data			MQTT Message that contains a list of objects. An object is characterized by its 2D pose in the corresponding coordinate system (compare to AGV_SELF_LOC), its classification, its size and further characteristics.	
INFRA_ENV_PER	Environment perception algorithm on an infrastructure using 2D lidar sensor data			MQTT Message that contains a list of objects. An object is characterized by its 2D pose in the corresponding coordinate system (compare to AGV_SELF_LOC), its classification, its size and further characteristics.	
FUSION	Fusion of received object lists by environment perception services from mobile AGVs or from infrastructure environment perception systems.			MQTT Message that contains a merged list of objects. An object is characterized by its 2D pose in the corresponding coordinate system, its classification, its size and further characteristics.	

7 Conclusions & next steps

This document presented an overview of the used testing methods and the Test-cases of all technical components, which are updated or newly developed, and later in the second step the trial test scenarios are added to evaluate the functionality of all modules, based on defined KPI criteria's, to ensure the functionality and performance and future indications of the solutions.

One difficulty was, that not all developments are started right now or even finished, to be able to identify the most important test scenarios for the PoC's and to describe all the new evaluation scenarios with the technical components of the demonstrator, which will be part of this next deliverable D6.2 at M30.

Furthermore, some relevant micro services have been described those benefits from the capabilities

of 5G mainly in industrial logistic applications. The next steps will be the finalisation of described services, the trials, and the planned test beds.

References

- [1] <https://www.docker.com/>
- [2] <https://www.sick.com/de/en/localization-and-positioning-solutions/lidar-localization/lidar-loc/c/g541272>
- [3] <https://standards.iteh.ai/catalog/standards/iec/12d221c7-3be4-49b0-a594-6c5204c4b81d/iec-ts-62998-1-2019>
- [4] <https://mqtt.org/>
- [5] <https://opcfoundation.org/>
- [6] <https://iec61499.com/>
- [7] <https://www.se.com/at/de/product-range/23643079-ecostruxure-automation-expert/>
- [8] <https://www.nxtcontrol.com/>
- [9] <https://universalautomation.org/>
- [10] <https://www.reepack.com/en/reenext-industry-4.0>
- [11] <https://www.se.com/de/de/product-range/22953172-harmony-p6/>
- [12] <https://onnx.ai/>
- [13] <https://github.com/onnx/tensorflow-onnx/blob/main/README.md>