

D2.1 - Definition & Analysis of Trials, KPIs & GDPR Compliance (Revised)

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

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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	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
RDF	Resource Description Framework
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

Executive Summary

Zero-SWARM includes 10 trials carried out in industrial experimental facilities over 3 nodes in Europe. During the first six months of the project, partners involved in the trials have worked together to define in detail present and future scenarios, the set-up of the experimental facilities, and identified a number of KPIs to measure the progress of the Trial at level of the System of the system.

The Zero-SWARM Trials are coordinated and managed following the Trial Handbook Methodology, where each trial is developed in several iterations, following a top-down approach, from the whole industrial scenario at high level, through business scenarios, where requirements, architecture and technical implementations are defined, to end up with the technical deployment and demonstration.

The result of this work is detailed in the following sections and is presented in a snapshot below:

- NN01: In cabinet production, the trial relies on digital twins implemented with products adhering to industry standards for various AI and AR use cases.
- NN02: Goals include deploying wireless sensors for advanced machine learning analytics in sustainable powertrains.
- NN03: The trial enhances resilience in mass customized production through remote operation of mobile industrial robots collaborating in different factory locations.
- NN04: Investigating 5G-powered PLCs for real-time communications to enable flexible manufacturing.
- CN01: 5G facilitates safe and autonomous goods transport on factory floors, ensuring low-latency communication between infrastructure sensors and AGVs.
- CN02: Utilizing 5G, AGVs become process-aware mobile manipulators interacting with the production environment.
- CN03: Adapting plug-and-connect 5G industrial network setups for rapid deployment in new locations, providing a seamless experience for industrial users.
- SN01: Aiming for high production efficiency, the trial focuses on a compact automatic packaging line using mobile agents on AGVs.
- SN02: Integrating an automatic packaging line with an edge-cloud continuum for smart maintenance and optimization.
- SN03: Leveraging 5G for remote quality control, ensuring zero-defect resilient manufacturing from initial design to in-line quality control processes.

The present deliverable, initially submitted in December 2022, has received several recommendations from the EC experts to improve the content. The present version 2.0 has been modified in alignment with the received comments. Details of our answers can be found in section 1.3.

1 Introduction

As early as 1971, Russell L. Ackoff¹ had used the term Systems of Systems (SoS) to describe combinations of individual systems that were bound together in some way. He described a collection of task-oriented or dedicated systems that pool their resources and capabilities together to create a new, more complex totality, which offers more functionality and performance than simply the sum of the constituent systems. The implications of this are that the constituent systems may, or may not have been designed to work together, but through some means, they are coupled so that they inter-operate. The ongoing industrial revolution is a good example, which has taken the SoS approach to realize the green and digital transformation or green digitalization. It adopts different digital technologies, either being new software solutions and platforms, data models and data exchange solutions, communication networks, automation technologies, etc. to transform tasks, processes, services or businesses, replacing non-digital or manual actions, aiming for a sustainable production. It calls for technological advancement in several areas such as:

- Connectivity
- Advanced IT solutions
- Automation
- Physical/virtual joint functioning
- Interactivity
- Interoperability
- Self-organization
- Smart decision making
- Virtualizing the assets
- Security support
- Interoperability among devices and systems

The Zero-SWARM ambition is to provide a methodological and technological framework, modular, open and re-usable (to address quick uptake of advanced 5G technologies by European manufacturing sector), for the engineering of the following major aspects of a data-driven, connected, cyber-physical² System of Systems (CPSoS)-based, trusted (safe/secure) production.

Although some amount of ambition is good for motivation to achieve goals and get very far, side effect of excessive ambition is the tendency to focus too stubbornly on one particular vision or end goal. This is what we would like to avoid in Zero-SWARM. Therefore, it is extremely important to frame as best as possible the “why”, the “how” and the “what” about our technical proposals before moving into an engineering phase and build them up.

To this end, it is worth to better understand the ecosystem that our technologies are going to be employed. One way to categorize the landscape of the industrial revolution is to divide it into two major categories from the perspective of “facility”, i.e. building(s), piece(s) of equipment, or service(s) that are provided for a particular purpose. If we accept this definition, then the following major categories can be drawn:

¹ Towards a System of Systems Concepts, Russell L. Ackoff, Management Science, Vol. 17, No. 11, Theory Series (Jul., 1971), pp. 661-671

² Each resource on the shop floor such as machines, robots, transporters, and so on, is an autonomous entity, namely a cyber-physical system (CPS) which is equipped with cognitive capabilities such as perception, reasoning, learning, and cooperation. Cyber-physical system of system (CPSoS) is a collective of networked CPSs

1. **Inside a single facility:** some major changes can be highlighted throughout the history starting from, the first industrial revolution, mechanical production powered by water and steam; the second industrial revolution, mass production based on division of labour and electrical energy; the third industrial revolution, electronics and IT for further automatization of production; and the fourth industrial revolution based on cyber-physical system as we are witnessing it now. Evidently, the industrial revolution will not stop here. It is foreseen that the next step is to change from today's 5-layer hierarchical automatization pyramid to autonomous and connected cyber-physical SoS inside the facility.
2. **Between multiple geographical distributed facilities:** the focus is mainly on the value chain and how the use of smart components (e.g. sensors) and connectivity components (e.g. 5G system) could reshape competition within industries but also could expand industry boundaries. We started moving away from the discrete products to the generation of smart and connected products that allows data to be collected, exchanged and analysed, which unlocks new value for manufacturers and end users. This shift continues with the formation of product systems, which consists of closely related smart connected products (e.g. tractors, platters, tillers, etc.), heading towards products system of systems that links an array of products systems together (farm equipment system, weather data system, farm management system, etc.).

Proposed technological solutions in Zero-SWARM, such as 5G system, possibly could be applied for both categories. However, it is important to keep in mind that under each category the value proposition, i.e. the link between the solution's benefits, features, provided experiences, with the customer's needs, desires, and concerns, should be contemplated with a proper emphasize. For example, while providing **a low latency, higher number of connected devices per antenna, scalability, flexibility and secure and reliable wireless connectivity** are examples of the main value propositions of 5G system inside a single facility; **ubiquitous connectivity, lower OPEX (operational expenditure), and long-term sustainability** could be some of the key points to emphasis in scenarios between facilities, covering a wider geographical location, e.g. a country. Shining light on the potentials emerging from the introduction of Zero-SWARM solutions in the European manufacturing sector is an important attempt that we will pursue in the course of the project, starting from the current deliverable D2.1 which represents the first in-deep assessment of the Zero-SWARM solutions by the partners involved in the context of 10 trials foreseen in the project.

1.1 Purpose of the document

The purpose of this deliverable (D2.1 Definition & Analysis of Trials, KPIs & GDPR Compliance) is to give an overview on the trials that will be conducted during the project inside the Industrial and Experimental Facilities provided by the project's partners.

Particularly, in this document we present:

- The state of the art of the implemented technologies.
- The experimental facilities and their equipment
- The present and future scenario of the trials
- The participants and their role in each Trial.

Finally, this document will set the scene for the development of the trials that will be conducted in parallel with the building of dedicated equipment and pilot sites, and with the design and development

of a common Zero-SWARM architecture and specific technical enablers.

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 an introduction to the Trials of the project
- **Chapter 3** presents an overview on the State of the art of the most relevant technologies that are implemented in the pilot, with the goal of providing the reader with the needed concepts to fully understand the Trials scenario
- **Chapter 4** describes in detail the Trials carried out in the North Node and particularly for each of them it includes: a general description, comprehensive of the facilities where the trial is carried out, participants and role, Trial present and future scenarios, Weaknesses and Bottlenecks to be solved, expected results and KPI and, when relevant, a short GDPR Assessment.
- **Chapter 5** describes in detail the Trials carried out in the Central Node and particularly for each of them it includes: a general description, comprehensive of the facilities where the trial is carried out, participants and role, Trial present and future scenarios, Weaknesses and Bottlenecks to be solved, expected results and KPI and, when relevant, a short GDPR Assessment.
- **Chapter 6** describes in detail the Trials carried out in the South Node and particularly for each of them it includes: a general description, comprehensive of the facilities where the trial is carried out, participants and role, Trial present and future scenarios, Weaknesses and Bottlenecks to be solved, expected results and KPI and, when relevant, a short GDPR Assessment.
- **Chapter 7** presents conclusions and next steps
- **Chapter 8** includes the references cited in the Chapter 3 and throughout the whole document.

1.3 Actions performed to address Reviewers' recommendations

Update September 2023. The present deliverable, initially submitted in December 2022, has received several recommendations from the EC experts to improve the content. The present version 2.0 has been modified in alignment with the received comments. In the following paragraph those recommendations are reported as well as the action performed by the Zero-SWARM consortium to address them.

1. Improve deliverable D2.1 by writing the system reference requirements specifications of CPSoS based on the Zero-SWARM technology according to best industrial practices (see e.g., the ISO/IEC/IEEE Standard 29148:2018 Systems and software engineering – Requirements engineering, the INCOSE Guide Writing Requirements, or the Volere template)
 - To address this recommendation a new section has been added to the deliverable, section 7, where first, in Section 7.1, the methodology on how to collect requirements and

specification is described. Following the experts' opinion, the adopted methodology is based on the Standards ISO/IEC/IEEE Standard 29148:2018 Systems and software engineering – Requirements engineering.

2. In its revised version D2.1 should provide the list of stakeholder needs, the list of system requirement specifications to be satisfied by Zero-SWARM, as well as, consequently, it should analyse those requirements regarding their validation with respect to the stakeholder needs. Also, their correctness needs to be demonstrated, including their consistency and completeness.
 - To address this recommendation, the description of the trials future scenario in Sections 4, 5 and 6, have been updated to include the needs of the stakeholders, i.e. the industrial players or suppliers, partners of the Zero-SWARM consortium, who possess a deep knowledge of the needs of their reference sector in the aspects covered by Zero-SWARM: industrial automation, 5G connectivity, data collection and analysis, distributed control, data spaces, edge and cloud computing, and so on.
 - Based on the needs described by each trial, the list of requirements for each trial has been provided by stakeholders, the list of requirements has then been analysed by the technology providers to ensure consistency, completeness and correctness.
3. As planned in the DoA, a requirements traceability matrix (RTM) must complete this deliverable, thereby tracing the sources of the elicited requirements with respect to the trials. In addition, when revising deliverable D2.1, clearly separate or mark what is background and what is foreground (see section Recommendations “Recommendations 5”).
 - Section 7.2 includes the Requirements traceability matrix, to trace the requirements to needs of the stakeholders and to the technical WP, where they will be fulfilled, and the related technical component, each one of them will be marked as background or foreground.

2 The Zero-SWARM Trials

The ultimate goal of Zero-SWARM is to pave the way towards the innovation sweet spot, offering viable, feasible and desirable solutions, demonstrated in industrial experimental facilities. To realize this vision, the project follows the Trial Handbook methodology designed and developed by Innovalia. It is a method of managing and developing business processes by experimenting, testing, and iterating while developing technological solutions, based on findings from tests and feedback, focusing mainly on the value proposition of the solutions and identify the “must have” items. After the initial assessments done by the project partners, we will work to obtain two main feedbacks:

1. Technical results from the project trials, which examines and verifies the feasibility of the proposed solutions;
 2. Feedback from the end customers and technology early adopters. This practice will be done in the coming months via the project community, where we share questionnaires with the community members and will incorporate their views in the future iteration of the proposed solutions.
- A rich number of testing facilities (16) in 3 main nodes in Europe, North, Centre and South are available in the project. They are existing facilities with prior private and/or public European, national or regional investment, co-created with reputable industry players. In-line with the presented categories of the industrial revolution, Zero-SWARM plans to deliver at least 10

trials over the mentioned facilities, each of which focuses on end to-end proof of concept of the envisioned solutions and their KPI quantification as defined in the project. Table 1 below presents the snapshot of Zero-SWARM trials, which will be detailed in the rest of this text.

#	<i>Trial</i>	<i>Facility</i>	<i>Location</i>	<i>Leader</i>	<i>Focus</i>
NN01	Smart assembly in cabinet production	ABB Finland's factory	Finland	ABB	The key component and enabler of the various AI & AR related use cases in the trial is the digital twin, which will be implemented by using the products which support the related industry standards and guidelines.
NN02	Sustainable powertrains	AALTO Industrial Internet Campus (AIIC)	Finland	AALTO	The trial includes goals for wireless sensors for advanced machine learning analytic to optimized operation, vibration control and prescriptive maintenance needs.
NN03	Improved resilience with remote operation in mass customized production	AALTO Factory of the Future (AFoF)	Finland	AALTO	Remote visualization and control of mobile industrial robots that is able to navigate and perform assembly in different locations at the factory floor in collaboration with other actors.
NN04	5G powered PLCs for real time communications in distributed control systems	Industrial Computing, Communication and Control Lab (AIC3)	Sweden	LTU	Study and measure the 5G powered PLCs for real time communications in distributed control systems. The end goal is to enable flexible manufacturing
CN01	Safe and autonomous transport of goods in the factory shop floors using 5G	Demonstration Factory Aachen (DFA)	Germany	CCI	A safety-critical use case enabled by the 5G information transmission with low latency between sensors placed in the infrastructure and an AGV. A reliable communication with low latency is mandatory. In a further stage, safe and even anticipatory driving and acting of AGVs on the shop floor could be obtained with the sufficient amount of reliable data.
CN02	5G enabled process aware AGVs	Production Technology Center (PTZ)	Germany	FhG	Control of a mobile manipulator (MM), consisting of a small industrial robot arm mounted on an AGV, interacting with its environment in a production facility. Use of data collected over 5G network to make the MM aware of its production environment
CN03	Plug & connect 5G industrial network setups for industrial operations	SMS digital GmbH testbed	Germany	SMS	A mobile 5G network setup is modified and configured to be set-up at new locations in short time following an overall 5G integration framework for productive environments. The approach should deliver a seamless overall experience for industrial users.
SN01	Mobile intelligent agents for integrated re-	Reepack's open innovation laboratory	Italy	PERK	Focus on a compact automatic packaging line, targeting a simplification of a typical industrial application for

	configurability of the zero plastic waste production line				high production. The trial will use the mobile agents, mounted over AGVs, to support a high degree of line re-configurability and automatic transport of packaging materials / products.
SN02	Edge-cloud continuum to support smart maintenance and optimization	Reepack's open innovation laboratory	Italy	PERK	An automatic packaging line fully integrated with automation platform (hardware and software), aiming for smart maintenance and optimization
SN03	5G enabled remote quality control for zero defect resilient manufacturing	Automotive Intelligence Centre and Laser Applications Center	Spain	INNO & AIM	Taking advantage of 5G technologies to ensure the manufacturability, reliability, resilient and quality of a target metal component from initial product design, implementing a zero-defect manufacturing (ZDM) approach ensuring robustness, stability and repeatability of the process by deploying in-line quality control processes among the manufacturing workflow.

Table 1: The snapshot of Zero-SWARM trials

3 State of the art

In this section, we have gathered the state of the art of the different technologies applied in the Zero-SWARM trials.

3.1 5G system

Compared to the previous generations of the mobile communication systems (2G, 3G and 4G) where the main focus was on increasing the data rate to/from the mobile phones, 5G introduced a paradigm shift in the way that we look at the mobile communication systems. In this sense, besides the connectivity throughput, 5G has incorporated the requirements of vertical industries³. 5G is able to offer connectivity services that can feature one or a combination of the following characteristics:

- Enhanced Mobile Broadband (eMBB): to support high bandwidth applications, providing faster download speeds and improved user experiences.
- Ultra-reliable low latency communications (URLLC): to ensure more efficient scheduling of data transfers, achieving shorter transmissions time, and scheduling overlapping transmissions. It supports highly important data transfer that requires low latency and very high reliability.
- Massive Machine-Type Communications (mMTC): to enable a huge volume of small data packets to be collected from large numbers of devices, simultaneously.

One thing worth to mention is that although 5G set a group of requirements and nominal Key Performance Indicators (KPIs), not all of them need necessarily to be used for all scenarios.

³ New markets markets such as automotive, energy, food and agriculture, city management, industry where 5G system can help digitise the economy and contribute towards global digital transformation.

Every generation of mobile communication networks go through a cycle of actions, i.e. Research (basic studies), Vision (ultimately agreed upon at ITU, International Telecommunication Union; level), Requirements (ultimately agreed upon at ITU level), Standardisation (3GPP, ETSI, and others), Launch, and Evaluation. Each step in this cycle might take years. 5G research started around 2008 – 2009 where many industrial and academic entities started to express their views about the 5th generation of the mobile communication systems. In early 2012, ITU set up a program to develop International Mobile Telecommunications 2020 (IMT-2020) vision for the 5G networks, devices and services. This effort was carried out under the ITU-Radiocommunication (ITU-R) sector. The framework and overall objectives of the future development of IMT for 2020 and beyond were published in September 2015. Consequently, IMT-2020 requirements were published in November 2017. 3GPP⁴ and other standards developing organizations (SDOs) were involved in the IMT-2020 requirements contemplation and had already started looking at standards to realize IMT-2020 vision and requirements. The initial version of 5G was accomplished with the freezing of 3GPP Release 15 specifications late-drop in summer 2019. The initial specifications of 5G, Release 15, provided the fundamental architecture of 5G and addressed the first set of crucial enablers, helping vendors to progress rapidly with chip design and initial network implementation during 2019. New features were incorporated in Release 16 in 2020 and based on that some vendors have already provided compliant equipment with this release. Probably, this is the latest type of equipment which can be dominantly found in the market today. Release 16 was a major release and necessary to broaden the overall system specification. It brought extensions to V2X communications to extend automated and remote driving, Industrial Internet of Things (IIoT) and Vertical_LAN, enhancements to URLLC and 5G Time Sensitive Communications, 5G Non-Public Network, numerous energy efficiency, among others. Release 17 features in the pipeline include new work and/or enhancements for URLLC, positioning, etc. Release 17 was frozen in Mid-2022 and soon we will see new emerging 5G equipment based on it. Release 18 is still under preparation at the moment and has not yet been frozen by 3GPP. 5G standardization journey will finish on Release 21 (the first 6G release) which has been foreseen for 2024 – 2025.

All these explanations make it obvious that the majority of 5G pilots and trials out there – that are using commercial (not experimental or pre-version) 5G device, radio and core solutions – are being demonstrated with 3GPP Release 15 and partially Release 16 functions and features. Thus, in this particular trial of Zero-SWARM project, we will also pay special attention on of-the-shelf available state-of-the-art 5G devices, radio and core solutions.

⁴ The 3GPP global initiative ensures that emerging technologies are compatible with usable radio access networks, service and systems aspects, and core networks and terminals, elements that constitute an overall cellular communication system.

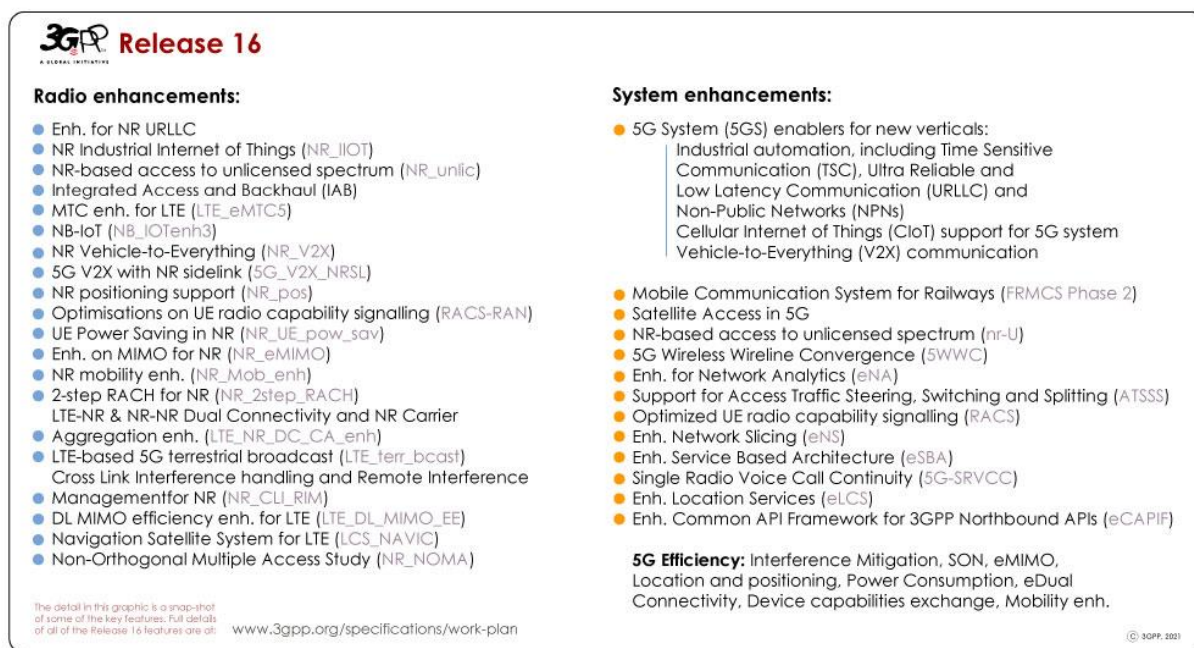


Figure 1 - 3GPP Release 16 Prioritized Features

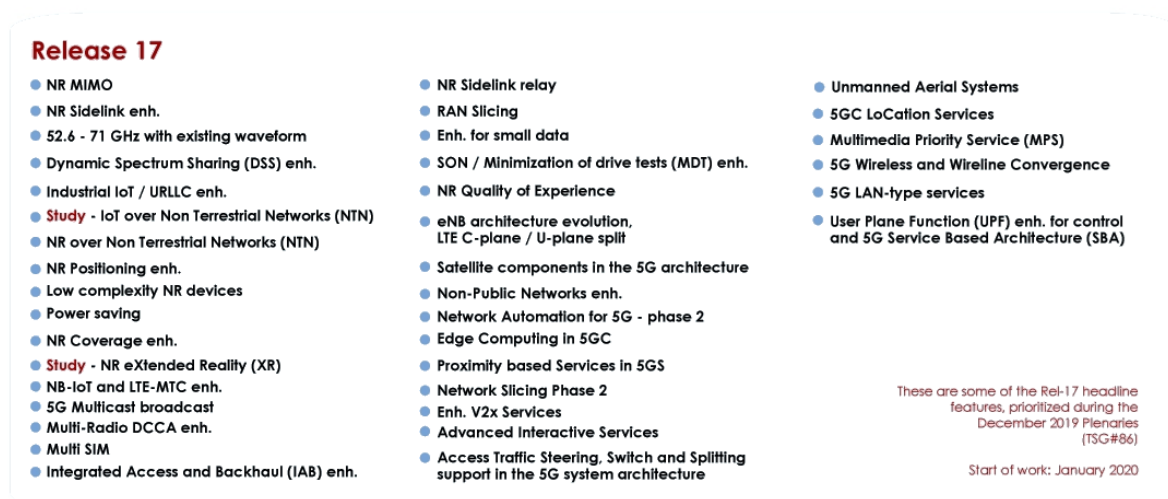


Figure 2 - 3GPP Release 17 Prioritized Features

3.1.1 5G mobile communication in an industrial automation system

In order to be able to deploy 5G for new and diverse use cases in industry 4.0 industrial automation system, there should be a harmonization effort between 5G systems and the communications technologies already used in such industries. For this purpose, 3GPP has made significant progress towards the integration of the 5G system with IEEE 802.1 working group specifications covering Time Sensitive Networking (TSN). This effort has been incorporated in Release-16, the following three distinct enablers:

1. Support for Time Sensitive Communications by seamlessly integrating the 5G system as a bridge to a LAN where TSN toolset functions are active, as specified in IEEE 802.1CM.
2. Support for Non-Public Networks.
3. Support for a 5G-LAN type service.

Besides the mainstream of cellular communication systems standardization and production activities, Industrial automation-related workgroups, such as 5G-ACIA, have been created to provide support to 3GPP as the central global forum for shaping 5G in the industrial domain. Within the working groups of 5G-ACIA, members can introduce or join, so-called “work items”. Work items will be presented among members and in a collaborative and consensus-based way, they will be prepared. The result of these “work items” will be used for several purposes including influencing SDOs like 3GPP, IEC/ISO, etc. So far, 5G-ACIA has influenced the direction of 3GPP to serve the industrial vertical. Some examples from 5G-ACIA that show how to utilize 5G network in a single facility and between multiple facilities are presented in Figure 3 and Figure 4.

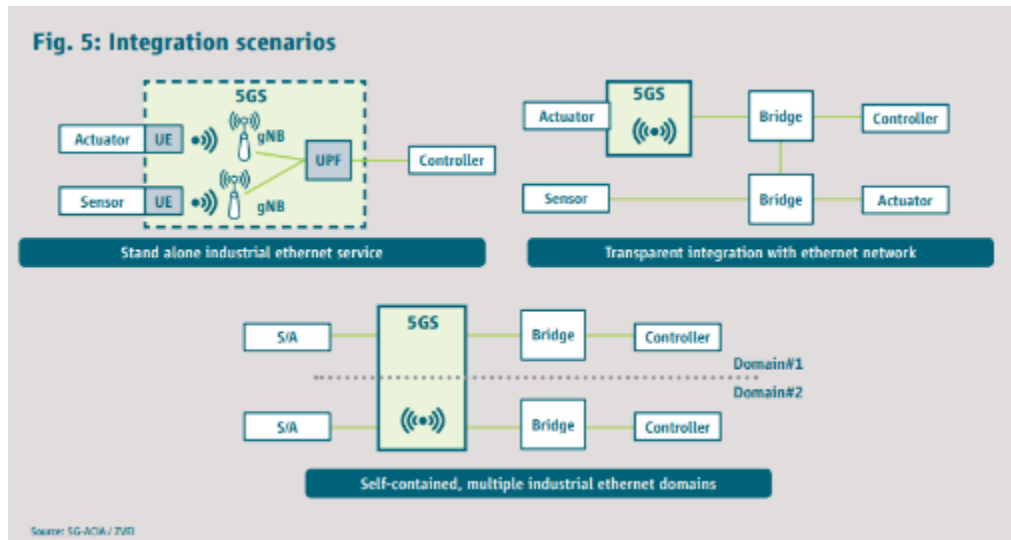


Figure 3 - 5G network utilization in the industrial automation for a single facility category, following 5GACIA/ZVEI

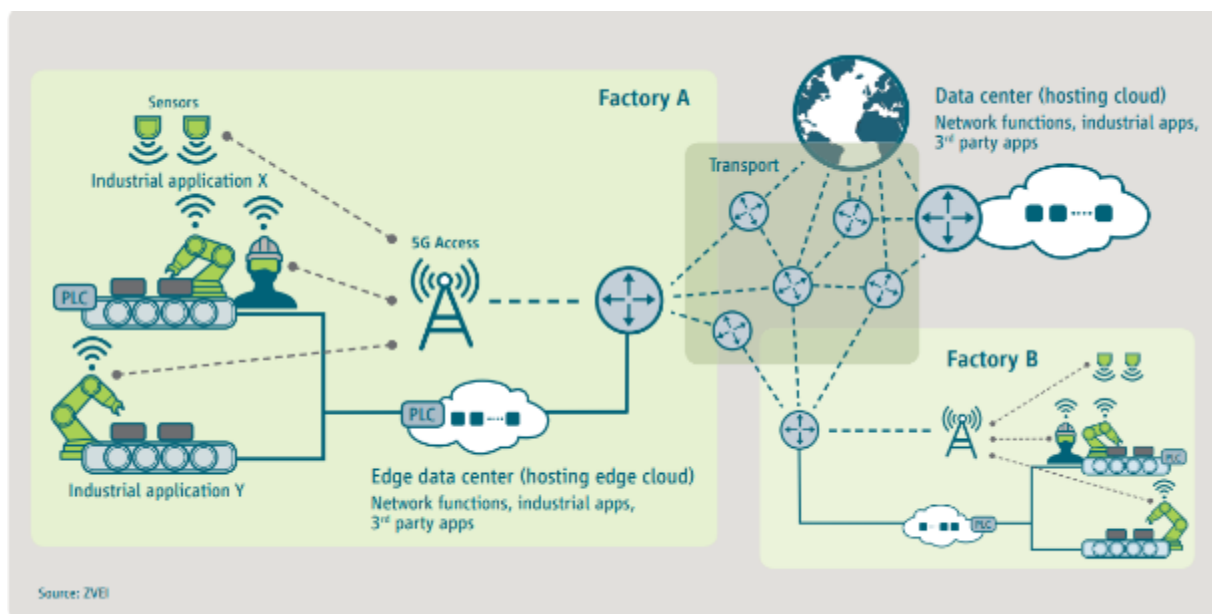


Figure 4 - 5G networks utilization in the industrial automation for between multiple facilities category, following 5GACIA/ZVEI

A private 5G Network is a dedicated and independent private network that can be deployed and managed on an enterprise's site. Private 5G networks are referred to as Non-Public Networks (NPNs)

in 3GPP terminology, which include two main implementations: i) Public Network Integrated (PNI) - NPNs, where the private 5G network is integrated with the public network, e.g. through a slice of the public 5G network, or ii) Stand-alone NPNs (SNPNs), where the private 5G network is isolated from the public 5G network, and contains all required Radio Access Network (RAN) and Core elements.

5G Spectrum licensing

5G spectrum is licensed according to specific use case requirements. In Spain, dedicated spectrum for the trials at the n77-upper band can be requested for experimental purposes. In addition, 26GHz spectrum may become available during the course of the project⁵. Private 5G networks have a vast potential to enable real-time deterministic use cases by providing a secure, reliable, low-latency, high-speed network that was previously challenging. Private 5G networks can take advantage of the technological benefits of 5G while maintaining the security, granular application, and better device control capabilities of a private network. Private 5G networks enable quality-of-service-based priority access compared with public 5G networks. An SNPN 5G network comprises a cloud-native mobile-core network along with the RAN, which further includes gNodeB and a radio unit with antennae. A private 5G network must be integrated End-To-End (E2E) to deliver the required application performance. The integration and testing of private 5G networks can be challenging, given the number of multi-vendor components and technologies involved. Most currently available radios and User Equipments (Ues) in the market support 3GPP-release 15 (5G phase 1), introducing hardware limitations, while most mobile cores support release 16 (5G phase 2).

3.2 OPC UA

OPC (Open Platform Communication) was first defined by a number of players in automation together with Microsoft all the way back in 1995. Over the following ten years it became the most used versatile way to communicate in the automation layer in all types of industry. Over the years it has evolved from the start with simple Data access (DA) over Alarm & Events (AE) to the more advanced Historical Data Access (HDA) to have quite extensive functionality and reach. Though there were always some gaps where it did not cover the needs and requirements from the more and more advanced control systems. It was out of those needs for model-based data and getting more platform independent that resulted in the creation of the OPC UA standard.

The most significant difference between classical OPC and OPC Unified Architecture (UA) is that it does not rely on OLE or DCOM technology from Microsoft that makes it possible to implement it on any embedded or non-embedded platform, with or without real-time capabilities. Another important difference to the OPC DA/AE is that in OPC UA structured and hierarchic object models can be created and reused/instantiated following needs of deployment. This means that the data tags or points can be grouped and be given context, which make governance and maintenance much easier. These models can be identified in runtime, which makes it possible for a client to explore connection possible by asking the server.

⁵ https://portal.mineco.gob.es/es-es/ministerio/participacionpublica/consultapublica/Paginas/Consulta_publica_licitacion_banda_frecuencias_26GHz_prestacion_servicios_comunicaciones.aspx

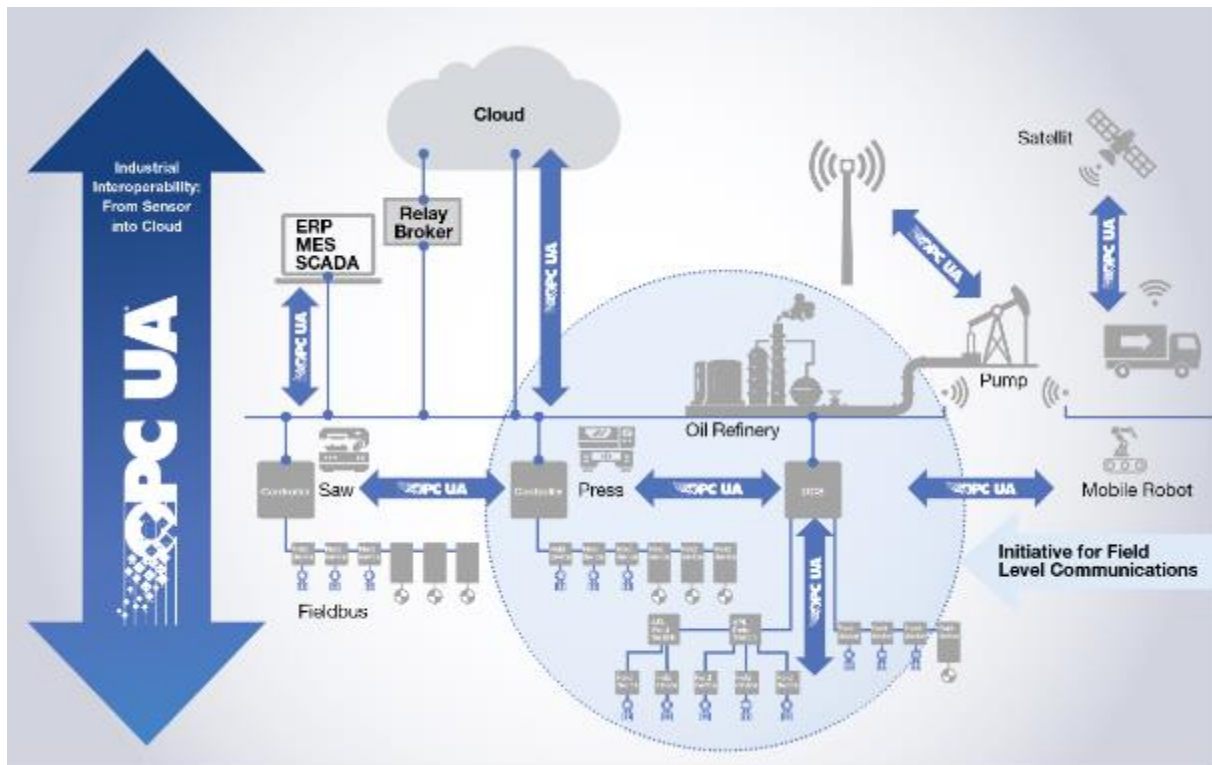


Figure 5 - OPC UA utilization in industrial automation, following the OPC Foundation

The OPC UA specifications partly developed under the OPC Foundation, but also as companion specification, defined under various other organizations such as VDMA. These specifications comprise:

- Information models creations and specification based on a number of object types, already defined in existing OPC UA specifications (core or companion – as defined above) – supporting from digital twins till online operations needing data representation and transfer
- Mechanisms of extending the sets of objects by customized models
- Security mechanisms end-to-end comprising device identity, certificates management, discovery of servers and secure channels of data transmission
- Client-server and publisher subscriber data transmission concept and encodings based on several transport mechanisms (TCP/IP, UDP/IP, MAC-Layer mechanisms and secure communication tunnels)
- Certification model for OPC UA servers and clients

In this platform-independent standard, the communication among various systems and devices can be performed by using Client/Server or Publish/Subscribe communication models. In the OPC UA Client/Server, OPC UA Binary is employed, together with OPC UA XML and JavaScript Programming Language (JSON) data encoding standards to describe how to construct these request/response messages. They are sent through OPC UA Connection Protocol (UACP), OPC UA TCP, and Simple Object Access Protocol (SOAP) over HTTP, OPC UA HTTPS and Web Sockets transport protocols according to the application. On the other hand, the OPC UA Publish/Subscribe (Pub/Sub) uses Message Mappings to specify the network message's structure and encoding. These Message Mappings include UADP and JSON, representing the payloads in the Transport Protocol Mappings for publishing messages, which are OPC UA UDP, OPC UA Ethernet, Advanced Message Queuing Protocol (AMQP) and Message Queuing Telemetry Transport (MQTT).

3.3 Time Sensitive Networking (TSN)

TSN is a set of features, meant to bring the wired Ethernet to a deterministic zero-loss data transmission environment. It was developed as a series of projects of extending the IEEE 802.1 Q specification relating to Quality-of-Service (QoS), adding an improved clock synchronization concept, following the IEEE 802.1AS, a high-availability frame transfer mechanism (IEEE 802.1CB) and an adaptation to front-end of 5G networks by IEEE 802.1CM.

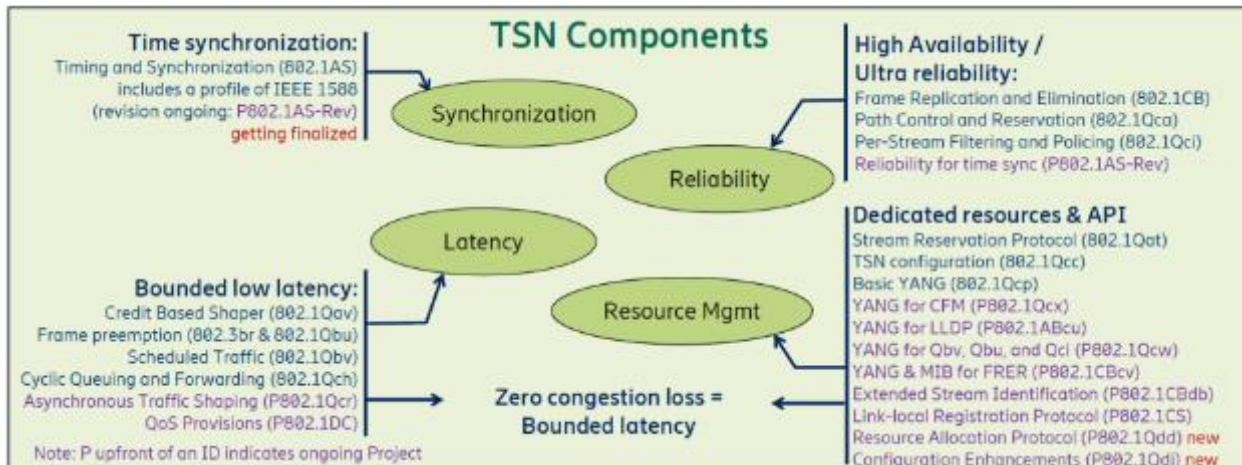


Figure 6 - TSN features and components, according to the IEEE 802.1

A future solution in an Industry 4.0 environment is expected to use standard Ethernet (IEEE 802.3), WLAN (IEEE 802.11) and 5G (3GPP) technologies, combined with enhancements for time-sensitive communication such as the TSN standards specified by IEEE 802.1.

Example of time-sensitive industrial applications

- Controller-to-controller
- Controller-to-device
- Device-to-compute

Industrial time-sensitive applications require:

- Several degrees of deadline stringency for data exchanges/communication as a notion of bounded latency
- Reduced to zero frame-loss, following application layer requirements and tolerance
- Mechanisms for support of clock synchronization with accuracies down to 1 microsecond

Industrial communication (traditional technologies):

- Wired solutions:
 - Traditional solutions: Ethernet-based fieldbuses, e.g. PROFINET, EtherCAT, Ethernet/IP, CC Link IE, Modbus TCP etc. and even the older non-Ethernet based fieldbuses (such as Profibus, CiA, ...)
 - **Problem** (need for compatibility): each technology addresses a particular set of requirements for specific applications. Thus, 'they are compatible from OSI Layer-1 till Layer-3. It means a large variety of protocols and hardware on factory floor, making the required Industry 4.0 interoperability and network management difficult to achieve.
 - **Solution:** IEEE 802.1 TSN Ethernet family has been introduced for real-time deterministic, enterprise-wide, low-latency industrial communication.
 - **Advantage 1:** compatible with standard IEEE 802.3 Ethernet on the physical and higher layers
 - **Advantage 2:** it is expected to cover an independent specification of the OSI Layer-2 and of network management capabilities'

- Wireless solutions:
 - Wireless communication for mobile, rotating and flexible objects is needed, especially for dynamic factories. As applications vary, the network needs to be prepared for such changes. Using cables also makes dynamic arrangements of production lines difficult. Traditional solutions were only limited to the open-loop control and manufacturing execution systems (MES) applications.
 - **Problem:** The main issue on the traditional solutions was the lack of availability, reliability and real time communication.
 - **Solution:** 5G communication systems with increased throughput, reliability, availability and low energy consumption
 - **Advantage 1:** lower installation costs
 - **Advantage 2:** upgrades and modernization of production facilities on a large scale

What does it mean an integrated network?

- Fifth-generation wireless communications (5G) and time-sensitive networking (TSN) technologies are key to future industrial communications. In combination, they offer wireless and wired solutions capable of creating the large real time network needed for industry 4.0 applications.
 - 5G for wireless connectivity (3GPP)
 - TSN for wired connectivity (IEEE)
- Industrial enterprise-wide communication needs to fulfil certain requirements:
 - Guarantee high availability
 - High throughput
 - Real-time transmission
 - Low latency
 - Low jitter
- **How 3GPP and IEEE standardized 5G and TSN technologies can be integrated for industrial communication?** IEEE TSN standardization is evolving, and specification of a TSN profile for industrial automation is currently under development. It is important that the 5G standard remains aligned with this evolution of TSN.
- **In integrated networks, 5G system will simply be perceived as IEEE-compliant virtual Ethernet-TSN bridges.**

Current standardization status:

- Time-sensitive networking (TSN) is a set of novel open standards specified by IEEE 802 to enable Ethernet networks to give QoS guarantees for time sensitive and/or mission critical traffic and applications. It provides deterministic, reliable, high-bandwidth, low-latency communication; it is envisioned as the future-proof wired technology for convergent industrial communication, e. g., for Industry 4.0 and smart factories.
- IEEE standards up to 2022
 - **IEC/IEEE 60802 TSN Profile for Industrial Automation:** It defines a TSN features to support industrial automation. It addresses the issue of compatibility for devices coming from different vendors by focusing on a common set of functions and configurations. It enables interoperability, testing and certifications. The **Field Level Communications (FLC) of the Open Platform Communications (OPC)** aims to provide specifications based on **IEC/IEEE 60802** to achieve a single common multi-vendor converged TSN network infrastructure.
 - **IEEE 802.1AS generalized Precision Time Protocol (gPTP):** TSN standard for time synchronization which is a profile of the **IEEE 1588** precision time protocol (PTP). It allows time synchronization over Ethernet only. Time synchronization is crucial to ensuring the deterministic behaviour of end-devices on time-aware systems. Also, some TSN mechanisms themselves require time synchronization.

- Clock synchronization (shared understanding of time) is required for specific applications and to support TSN scheduled traffic (**IEEE 802.1Qbv**) and probably for per-stream filtering and policing (**IEEE 802.1Qci**)
- Time-division-based resource allocation for various traffic classes is called scheduled traffic. It has been standardized in **IEEE 802.1Qbv** and has been included in **IEEE 802.1Q** (the networking standard that supports virtual LANs (VLANs) on an **IEEE 802.3** Ethernet network. The standard defines a system of VLAN tagging for Ethernet frames and the accompanying procedures to be used by bridges and switches in handling such frames)
- Frame pre-emption specifies how packets of high-priority traffic can pre-empt lower-priority traffic in order to decrease interference. It can be combined with scheduled traffic to decrease interference further. Frame pre-emption has been standardized in **IEEE 802.3br** (now incorporated into **IEEE 802.3-2018**) and **IEEE 802.1Qbv** (now incorporated in **IEEE 802.1Q**)
- **IEEE 802.1Qci pre-stream filtering and policing (PSFP)**: it allows the identification and management of non-compliant traffic, such as intentional and unintentional excess bandwidth usage or incorrect prioritization within a given time interval. PSFP requires the implementation of stream identification as specified by **IEEE 802.1CB**
- **IEEE 802.1CB frame replication and elimination for reliability (FRER)**: it takes care of redundancy in critical applications by defining mechanism for multiplying packets belonging to a given stream (in a transparent way for the application) while avoiding unnecessarily network overload due to frames duplication.

3.3.1 Management mechanisms proposed by IEEE 802.1

- **IEEE 802.1** specifies two main ways for the external configuration of network bridges:
 - Management information base (MIB) files for configuration via the Simple Network Management Protocol (SNMP)
 - YANG modules for configuration via NetConf or RESTconf
 - The proposed architecture includes two modules:
 - Centralized user configuration (CUC): it collects the requirements of the various applications in the network and forward them in collections per stream to the CNC (one talker, multiple listener). Upon configurations of bridges by CNC, CUC forwards the final configurations to the end-devices.
 - Centralized network configuration (CNC): CNC configures the bridges based on the CUC message. The CNC either knows in advance the capabilities and boundaries of bridges via file descriptors, or it can read it at runtime.
 - **IEEE 802.1Qcc-2018**: defines data structures for the requirements per talker and listener, all necessary information for talkers and listeners, and the final configuration
 - **IEEE P802.1Qdj project authorization request (PAR)**: is about enhancements to the centralized configuration. It is expected to be completed in October 2022.
 - **OPC Foundation** is currently defining communications between their end devices and the CUC
- Interworking of 5G with TSN is seen as a major objective in order to make 5G suitable for future Industrial Internet of Things (IIoT) solutions. So far, this effort includes understanding how TSN is applied in a smart factory environment, what kind of integration and interactions with 5G are envisioned, and what functionality is required by a 5G system.
 - The introduction of specifications for ultra-reliable and low-latency communication (URLLC) from Release 15
 - 3GPP release 16 specified 5G support for TSN.
 - Further enhancements are presented in release 17 and beyond.

3.4 Digital Twin

The term digital twin has evolved since its first appearance in 2003 by Grieves⁶ in his course on product lifecycle management. He proposed that a digital twin had three parts: physical product, virtual product and their connections. In 2012, the National Aeronautics and Space Administration (NASA) defined it as “a multi-physics, multiscale, probabilistic, ultra-fidelity simulation that reflects, in a timely manner, the state of a corresponding twin based on the historical data, real-time sensor data, and physical model”. Other companies and researchers have definitions of digital twin using digital twin for more than just simulation. To avoid multiplicity of terms, Industrial Internet Consortium (IIC) has proposed the following definition for digital twin: “Digital representation, sufficient to meet the requirements of a set of use cases.” Digital representation is defined as “Information that represents attributes and behaviours of an entity”. An entity is defined as an item that has recognizably distinct existence, such as a person, an organization, a device, a machine tool, a production line, a subsystem or a group of such items.

- A digital twin is a formal digital representation of an entity, with attributes and optionally computational, geometrical, visualization and other models, offering a service interface for interacting with it, adequate for communication, storage, interpretation, process and analysis of data pertaining to the entity in order to monitor and predict its states and behaviours within a certain context. The content of the digital representation is determined by the set of use cases for which digital twin is designed.
- The industrial systems and the industrial usage scenarios are complex and diverse; therefore, their requirements on digital twin are naturally complex and diverse as well, leading to different flavours of digital twin implementations. Some implementations of digital twin may contain many attributes and data, computational capabilities and perhaps even a formal interface for communication to satisfy the application requirements, some others may only need a small set of attributes and data to be sufficient to support their application.
- A digital twin construct organizes and enables access to the data in association with its corresponding real-world objects from an Operational Technology (OT) perspective, rather than the usual data tables in databases from an IT perspective, making it better suited for running computational models and developing applications.
- With a digital twin, we can describe, simulate, predict the state and behaviour of its real-world counterpart based on the computational models evaluated on historical and real time data, and consequently, can respond optimally to changing conditions of the real-world twin.

A digital twin consists of three elementary aspects:

- **Data:** a digital twin may contain data collected from and about its real-world counterpart spanning its full lifecycle. These data include the as-designed data (e.g. product design specifications, process and engineering data), as-manufactured data (e.g. production equipment, material, method, process, quality assurance and operators), and as maintained (configurations, telemetry and real time and historic usage data, and maintenance records) of the real-world counterpart. These data may also include transactional records. How to collect, process, store and manage these data to facilitate the necessary monitoring, computation and

⁶ Digital Twin and Asset Administration Shell Concepts and Application in the Industrial Internet and Industrie 4.0. An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper. 2020

analytic is a major function of a digital twin. For example, how to create a single truth of data, i.e. concept of its master data is important to the successful implementation of digital twin. Digital twin may include Historical and real time data during the full lifecycle of the entity that among others represents:

- design specification data,
- manufacturing process data,
- usage data,
- Transactional data, etc.
- **Models:** a digital twin may contain a variety of computational and presentational models pertaining to its real-world counterpart ranging from those first-principle-oriented (natural laws), data-oriented (statistical, machine learning or artificial intelligence), geometrical and material (CAx models such as CAD, CAE) or visualization-oriented (3D simulation and virtual/augmented reality). Computational and presentational models could include
 - Physical models.
 - Statistical models.
 - Control or transactional model.
 - Machine-learning models.
 - Geometrical and material (CAx models such as CAD, CAE).
 - Visualization models (for various 3D applications like 3D simulation and VR/AR/MR)
- **Service interfaces:** a digital twin may provide service interfaces for software applications to access its data and invoke commands, or run models. The service interfaces, perhaps implemented in the form of a RESTful API, enable connectivity and interactions among the twins and applications and is a differentiator from a mere 3D model or any other computational model. Standardized service interfaces are key for interoperability. The connection between a digital twin and its real-world counterpart may be dynamic, possibly real-time and bi-directional. Sensor data and operational states of the real-world entity (e.g. an asset) could be sent continuously to the digital twin; any operational instructions resulting from decisions based on analytics in the specific application context could be sent back to the real-world entity to be executed. A service interface is used for communicating and interacting with the digital twin (and thus with the corresponding asset as well).
 - With a digital twin, we can describe, simulate, predict the state and behaviour of its real-world counterpart based on the computational models evaluated on historical and real time data, and consequently, can respond optimally to changing conditions of the real-world twin.

3.4.1 Asset Administration Shell

An asset is “anything that requires a connection for the Industry 4.0 solution,” including machines, machine components, materials, products, drawings, wiring diagrams, and even contracts and orders. All these various assets must be identifiable — other devices, systems, and services within the Industry 4.0 network must be able to read and understand the asset’s type, operational and technical data, status, and other asset-specific information. It means, rather than interpreting the state of a production facility by reading individual sensors and actuators, Industry 4.0 proposes to represent assets as an entity in the information realm to enable meaningful interaction with IT systems. I4.0 considers that assets are more than just machines, production modules, or systems; but also individual products, software installations, intellectual property, or human resources. An asset must be an identifiable entity, with a known asset type, asset lifecycle stage or instance, and asset state.

Depending on the degree of the asset's existing instrumentation, automation, and communication abilities, it may have to be retrofitted to enhance its abilities.

The logical representation of the asset is called the Asset Administration Shell (AAS). Together with the asset, the AAS forms the Industry4.0 Component (I4.0 Component). In other words, the asset is the physical part, and the administration shell is the digital part, storing identification, operational, technical, and status information about the asset over its entire lifecycle. The asset administration shell provides a standardized, secure communication interface between the asset and the Industry4.0 network. It requires an asset to communicate in an I4.0-compliant manner by using a standard for communication. In addition, the real-time parameters, the production capabilities and state of the asset must also be communicated. The standardization of the administration shell reduces complexity and allows scalability.

The AAS includes a concept of submodels, each of which can characterize the asset by describing its aspects in different domains. Domain examples include identification, communication, engineering, safety, security, lifecycle status, energy efficiency, health status, process control. Submodels also describe the asset's functions: drilling, milling, welding, assembling, mixing, heating, reacting, etc. Each submodel is described by several properties defined by a unique global identifier and a set of well-defined attributes. AAS attributes are preferred name, symbol, unit of measure, definition, etc. Existing IEC and ISO standards are considered for use within the AAS for specifying properties and property values. The structure of the AAS must be standardized to enable exchanges. Examples and an advanced definition of this standard can be found in documents prepared by ZVEI, the German Electrical and Electronic Manufacturers' Association. To exchange information, the AAS instance can be mapped to OPC UA, MQTT, or other formats. The AAS type is likely to be expressed in the AutomationML standard. Particularly, the AAS specifies a technology-neutral information model. The AAS derives concrete formats for interoperability from this technology-neutral information model: XML, JSON, RDF, OPC UA and AutomationML are provided. For supporting the offline-use case of information exchange a corresponding package format (AASX) for file exchange of AASs, is defined.

The Reference Architecture of Plattform Industrie 4.0 (RAMI4.0) shows the different life cycle phases of an asset. For different life cycle phases different formats and protocols are considered to be appropriate. For the operation phase, for example, a mapping of the AAS to OPC UA is done. For connectivity across plants and companies also http and MQTT are considered. For the life cycle phase "engineering," AutomationML is considered an appropriate serialization. For exchange of information between different partners on file basis, XML and JSON formats are provided (together with the definition of a file exchange format AASX). For analysis purposes, a Resource Description Framework (RDF) mapping is provided.

Asset Administration Shell Types

Currently, three types of Asset Administration Shells are distinguished:

- Type 1: Asset Administration Shells with serialized files, e.g. XML, or JSON files. Serialized Asset Administration Shells contain static information and may be distributed as files. The data model of type 1 Asset Administration Shells is defined by the AAS Meta model.
- Type 2: Asset Administration Shells exist as runtime instances. They are hosted on servers, and may contain both static, i.e. less frequently changing information, but may also interact with other components. In this way, Type 2 AAS provide a frontend for example to device services,

live data from sensors, products, or real-time availability and delivery times for spare parts. Type 2 Asset Administration Shells provide properties and operations, and is able to signal changing conditions with events. The data model of Type 2 AAS is also defined by the AAS Meta model. In addition, the AAS defines a generic runtime interface that enables accessing properties, operations, and events. Type 2 Asset Administration Shells therefore can realize unified interfaces to heterogeneous entities.

- Type 3: Asset Administration Shells extend type 2 Asset Administration Shells. They additionally implement an active behaviour, i.e. they can start to communicate and to negotiate on their own. VDI/VDE 2139 defines a language for type 3 AAS.

3.5 Connectivity/Communication models and standards in RMS scenarios

The Industrial Internet Connectivity Framework (IICF) published by IIC extends the Industrial Internet Reference Architecture (IIRA) to map the rich landscape of IIoT (Industrial Internet of Things) connectivity. It clarifies IIoT connectivity with a new IIoT stack model, defines an open connectivity reference architecture, and helps practitioners to categorize, evaluate and determine the suitability of a connectivity technology for the IIoT system at hand. The connectivity challenges in IIoT systems include meeting diverse requirements, supporting many transports and connecting an overwhelming array of “things” from small devices to huge, intelligent networks of complex subsystems. It focuses on the transport and framework layers that have emerged and less well-understood standards. It puts forward DDS, OPC UA, Web Services and OneM2M as candidates for core connectivity standards from which IIoT system architects can choose to adopt based on their specific system needs. Existing networks and devices with legacy connectivity technologies can then be bridged to the core standards to ensure interoperability.

These core connectivity standards can also be bridged by gateways to each other to ensure interoperability between IIoT systems. Furthermore, more than one core standards, such as DDS and OPC UA, can be deployed in a single IIoT system to take advantage of each other’s strengths. For example, OPC UA is adept at device integration and interchangeability and DDS ideal for software integration. However, any additional gateway or bridge would often introduce an increase of costs and a reduction in quality of service, for example in latency and reliability. IICF presents a connectivity interoperability model in which device-to-device, device-to-application and application-to-application interoperability between IIoT subsystems can be achieved. In this manner, with standard gateways bridging core connectivity standards, RAMI 4.0 and other IIoT subsystems (that are based on other core connectivity standards like DDS, OneM2M and Web Services) can be integrated to provide interoperability.

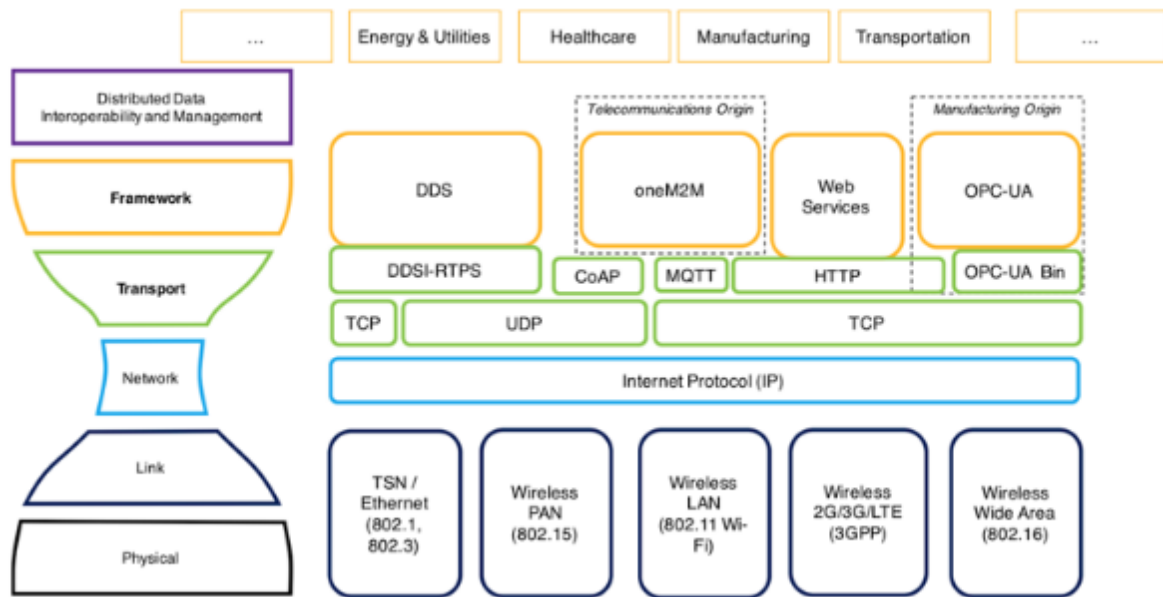


Figure 7 - IIoT connectivity stack from IICF

3.6 Autonomous guided vehicles (AGV)

AGVs have been used in the industry for many years. It started with simple navigation algorithms like line following, which are still common. Nowadays free navigation algorithms based on scanning the surroundings are more preferred, at least in research applications.

With the ROS (Robot Operating System) Navigation Stack, ROS offers a collection of useful algorithms for autonomous mobile robot navigation[1], like Simultaneous Localization and Mapping (SLAM). This includes using 2D laser scan data and odometry data to calculate default velocities that are sent to the robot. In detail, the navigation is divided into a localization module, which estimates the pose of the robot with respect to the environment map, and a concurrent path planning module. The localization can be done with the Monte Carlo localization (amcl). For the purpose of state estimation, the robot continuously sends odometry data, which represents a transformation of the robot with respect to its starting pose. To compensate for errors in pose estimation that occur over time due to inaccurate odometry-data, a variation of the Monte Carlo localization is used[2].

In addition to localization, the task of the robot controller is to calculate a plan in order to drive to a defined target. This plan is divided into local and global planners to be linked with each other. The planning includes static as well as dynamic obstacles in the calculations using the environment map and laser scans. The output of the planning module is a default velocity that is passed to the robot's base drive controller.

The task of the global planner is to create an executable plan with minimal cost from the current robot pose to the target pose. The plan becomes infeasible if it passes through grid nodes that are occupied by obstacles. In addition, grid nodes that are close to obstacles are more expensive.

The local planner is responsible for the computation of trajectories within a defined spatial window around the robot. In contrast to the global planner, the local path planner also reacts to dynamic obstacles detected by laser scans[4],[5]. Both localization and path planning are highly consuming computing resources.

A mobile manipulator consists of an AGV and robotics arm as well as additional sensors to detect objects and to interact with them. The main advantages of mobile manipulation are that it does not require a lot of space and the system can move independently. The disadvantages are that the mobile component increases the inaccuracies that occur in the system, which is why appropriate fine adjustments become necessary. In addition, further developments are needed before the system can reach sufficient accuracy without the use of artificial markers.

Deploying navigation algorithms on an edge or cloud server according to the Software-as-a-Service paradigm has many advantages like cooperative planning and less on-board energy consumption. Under normal conditions, modern wireless networks already meet quality of service requirements for outsourcing real-time critical control functions of mobile robots. However, implementing this approach requires a high level of reliability, which cannot be guaranteed neither by the connecting network nor by the outsourced computing infrastructure. A service-based approach with specialized services for individual tasks has proven to be successful. Within this architecture the services can be deployed on the computer on-board of the AGV or with sufficient communication infrastructure on an edge or cloud instance. This allows hardware-related services to be provided directly on the device whereas computational complex services make use of the power provided by centralized infrastructure.

In-device computation of navigation algorithms enables real-time capability, but requires powerful hardware and has high energy consumption, which results in lower uptime. Cloud Robotics as a paradigm promises to solve these problems[6]. The complex computations of the algorithms are to be performed by fast, efficient and massively parallelizable hardware on an outsourced edge or cloud server. Communication to this server takes place via a wireless network such as Wi-Fi or 5G. The main advantage of 5G here is the extra reliability of the connection, seamless mobility support, QoS guarantee, deterministic and time sensitive behaviour which can't be fulfilled so far by alternative wireless solutions. The mobile robot can also benefit from the advantages of the virtualized cloud such as elastic horizontal and vertical scaling of computing resources and centralized software updates. In addition, robots can access and share global data. This allows actions to be coordinated and cooperatively planned and executed.

With the growing complexity of algorithms used in robotics and the increasing demand for intelligent networking of machines, the paradigm of cloud robotics is of high relevance[7], [8]. Arumugam et al. implemented the SLAM algorithm FastSLAM on a cloud-based Hadoop cluster and were able to significantly improve the performance. Subsequently, algorithms for speech processing and machine vision[9], [10],[11] were validated for their functionality on cloud-based platforms. Lam et al. were able to successfully outsource navigation modules to a cloud environment[12]. Similarly, Vick et al. successfully outsourced planning algorithms for a robotic arm[13].

As part of a larger fleet, networked robots can also benefit by sharing knowledge from each other [14]. Especially in the context of the increasing mobility on factory floors, the cooperation of individual robots is essential. The combination of cloud robotics and algorithmic advances in path planning for multiple robots is an interesting research area[15]. Due to growing requirements regarding flexibility in industrial production systems, the use of AGVs and AMRs is relevant. In this context, the exchange of information with other information technology systems is essential[16]. Lambrecht et al. successfully demonstrated that the offloading of real-time critical navigation modules using 4G campus networks is feasible in an industrial scenario. Besides the potential of using high-performance

outsourced hardware and saving it locally, edge or cloud computing can also significantly minimize local energy consumption[17].

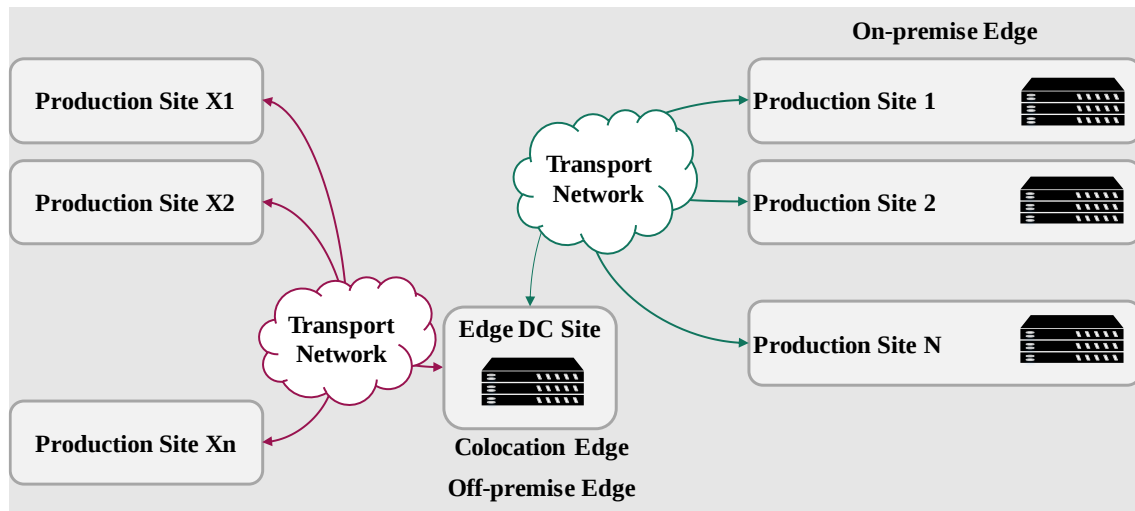


Figure 11 - Production sites with on-premise private edge cloud compared with production sites relying on off-premise edge (DC refers to Data Center).

3.7 Edge computing

Edge computing is a distributed computing paradigm that brings computation and data storage closer to the sources of data. And in the Information Communication Technologies (ICT) context, edge computing is a way to process the data coming over wireless communication technologies, i.e. 5G networks, as close as possible to the 5G or Non-5G end devices, that ultimately brings delay, privacy / security and user plane bandwidth advantages to the applications. In 5G-network environment the location of edge computing can vary depending on the use case QoS requirements. However, as a general practice, the edge computing resources along with specific applications and Local Breakout (LBO) mechanisms are usually co-hosted on a physical platform, where the User Plane Function (UPF) of the 5G SA Core Network Function is also hosted. Therefore, the platform physically resides between the 5G radio and 5G applications due leverage the aforementioned advantages.

The data generated on each IoT device can be processed and analysed either on the device itself, or close to each individual device. They can be also sent to a central location, as in cloud computing for analysis and decision making. Another option, which is more realistic, is a private edge cloud on-site at production locations, as it has neither the disadvantage of on-device solutions nor the latency obstacles of the cloud employing edge cloud solutions connected via an intra-factory real-time communication network to interconnect factory shop floors offers new, economically highly attractive possibilities, especially for large manufacturers. On the other hand, it might be too expensive for the SMEs, which are more in favour of solutions with less infrastructure and acquisition costs. In such scenario, off-premise (or colocation edge) sound like a very advantageous solution. However, outsourcing of control functions to off-premise edge clouds put particular requirements on the networking infrastructure between production lines and edge compute resources. In such a scenario, the transport network should offer real-time, high speed, and low-latency communication links between the production sites and edge clouds to make this paradigm a reality.

To manage and orchestrate these increasingly complex systems, cloud connectivity is becoming more

relevant. The complex IoT systems depend vastly on data-transfers among a steadily growing number of participants, which raises the need for data sovereignty [18]. The IDS (Industrial Data Spaces) standard is currently one of the most detailed funded and supported solutions for sovereign data sharing [19]. The IDS radar provides an overview of the current data spaces scenarios, covering use cases and pilots of different levels of maturity from planned use cases to pilots or fully operational data spaces [20].

Edge resources have limited capability and without any coordination and federation at the data level, it is impossible to host such a huge amount of data. Apart from this challenge, we are witnessing a big change on a higher level, i.e. the operating systems. These are expanding beyond traditional computing systems into the cloud, edge and IoT devices. Such OS is an emerging technology that will soon become ubiquitous. Actually, the next generation of higher-level (Meta) operating systems (MetaOS) enables smart Internet of Things with strong computing capacity at the smart device, system and edge-level, embedded in a compute continuum from IoT-to-edge-to-cloud. Such operating system should be device independent and implement advanced concepts such as ad-hoc clouds, time-triggered IoT, and decentralized intelligence. Despite the apparent differences among existing OSs, they all have in common so-called “software-defined” capabilities — namely, resource virtualization and function programmability. MetaOS or Internetware is an enabling paradigm for new types of applications that are autonomous, cooperative, situational aware, evolvable, and trustworthy. Internetware consists of a set of autonomous software entities distributed over the far-deep-edge-cloud continuum (public and private owned), together with a set of connectors to enable various collaborations among these entities. Software entities sense dynamic changes in the runtime environment and continuously adapt to them through structural and behavioural evolutions. It includes a set of software-defined features to abstract the low-level resource management functionalities of Internetware applications. Within MetaOS, an Internetware application runs on top of the existing hardware systems including the cloud, edge and IoT devices. The Internetware OS core provides abstractions to manage both cloud and edge resources, while an application framework layer accommodates applications for different domains—for example, enterprise computing, mobile computing, and data as a service (DaaS).

If we consider the possible architecture of the MetaOS, it is possible to identify some key components: 1) Internetware processing core or cloud continuum core which will work on real time mesh / ad-hoc edge optimization, automated operations and continuum orchestration; 2) Internetware data core or data core which works on data sovereignty and end-to-end security and trust; and 3) Internetware networking core or network core where dynamically adaptable resources/services/content management and network availability and reliability are the main concerns.

Given this, the unified solution should be a modular and extensible reference architecture for a Meta operating system fabric, facilitating the in-time orchestration of dynamic hybrid cloud-edge deployments over a trusted ecosystem enabling collaborative computing. It should introduce novel algorithmic mechanisms for service placement that can be used in orchestration frameworks for hybrid cloud-edge computing continuums to facilitate the runtime optimization of key performance indicators that may involve multiple objectives including latency, availability, data privacy and quality restrictions as well as energy-consumption. Also, distributed trust assurance mechanisms enabling the autonomous authentication and verification of interacting entities for the formation of opportunistic compute communities over dynamically expanding network fabrics that seamlessly facilitate community discovery, as well as, secure and efficient data and resource sharing between trusted

peers.

To handle the concerns of the data and model owners, and act per the privacy-protection laws, the field of Privacy-Preserving AI has emerged. The concepts used within Privacy-Preserving AI, have been around since the last century, however, only in the last decade, they have started to be utilized practically. Privacy-Preserving AI aims to provide tools that guarantee protection against attacks on the data, the model, or possible reconstruction of important information from the dataset or model parameters. To realize the Privacy-Preserving AI concept in this trial we take advantage of the in-house built Distributed Learning Framework (DLFi)⁷ at Fraunhofer HHI. DLFi is our modular, pluggable, and cloud-native solution for distributed training of ML models. DLFi allows training of ML models over geo-distributed datasets. It can be used to train and validate models based on both Pytorch and TensorFlow machine learning libraries. The framework operates in a modular fashion, which allows different downstream tasks (e.g., image recognition) to be plugged-in to the framework. The framework is interfaced with a customized performance monitoring dashboard based on Grafana which provides real-time monitoring of traffic flows among different modules of the framework and of the available resources on the distributed sites.

3.8 IEC 61499

Distributed industrial automation systems pose a significant challenge for their efficient verification and validation due to their heterogeneous structure, use of wireless communication and decentralised logic. The inherent inter twinning of computational and communication processes with complex physical dynamics has called for the term cyber-physical systems (CPS) to emphasize the challenges and the need for new development approaches. In industrial automation, the function block architecture of the IEC 61499 standard is increasingly used for modelling complex distributed automation systems in such challenging applications as SmartGrid, process automation, and material handling systems. It has been proven also as an efficient way of modelling CPS in automation.

The distributed control system expressed in terms of the network consists of function blocks in IEC 61499 standard and it provides an event-driven approach to design the system's controller logic in terms of a state machine. IEC 61499 is based on the same concepts of event-driven block diagrams that allow for the modelling of CPS composed of physical processes (a.k.a. plant) combined with control and communication. The model can be used for the validation of system-level properties before deployment.

3.9 Architecture

IEC 61499 was introduced as a system-level architecture for distributed automation systems, extending the software model of popular programmable logic controllers (PLC), known as IEC 61131-3 standard, with the means of describing complex distributed systems composed thereof.

The central structural unit of the IEC 61499 architecture is the Function Block (FB). As shown in Figure 8, function blocks have clearly defined interfaces of event and data inputs and outputs. Event inputs are used to activate the block. There are basic, composite and service-interface kinds of function blocks. A basic function block may have internal variables which are fully protected, i.e. not directly

⁷ <https://www.hhi.fraunhofer.de/en/departments/pn/products-and-solutions/dlfi-the-distributed-learning-framework.html>

accessible from outside. As a result of internal computations, the block may change output data variables and emit output events, which, if connected to event inputs of other blocks, will activate them.

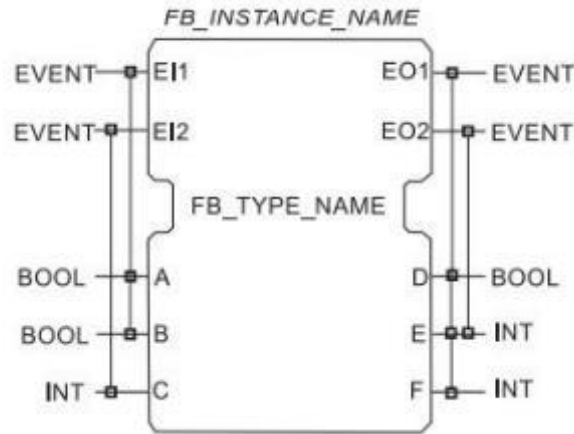


Figure 8 - Interface of function block

The behaviour of a basic function block is determined by a state machine, called an execution control chart (ECC), illustrated in Figure 9. Semantically, ECC is equivalent to a Moore type finite automaton. States of ECC can have associated actions, each consisting of invocation of an algorithm and emission of an output event. Algorithms can be programmed in different programming languages even within a single basic FB. Thus, basic FBs can be regarded as portable abstract models of a single controller.

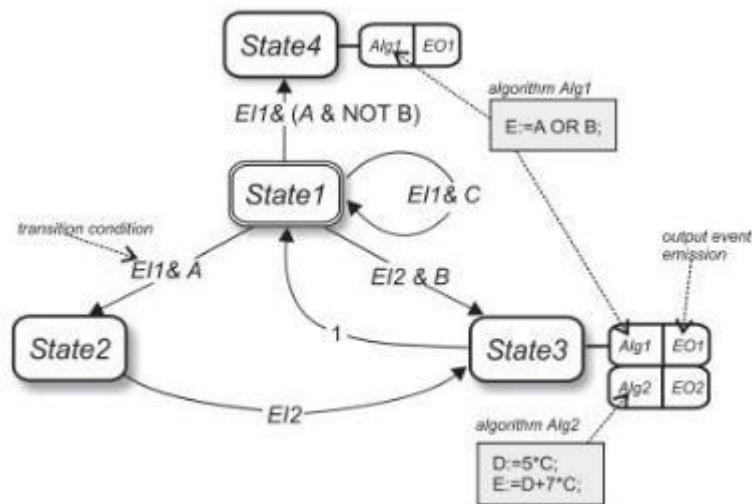


Figure 9 - ECC: A state machine, defining the behaviour of a basic function block⁸

Function block instances can be connected one with another by event and data connection links, thus forming function block networks. The connections define control and data flow between FB instances thus determining the network's execution semantics. FB networks are seen as a universal model of control systems, both distributed and centralized. The functionality of composite function blocks is

⁸ A Formal Model of IEC 61499-Based Industrial Automation Architecture Supporting Time-Aware Computations, DOI: 10.1109/OJIES.2021.3056400

defined by a network of function block instances, some of which can also be composite.

In distributed systems FB instances included in a network can be regarded as independent processes. Communication between them is abstractly modelled by events and data passing.

The IEC 61499 standard includes a mechanism to add more details to the abstract FB network model of a system. Application FBs can be allocated to distributed devices, and communication FBs inserted whenever event or data connections cross the borders of devices.

The event-based communication of FBs in IEC 61499 can be seen as a mechanism making the behaviour of applications partially agnostic to the underlying distributed hardware architecture. This mechanism, which can be seen as an abstraction of message passing, preserves the causality of events regardless of the internal execution specifics of devices, where parts of the application are executed.

3.9.1 IEC 61499 & Multi-Agent Systems (MAS)

The Industry4.0 requirements for flexibility and re-configurability of manufacturing systems imply wider use of the so called Intelligent Mechatronic Components (IMC), such as drives, motors, etc., where the word intelligent stands for their ability to integrate into systems and achieve desired functionality without the need to program the resulting system explicitly. Such devices are already available on the market and include embedded control devices. The control devices can be programmable, and are equipped with a microcontroller programmable in a way, traditional to Programmable Logic Controllers (PLC) and known as IEC 61131–3 standard. The reliance on industrially accepted ways of programming the internal functionality of such devices is beneficial for the maintenance of the systems. A machine composed of such programmable mechatronic units will have distributed control system and decentralised logic of operation. Coordination of such distributed nodes into the desired logic of operation is a challenging task. The integration of PLCs into a system presents new synchronisation challenges, which required extension of PLC programming with distributed systems programming constructs, resulting in the new standard IEC 61499. The latter helps resolve synchronisation problems but does not automatically solve the problem of achieving self-configuration and adaptability of the resulting system in a plug-and-play way. On the other hand, the multi-agent systems (MAS) architecture provides necessary features for the seamless integration of individual functionalities of modules (called agents) into the system's behaviour by self-configuration. There are implementations of MAS, which include powerful mechanisms of programming individual agents in a way resembling human reasoning. Taking advantage of such tools could simplify the integration of IMC into intelligent machines and flexible production facilities. IEC 61499 standard enables the design of flexible distributed automation systems through provisions of interoperability, portability and re-configurability. This feature of IEC 61499 matches well the capabilities of MAS and provides the freedom and flexibility necessary for dynamic reconfiguration within the MAS layer required by flexible production.

3.9.2 IEC 61499 Engineering Tool

The engineering tool from nxtControl follows a modular approach which allows to extend the tool with developments from the project and extend and integrate the results into an industrial grade Integrated Development Environment (IDE).

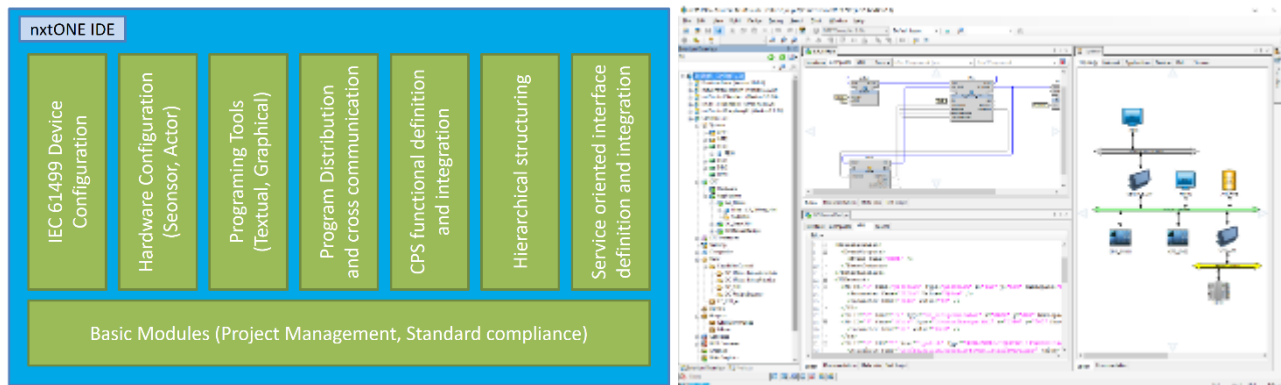


Figure 10 - IEC 61499 tool functional blocks

has the following features supporting the application designer to create object-oriented distributed control application:

- It includes the capability to create, populate and manage libraries of created IEC61499 function blocks for reuse and increased modularity.
- It is possible for the users to 'privatise' FB implementation to hide away algorithms and execution details so trade secret is not exposed when the FB is being reused to protect intellectual properties.
- To provide further control, licensed-based mechanisms are included to define features available to different users and on each type of device.
- Moreover, the IDE supports individual compilation of function block, making it possible to supply binary version of created function blocks, further increase the security of intellectual properties.

The IDE allows control application created, in the form of systems of connected function block networks, be easily divided (modularised) and distributed to different hardware device, where necessary communicating event and data connections are made automatically. It hides away the complex configurations required in enabling cross-communication between devices within a system, and across the system boundary.

The IEC 61499 engineering tool supports individual compilation of function blocks, making it possible to supply binary versions of created function blocks, which further increases the security of intellectual properties.

The engineering tool allows application engineer to encapsulate within the same programming object, both the control algorithms representing the functional logic and artifacts enabling monitoring and user interaction with the system (CAT).

The engineering tool also allows an application engineer to encapsulate both the control algorithms representing the functional logic and artefacts enabling monitoring and user interaction with the system, within the same programming object called Composite Automation Type (CAT). The CAT is a software representation of a real device in an automated system.

A CAT includes:

- the control logic for the object
- the visualization for the object with symbols and user dialogues
- the connection to the process, so the connection to the hardware specific Inputs and outputs of the devices
- the documentation
- is extensible to additional aspects

A selection of CATs representing devices and functions used in specific application or industries are consolidated in libraries. Even hardware components (control hardware of a certain vendor) are reproduced as CAT and offered as libraries.

A variety of visualisation devices are used for operating and monitoring of plant and equipment. nxtControl offers advanced runtime systems for Human Machine Interface (HMI) and Supervisory Control and Data Acquisition (SCADA) applications. As visualisation is an integrated part of the engineering tool and as CAT objects also include the visual appearance of devices, there is almost no engineering effort needed to build a visualisation application. The visualisation is just there – automatically.

The abstraction of HMI artifacts with control logic within the same programming object encourages concurrent development of HMI and control, further increase the modularity of software program developed.

The IDE provides capability to test individual component (i.e. basic FB) of the system, allowing incremental testing as the application is being developed, shortening the time and complexity of the testing for the final system developed. Watching and forcing of events and data remotely from the engineering tool is available to the user. The objectives of the development are verified by deploying an IEC 61499 program onto the devices, either as a program as a whole (without cross communication) and as part of a distributed application (member of a cross communication network).

3.9.3 IEC 61499 runtime

An IEC61499 runtime enables the IEC 61499 execution model running on a given OS and hardware platform, for example, the Linux Debian OS running on an ARM cortex platform. The runtime includes an event scheduler module responsible for scheduling the execution of algorithms; a resource management module to handle the creation, deletion, and lifecycles of managed function blocks in a deployed application and modules to provide timer, memory, logging, IO access and communication services. The combination of hardware, OS services, and the IEC 61499 runtime are collectively known as a device in the IEC 61499 context and a planned architecture for such a device is illustrated in Figure 11. The architecture accords with the shared management model described in Figure 8b of IEC 61499-1 standard.

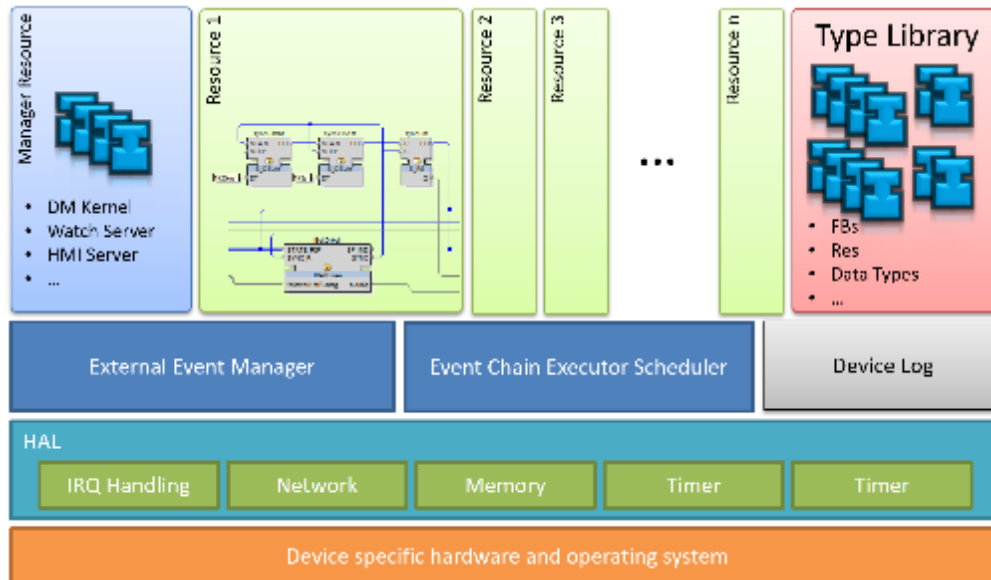


Figure 11 - IEC 61499 runtime architecture

A control application is developed using the Engineering tool described in the previous chapter and then deployed to the device, where, when necessary, utilises different communication protocols and OS services to interact with other devices and the physical world (e.g. IO access). The IEC 61499 runtime can be extended to support the different communication stacks, field buses and OS service and they are to be encapsulated as SIFB function blocks where the control application can access their services by making event and data connections to them. In this way, the application designer does not require any knowledge about the technical details how the communication will be established.

To enable deploying the IEC 61499 application to reference hardware devices, IEC 61499 Runtime is ported to dedicated hardware platforms.

IEC 61499 runtime manages fundamental tasks such as event-based communications between IEC 61499 runtimes, real-time clock synchronization between runtimes and authentication and security. In addition, the IEC 61499 runtime is extended to provide the auto-discovery and self-declaration functionalities which will be described in detail in the next section.

Auto discovery and self-declaration

To enable faster, easier and less error-prone configuration of a network of CPSs in a dynamic changeable network topology, auto discovery and self-declaration functionality are added to the IEC61499 Runtime. To allow this, each device must be capable to create semantic description of its own interface and functional automation capabilities, make its existence on the network (presence) known to other devices by advertising it's entrance and leaving of the network and make necessary exchange of information in standardised, unambiguous syntax and semantics.

For the CPS to easily adapt to the dynamic network topology (imagine wireless CPS devices on a mobile platform) where CPS may join and leave local network at will, the auto-discovery must be based on a zero-configuration (zeroconf) technology where there is no need to manually reconfigure the network layout or a need for a centralised DNS server where it becomes a single point of failure. A CPS device participating in a zeroconf network will be automatically assigned with address and hostnames, making low-level network communication possible immediately after a device joins a network. Multicast DNS,

a subset of the zeroconf technology, will further allows CPS to subscribe and be automatically notified of changes to the layout of the network. Possible implementation supporting zeroconf technology includes the Bonjour service on Windows platform and Avahi services on Linux platform. The Avahi services are incorporated into the IEC 61499 runtime communication stack.

To support the exchange of semantic information used for identification of other CPS's capabilities in the network, MQTT is chosen as the transport protocol and is included in the IEC 61499 runtime.

3.9.4 AI algorithms

The use of Machine Learning and artificial intelligence in general in the application domain of medicine dates back to the 1950s, but it is only in recent years that there has been a transfer of academic knowledge into the real industrial applications.

With the advent of more complex data collection and readily available data sets in daily processes routine, both sample sizes and potential predictor variables require approaches to rapidly process a large amount of information. Artificial intelligence (AI), particularly machine learning methods, is increasingly being utilized for prediction models, pattern recognition, and deep-learning techniques used to combine complex information fast. The underlying concept is that a machine will learn by trial and error from the data itself to make predictions without having a predefined set of rules for decision-making.

Considering the industrial state of the art, and the recent lectures, there are multiple aspects that enable a new frontier of artificial intelligence applications and approaches where 5G and cloud-to-edge play a role.

The increasing use of robots, where they coexist with humans, requires a higher level of intelligence, including adaptability and growing awareness of the Robot's environment. Algorithms must be efficient to accomplish more sophisticated tasks limiting the usage of computational and communication resources. The capability of "being coordinated" by a central application and the self-coordination of robots is also an important issue in certain cases.

Math-Optimization and Machine Learning techniques can be usefully combined in some cases. For example, machine learning can be used to provide information to an optimization layer (e.g., estimating the battery-discharge time of robots based on a series of dynamic parameters), or machine learning might act as a "black box" in back-box optimization algorithms. In this configuration, the Machine learning estimates the objective function value to the optimizer.

The important aspect of "context awareness" of AI components benefits from the increasing number of sensors and data that the system, the environment, the Robot, and the machines generates.

Situation Awareness (SA) is a faceted concept encompassing many different elements ranging from cognitive mechanisms and decision-making processes to information processing and human factors. Consequently, providing a universal definition of SA fitting for different contexts is not an easy task. Intuitively, SA means to understand what is happening around us in a specific moment in order to be able to perform a correct action or make a coherent decision with respect to our goal. One of the best definitions is the one provided by Endsley in 1995 [17]:

"Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future".

In this definition, the three levels which concur with the formation of the SA can be identified: perception, comprehension, and projection. The first level of SA (level 1 SA) is the perception of the status of the elements in the environment. The second level to achieve good SA (level 2 SA) is understanding what the data perceived at level 1 means in relation to goals. Level 3 SA means to predict what the perceived elements will do in the future with respect to the goal.

The situation, in the case of manufacturing and intra-logistics application, involves environmental aspects, human-machine and machine-machine interaction aspects.

3.10 IDS – Data spaces

The role data plays in enterprises are changing as the digital transformation in many sectors gains speed. New business opportunities through data-driven innovation emerge from data sharing in ecosystems. In ecosystems, the interest of the individual must be brought into alignment with the interest of the ecosystem. Trust between participants, data interoperability, and data sovereignty are key requirements which can be met by data spaces. Data spaces are a distributed data integration concept which is taken up by consortia aiming at supporting ecosystem. GAIA-X and IDS (International Data Space) specify reference architectures for distributed data infrastructures and data spaces, respectively. While the benefits of data spaces for a fair data economy are recognized by business and policy makers, a deeper understanding is required about the design and evolution of data spaces.⁹

Figure 12 shows the architecture model of a mobility data space, which aims at enabling data-driven mobility services, for example, intermodal mobility as a service (MaaS).

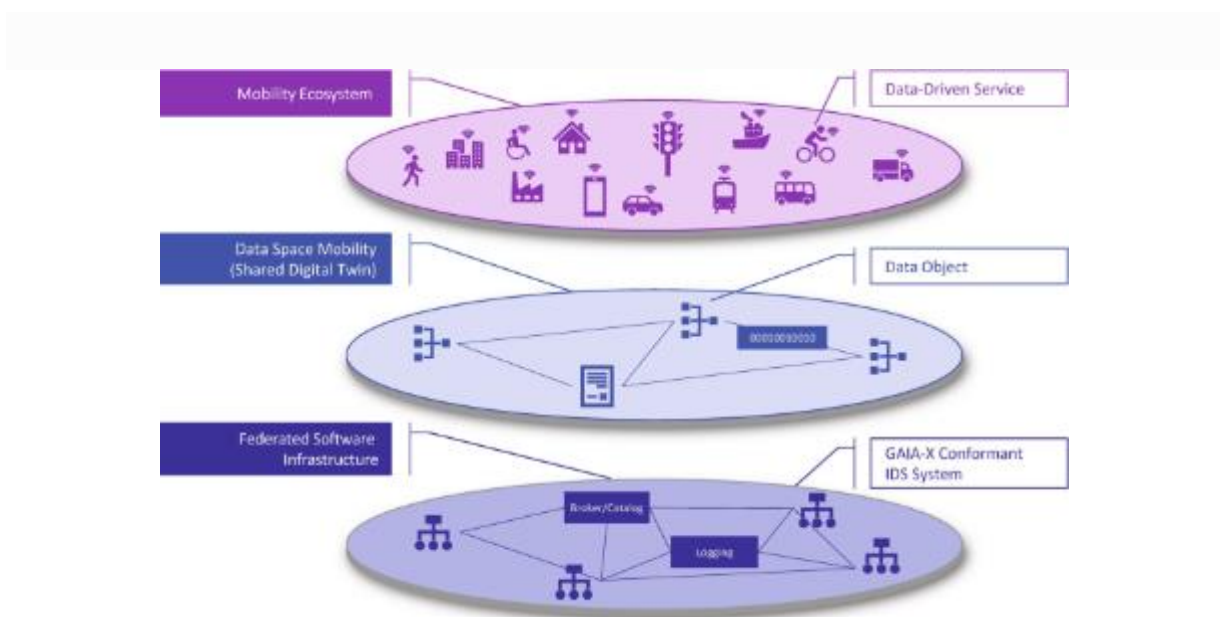


Figure 12 - Mobility Data Space - An example of (©2021, Fraunhofer ISST)

The architecture consists of three layers. The mobility ecosystem represents the first layer on which services are offered to the mobile citizen. These services improve the mobility experience of the individual, allow for better management of traffic flows, and increase the utilization of means of

⁹ Otto, B. (2022). The Evolution of Data Spaces. In: Otto, B., ten Hompel, M., Wrobel, S. (eds) Designing Data Spaces Springer, Cham. https://doi.org/10.1007/978-3-030-93975-5_1

transportation, among others.

The services on the first layer require a mobility data space in the narrower sense, i.e., a “shared digital twin” of the various constituents of mobility ecosystems. The digital twin consists of the data of the individual digital twins and comprises, for example, timetables, charging statuses of electric scooters, utilization of buses and trams, the travel preferences and plans for individuals, etc. The shared digital twin represents the second architecture layer.

Data sovereignty must always be ensured for all participants in this data space. Data providers must have control and transparency of what happens to their shared data, and data consumers must be able to trust both data providers and data sources. A federated software infrastructure is needed as the third architecture layer. Relevant software services ensure data interoperability, data sovereignty, and trust among participants.

4 North Node Trials

4.1 NN01. Smart Assembly in cabinet production

4.1.1 General Description

The proposed solutions in the trial are key enablers for establishing a secure and trusted information continuum that supports data driven applications and smart manufacturing. The key component and enabler of the various Artificial Intelligence (AI) & Augmented Reality (AR) related use cases in the trial is the digital twin, which will be implemented by examining newest industry standards and guidelines. A 5G private and Non-Public Network (NPN) is to be used to achieve full connectivity of the factory floor, allowing for flexible production lines that can easily adapt to customized orders and a continuously evolving product portfolio. A degree of communication reliability and determinism needs to be achieved in order to ensure uninterrupted production. Together, the digitization effort combined with 5G will help achieving values of the Zero adverse policies, e.g. zero-waste, zero-defect, etc. at the cabinet production area.

In particular, a low voltage drive¹⁰ cabinet production area located at ABB Finland’s factory will be used for the purposes of the project. Cabinets are built-to-order using paperless production with server based online software that supports phased assembly and automatically generated wire markings. 3D models and views of the cabinets and their electrical components and wiring routes are available digitally. A 5G test network is also available where computer vision is used to provide live guidance for a single assembly phase.

The drive cabinet production area will be improved upon by implementing digital twins of the cabinet builds. The digital twin component will enable further automation of the assembly process and facilitate more advanced use cases, such as ensuring quality assurance in the production process by utilizing machine vision with the support of AR & AI functionalities. Cellular 5G network is a good candidate to enable wireless/cordless tools and systems in place, enabling live tracking of the status of the cabinet throughout all the different assembly phases. The improved flow of information and guidance provided to assemblers are expected to improve quality, increase productivity & work

¹⁰ Drive is a set of electrical or electronic devices that regulate motor speed, torque, and position.

satisfaction, provide online process status and control in multi-site production, and support production and product ramp-ups. Adding further digitalization to the production line via the use of digital twins allows for better utilization of the existing models and information i.e. continuum between different product manufacturing life-cycle stages.

4.1.2 Participants and roles

ABB will lead and define the use cases for the trial and contribute with devices and know-how specific to industrial automation environments. ABB is an industrial automation vendor which is active in several specific areas, such as: process automation, factory automation, robotics, electrical equipment and building automation.

Aalto contributes with the expertise on wireless communications and industrial protocols to be used in the trial.

Visual Component will provide the digital twin of the system based on input collected from equipment with data structure indicated by ABB.

Huawei will provide the know-how specific to 5G communication system and contribute with 5G modems and equipment for the use cases shown by ABB. Huawei is a leading global provider of information and communications technology (ICT) infrastructure and smart devices.

CERTH will provide security related tools, such a penetration test tools to be installed on computers.

4.1.3 Trial Present Scenario

This trial will consider several use cases for itself, in order to be able to show the potential improvements the usage of digital twins and of wireless networks:

- Use case 1: Connection of several industrial automation islands over a 5G network and an IIoT Gateway/Edge device
- Use case 2: Connection of some individual industrial automation end stations (devices) also over a 5G network (without IIoT Gateway/Edge device)
- Use case 3: Connection of all individual industrial automation end stations (devices) over a 5G network (without IIoT Gateway/Edge device)

For all use cases, at the cloud level, there are available digital twin representations of the end stations / industrial automation devices and of the cabinets.

Use case 1. Connection of several industrial automation islands over a 5G network and an IIoT Gateway/Edge device

Islands of automation are automated isolated sub-systems which are not integrated with other systems/subsystems in the shop floor with which it interacts. In other words, the islands of automation are a condition in which automation systems or technologies cannot communicate and are not integrated into another system. It is a usual scenario in many shop floors due to an unsystematic IT planning and infrastructure approach as well as unintegrated establishment of databases, systems & applications and the absence of coordination between internal departments.

We propose a solution as presented in Figure 13.

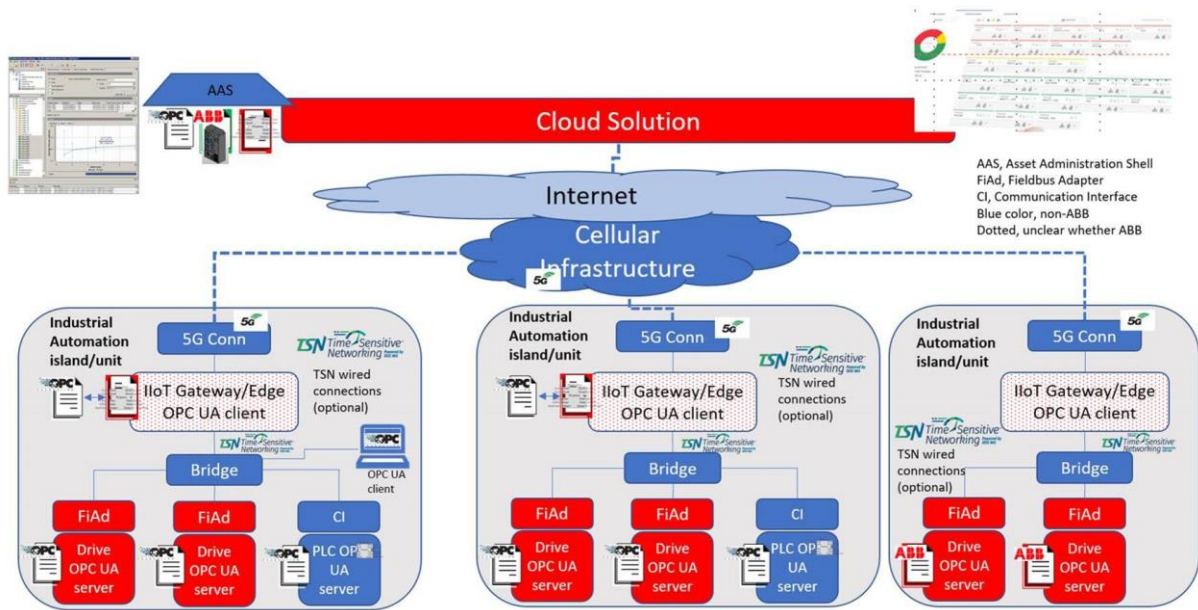


Figure 13 - Zero-SWARM architecture example for industrial automation islands connected over a 5G network

Today, there are alternative ways to address this issue, but in a little bit different architecture, as presented in Figure 14. In this alternative solution, OPC UA is not very much used, mostly the fieldbus adapters are running and now classic industrial Ethernet communication environments, such as Profinet, Ethernet/IP, Ethercat, Powerlink. The role of the edge device is to gather some online data about the industrial automation end stations and send it to our cloud solution, for visualization at a customer site.

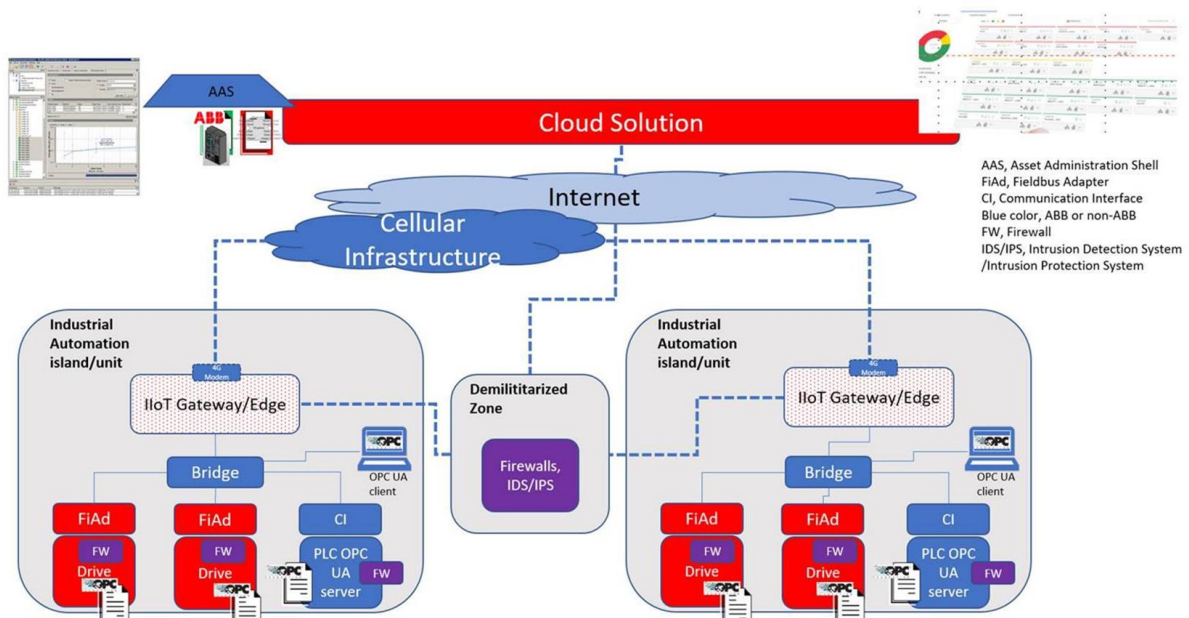


Figure 14 - Example of architecture used today

There are quite some limitations, as support needs to get intensive contact with the customer, in case some issues appear, information even if digitally accessible, it is shared and present in many different tools and over different environments, as the management of the system is less efficient. Digital twins are used, but again, to a limited extent.

Another limitation is the lack of a standard IEEE 802 mechanism to provide deterministic communication and zero-loss in the wired automation islands.

Use case 2: Connection of some individual industrial automation end stations (devices) also over a 5G network (without IIoT Gateway/Edge device)

Some customers prefer having a wireless connectivity to some or all of our industrial automation end stations. Let us then consider the figure 6. In the architecture, the customer has decided to gather data only from a set of devices (it could be all, there is no imposed limitation) over their installed 4G modems. In order to be able to perform such operations, the right hardware needs to be ordered during the ordering process of all of the industrial automation devices.

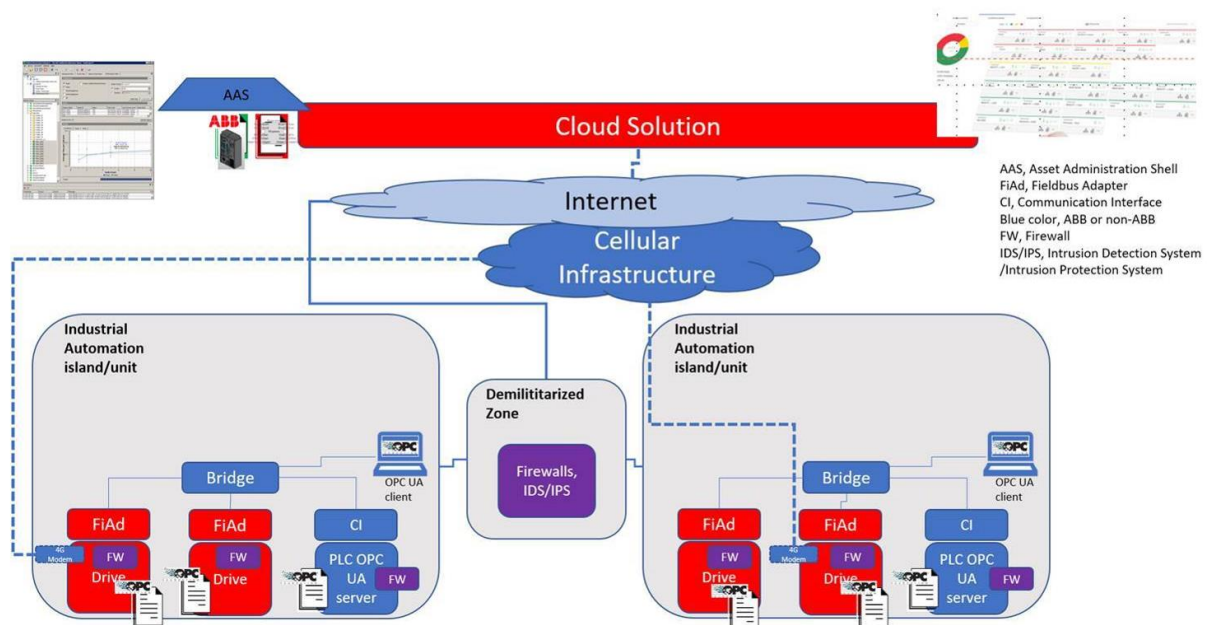


Figure 15 - Example of architecture used today, containing GSM services

A limitation of this approach is the performance, as the connectivity of a 4G modem brings several architectural limitations for some of the industrial automation devices.

In order to overcome such shortcomings, the Zero Swarm project may consider the addition of new 5G modems, connected over high performance mechanisms to industrial automation devices, as depicted in Figure 16.

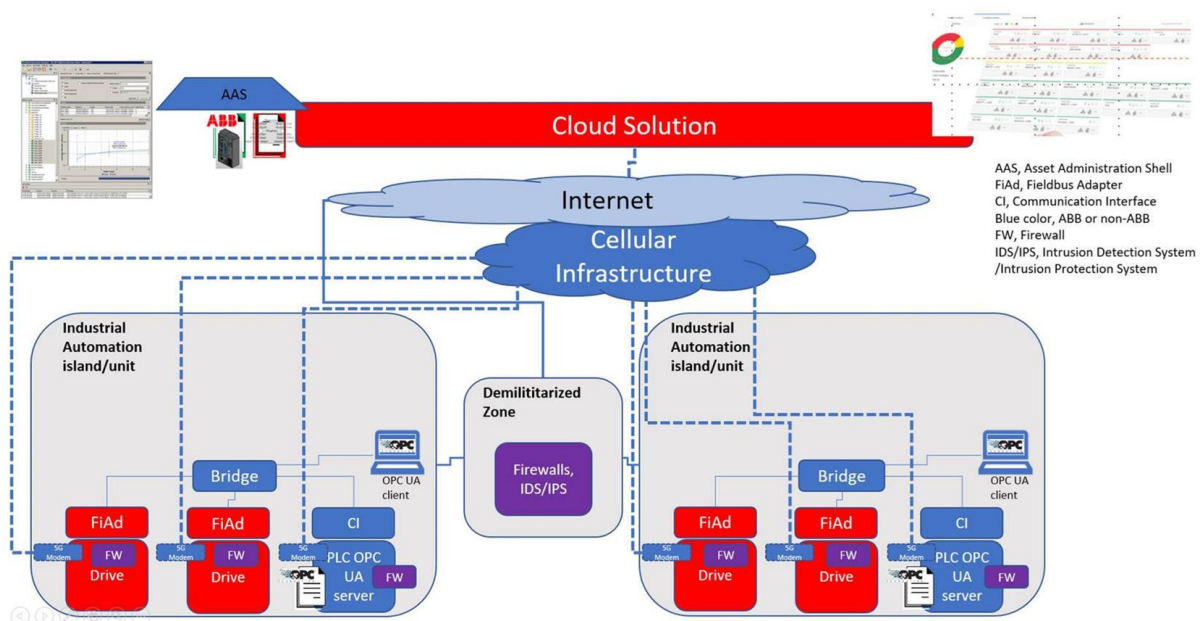


Figure 16 - Zero-SWARM architecture example using 5G modems for data transmission

This architecture would allow our customers to overcome many shortcomings and improve the three weak points described previously in this chapter, without a large added cost for our industrial automation devices and without important security limitations. In short, the utilization of 5G modems connected on a high-performance mechanism to the industrial automation devices would solve the issues of the performance detected in current practices. The presence of TSN features in the wired networks of the industrial automation units would add the interoperable capability of including different vendors of industrial automation and of network infrastructure equipment. The presence of OPC UA servers in the industrial automation devices and of OPC UA clients at the cloud level would improve the support and data availability capacities. The presence of digital twins will improve at the reusability of design and at the simulation capabilities. ABB has already a notion of a virtual drive, as a product, which starts to get into the direction of a digital twin. But the utilization of 5G equipment can go even further. This leads to Use Case 3.

Use case 3: Connection of all individual industrial automation end stations (devices) over a 5G network (without IIoT Gateway/Edge device)

In this case, 5G wireless connectivity penetrates even further into the industrial automation unit, even at the level of the individual automation end station. It can be considered as an ideal case where all automation end stations are connected wirelessly which of course is a very challenging scenario.

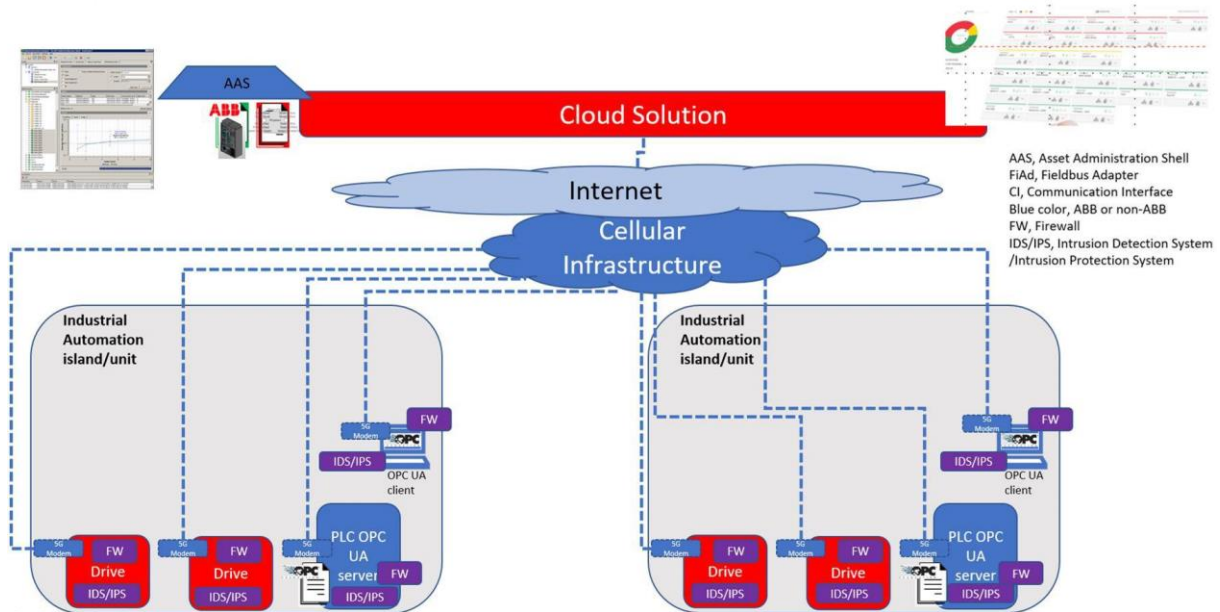


Figure 17 - 5G-intensive architecture example

This use case - even if technically possible and interesting - adds several challenges and risks which should be investigated during the trial, so that important feedback can be given to industrial automation and potentially to standardization bodies related to usage of 5G in this domain (e.g. 3GPP, OPC Foundation, 5G ACIA):

- The security challenges & risks
 - o DMZ disappears: it should be replaced by similar functionalities in industrial automation end stations and in computers
 - o Number of industrial automation end stations connected over 5G increases: it may be necessary to recur always to private spectrum
- The cost challenges & risks
 - o The security challenges potential resolutions may increase significantly the cost of industrial automation end stations and the whole system cost, due to the needs of private spectrum leasing costs
- The customer trust challenges & risks
 - o The customers may be very reluctant to rely so much on a GSM services provider for the functionality of their network and system.

4.1.4 Weaknesses and Bottlenecks

Benefits of eliminating islands of automation:

- Integrated systems help to avoid duplication of information.
- Saves time by avoiding entering the same information in different applications.
- It helps the employees to develop their efficiency and skill as they learn only one application thoroughly instead of learning many applications.
- Increases productivity.
- Minimize the errors by avoiding manual entry.
- It helps to get complete and accurate reports quickly and easily.

4.1.5 Trial Future Scenario

We are able today to make projects, which cover the production lines support with motion equipment (controllers, drives, encoders, motors, etc). Nevertheless, there are several complex points, which today raise challenges related to:

- Planning efforts
 - Simulations: before starting the effort of building a green field system or modifying an existing system (called as 'brown field' system), the end customers may want to know what to expect
 - Reusability: Digital twins facilitate simulations, but also reusability, so that parts of existing systems or functions of a system can be reused by the customer in other installations
- Cabling efforts
 - Documentation: each connection has to be documented in a CAD document, which needs to be created by the system integrator (which can be a company such as ABB) and further on maintained by the end customer or their related teams
 - Costs: cables between various industrial automation islands or plant sections must be installed with regards to personnel and functional safety, thus following standards, which may require effort and equipment costs
- Time to bring a new system online: the efforts of cabling and their installation, between existing automation islands require time and verification as to comply with existing required standards
- Extendibility/Modifications efforts
 - Many systems do not remain the same during their life cycle, the end customers willing, in time, to extend an existing plant or factory
 - Many systems need adaptation to new production needs, thus reconfiguration is a very relevant use case
 - Each modification or extension brings in again, the main efforts shown in the points above
- Privacy related aspects
 - Spectrum usage is private, unlike in other wireless mechanisms
- Comparison to other wireless solutions compared to 5G system
 - LoRA, NB-IoT, WiFi6e, WiMax, ...
- Aspects: performance (cycle time supported), data amounts, ease of configuration, security, privacy, etc.

The needs to be addressed are the following

- Availability of cellular equipment following 3GPP standards
- Clock deviation measurements over 5G-System
- QoS and traffic shaping capabilities of a 5G-System
- Challenges of traffic shaping capabilities of a 5G-System
- Security Aspects
- Utilisation of smart tools in cabinet manufacturing using a wireless 5G System for their interconnection

The proposed Zero-SWARM solutions in these trials pave the way for the use of various Artificial Intelligence (AI) & Augmented Reality (AR) related use cases in the future shop floors with the help of the digital twin.

4.1.6 Expected Results and KPIs

ID	KPI Name	Description	Unit	Current value	Future expected value	Expected date of achievement**
1	5G equipment availability	Availability of needed 5G equipment	N/A	N/A	N/A	End of trial setup
2	Configuration abilities	Configuration capabilities of the equipment	N/A	N/A	N/A	End of trial setup
3	Clock synchronization precision	Precision required for at least 1 ms (between devices in and outside of the same industrial automation island)	ms	1	1	End of trial setup
4	Traffic shaping capabilities	Capacity of shaping the traffic so deadlines of data transfer are reached – cycle times supported	ms	2	2	End of trial setup

Table 2 - NN01 KPIs

4.1.7 GDPR Assessment

There will not be personal data processing needed in this trial.

4.2 NN02. Sustainable Powertrains

4.2.1 General Description

The objectives of this trial consist of the validation of using 5G networks to collect data from sensors used in rotating machinery like powertrains that include electric motors, drives, shafts and other machinery. This is one of the first steps to form a wireless closed-loop automation systems in the shop floor where a continuously monitoring, measuring, and assessing real-time operations becomes possible. When the feedback is received and is taken into account for further action, an “automatic” action can be taken by the controller. The life cycle requirements of the process, depending on the scenario, could be in order of seconds down to few milliseconds.

5G is expected to deliver time sensitive data from the sensors of devices in those rotating machinery. Given the expected life cycle, ultra-low latency performance is expected from the 5G connection. At the same time, since the reliability of the connection is important to maintain a secure and trustable close-loop operation, connection reliability is another important requirement.

At the same time, the quantity of data might be large. Therefore, besides providing high bandwidth wireless connection, the usage of edge computing for local processing or running machine learning applications close to the rotating machines will be another objective of this trial.

Given the complexity of the environment, this trial will test in this concrete industrial context, initially, what is the impact of radio interference and low latency requirements for collecting data from advanced sensors installed in the rotating machinery. Later on, we will investigate how to improve end to end 5G system performance to meet the latency, reliability and band width requirements of the mentioned scenario in this trial.

Other objective for this trial due to the sensitive of data collected, is to study the security requirements and trusted connectivity in industrial conditions for collecting data from advanced sensors including usage of distributed intelligence. The trial will also analyse the usage AI/ML tools in industrial environment for collecting data from the operation of these systems.



Figure 18 - Powertrain with embedded wireless sensors for monitoring.

4.2.2 Participants and roles

Aalto Industrial Internet Campus (AIIC) offers both physical and digital infrastructure including IIoT platforms. Aalto will contribute with the 5G infra for connecting the sensors installed in the rotating machines with the measurement devices installed in centralized control room. Aalto will also contribute with the 5G devices to be used for measuring the communicating with fixed devices. Aalto Communications and Networking Department (COMNET) in cooperation with Aalto IT will provide 5G SA non-public networks to be used by AIIC.

ABB will define the use cases and scenario requirements.

Visual Components will provide the tools for deploying digital twin of the factory and sensors

Acceleran will provide the HW and SW for deploying O-RAN radio in the NPN to be used for the trial.

Huawei to set requirements for testing of the proposed 5G capabilities in this trial. It also contributes to the further investigation of extra cases that consists roaming between public MNO and NPN. Also, to use public slice in the public network covering the private network. Furthermore, to use slice in the NPN to be used as part of the public MNO. In addition, Huawei could work to improve the local break out capabilities of 5G system to guarantee the full presence of sensitive data at the local enterprise premise.

4.2.3 Trial Present Scenario

The trial will utilize latest 5G network components and mobile devices to obtain the best performance possible when connecting over the 5G network. The first scenario that will be deployed consists of delivering time synchronization to the 5G devices in order to collect sensing data with accurate timestamps for post-processing in the application server located in fixed LAN.

Aalto Industrial Internet Campus (AIIC) offers both physical and digital infrastructure including IIoT

platforms and 5G connectivity for this world class applied research trial. Smart and connected systems along with remote access and machine learning are among the key focus areas. The research group involved in Zero-SWARM focuses on rotating machinery like powertrains, including electric motors, drives, shafts and other machinery. Industrial need for collecting data from the operation of these systems requires advanced sensors, distributed intelligence and secure trusted connectivity in industrial conditions.

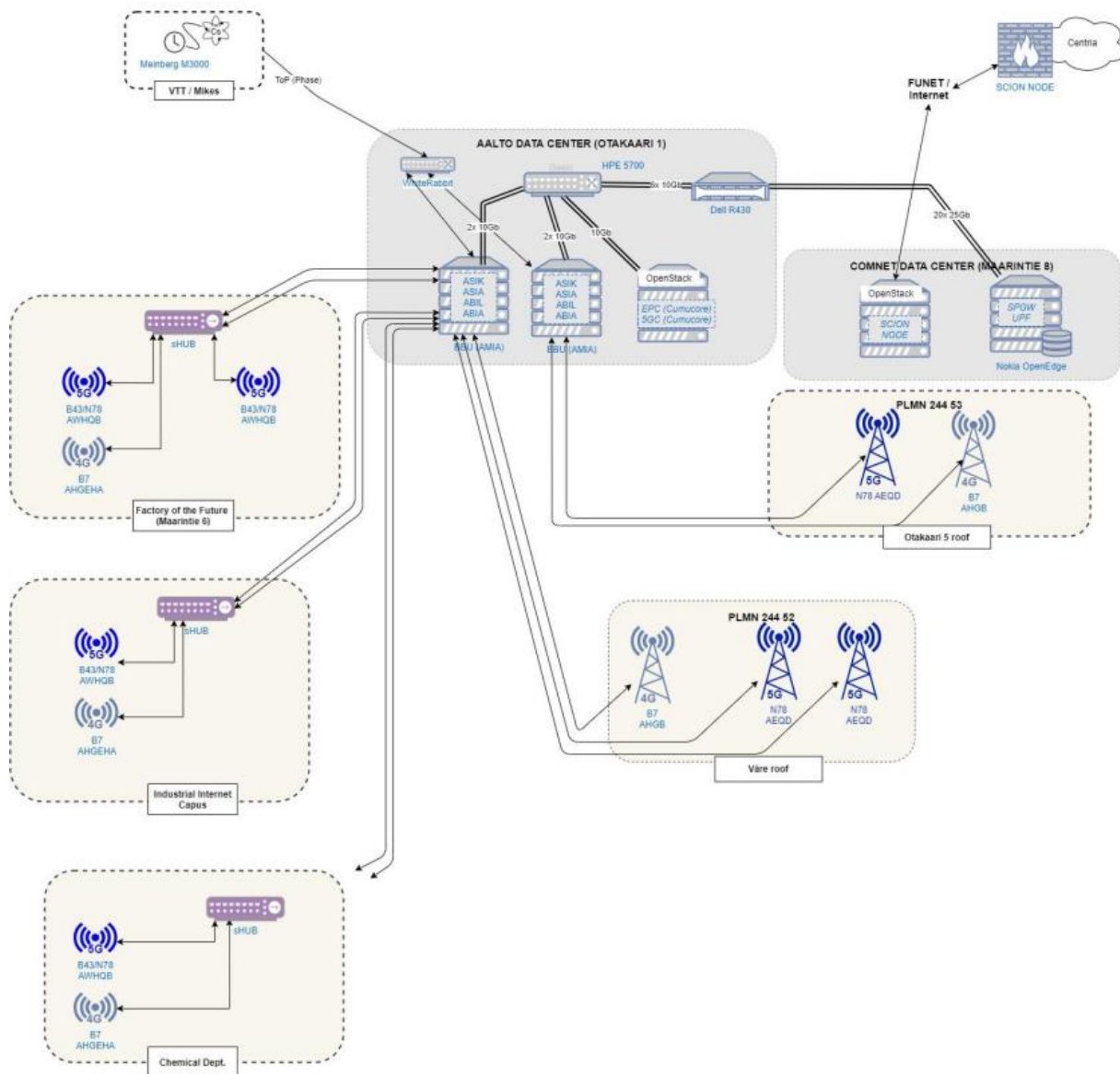


Figure 19 - Aalto 5G infrastructure with industrial private network and outdoors public 5G network.

Currently, AIIC is equipped with a standalone AALTO 5G network (a 5G NPN). In the near future, AIIC is planning to integrate this private test network with a commercial 5G network to further study the operation of 5G public and NPN networks for global coverage. Powertrain trial includes goals for wireless sensors for advanced machine learning analytics to optimized operation, vibration control and prescriptive maintenance needs. Trusted and secure 5G technology is tested in industrial context where radio interference and low latency requirements set high demands for connectivity. In addition,

edge computing for machine learning applications is studied.

4.2.4 Weakness & Bottlenecks

WEAKNESS & BOTTLENECKS	DESCRIPTION	AREA ¹	IMPACT IN THE COMPANY <i>At processes (manufacturing) level and business level</i>
Accurate timestamping	In order to provide accurate time information, it is required that 5G devices or modems support hardware timestamping	Process	Accurate timestamping will allow tracking and analyzing the performance of a manufacturing process over time
Ethernet PDU	To deliver time information is required to transfer L2 (i.e. Ethernet) messages across 5G system which currently only support IP data transfer	Process	

Table 3 - Weaknesses and Bottlenecks addressed in NN02

4.2.5 Trial Future Scenario

After providing the enablers to collect the data using the 5G connectivity from the powertrain, on the next step we will work on the other side of a close-loop automation system, i.e. ML/AI decision making process and will investigate how 5G system has to meet the life cycle requirements of the reaction path on the close loop automation system. For example, what will be the packet lose tolerance or packet arrival delay tolerance, and how we can improve it etc.

Needs to be addressed are the following

- Remote PLC connectivity using a 5G-System
- Advanced sensing
- Distributed Intelligence
- Secure connectivity
- Plug & Play concept to add devices to a 5G-System
- Commonly accepted industrial automation system architecture in relation to a 5G-System
- Reconfiguration use cases for the customer requested changes in the industrial automation system
- Optimisation of the whole system functionality (5G-System and industrial automation) using remote mechanisms

4.2.6 GDPR Assessment

There will not be personal data processing needed in this trial.

4.3 NN03. Improved Resilience with Remote Operation in Mass Customized

Production

4.3.1 General Description

The increasing trend of mass customization of production, disruptions in the shop floor drives the shift from fixed production line towards distributed, dynamically reconfigurable production islands which grant high flexibility and agility. Some production islands can have mobile capability (e.g., in the form of AGV attached with industrial robotic manipulator) which allows changes in the physical layout and enables flexible material flow across production islands in the shop floor.

Originally, a concept proposed by the University of Michigan College of Engineering's Research Center, a reconfigurable manufacturing system (RMS) is a system used by manufacturers that emphasizes the importance of being able to change and evolve rapidly in order to adjust its productivity capacity and functionality. When a sudden change occurs in the market, the reconfigurable manufacturing system changes in response, allowing the company to produce products or goods in an efficient manner. There are six characteristics of RMS:

- **Modularity** — machines, controls, tools and other items within the manufacturing system should be modular, meaning they can be added, removed and switched for other items with relative ease.
- **Integrability** — manufacturing companies should be able to integrate modules rapidly and effectively, at both the machine level as well as the system level.
- **Customized flexibility** — the system should be flexible enough so that manufacturers can upgrade and add new modules.
- **Scalability** — this refers to the system's ability to add new products by rearranging the manufacturing system.
- **Convertibility** — the ability to transform existing systems and designs to suit new production lines.
- **Diagnosability** — the ability to automatically read and analyze a system for defects, errors and related problems.

The objective of this trial is to validate in the benefit of Zero-SWARM technologies in mass customized production considering distributed modular, flexible production units. Particular focus of this trial will be in validating Zero-SWARM virtual commissioning, dynamic reconfiguration enablers of production system in light of 5G enabled shop floor.

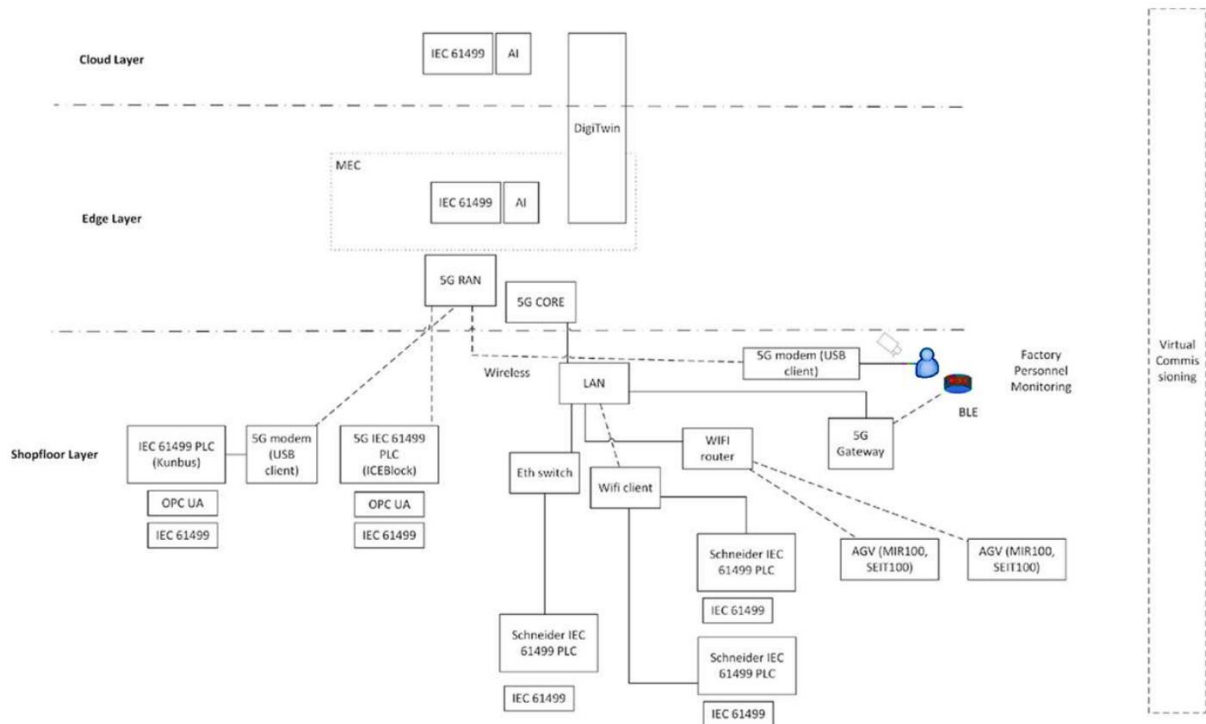


Figure 20 - Architecture example of the shopfloor to be considered for the trial

4.3.2 Participants and roles

Aalto University (Aalto Factory of the Future / AFoF): Aalto University is a multidisciplinary research and education institution in the fields of science, business, and art and design, with main campus located in Espoo, Finland. In this trial, the Information Technology in Automation group at Aalto University will provide the Aalto Factory of the Future testbed, which consists of modular production islands with mobile production units, connected to Aalto's own 5G infrastructure.

Aalto University Communications and Networking Department (COMNET) in cooperation with Aalto IT will provide 5G SA non-public networks to be used by AFoF in this trial.

ABB will define the use cases to check the objectives indicated in previous section and contribute to the test setup with OPC UA components to be part of the validation.

Visual Components will contribute with digital twin of the test setup to visualize the status of the system. It will provide the tools for deploying digital twin based on the information collected from real equipment deployed in the AFoF.

Acceleran will deliver the O-RAN gNB with URLLC or other features required to provide end-to-end system for the test setup, i.e. it will provide the HW and SW for deploying O-RAN radio in the NPN to be used for the trial.

Huawei will bring the know-how about the 5G mobile system to support URLLC requirements of this use case. In addition, it will work closely with the partners to identify extra enhancements needed to improve URLLC capabilities of 5G and mobile edge computing to serve better the needs of re-configurable assembly lines in the future shop floors, e.g. QoS guarantee beyond the best effort for some of the various data streams transversing the 5G system.

4.3.3 Trial Present Scenario

This trial assumes modular distributed production islands, with remote (cloud-enabled) monitoring and virtual commissioning capability that can enable simulation, remote monitoring, remote reconfiguration, and control of production islands. There will be production islands with mobile capability that can relocate and perform assembly individually or collaboratively in different locations at the factory floor with other actors, e.g., assembly machines controlled by IEC 61499-compatible PLCs or with onsite factory personnel. Data collection and exchange involves the use of OPC UA protocol.

The trial is hosted at the Aalto Factory of the Future (AFoF) facility, a 5G supported pilot facility for innovation in future industrial automation, I4.0 and beyond, at Aalto University. The facility focuses on achieving revolutionary high flexibility by exploiting the architecture of modular production units. AFoF is highly suitable for investigating and trialling various enabling advanced technologies for production systems that include: AI, I4.0, IIoT, wireless communication (5G, Wifi6), edge/fog/cloud computing paradigms, virtual integration, digital twins, remote commissioning, operation and predictive maintenance, human-robot collaboration, simulation, virtual and augmented reality. At the Aalto Factory of the Future testbed, modular production units are controlled by distributed automation based on IEC 61499 standard with available OPC UA interface.

While 5G technology is expected to support customizable and more capable mobile network to improve flexibility and cope with the need of factory operations, e.g., with network slicing, various Zero-SWARM technologies such as virtual commissioning and dynamic reconfiguration enablers will be tested, which are executed on top of wireless connectivity such as 5G. The setup will include AGV with robotic manipulator that can perform assembly, and EnAS production island which consists of closed loop conveyor system with assembly manipulators.



Figure 21 - Mobile Production Island working collaboratively with another production island at the Aalto Factory of the Future

4.3.4 Weaknesses and Bottlenecks

Presently the setup relies on wired connectivity and traditional Wi-Fi at some part. This physical connectivity restricts the capability of the setup in its physical reconfigurability.

In addition, when the shopfloor is to be reconfigured to certain setup, it is difficult to determine whether certain production plan and setup delivers the expected performance and output especially

when the production system gets reconfigured frequently. This prolongs the time required to complete the reconfiguration process and delays the product time to market. Furthermore, the inability to test and simulation of various possible configurations in order to decide for the configuration can lead to the risk of disruptions when it is deployed in real process.

4.3.5 Trial Future Scenario

The following scenarios are considered in the trial in order to investigate and test how Zero-SWARM technologies and frameworks can improve resiliency in production system

1) Virtual commissioning

As it is difficult to determine whether certain production plan and setup delivers the expected performance and output especially when the production system gets reconfigured frequently, Virtual commissioning plays a role in facilitating and automating benchmark, simulating, and testing of various setups (with potentially various possible connectivity used), to validate implementability and performance of certain setups, in the hope to achieve resilient production. A prototype simulation environment of the EnAS and the mobile production island has been developed by AFoF using Visual Components software, which can be used as an interface by the engineers and remote visualization to support remote operation.

The challenges / requirements with regard to virtual commissioning in this case:

1. The Virtual commissioning technology should be able to model different connectivity and automation architectures considered in the scenario and see the behaviour differences.
2. The virtual commissioning may need to model hybrid architectures where a part of devices is real and another part is virtual

The following stages will be taken to develop the trial:

1. Wired decentralized control with IEC 61499, as a reference case. Wired connectivity limits the shopfloor flexibility where it hinders physical mobility of the production islands.
2. Wireless decentralized control with IEC 61499. Wireless connectivity alleviates limitation on physical mobility. Clock synchronization will be introduced in this stage, where the connectivity will start from traditional Wi-Fi and then towards 5G connectivity in certain subsystem. This could lead to the case of hybrid connectivity where some part of the system uses 5G connectivity while some other parts may still rely on WiFi due to technical limitation of the corresponding control devices (user equipment).

In such scenario where the virtual and physical world interacts the role of deterministic, reliable and low latency 5G communication will be more highlighted. Each reconfiguration interaction shall be synchronized with a reference clock (which can be probably provided by the 5G system). At the same time, it is important to understand better the packet lose and packet delivery delay requirements of this virtual/physical interactive scenario.

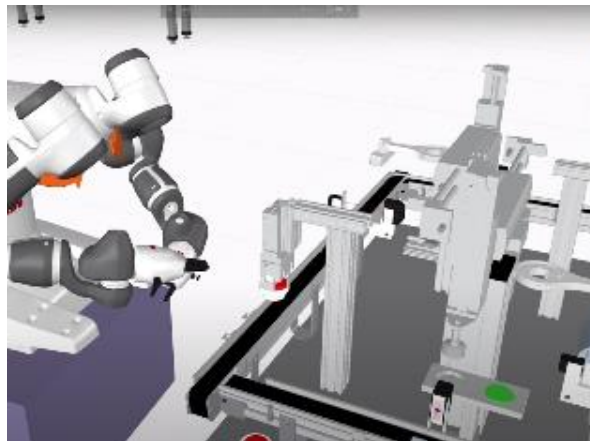


Figure 22 - Visual Components 3D environment representing two modular production islands, that can be used for simulation and demonstrate virtual commissioning

2) Dynamic composition of a flexible production system composed of smart production modules, with IEC 61499 standard.

The execution of assembly and manufacturing processes of a product is determined from the recipe. The trial scenario will consider an approach of establishing production system by dynamically composing from available production modules in the shopfloor.

The recipe of the product will initially be assessed for its implementability. This involves steps of discovering and checking the availability of production modules, in addition to virtual commissioning. They altogether assess the possible composition of the island or modules into system based on the availability of the modules and metrics applicable. Upon positive results of implementability, the production system can be composed during runtime from distributed modules based on multi-agent concept and plug and play approach. The approach, which will be developed as part of Zero-SWARM technologies, will include the use of skill concept to describe production island capabilities and functionalities, dynamic discovery of skills during runtime, and semantic graph model of skills and reasoning on the semantic model to check feasibility or identify missing components. This is expected to reduce effort in dynamic composition in case of unexpected disruptions.

4.3.6 Expected Results and KPIs

ID	KPI Name	Description	Unit	Current value	Future expected value	Expected date of achievement**
1	5G connectivity	The setup is connected to the 5G network	%	0	100	During implementation
2	Plug and play	The production system is able to be reconfigured with plug and play approach, multi agent concept	%	0	100	end of the implementation
3	Virtual commissioning	The system can be simulated, tested based on virtual commissioning technology	%	0	100	End of the implementation

Table 4 - NN03 KPI

*** During the implementation / end of the implementation / before 6 months after implementation / before 12 months after implementation / before 24 months after implementation / more than 24 months after implementation*

4.3.7 GDPR Assessment

Any personal data involved in the trial will be handled with due diligence following Aalto University guide ¹¹, which is developed to comply with the Finnish personal data Act and the EU GDPR. Aalto University has strong support services in place to ensure that all requirements with handling personal data during research project are satisfied.

4.4 NN04. 5G Powered PLC's for real time communications in distributed control systems

4.4.1 General Description

Ensuring intrinsically safe, secure and low-latency communication between Cyber-Physical systems (CPS) in industrial automation is quite challenging due to the complex interaction of intelligent mechatronic components equipped with embedded control devices, especially when it comes to the wireless communication. This trial studies the deployment of the distributed system using 5G-powered PLCs to measure the various KPIs related to latency and security. The validation and interoperability between different protocols such as OPC UA, MQTT etc. with IEC 61499 standard for communicating with other tools and services via 5G enabled controller devices will experiment and thus trial analyses controller usage based on standard IEC-61499 for distributed control systems. The trail extends the IEC 61499 for supporting the dynamicity of CPSoS models by introducing dynamic discovery and registration of agents with semantic skills to implement the plug-and-play feature. Explore the possibilities of secure and trusted communication between agents via NFT messages to protect against cyber threats and respond to attacks.

To this end, we will study the deployment of distributed systems in AIC3 lab to control different systems. Analyse the usage of controllers based on standard IEC-61499 for distributed control systems. Validate the interoperability between different protocols such as OPC-UA, IEC-61499 for communicating with other tools and services.

Specific targets:

- An open framework for development and implementation of re-usable I4.0 framework to govern the behaviour of 5G-enabled agents as part of an Intelligent Swarm
- Carbon footprint tracing of 5G communication infrastructure based on updated Asset Administration Shell (AAS). The network itself will be treated as an asset in the near future being described and managed by AAS. Explore the use of the digital twin of 5G user ends and network gears to forecast potential network loads in given industrial applications and to negotiate the quality-of-service parameters needed in the actual application, i.e. latency and reliability of 5G connection. We target extending and demonstrate 5G AAS structure & sub-models, modelling and building digital twins that are seamlessly integrated with their real-time

¹¹ <https://www.aalto.fi/en/services/how-to-handle-personal-data-in-research>

intelligence, hence allowing “the first green production” by including carbon footprint of communication infrastructures, physical assets and services, encompassing the whole value chain of a networked production scenario.

- Qualitative and quantitative performance indicators to evaluate 5G role in the Zero-X manufacturing and using digital twins to integrate 5G into production networks.
- Developing extensions to the IEC 61499 for supporting the dynamicity of CPSoS models and seamless operation with the semantically tagged information and knowledge.
- Explore the use of vertically and horizontally secure and trusted designs (Security-by-Design) and Runtime Cybersecurity monitoring to protect against cyber-threats and respond to attacks.

4.4.2 Participants and roles

AIC3 will contribute with equipment such as PLCs from many different hardware vendors to be used in the trial. The 5G network in the AIC3 lab is provided by **Telia** using equipment from **Ericsson**.

Huawei will contribute with the know-how on the carbon footprint tracing of 5G communication infrastructure based on updated AAS to make production green.

Acceleran to provide O-RAN gNB to be deployed at AIC3 and build non-public 5G network.

Aalto will contribute in developing virtual commissioning and multi agent plug and play technologies.

4.4.3 Trial Present Scenario

AIC3 is a 5G ready test bed for demonstration of I4.0 applications. The 5G infrastructure is supported/provided by Telia (telecom operator) as the service provider and Ericsson (telecom vendor) as the technology provider. AIC3 uses PLCs from many different hardware vendors (5 different vendors and over 40 PLC's) showcasing interoperability and portability. It is a world-unique model representing the synergy of various production systems with the energy supply and monitoring infrastructures. The testbed consists of an integrated model realistically representing at laboratory scale the material and control flow of production plants connected with the hosting intelligent room/building infrastructure and energy distribution infrastructure. The autonomous robot infrastructure is an ideal setup for trials. Distributed systems form the core of this lab and a truly distributed control architecture is used to control different systems. The controllers use standards such as IEC-61499 for distributed control systems and interoperability protocols such as OPC-UA for communicating with other tools and services. Particular areas of application include factory and process automation, farm automation, logistics, smart energy systems and data centres. The use case at this facility will complement the AIC trial of AALTO by extending it to include the complete vertical of a factory floor. The trial will study and measure the 5G powered PLCs for real time communications in distributed control systems using IEC 61499 standard. We propose to use 15+ PLCs in this test bed.

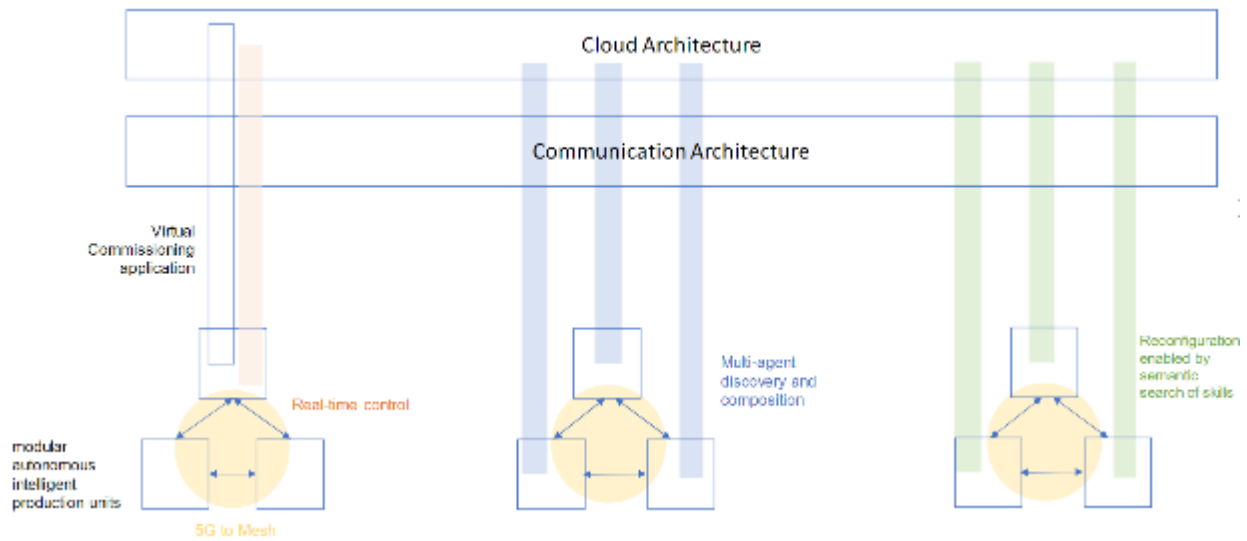


Figure 23 - Architecture

4.4.4 Trial Future Scenario

In this Trial the following scenarios will be implemented

Decentralised automation in Real-time execution and virtual commissioning

Machine 1: FESTO Processing Station

- Decentralised control in the system (mechatronic actors Drill, Checker, Table, Battery) Shift from the centralized control system (Figure 24) to a distributed (Figure 25) Where special attention is considered to the re-configurability and simplicity of the final program solution.

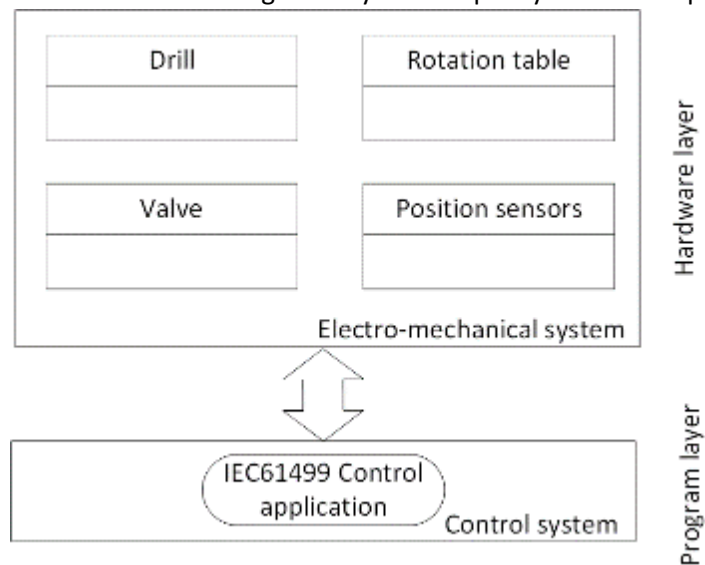


Figure 24 - Structure of the electro-mechanical system with centralized control.

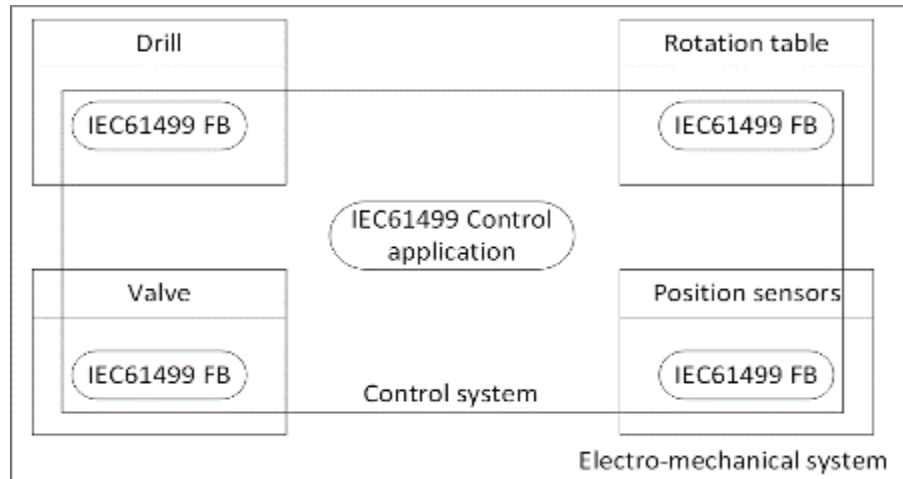


Figure 25 - Structure of the distributed control system

- Docking
The docking system is implemented in a way pair of infrared emitter and receivers where these two parts are deployed physically on different equipment (stationary and movable for example) as it is presented in Figure 26.

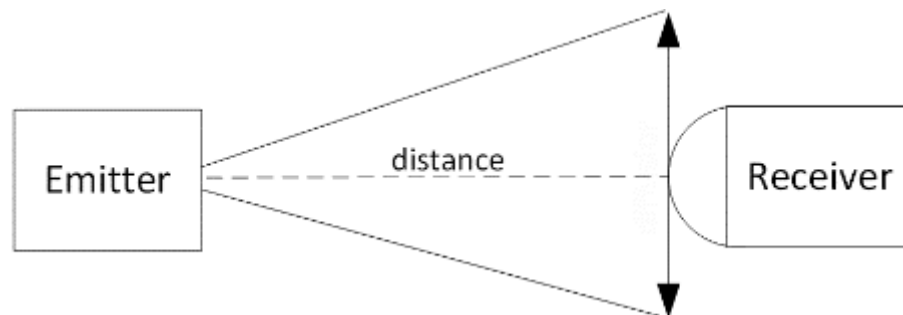


Figure 26 - Schematic view of the docking system.

- Collaboration with other stations
Collaboration with other stations is implemented based on the OPC UA communication protocol (connection type - wireless) as it is presented in the figure below:

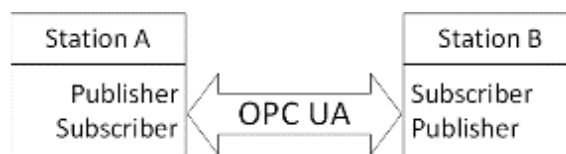


Figure 27 - Collaboration between stations.

Energy saving and battery management

An energy saving system is implemented in the decentralized control application shown in Figure 25. Here current and voltage sensors are implemented virtually (the amount of consumed power is assigned to each device by one physical current and voltage sensor). The structure of such a system is presented in the following figure.

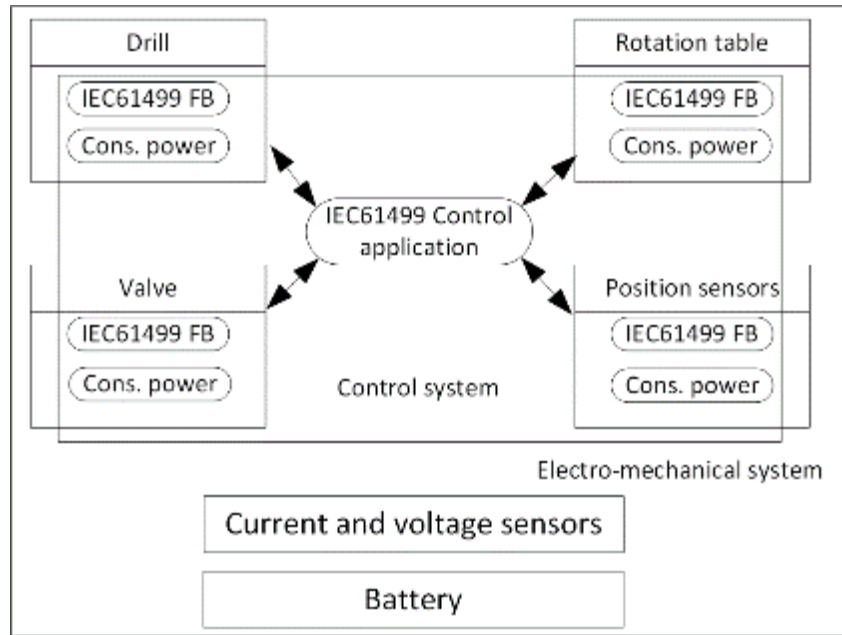


Figure 28 - Structure of the energy saving system

Machine 2: 3 Axis Manipulator (Collaboration with Aalto)



Figure 29 - 3 Axis Manipulator

The 3 Axis Manipulator is used in LTU's AIC3 facility as testbed to investigate the capability of IEC 61499 to satisfy requirements in distributed motion control scenarios. 3-axis manipulator solves the interpolation task in decentralised manner. Each axis in the 3-axis manipulator is equipped with its own control device, a "nano"-PLC. The control logic of each axis is implemented with IEC 61499 standard. Such tasks are typical cases of motion control which have strict timing performance requirements, hence investigating the performance boundaries of decentralised architecture considering various connectivity scenarios (hybrid 5G and Wi-Fi, pure Wi-Fi, with or without clock synchronization, etc.) between "nano"-PLCs is extremely important to better understand their impact and towards better decision-making regarding control architecture and connectivity options.

A digital twin of 3-axis manipulator is developed in collaboration with AALTO. In this trial, in

collaboration with AALTO, this digital twin of 3 axis manipulator will be connected to its distributed control logic which is run on virtual /simulated PLCs and establishes an infrastructure to demonstrate and evaluate the virtual commissioning technology developed in the Zero-SWARM project. Virtual commissioning approach will be utilized in realizing automated benchmarking, testing, and evaluating various parameters, and architecture of the corresponding system to find the most optimized ones that fit the relevant metrics (e.g., the least energy-consuming architecture, the least execution time). The trial setup is planned to integrate clock synchronization features to be accessible/adjustable also from the IEC 61499 application level, therefore allowing comprehensive experimentation and benchmarking which include both the 61499 application and the connectivity layer.

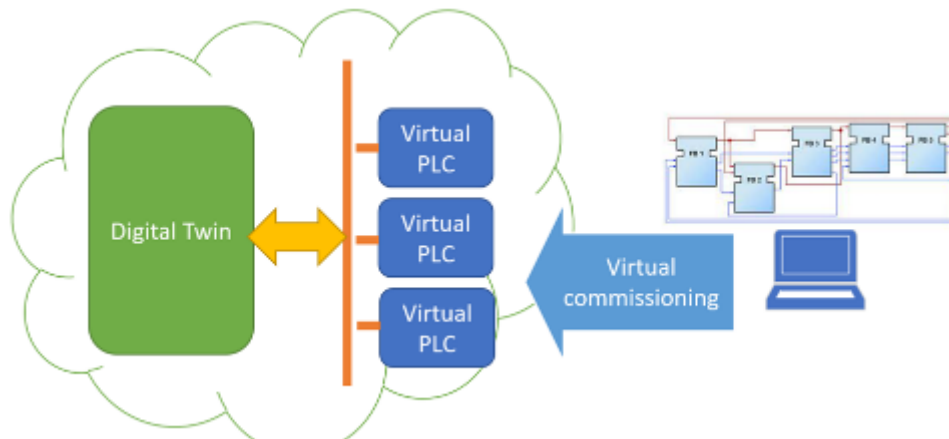
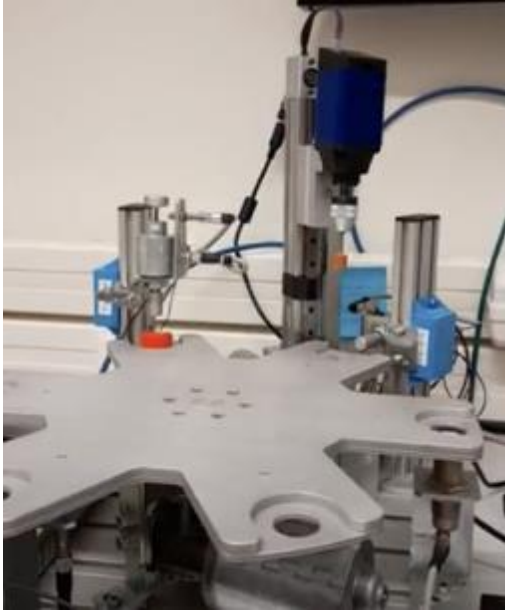


Figure 30 - Virtual commissioning of 3-axis manipulator

Multi-agent discovery in plug and play

Machine 3: FESTO processing station & EnAS simulation system in visual components

Features: – Introducing IEC 61499 dynamic discovery and registration of agents with semantic skills to implement the plug and play feature – Flexible and reconfigurable agent implementation in EnAs simulation developed in Visual Components. – Enable the secure and trusted communication between agents via NFT messages.	
	Figure 30 - SEQ Figure * ARABIC 31 - Festo processing station

The FESTO processing station in the AIC3 laboratory is used as an experiment to show the dynamic discovery and registration of agents with semantic skills to enable the plug and play feature. The processing station system in Figure 31 is composed of several mechatronic components like a drill,

clamp, and rotating table. It is assumed that the mechatronic components are smart, i.e. they are equipped with their own control devices, implementing their basic operations. The control logic of each mechatronic component is implemented as a function block which follows the IEC 61499 standard. It is assumed that the smart mechatronic components are delivered by their vendors together with the software components for implementing their control logic. They are integrated into the processing station in a way, that assumes that the control of internal operations in each mechatronic component is implemented by its predefined function block, and the integrator tries to minimise its software development effort by reusing the software components received from the vendors. The mechatronic components in the processing station and its associated agent's skill and capabilities are registered on graph DB using SPARQL queries using high-level programming paradigms like Node Red. IEC 61499 function blocks interact with Node-Red software agents via MQTT topics. The dynamic discovery and registration of agents with skills is proposed in the trial.

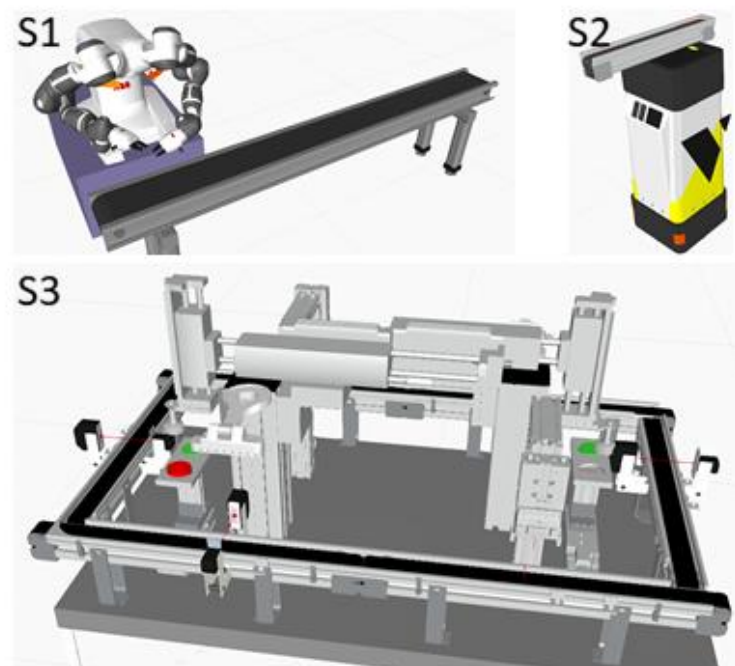


Figure 31 - Isolated IRB-subsystem of plant, S2) Isolated AGV-subsystem

As a case study, the Energy Autarkic Actuators and Sensors (<https://www.energieautark.com/>) (EnAS), a test bed located at Aalto University, representing a small-scale industrial production scenario and is used for the development and testing of various industrial automation techniques. Included sets of pneumatic operators such as jacks and grippers, motor driven conveyors and laser sensors.

An accurate simulation model of EnAS has been developed using a Visual Components 3D simulation environment. In this research, the simulation model was connected in a loop with the automation controllers. Figure 31 shows the visual representation of the digital twin. The major components are the main plant, the Automated Guided Vehicle (AGV), and the IRB. The controller for the plant is created using Ecostruxure Automation Expert (EAE) Schneider Electric (SE) and it is connected to the plant in Visual Components via OPC UA communication protocol, so that the controller can receive status updates from the plant, as well as control the plant through various signals.

This trial implements flexible and reconfigurable agents in EnAS simulation using Visual Components.

The semantic web ontology technology stack is used to build the multi-agent and the W3C web ontology language (OWL) is used to describe the capabilities and skills of the agent. This multi-agent system built on a semantic web ontology stack provides scalable and flexible solutions for reconfigurable production lines to produce customised product on customer demand.

Needs to be addressed are the following:

- Customizable and Distributed Production Systems with Plug-and-Play Capabilities
- Security of distributed industrial production systems
- Advanced Development Tools for Distributed Control Systems based on IEC-61499
- Data streaming from IEC 61499

4.4.5 GDPR Assessment

There will not be personal data processing needed in this trial.

5 Central Node Trials

5.1 CN01. Safe and Autonomous Transport of Goods in the Factory Shop Floors Using 5G

In trial 1, we are addressing the topic of enhancing efficiency in the operation of automated guided vehicles (AGVs). By creating transparency regarding key information of moving and unmoving objects in critical areas, participants of the shop floor traffic are known and automated systems can adjust their driving behaviour accordingly. In doing so unnecessary stops at junctions as well as last minute reactions, in form of emergency breaks, can be reduced. Implementing anticipatory driving in formerly critical areas with restricted view, limits the necessity of risk management by mandatory stopping regardless of the traffic situation.

This set up requires data sources with a low-latency, high availability solution for data transmission. Integrating sensors in infrastructure as well as from vehicles (AGVs) necessitates adequate hardware, like e.g. gateways, edge / cloud computing devices, as well as software for analysis and fusion of sensor data, algorithms and control systems for collision detection, order creation for the vehicle, etc.

Furthermore, AGVs are associated with high acquisition costs. The use of on-board sensors of AGVs (e.g. for safety applications) creates synergies and offers the possibility to realise additional Industrie4.0 use cases at reduced energy costs (compared to double equipment). Consolidating multiple edge computing devices helps save energy and reduce costs.

For the needed wireless connection of the moving system as well as the specific requirements of the use case, 5G is a promising solution. A mobile 5G set up and 5G capable edge devices will be tested and validated for this use case as well as all components of this set up, like e.g. the edge device.

Components and assemblies are produced as contract production. Due to the different products and customer requirements, both the production and its processes must be flexible. Manual activities and workers are part of shop floor processes and intralogistics. The combination of these requirements (need for flexibility) and surrounding conditions (changing processes, e.g. in intralogistics

transportation) form an ideal test field for the use case. Safety must be guaranteed, but at the same time, the efficiency of the intralogistical processes is difficult due to changing processes. To date, this problem cannot be solved by off-the-shelf AGV automation solutions.

5.1.1 General Description

The autonomous transport of goods on flexible shop floors is generally realized with automated platforms (AGV – Automated Guided Vehicle). They can navigate freely in the infrastructure and are not limited by guidance systems such as rails. To meet safety requirements, these AGVs are currently equipped with special safety sensors that detect obstacles or moving objects at a critical distance from the AGV. If an object is too close, the AGV stops until the object leaves the detection range. Consequently, the AGV has to slow down in areas with a limited field of vision, like e.g. an intersection. There, the AGV cannot detect objects around the corner, i.e. approaching objects on crossways. To avoid collisions in these situations, speed and autonomous actions of AGVs are restricted in current automation processes at the expense of efficiency. In addition, the lack of coordination and communication between AGVs and other moving objects on factory floors also limits efficiency (e.g. priority at intersections).

One of the objectives of this use case is to create transparency about neuralgic areas of shop floors in order to enable more efficient processes. By combining data from sensors in the infrastructure as well as from the moving AGVs, the situation in a neuralgic area can be interpreted in more detail. Based on this data, actions such as slowing down the AGV, can be deduced. Since, on the one hand, the situation on shop floors with moving objects changes quickly and constantly and, on the other hand, the risk of collisions represents a safety risk, low latencies and availability for the transmission and processing of data is key.

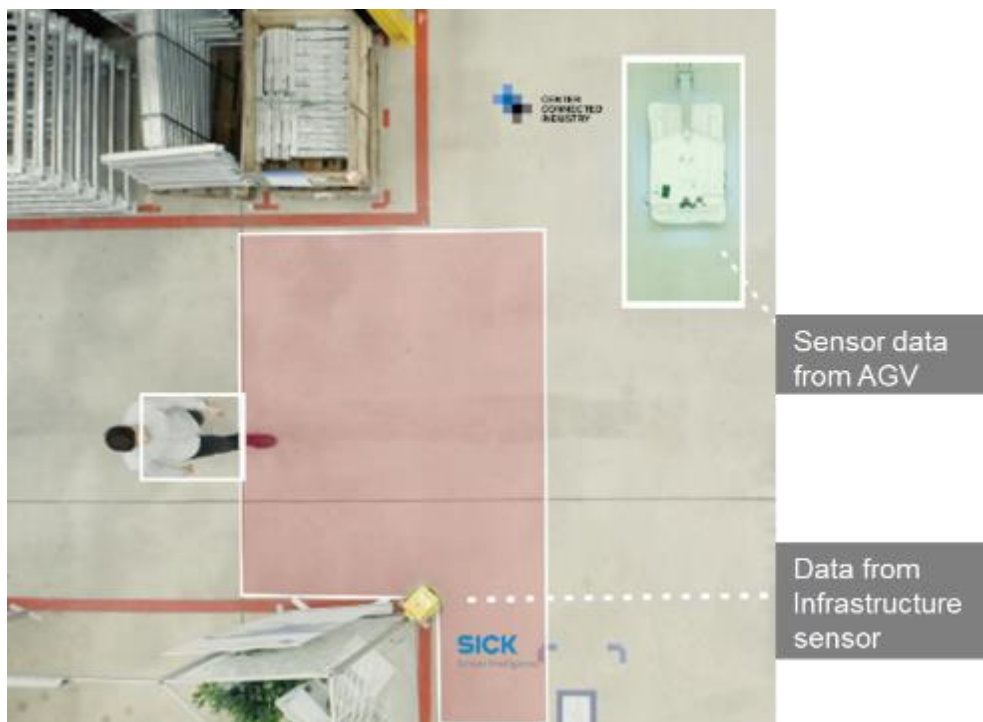


Figure 32 - Demonstration Factory Aachen

The planned test field is an intersection area, in the Demonstration Factory in Aachen (DFA). In this neuralgic area data from one infrastructure sensor and one AGV each will be transmitted via 5G. A

virtual image of the current situation with objects and their movements will be created based on the combined data of the sensors. With this information, the possibility of collisions can be calculated. If a collision is expected, the AGV can be slowed down in order to give way to a person, for example. This requires a form of intersection-specific controller that has yet to be developed.

In the future accurate, reliable data on a sufficient scale could lead to better coordination of intralogistics traffic. This could involve, for example, map-based localization applications that rely on up-to-date maps of the environment, or applications that are designed to work both indoors and outdoors. Since the AGV only needs to brake if there would be a collision, it can continue driving without stopping in all other cases. The virtual extension of the field of vision of an AGV described above can also lead to higher driving speeds, as the extended braking distances can be taken into account in the collision calculation.

5.1.2 Participants and roles

The role of the end user will be taken by Demonstration Factory Aachen (DFA) and by SMS Group. Both contribute to identifying the requirements and testing the suitability of the prototype. Initial integration and tests will take place in the DFA. In a second step, the SMS Group will assess the transferability to their factory floor.

The DFA offers various production processes that go beyond the state of the art, since it is prototype testing site for entities of the RWTH Aachen Campus. In this environment, new solutions for future processes are tested against the requirements of various industrial end user. Production ranges from prototypes to small batch series in metal processing, such as welding, bending, laser cutting.

SMS digital is challenging the trial e.g. with requirements from their shopfloor and infrastructure.

In this trial **SICK** has two main contributions on technical side. The first technical contribution will be the development of a 5G capable edge computing device. This device will be able first to connect to the given 5G network to enable a communication from the edge device to other 5G connected devices. Second the device will have sufficient interfaces to connect local sensors and actuators. And third the edge computing device will have enough computation power to enable local data processing. The second technical contribution will be a lidar-based localization algorithm to localize mobile platforms in intralogistics environments. An advantage of using 5G technology will be here the possibility to update the local maps that are necessary to enable a lidar-based localization algorithm, because the maps can have large sizes depending on the size of the factory to locate in. A further advantage can be the possibility to change the environment for mobile platform from indoor to outdoor scenarios.

For trial 1 **Center Connected Industry (CCI)** provides organisation with and integration into the testfield of the DFA. One of the ongoing tasks is to challenge the trial with requirements arising from the use in shopfloor situations. Additionally, CCI provides and enables an AGV to act in the infrastructure of the DFA. During the trial, we will implement interfaces tailored for the trial use case. The AGV will need to navigate on the shopfloor, including accepting orders and driving to destinations. In order to prevent collisions, we will integrate additional data, e.g. from a SICK sensor in the shopfloor. CCI will fuse the available data, implement a logic to prevent collisions and control the AGV accordingly.

IT Center of RWTH Aachen University. In this Zero-SWARM trial, particular focus will be on establishing 5G technology as the basis for safe transport applications evolving around AGVs. IT Center operates a 5G technology test bed based on a proprietary network core software and Open RAN components, in addition to an extensive 802.11 Wi-Fi network.

Of note, several customers of IT Center use the existing Wi-Fi network for their IoT applications, showing a number of limitations: Wi-Fi airtime needs to be shared between IoT, VoIP-over-Wi-Fi and general Internet access. Prioritization / QoS of Wi-Fi traffic is not generally implemented, and providing availability or latency guarantees on the network appears to be rather difficult. We expect 5G to fare much better in this field and hope to be able to show this as part of the trial, for which we contribute access to our 5G network. Wi-Fi will be available as a fall-back, which may very well provide practical proof that 5G capabilities actually are needed to successfully achieve the objectives of the trial.

5G networks still prove to be somewhat difficult to set up, at times involving a considerable amount of proprietary hardware and software. With the 5G testbed at IT Center, consisting of Open RAN and common off-the-shelf server hardware, we hope to show that 5G networks can be fairly easily introduced at the places they are needed. The extensive dark fiber network at our university is hoped to be a considerable factor in this, enabling the locations of centralized server / network hardware and of the RAN units to be separated over large distances. We contribute fiber optic connections between our 5G network core components and RAN components at DFA, providing on-site 5G coverage for the AGV trials.

5.1.3 Trial Present Scenario

Intralogistics Process

As contract manufacturer the product portfolio of the DFA varies according to customer orders. The range of products extends from small components to large assemblies in various quantities. Therefore, internal processes like e.g. logistical transports, need to be flexible. Since DFA is a small SME, complete automation of all processes incl. integration of business application systems is not economically possible. Especially, since the shop floor is used by employees as well as vehicles. Since it qualifies as a zone of collaboration between humans and robots, high requirements regarding safety need to be applied.

The production is structured as workshop production with the areas warehouse including inbound area, laser cutting, manual welding, automated welding, bending, assembly and outbound. Intralogistics transportation is realized by employees or AGVs with carts.

For transportation with an AGV the following flow diagram is an exemplary process. With our trial in Zero-SWARM we especially address the behaviour during the process step “Intralogistics route”:

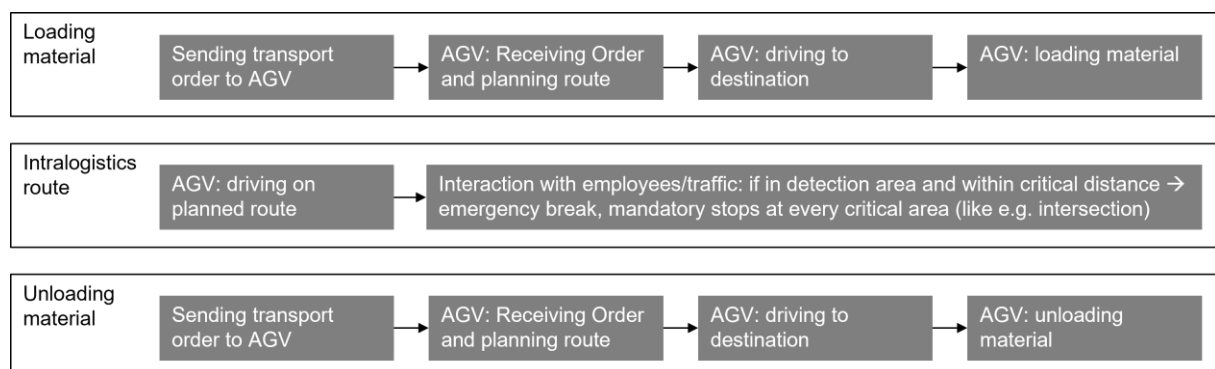


Figure 33 - Present intralogistics process in DFA

If the AGV encounters objects, like e.g. employees or vehicles, within a critical distance, it performs an emergency break. Objects outside the critical distance but within the detection range of the sensors

can result in the AGV slowing down or, to a limited extend, an evasive manoeuvre.

Objects approaching from an angle not covered by the AGVs sensors are not part of the perception. Therefore, the AGV can only perform an emergency braking if the objects enter the AGVs track, e.g. by approaching from an intersecting way. If the object is too close because, e.g. a person has stepped in front of an AGV from behind a welding curtain, a collision is the result. To prevent accidents, the AGV is forced to slow down in critical areas, resulting in lower efficiency.

5.1.4 Weaknesses and Bottlenecks

WEAKNESS & BOTTLENECKS	DESCRIPTION	AREA¹	IMPACT IN THE COMPANY <i>At processes (manufacturing) level and business level</i>
High tech sensors on AGVs are only used locally, for the AGV.	In order to obtain safe behavior, the AGV is equipped with a great number of sensors. They are only used for locating and navigating the AGV as well as to detect obstacles. (Data cannot be shared with present technologies)	Manufacturing / Warehousing	Since AGVs contain a great number of sensors and analysis systems they are expensive and can only be used for transportation purposes. With the means of e.g. WIFI only a small amount of data can be shared (if any). Creating synergies is therefore not possible and all automated operating systems need to bring their own sensors (high costs).
Limited information regarding traffic / (moving) objects on the shop floor	Moving objects, like vehicles (e.g. forklifts) or employees and unmoving objects, like pallets, are not tracked. Their location, velocity and direction are unknown. This enhances the risk of accidents with automated vehicles (due to their limited detection field)	Manufacturing / Warehousing	Automated/autonomous traffic is reduced to specific areas. If the automated vehicles are operated on areas with non-automated traffic, velocity and degrees of freedom are limited due to safety considerations. This causes the efficiency to decrease. (Longer transportation times result in longer process times and higher costs)

Table 5 - Weaknesses and Bottlenecks addressed in CN01

5.1.5 Trial Future Scenario

With our trial we aim at a more efficient operation of AGVs during their driving, as well as an improvement of transparency on the shop floor. The AGV is given driving orders, implemented by CCI, to send it to the next destination.

During the process step “Intralogistics route” the AGV will receive close real time information about the traffic situation of critical areas, like e.g. intersections- In the trial we test if this can be made possible with low latency and high reliability of 5G.

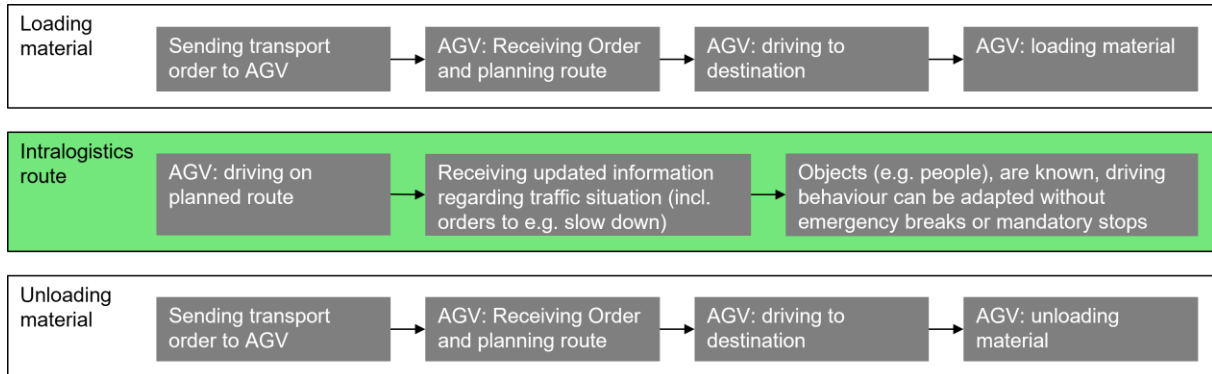


Figure 34 - Possible future process

Sensors installed in the infrastructure will collect and analyse data from objects (e.g. speed, direction) and send it to an intersection specific controller installed on an edge server. The controller implemented by CCI will receive data from different sources (e.g. sensor in infrastructure and AGV) and will use them to monitor for collisions. If a collision is imminent, the controller sends a command to the AGV that prevents the collision (e.g. order to slow down to 0.5 m/s).

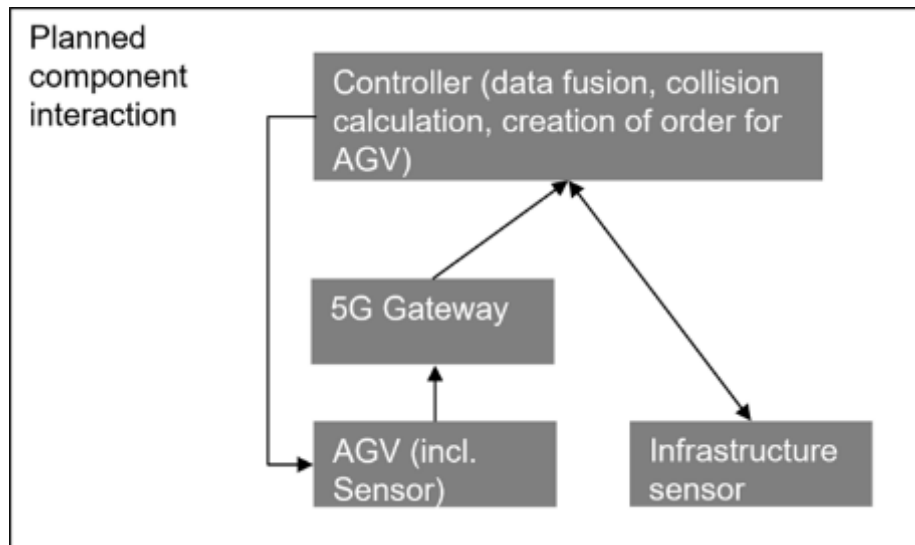


Figure 35 - Planned component interaction

Since low latencies and a reliable connection are necessary, 5G seems a good technological fit for this use case. Tests with a mobile 5G system on the grounds of the DFA are planned (ITC RWTH Aachen).

Within Zero-SWARM SICK will develop and provide a 5G capable edge control device that can be included easily in the available 5G network on the one hand and provides sufficient computation power for mobile applications on the other hand.

Furthermore, SICK will develop sufficient algorithms for environment perception on the AGV as well as in the infrastructure using 2D lidar sensors. Both data will be merged in further developed algorithms. Finally enhanced algorithms for lidar based self-localization will be developed that uses the advantages of 5G communication (e.g. for fast and reliable map updates).

In this use case the developed edge computing device will be used to run the mentioned algorithms directly on the AGV or at the distributed intersection sensor nodes.

The needs to be addressed are the following:

- **Low Network Latency:** Ensuring the optimal performance and safety of AGVs depends on several critical factors. A key concern is the fast responsiveness of the network, with a threshold of less than 100ms for the round-trip time between the control system and the AGV. This responsiveness is essential for timely emergency intervention.
- **High Network Stability:** Equally important is the consistency of the network connection. Network interruptions not only compromise safety, but also the advanced safety features associated with increased environmental awareness. Although backup strategies are available, they should only be used as a last resort.
- **High Network Bandwidth:** Efficient data communication plays a crucial role. AGV coordination may require a data flow of 10MB/s to ensure they receive constant updates with relevant data. To optimize bandwidth usage, it is advisable to process data at the source and on the AGV using a TDC. This method filters out redundant data, leaving only relevant information for transmission.
- **Ease of Connection:** Additionally, seamless integration is crucial, and devices such as AGVs and their sensors must connect effortlessly to the local wireless infrastructure to ensure efficient operations.
- **AGV Data Availability and Controlling:** The trajectory and velocity modulation of the AGV is critical to safely transport goods, especially in restricted spaces such as warehouses. The AGV requires instant emergency braking systems, even if hazards are not detected by its on-board sensors. Additionally, it is crucial for the AGV to receive feedback from multiple sensors and external data sources to adjust its speed accordingly, ensuring it stays in sync with its environment.
- **Sensor Data Availability:** Gaining insights from sensor data, whether raw, processed or analyzed, is paramount. It guarantees that the AGV is aware of possible obstacles or objects that may be out of its view but have been identified by other monitoring devices or AGVs.
- **Centralized Control System:** A centralized control mechanism is essential for synchronizing the movement of all entities and AGVs. This streamlined system enhances coordination and ensures that operations run smoothly.
- **Sustainability Aspects:** Sustainability strategies, such as using predictive speed adjustments, can prevent unnecessary stops and starts, conserving power and reducing wear for sustainable and long-lasting operations.

To summarize, effective and safe AGV operations depend on a combination of fast response networks, reliable connectivity, streamlined data communication, seamless integration, and a unified control mechanism, all supported by sustainability principles.

5.1.6 Expected Results and KPIs

Integrating moving objects with high requirements regarding latency and availability is right now, with the existing technologies like WIFI due to insufficient performance, not possible. Therefore, the KPIs are new and can only be achieved in case 5G proves to be adequate. First tests with prototypes (as

described previously) proved to be promising. Building on this the expected values are estimated for the prototype in this trial (not taking into account the necessity and effort of a full integration into all operating systems, like e.g. warehouse planning systems, existing control centers for traffic).

ID	KPI Name	Description	Unit	Current value	Future expected value	Expected date of achievement**
1	Efficiency of intralogistics transport with AGVs	Enhancing overall efficiency of automated intralogistics transport with AGVs due to integration of traffic information of a critical area into driving behaviour.	%	0	100	End of trials
2	Transparency of shop floor activities	Enhancing transparency of shop floor activities in critical areas by integrating former data silos and combining it with additional sensor information (e.g. AGV + infrastructure sensor)	%	0	100	End of trials

Table 6 - CN01 KPI Table

5.1.7 GDPR Assessment

The reason for the intransparency of intralogistics processes in mixed-use areas with traffic participants consisting of people, movable objects (e.g. forklifts) and other objects (e.g. pallets) is the non-recording of personal data.

People are not being tracked, there is no information about movement patterns. Additionally, vehicles like forklifts or pallet trucks are also not normally recorded. Since we do not change this fact with our use case, no personal data is collected in our trial.

5.2 CN02. 5G Enabled Process Aware AGVs

The main scenario of this trial is the control of a mobile manipulator, a small industrial robot arm mounted on an AGV, interacting with its environment in a production facility.



Figure 36 - Current setup of the mobile manipulator.

The main objectives in this scenario are

- Make the mobile manipulator aware of the production environment for interaction. Take advantage of 5G infrastructure to collect data from different data collection points (5G devices with SIM or USIM or Non-5G Devices talking through 5G gateway devices)
- Perform data processing and decision making over the Edge continuum
- AlaaS for ML-assisted AGV or robot trajectory planning
- Provide a sovereign data exchange, based on IDS initiative

5.2.1 General Description

The physical part of the trial will take place in the Production Technology Center (PTZ) Berlin, where the Fraunhofer IPK is co-located.



Figure 37 - Impression of the PTZ test field

The planned scenario consists of a small industrial robot arm installed on top of an AGV, which is enabled to pick & place an item. The control software of the robot and AGV are distributed in a way that basic tasks are on-board of the mobile manipulator and complex functions will be realized as services that run on a cloud infrastructure.

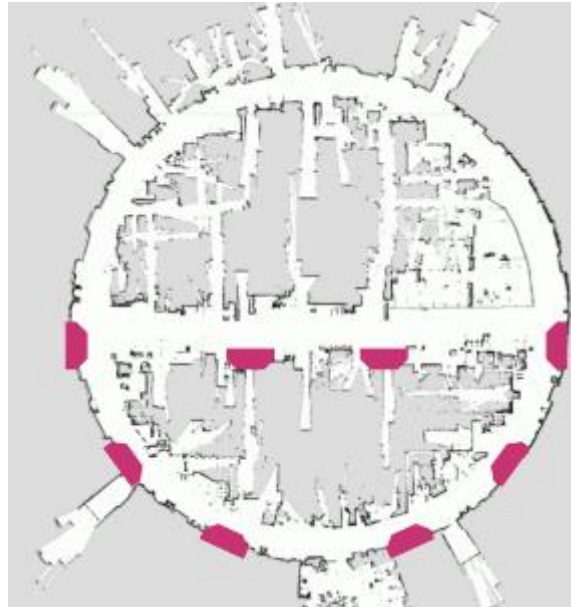


Figure 38 - Top view of PTZ test field, scanned with a hand driven AGV, and marked 5G antenna positions

The setup of the trial will start with a pick & place demonstration with marker-based localization using the edge cloud. An extension with an environment model is planned. As stationary counterpart a robot workstation including magazine holder is setup and included in the trial. Additionally, a warehouse for magazines will be setup.

As illustrated in Figure 38, 5G antennas and base band equipment are already installed.

However, a cloud-edge continuum is spanned at least between Fraunhofer IPK and Fraunhofer HHI, which will host and operate the processing infrastructure. Parts of the control software for the AGV and robot will be moved to an edge cloud at HHI, while the components to be controlled will be situated at IPK. The edge instance at Fraunhofer HHI is composed of 208 CPU cores with 1.5 TB RAM and 45 TB HDD. It is equipped with 6 NVIDIA Tesla A100 GPUs as AI accelerators for high performance computing.

5.2.2 Participants and roles

In terms of the trial, the test field of the **Production Technology Center (PTZ) Berlin** will act as the end user. The PTZ is formed by the Fraunhofer IPK and the TU Berlin Institute of Machine Tools and Factory Management (IWF).

The Fraunhofer Society is a German research organization with 76 institutes spread throughout Germany, each focusing on different fields of applied science, with some 29,000 employees, mainly scientists and engineers. In this project, two of these institutes namely, **Fraunhofer IPK and Fraunhofer HHI** are involved in this trial. The automation and robotics department of Fraunhofer IPK with 12 people is providing expertise in the field of service-based robotics application. Fraunhofer IPK will contribute with a mobile robot platform that consist of an industrial robot arm mounted on an AGV as well as with a production hall located at PTZ to serve as a shop floor for the implementation of the trial. Fraunhofer IPK will focus on the development of the robot control that will take decisions based on the data collected through the 5G network. Digital Signal Processing and Data Analytics (DSP) group at Fraunhofer HHI with 14 people is responsible for providing the edge cloud and 5G network infrastructure.

Opticoms GmbH based in Munich is an E2E 5G Campus Networks System Integrator with strong experience in Telecommunications and IT operations. Opticoms offers turnkey connectivity solutions to enterprises enabling the transformation journey. As one of the first local spectrum license owners in Germany and with strong ecosystem partners in networking, device, process analytics, and AI, Opticoms can deliver end-to-end solutions. The products and services of Opticoms can be summarized as following:

5G Private Networks Engineering Services

Opticoms offers full-fledge engineering services around 5G private networks thanks to its in-house framework with an extensive portfolio of tools, skills and experience to offer unique engineering supports to its customers.

Customized 5G Private Networks Solutions

Opticoms customized 5G private networks solutions take all the aspects of designing, building, integrating and operating 5G private networks with very flexible and scalable deployment options.

Standard 5G Private Networks Solutions

Opticoms' standard 5G private networks solutions provides a fully isolated, flexible, portable, easy to deploy and operate, cost effective and high-performance connectivity solution.

5G Private Networks Managed Services

Opticoms' optionally offered tailored managed services ensure the 7 x 24 operations of 5G connectivity solution with fully stipulated SLA conditions as one of the most important components of its product portfolio. Opticoms has already successfully employed 5G Private Networks in Bauma Fair 2022 to make sure that the end user gets the guaranteed QoS for remote controlled work machine

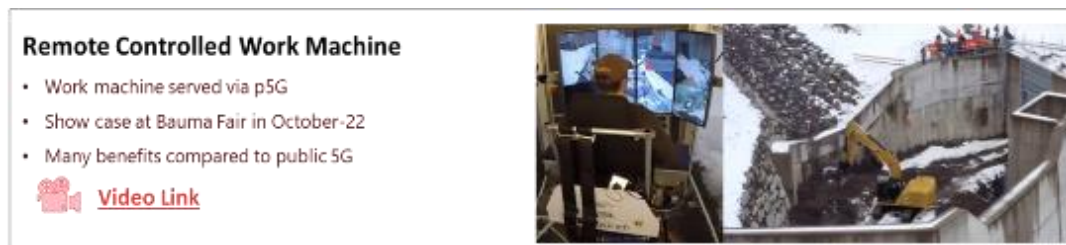


Figure 39 - Remote Controlled Work Machine

Private 5G has been deployed commercially for one of the biggest logistic companies of Germany with reliable coverage and smooth mobility from day 1.

Opticoms will contribute a 5G SA Core for this trial that is provided by Opticoms partner Druid and includes some fundamental virtual network functions (VNFs) such as AMF, SMF, UPF, etc. that are mostly compliant with 3GPP release 15 and partially also with 3GPP release 16. The software will also offer a HTTP-based management API which follows the RESTful API principles, for consortium. The exact VNFs as per the trial requirements and the availability of specific 3GPP release 15 or 16 features and functions shall be defined in the trial and Opticoms will check and try to deliver these requirements with the help of its partner Druid. However, it is not guaranteed to have all the requirements from 5G SA Core in place for this trial as the availability of these specific requirements are highly dependent on the vendor implementations and availabilities.



Figure 40 - 5G Private Networks for Intralogistics

The International Data Spaces Association is a coalition of more than 130 members that share a vision of a world where all companies and organizations self-determine the usage rules of their data in secure, trusted, equal partnerships. Their goal is a global standard for international data spaces (IDS), as well as fostering the related technologies and business models for open, federated data ecosystems and marketplaces which ensure data sovereignty for all participants. As shown in the infographic below, IDS enable trusted data exchange between data providers and data consumers. All participants in IDS can trust each other, because they all adhere to a common trust framework. This framework specifies that everyone must use a specific data end point: the IDS Connector. To ensure that each IDS Connector behaves as it should, it is certified against security criteria and so is any participant in data sharing. On this basis of trust, IDS improve cooperation, lower the barriers to entry and enhance innovation for the future of data economy.

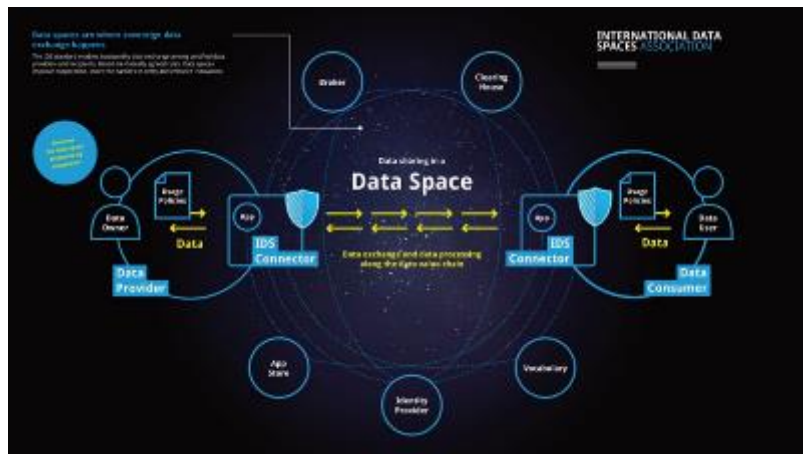


Figure 41 - IDS Connectors between partners in the international data space.

5.2.3 Trial Present Scenario

The desire to use plants flexibly to manufacture different products is increasingly pushing rigid automation solutions to their limits. This is giving rise to new requirements: On the one hand, robot systems need to be able to handle variations in the shape and position of components on their own. On the other hand, the material flow within a factory must also be able to respond more dynamically to orders. Chains of conveyor belts get in the way of rapid changes in process and production layout. They will be replaced by autonomous vehicles, which ideally enable order-specific interlinking of the systems. To meet this demand, researchers at the Fraunhofer IPK develop a system, which combines an autonomous vehicle and a built-in robotic arm. To work successfully in less rigid surroundings, the robot needs to learn to adapt to the highly complex environment. The vehicle therefore supplies information about the environment through two laser scanners while a camera atop the robot provides a depth map and another camera on the vehicle provides a 2D image in the direction of travel.

All of this information needs to be evaluated so that the robot can draw conclusions about the situation. The necessary algorithms require powerful computing hardware. However, while several solutions for 6 degree of freedom path planning exist, it still is a challenge to fast and reliably produce a valid path. A significant improvement is expected using an edge cloud instance to compute valid trajectories. The autonomous and mobile nature of the system limits space and battery capacity, thus an offloading of the computing operations in the cloud is desired. Currently WiFi is used but shows a poor performance. By a transition to 5G, a more reliable communication especially during the movement of the AGV is expected. Furthermore, the integration of an edge cloud is lacking.

5.2.4 Weaknesses and Bottlenecks

Weakness related to data sovereignty:

Today there is no control of the data after it has been accessed. Organizations need to work together and share data, but data becomes a strategic asset, so trusted infrastructure share strongly required to share data between organizations. Data-related security is a significant requirement today that must be considered according to the results of a security management analysis, e.g. according to IEC 62443 or regulatory laws and standards. Enhancing mobile connectivity to fulfil the real-time communication needs of this use case is also an important challenge to be addressed.

WEAKNESS & BOTTLENECKS	DESCRIPTION	AREA¹	IMPACT IN THE COMPANY <i>At processes (manufacturing) level and business level</i>
Missing integrated scenario	The mobile manipulator is not yet shown in an integrated scenario showing a complete process	Sales	With an integrated scenario the demonstration of the technology is more relevant to the customers, esp. industry partners
Unstable communication	The Wi-Fi connection currently used is not reliable enough during AGV movement to allow continuous control from the cloud	Technical, Marketing	As long as the communication is not reliable, the benefits of the technology cannot be shown.
Distributed computing power	An edge cloud integration is missing for the offloading of the of path and trajectory planning	Technical, Marketing	The on-board computation power is limited. Its energy consumption is high. Complex path and trajectory planning as well as coordination and cooperation between AGV and robots is not possible. Centralized software updates are not possible.
AGVs have no 5G communication available today	Currently only Wi-Fi is used on AGV.	Purchasing	Wi-Fi is not reliable for outsourced real-time computations.
AGVs are missing environmental perception	Currently on-board navigation computation is used. Global real-time data from other AGV is not used.	Technical, Manufacturing	Complex path and trajectory planning as well as coordination and cooperation between AGV and robots is not possible.
Realtime route adaption with distributed intelligence	Intelligence distributed over AGV, edge and cloud not yet implemented	Technical, Manufacturing	Holistic view over multiple AGVs by using cloud processing.
Lack of business models among technology vendors and end	The AGV, 5G, Analytics, and other software technology providers have lack of clear business case for each, that does not create enough	Management	Industry partners are not convinced by separate technology demonstrations without a complete use case. Feasibility of a complete use case must first be demonstrated. An integration of AGV, high performance navigation computation, manipulator,

customers	push power to work in ecosystem		workstation to show the benefit of 5G in a production environment is necessary.
Data sovereignty and privacy concerns	The manufacturers hesitate to share the operational data from their business and shopfloor because their fair on losing the control over sensitive data such as production capabilities.	Management Technical support	To enable new scenarios based on network-based data access control with data sovereignty in the industrial data sharing system between companies.

Table 7 - Addressed weaknesses and bottlenecks in CN02

5.2.5 Trial Future Scenario

The workstation issues a request for new parts, as the magazine runs out of parts. The AGV drives to the warehouse and the robot loads a full magazine onto the mobile manipulator. The AGV drives through the test field of the Production Technology Center (PTZ) Berlin to the robot workstation. The destination position is reached by a few centimetres, the environment is scanned with a camera streaming this information in the cloud. A cloud-based service generates the environment model, calculates the position of the robotic arm relative to the machine and calculates an optimal trajectory to pick up the empty magazine and load the full magazine. The calculated trajectory is communicated to the robot arm basic controller and executed. After the exchange of the magazine, the empty magazine is returned to the warehouse. However, this route will be changed due to some changes either in the production line or some other obstacles on the way back. In this case, AGV needs to receive an updated route based on the changes occurred to the production line. The route planning should be based on the data collected from the shop floor environment, and be performed on the edge-cloud, and fed back to the AGV over the 5G network.

5G features can support the process of environmental perception, self-positioning, and self-guiding of the AGV by the high precision **positioning capability** and the **handover capability** between 5G cells incl. indoor & outdoor mobility.

With regards to **positioning capability** of 5G, there are several 3GPP independent technologies such as various sensor technologies (incl. Radar and Lidar), GNSS, Blue-tooth, and WiFi signal strength-based estimations to let AGVs position itself in an indoor environment. However, GNSS, various sensor technologies, WLAN, Bluetooth, and any other non-3GPP positioning technologies have their own limitations and drawbacks that at the end limits the overall capability of positioning. Thus, 5G incorporates and complement all non-3GPP technologies for high accuracy and reliable positioning solutions. There are dedicated reference signals, measurements, features and procedures introduced into 5G with 3GPP release 16 and are being continuously improved from release 17 onwards. 5G has also introduced new NR positioning protocol A (called NRPPa) between the NG-RAN and the core network to carry the positioning information between the NG-RAN and the (Location Management Function) LMF of 5G Core over the next generation control plane interface (NG-C). As explained in 3GPP TS 38.455 version 16.1.0 Release 16 NRPPa implements new functions on top of 5G that can be summarized as below:

1. E-CID (Enhanced Cell-ID) Location Information Transfer
2. OTDOA (Observed Time Difference of Arrival) Information Transfer
3. Reporting of General Error Situations
4. Assistance Information Transfer
5. Positioning Information Transfer

6. Measurement Information Transfer

7. TRP (Transmission-Reception Point) Information Transfer

Currently in 3GPP release 16 as the foundation for 5G NR (New Radio) positioning, it is possible to achieve around 3 to 10 m of indoor / outdoor positioning accuracy with 5G. The positioning performance and the capability of 5G NR is further enhanced with 3GPP release 17 down to 30 cm absolute positioning accuracy along with the positioning latency of around 10 ms. However, it is worth mentioning that the selection of the soft-ware components that are offering 5G Radio and Core network functions is crucially important for trials to have the right and sufficient features and functions in place.

With regards to **handover capability** of 5G, seamless user and control plane data continuity during indoor and outdoor mobility scenarios is one of the most distinguishing advantages of 5G compared to any other wireless communication technologies (i.e., WiFi, LPWA, etc.) which makes it unique in terms of seamless mobility. There are two states of 5G devices: 1) idle mode and 2) connected mode, and the mobility in 5G, thus, also called idle mode mobility (cell reselection, tracking area update, etc.) and connected mode mobility.

The connected mode mobility is a type of mobility in 5G which allows 5G devices roam from one cell to another cell (cell change in connected mode) while the user and control plane data are not being interrupted by the mobility. One of the most critical KPI of mobility is the HIT (handover interruption time), which was around 30 to 60 ms with 4G, but is now aimed to be 0 ms with 5G. For this purpose, 3GPP introduced new function called DAPS (Dual Active Protocol Stack) in 3GPP release 16, which allows user plane (PDCP) packets to be sent to / received from both the source and destination cells simultaneously and syncing / sequencing these packets on the destination cell thanks to the forwarding of downlink data packets. 3GPP has introduced another new handover procedure called CHO (Conditional Handover) in release 16, which allows 5G devices whether to perform handover when the certain conditions are fulfilled. This gives the right to UE to be able to decide whether the handover will be executed, and thus, reduces the risks of handover failures drastically compared to decision taken by the network reactively before the CHO. Fundamental mobility skills of 5G NR along with enhanced mobility functions DAPS and CHO functions introduced in 3GPP release 16, will allow AGVs move in large indoor and outdoor footprints with seamless data continuity, zero HIT and improved data integrity and reliability. However, it is again important to mention that the aforementioned functions need to be available and fully supported by the software components, specifically by the 5G Radio and Core network functions, of the 5G infrastructure used for the technology demonstrations.

Thanks to ultra-reliable low latency communication (uRLLC) offered by 5G real-time applications can be outsourced, but are still reliable and can be then researched, implemented and demonstrated: improved environment perception and even real-time control of the manipulator like visual servoing and impedance control become possible. Important techniques to compensate for AGV position inaccuracy. Besides uRLLC the 5G feature of enhanced mobile broadband for higher data rates (eMBB) allows to stream raw sensor values or videos to the cloud where it is evaluated on high performance hardware.

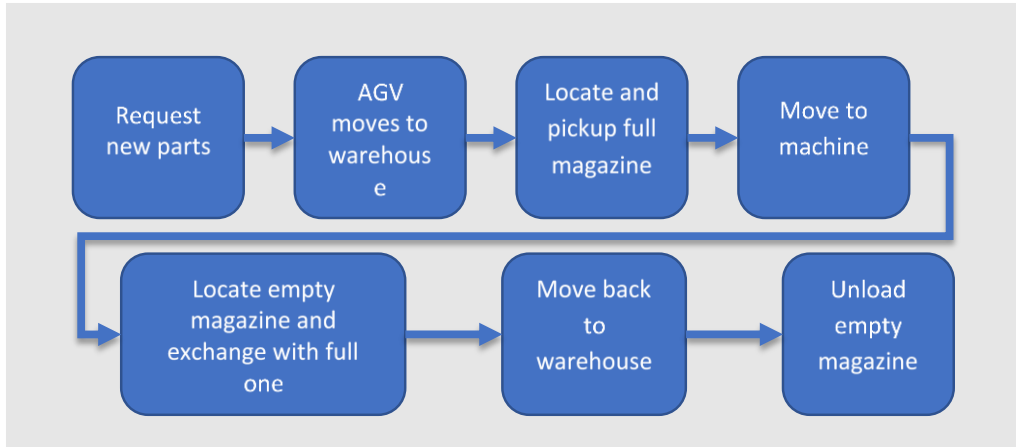


Figure 42 - Flow diagram of the planned scenario

Further, the 5G feature of massive machine type communication (mMTC) allows a dense integration of various modular and flexible sensor types that are streaming their data directly to the cloud. Such sensors are beneficial to monitor the production process, but must be modular to enable a workstation to be reconfigurable for product changes.

The Figure 43 below is a very specific example of 5G Private Network in a manufacturing shop floor on a high-level illustration. Each red dot represents an enabling device that is 5G communication capable, and also potentially playing the router or gateway role on the downstream towards a particular object it is attached to (such as industrial 5G router). This device enables non-5G capable objects (AGVs, robot arms, machinery, etc.) to communicate with the 5G network without big investments on the objects itself. The analytics of the intended use case can be deployed to three locations: 1) on the device (i.e., Mobile Manipulator), 2) on the edge (close to 5G RAN / Devices) and 3) on the cloud (behind the 5G Core) depending on the performance (delay, throughput, etc.) and the resource (RAM, storage, processing) requirements of the operation. Finally, the intranet behind the “Cloud App” in Figure 16 represents all IT and OT systems of the enterprises.

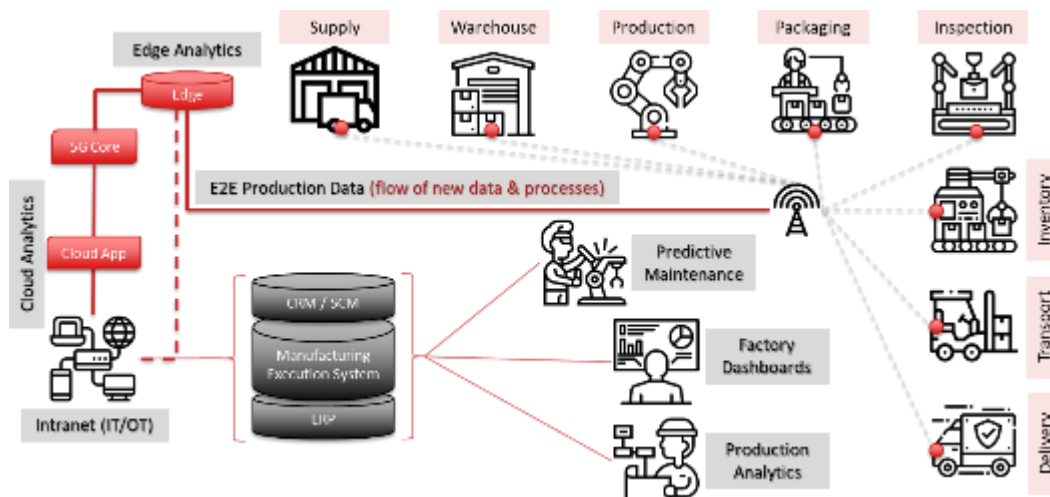


Figure 43 - Outlook to 5G in Manufacturing Shopfloor

Devices and assets (AGVs in the trial) collaborate to optimize the manufacturing process as has been explained before. During the manufacturing process, the AGVs and machines produce messages related to the production process and these data will be collected and analysed by different tools and

services. The technology tools and services for AGVs re-scheduling and process optimisation are not always available within the company and sometimes 3rd party experts and algorithms are located on external clouds. IDS brings to the use case how to assure that those data is used according to the company agreements established in the contract.

Participants in secure data sharing are the data supplier that assumes the role of data creator, data owner and/or data provider. The Data creator (the AGVs) creates data e.g. the camera on the AGV or from sensors. The Data Provider makes data technically available in the IDS for being transmitted to a Data Customer on behalf of the Data Owner. In this trial, the data consumer is a Service Provider or Cloud-based service provider that re-schedules the AGVs routes according the real time production planning.

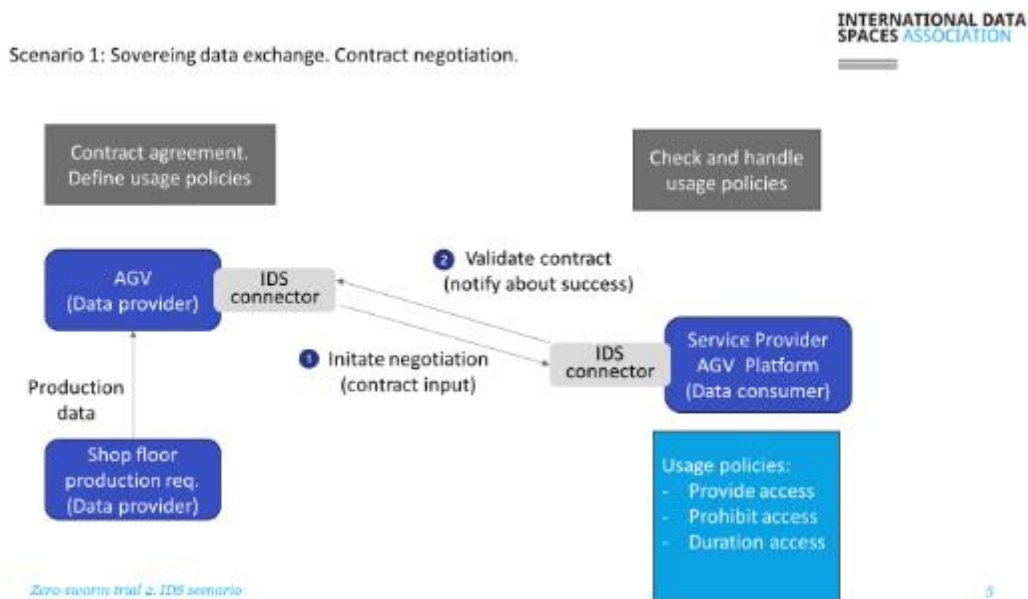


Figure 44 Entities in a sovereign data exchange scenario

In flexible production environments, batch sizes vary rapidly and product life cycles shorten. New product variations need to be integrated on a short term. To scale the production cost-efficiently concerning hardware and implementation efforts for new automation solutions, renting robotic hardware and skills creates new business opportunities (robot as a service). This will reduce the investment cost and the need for expertise in the company. Technically, it is required to outsource algorithms and control to the edge-cloud-continuum. For mobile robots, 5G enables then a sufficient quality for wireless communication.

Further, a flexible and distributed automation platform that allows a fast integration of wireless equipment and sensors shortens the setup or re-configuration time for production lines. From a business point of view this increases the production time.

Wireless sensors can be easily integrated at existing machines delivering real-time data for process monitoring. In that way, maintenance can be improved and processes can be optimized (e.g. energy consumption). A flexible and distributed automation platform that can integrate advanced robotic solutions brings the opportunity to automate new applications.

5.2.6 Expected Results and KPIs

After successful implementation of the trial, a complete process can be presented as an integrated scenario, showing the interaction of mobile manipulators with their environment.

ID	KPI Name	Description	Unit	Current value	Future expected value	Expected date of achievement**
1	5G communication	The mobile manipulator is integrated in a 5G network on the campus	%	0	100	During implementation
2	Edge-cloud integration	The edge cloud of HHI is connected to test field of PTZ	%	0	100	During implementation
3	Data sovereignty	Preserve the data Sovereignty of the data owners (providers) by providing the IDS connector	%	0	100	End of the implementation
4	Data Privacy and remote execution	Preserve the privacy of the data owners by means of adopting the distributed learning paradigm and privacy preserving AI mechanisms	%	0	100	End of the implementation

Table 8 - KPI overview

**** During the implementation / end of the implementation / before 6 months after implementation / before 12 months after implementation / before 24 months after implementation / more than 24 months after implementation**

5.2.7 GDPR Assessment

This trial lasts for a duration of three years. Any data held during this period will be stored with the consent of the individual entities involved in the trial and in accordance with the general privacy policy of the project.

The scenario uses 2D and 3D cameras. The data produced by the sensors (e.g. cameras) is not persistently saved but only used during processing in one control cycle of about 50ms (depending on the 5G communication delay and computing capabilities).

Any data collected within the life span of the trial development will not be commercially exploited. The results of this trial will be used by the trial participants, presented at national and international conferences and exhibitions, and published in peer-reviewed scientific and academic journals with a focus on open-access journals.

5.3 CN03. Plug & Connect 5G Industrial Network Setups for Industrial Operations

5.3.1 General Description

A dedicated network for industrial production

One of the hurdles in the comprehensive digitalization of the manufacturing industry is the lack of broadband in many areas. The industry needs a scalable, powerful, and robust network that meets the specific demands of the industry in terms of latency, reliability, availability, energy efficiency, and security – and that is exactly what Industrial 5G promises. The fifth generation of mobile technology

delivers high data rates and secure availability, including for critical applications, extreme reliability and accuracy, and real-time connectivity while providing energy-efficient and improved security for people and machines. In this way, even complex industrial processes can be fully mapped and optimized.

At the same time, 5G is the first network for which companies in Germany have been able to apply for licenses since 2019 and so operate their own industrial 5G network. The German federal government has reserved 100 MHz bandwidth (from 3.7 GHz to 3.8 GHz) for local use. Unlike public 5G networks, which are provided by mobile telecom operators that make 5G available regionally, a private, industrial 5G network is operated by users such as industrial companies themselves, and it can be designed and configured to meet their individual requirements, similar to the currently most commonly used WiFi.

For example, this is leading to the creation of local area networks, known as campus networks, which can be used either in isolation or in conjunction with public mobile networks. Within this protected and particularly secure network, all wireless devices connect to the wireless network, thereby creating a comprehensive digital infrastructure. In environments where mixed networks consisting of different wireless technologies (e.g. WiFi, Bluetooth Mesh, LTE, or 5G) are used in combination with wired networks, this kind of industrial 5G network will be all that is needed.



That is what the SMS digital is doing at the subsidiaries in Hilchenbach and Mönchengladbach in Germany.

Figure 45 - Campus Network at Hilchenbach

In relation also to our partner solutions a general sketch of the predictive maintenance use case to be deployed and tested using 5G.

where improved network capabilities (e.g. high reliability, availability, latency, number of connected devices, etc.) are needed 5G would be a better candidate. Campus networks are exclusive mobile communications networks or a dedicated local company site, a university or individual buildings such as an office building. They are tailored to the individual needs of the users and meet future requirements in the outline for Industry 4.0

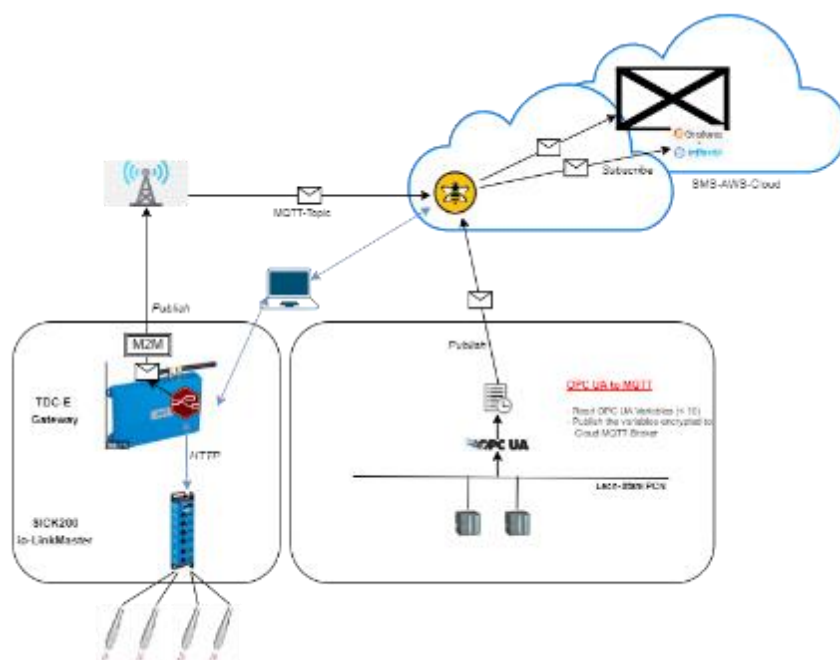


Figure 46 - 5G Architecture

environment. It is also worth to mention that, 5G helps us to serve various connectivity requirements over a single infrastructure installation. This concept is called Slicing, which means a portion of network capability can be configured in a way to serve scenarios with very low latency requirements (e.g. moving robot arms) while over the same physical network installation we can configure another portion of the network capacity to meet the high bandwidth requirements of other scenarios (e.g. cameras streaming, real time video).

SMS digital the specialists when it comes to optimizing processes and achieving operational excellence.

SMS digital already supplies comprehensive software and data-based services for steel mill operators. Initial experience with wearables for worker assistance and safety under 4G and Wi-Fi has also been gained in joint customer projects. For SMS digital, 5G thus represents an enabler that expands existing applications. Its teams consist of various experts who can be flexibly assembled, work agilely and develop user-centric software solutions together with the customer on site. The customer is there from the beginning and gives them feedback at every stage of development.

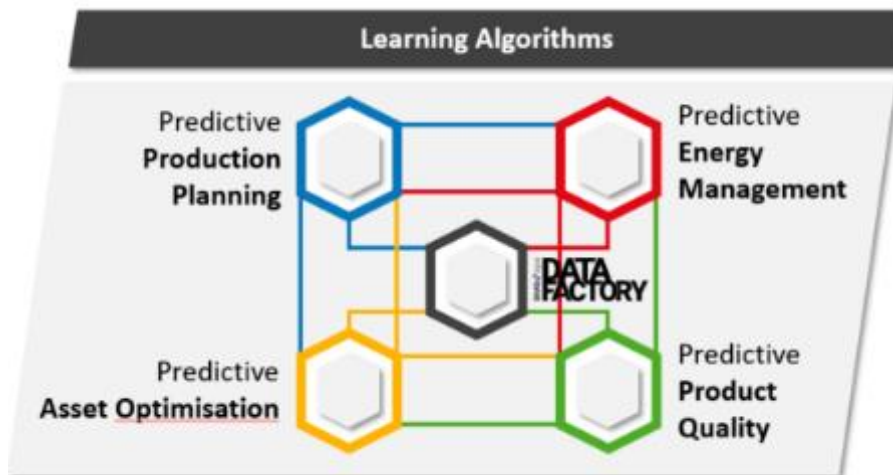


Figure 47 - SMS Digital solutions

SMS digital focuses on infrastructure solutions, predictive production planning, quality management, condition monitoring and energy management. In addition to digital products and solutions, they offer their customers a wide

range of consulting and development services in the context of digitalization.

Customers can choose between various contract models that precisely address their needs and provide the opportunity to convert high investment costs into lower operating costs. This is made possible, for example, by software-as-a-service and performance-based contract models.

SICK AG

SICK will test the 5G capable edge computing device in this test bed. Furthermore, SICK will contribute to the requirement specification and use case description.

CCI

Center Connected Industry (CCI) is a unit of the EICe Aachen GmbH located on the RWTH Aachen Campus. Focus of the CCI is on new technologies and their use and potential for the optimisation of production and logistics through digitalisation. The founding idea is to close the gap between research and industrial use of new technologies. Industrial partners put forward challenges and requirements which are addressed in joint projects. Benefit and suitability of technologies, like e.g. 5G, are tested and validated for the use cases. The integrations and tests in the form of prototypes or proof-of-concepts take place in the Demonstration Factory (DFA).

Operating as contract manufacturer requirements can be challenged in the environment of the DFA. As a specialist welding company, the focus is on metal products with the operations laser cutting, bending, welding (by hand and robot) and assembly. Caused by the varying product specifications, the logistical processes vary depending on the product.

Activities most related to Zero-SWARM are their projects with AGVs. In different projects they tested technology combinations for e.g. connectivity, camera or sensors combined with data analysis on edge and cloud systems. In one of the projects with SICK CCI realized a first proof of concept for data transmission between moving automated vehicles and sensors in infrastructure with edge components via 5G.

5.3.3 Trial Present Scenario



By establishing dedicated 5G networks and providing an integrated wireless infrastructure to its customers, SMS is taking a further decisive step toward autonomous production. After all, lasting results can only be guaranteed with complete connectivity in real time and the overall coordination of all processes.

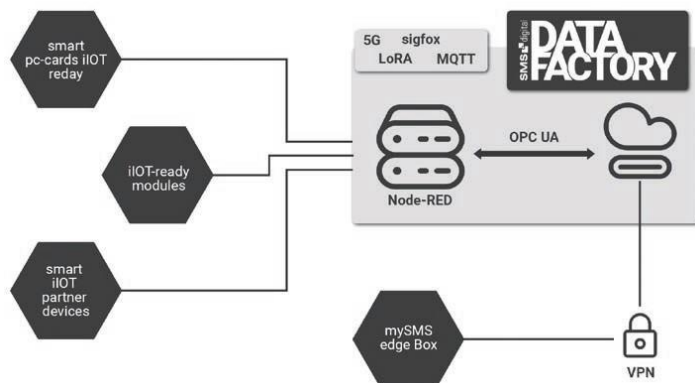


Figure 48 - DataFactory Data Workflow

Data silos have to be broken down to be able to extract the information that's vital for adding value. Only then can data be turned into information, and information into added value. But it's a time-consuming task. The SMS DataFactory is the foundation for a 'learning steel mill', and makes the data from plant automation, sensor technology, and production-level IT systems available for design, maintenance and quality assurance

applications. This makes it possible to fully work up and analyse all the plant data. This is where OPC UA acts as a key language that links sensors and smart devices from partners of all kinds directly to the SMS DataFactory or via the SMS IIOT platform.

Technological drivers of the learning steelworks

The learning steelworks has one goal: to use data to make production faster, more efficient, more robust and more sustainable. Software picks up the data from a plant, turns it into information and ultimately refines it using artificial intelligence and machine learning. This generates important insights for practical implementation, saving costs and resources in the process.

The SMS DataFactory architecture

The SMS DataFactory manages the entire data life cycle from reading the data in to cleaning it up, storing it securely and efficiently, and backing it up and providing long-term archiving. In doing so, it takes the steelworks to "digital ready" level.

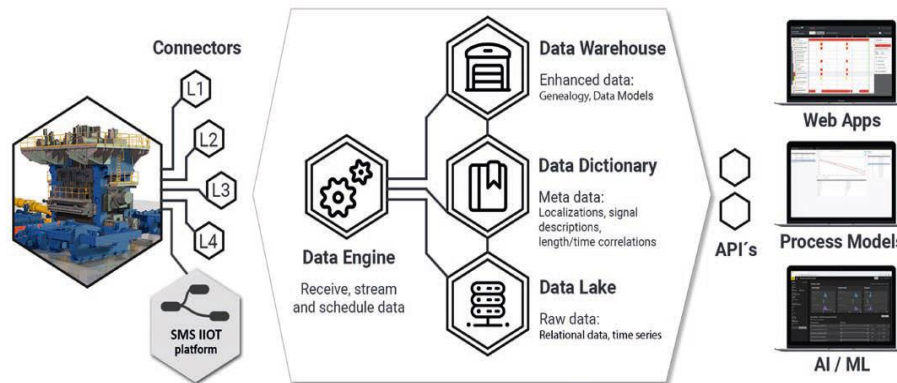


Figure 49 - SMS DataFactory data lifecycle

It also provides a meaningful catalogue for data interpretation in addition to permanent access to the required data, for example via Data Warehouse or customised SQL views. The Edge layer organises and provides efficient support for data and signal collection from OT systems and industrial plant. The edge systems are collecting data over a range of communication protocols. The data are collected, consolidated, buffered and forwarded locally. When required, powerful, smart Edge boxes are used to perform analysis directly and process business applications using AI/ML models. This is where OPC UA forms an important bridge, and uses a companion stack such as umati to facilitate a much simpler and faster connection to applications outside the steel industry. The documentation and designation of the data sources are standardised, which means the variables are easy to incorporate regardless of the manufacturer. Depending on the task to be resolved, the data is made available in various formats. Data volumes that become necessary in the future will require 5G, mySMS-Box and standardised protocols such as OPC UA to enable them to be completely managed.

Technology expertise meets domain expertise

By having the data available in the appropriate form, it's possible for the learning steelworks to analyse and process it using IT systems. The data is then enriched using metadata, which makes it faster to locate and gives it meaning. The most important thing in this regard is to combine technology expertise with domain expertise. Within the SMS DataFactory, the Data Dictionary provides the process experts with deep insights into the available data using mutually linked data elements based on their origin, purpose and type. To fully network all machines and applications, SMS digital provides a state-of-the-art, flexible and scalable basis in the form of the mySMS platform. This platform can be used to integrate inhouse and partner digital applications and expand the portfolio.

Therefore, the first tests have been placed with approved existing technology:

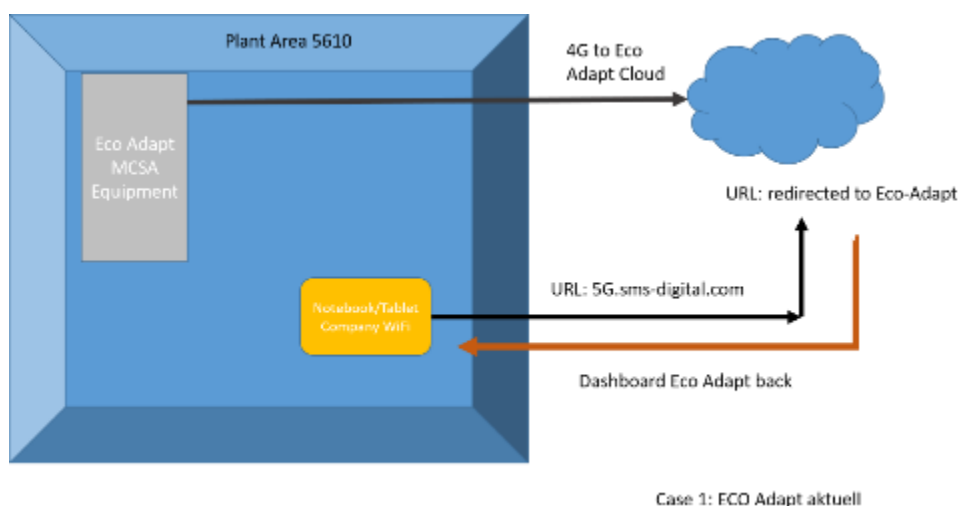


Figure 50 - DataFactory mySMS platform – Case 1

Now expanded on the existing possibilities:

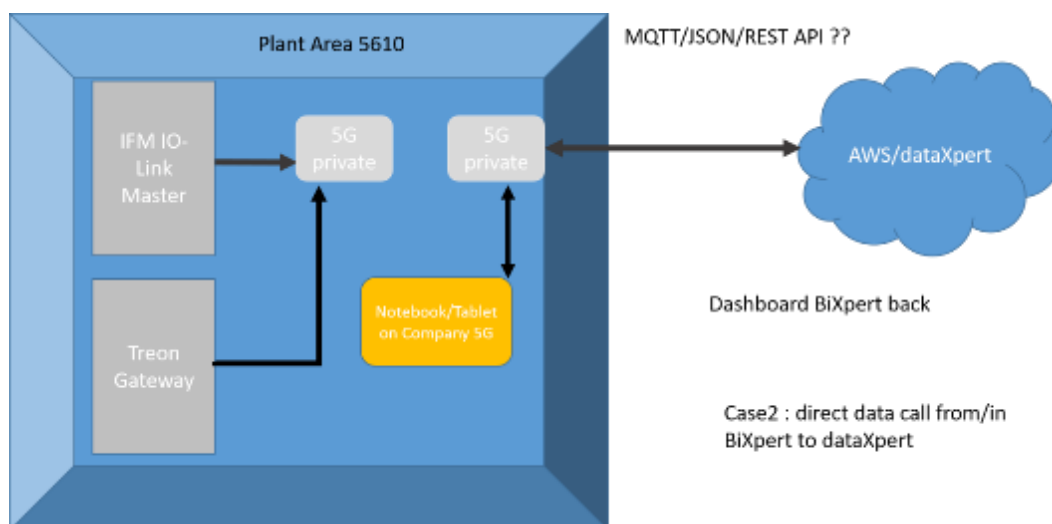


Figure 51 - DataFactory mySMS platform – Case 2

5.3.4 Weaknesses and Bottlenecks

WEAKNESS & BOTTLENECKS	DESCRIPTION	AREA ¹	IMPACT IN THE COMPANY
Starting ROI on User Story for deployment at the end-customer must be easy to reach with the small pop-up system	That should avoid the actual topic (weakness) of the big invest in starting with industrial 5G, the small entry hurdle must be clearly shown - The Investment from customer side cannot be based on one use case	sales	Change the thinking to the sales and business team in promoting small entry-PoCs for wireless solutions and get the business step by step.

Implementation in existing networks takes too long	The outcome of the trial should solve the integration hurdle with a checklist or an integration blueprint with the most important starting information and steps for integration	Technical support	
European regulation on private frequencies	Not every country will offer private frequencies, so the design of the industrial part in a public section is every time a customized solution	Regulatory topic	Big impact on the possible solution, because in many cases SMS has then to work with a provider, causing big additional cost
Data ownership not clear, when working with several different cloud systems	According to the pending document of the EU data act, the trial or the whole project should check the influence of this regulatory paper, having impact on the future business models	Regulatory topic	The biggest impact on the future business models. If that is not clarified, SMS has to rethink a lot of solutions
New roles of IT/OT on site to be explained and established	For the end-customer it must be clear, according to the type of net-providing role, what new roles will appear in IT/OT teams	Management/Technical support	
Net-planning and coverage methods for the optimized coverage according to the specific plant area are not detailed enough	The environmental frame conditions in a specific plant area (e.g. high Assets, EMC, high stocks and long distances) must be checked over a detailed Site visit-guide (or Assessment Guide) from the project team, this guide must be the outcome of the trial and expand to the end of the project	Technical support, Manufacturing	A stable coverage is finally the base for all further business models generated over the additional transferred data by industrial 5G
Solutions for industrial 5G are deeply connected to the deployed release in the 5G chips	The trial should solve or check the possible update or interconnectivity of devices with different 5G releases on the chips or how that can be upgraded	Technical support, Sales	High impact on the business models when expanding the first PoCs with new devices at the customer

Table 9 – Weaknesses and bottlenecks addressed in CN03

5.3.5 Trial Future Scenario

In Trial 3 of the Central Node the following combinations will be in use or set up to life:

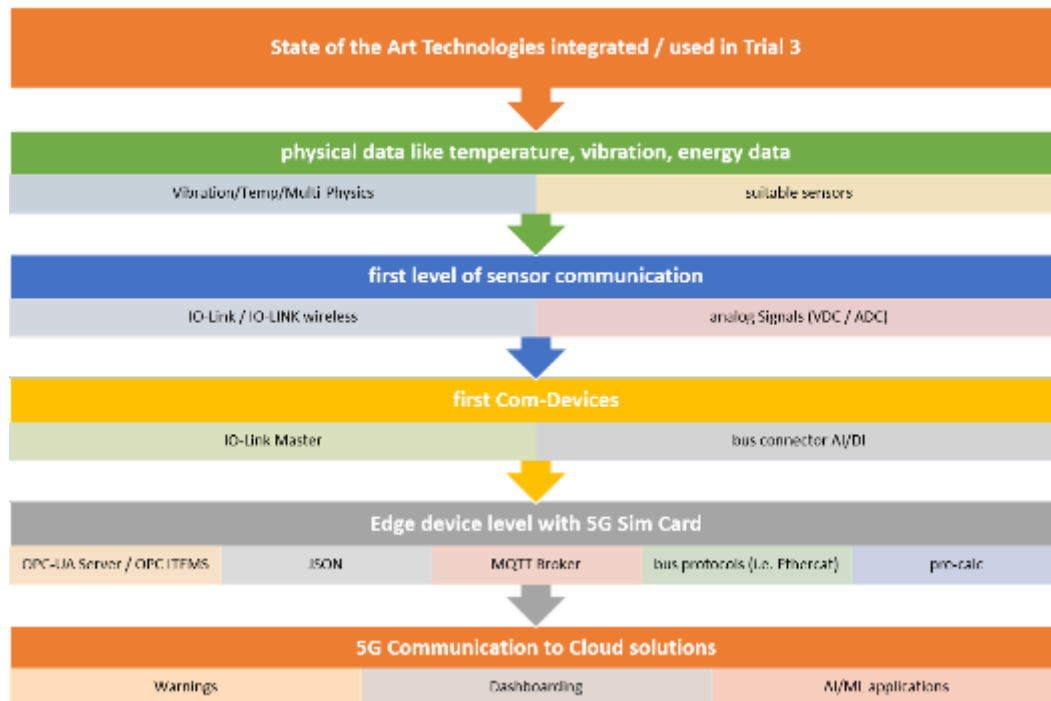


Figure 52 - Components of CN03 future scenario

The Industrial 5G network is revolutionizing the monitoring and control of complex production processes. 5G will allow for rapid intervention even if production is unmanned, which in turn can radically reduce downtimes and product rejects. This not only has a positive impact on product quality, but also helps companies to make processes more sustainable by reducing their resource consumption. In this way, Industrial 5G is becoming a driving force on the road to green, CO2-free steel production.

5G is the answer to many challenges facing the steel industry, with retrofitting projects, the technology offers significant savings and optimization potential for a manageable financial investment by turning data into success and ensuring greater security and sustainability.

Sensor-to-cloud pipeline for closed-loop monitoring in steel production.

Conventional industrial monitoring systems are hardware-based and can only be operated on dedicated hardware systems. Thereby, possible potentials in flexibility as well as optimal resource utilization are not exploited. In this trial, existing industrial monitoring systems are virtualized and outsourced to heterogeneous IT environments, such as the edge cloud. The focus is on a cloud-based monitoring application for production processes in the steel industry. The aim here is to virtualize and outsource existing industrial solutions to cloud systems. By operating in an IT environment, 5G-capable sensors can be used flexibly and scalably for data acquisition. In addition, machine learning algorithms for optimizing industrial applications are developed and operated on the same IT platform.

The connected worker – IIoP industrial internet of People



Figure 53 - The connected worker

As also mentioned in the previous description, in the state of the art, occupational safety in steel mills is primarily ensured by PLCs, laser barriers and wired sensors, since, for example, when a non-secure zone is entered, equipment or functions must be shut down within a guaranteed latency period. The possibility of guaranteeing a comparable real-time via cameras and smart wearables represents an interesting opportunity for plant engineering in general and steel mills in

particular to quickly and cost-effectively expand and extend existing security solutions.

Wireless technology continues to make integration into existing plants, some of which are more than 40 years old, an important step toward modern, safe working conditions. Corresponding ideas for the expansion of plant safety through wireless 5G applications are currently being published by the first providers, especially in the Chinese region. Market-ready solutions are not known. Instead, plant safety is nowadays addressed by wired solutions, light barriers, instructions, and access barriers.

This trial would like to take the first steps towards a wireless solution in the mentioned areas for the steel production.

5.3.6 Expected Results and KPIs

ID	KPI Name	Description	Unit	Current value	Future expected value	Expected date of achievement**
1	First Pop-Up Package ready	Assessment Planning Guide finished for One Site visits	%	0	100	End of trials
2	First Pop-Up Package ready	Integration Guide for customers ready	%	0	100	End of trials
3	Dashboarding solution of the processes in the plant area of SMS Group at Hilchenbach & Mönchengladbach implemented	Data acquisition with SICK Edge Box under 5G and dashboarding on a 5G tablet with data/BI-Xpert under function	%	0	100	End of trials

Table 10 - CN03 KPI Table

5.3.7 GDPR Assessment

The main topics to touch GDPR relevant actions and solutions will be related to the use of cameras in quality or safety applications in the trial.

First trial will be done with volunteers in accordance with the workers' council and a strict regulation

and the Four-Eye principle for the first analytics.

In our internal solution, the “smart Safety Guard” we are already GDPR compliant. Regarding the use of cameras, the SMS digital is actually evolving and testing in a funded project in parallel, what can be done to make this application GDPR compliant, knowing the challenges.

6 South Node Trials

6.1 SN01. Mobile intelligent agents for integrated re-configurability of zero plastic waste production line - SN02. Edge-cloud continuum to support smart maintenance and optimization

Note: Trial SN01 and SN02 have been merged since they will be built in parallel over the same set of equipment.

This trial will exploit the project technological solutions to design, deploy and operate a new generation of automatic lines, based on the concepts of agile re-configurability of the production lines. The improvement of traditional logistics in food packaging lines, through the integration of intelligent agents and AGV technologies, is going to become essential within the context of the distribution of packaging materials (mainly trays, film but also labels for product traceability, etc.), Products to be packed (mostly combined according to meal recipe) and people according to production plan, as well as spare parts for maintenance according to maintenance plan or maintenance emergencies. In addition to this, also the improvement of timing and operations for production lines set-up and re-configuration, referred to primary packaging machine and also to secondary stand-alone devices (dosing and labelling units, CoBot cells, etc.) directly connected, will be central to a new generation of automatic systems.

In this trial, technologies like Zero-SWARM 5GNPN and AIC will be used to provide time **sensitive connectivity to AGVs** and other machineries as well as **smart decision** making based on the **collected information from the reconfigurable production line**. This trial is in line with project general objectives, demonstrating efficient collected information bundled with the processes along the edge-cloud continuum, aiming to reduce production and plastic waste in the packaging sector.

The strong need to enable **Plug&Produce** paradigm is one of the main objectives of this Trial in order to face with the increasing fluctuation of the market demands that requires maintaining high production performance for small production batches. This means that concepts like **production line reconfigurability and smart layout modification procedures**, according to daily menu changes, will be provided thanks to the support of digital twin models and smart AI algorithms directly integrated within the IEC 61499 control solution.

The objective to obtain a zero plastic waste production line has to be achieved using AI algorithms to improve and maximize the product quality: the higher is the level of production quality the lower is the amount of plastic wasted. For this reason, one of the key objectives of this Trial is to develop a **Smart Quality module** based on the Zero-SWARM technologies and tools developed during the project implementation.

Finally, as backbone of SN – Reepack Trial there is the need to build a **common infrastructure composed by (Scenario 1) an intelligent supervisor and coordination system based on IEC 61499 control approach and smart algorithms** with the possibility to govern the different intelligent agents over a 5G/Wi-Fi network and **(Scenario 2) smart data gathering tools enabling the feeding of algorithms** and models with the right amount of data coming from the production line.

Scenario 2

Excluding possible sporadic cases where a project leader company specialized in software integration develops customized solution, all devices are not effectively integrated and interconnected in a unique remote industrial control platform, multi access and multi tasks with cloud storage, able to schedule the orders, supervise the single or overall efficiencies and costs, manage and perform the maintenance, reconfigure and control each device or the complete production line, starting from a common database of shared information. *Scenario 2* of the South Node focuses on the mentioned integration, thanks to the project technologies of smart maintenance and optimization functionalities for Reepack’s production site, exploiting the edge-cloud continuum to have digital twins of the manufacturing systems directly usable for site optimization. Moreover, it will be possible to drastically improve the quality of maintenance operations, in particular during emergency situations. The use of 5GNPN enhanced with mobile edge computing is crucial here to support the required bandwidth and latency needed for such maintenance and optimization processes. The presented Trial is the automatic packaging line already described for *Scenario 1* adding the Reepack’s edge hardware and software platform called ReeNEXT. Reepack’s edge platform will be enhanced with all the functionalities offered by Zero-SWARM, in particular for the seamless usage of the CPSoS digital twin but also thanks to the connectivity to the AI-based optimization services present in the cloud. 5G/Wi-Fi will be essential to guarantee that all the CPS involved in the systems are able to communicate effectively and securely with each other and with the IT domain.

In addition, the possibility to set up on top of the developed platform smart maintenance algorithms, production optimization approaches and safe human machine collaboration procedure completes the set of objectives to be achieved with this *Scenario 2* Trial.

6.1.1 General Description

Scenario 1 and *Scenario 2* Trials will be built over the same set of mechatronic equipment consisting of a compact automatic packaging line, which targets a simplification of a typical industrial application for high production rates composed by:

- a. De-Nester unit: device to unstack a pile of plastic trays;
- b. Infeed chain conveyor: to transport trays while they are loaded with food;
- c. CoBot automatic loading station: to automatically load products into trays – instead of/in collaboration with a manual loading;
- d. Tray Sealer machine: to pack, thanks to dedicated die-set, the food-product into trays in MAP (Modified Atmosphere Packaging).

Scenario 2

- a. Quality Control Unit: to detect and discharge NO-Compliant Trays due to Wrinkles on Top Sealed Film or Trays Implosion for missing Gas Injection
- b. AGV Device



Figure 54 - Compact Packaging Line based on ReeECO Tray-Sealer Machine

Scenario 1

This packaging line will be integrated with the usage of mobile agents, mounted over AGVs, to support high degree of line re-configurability and to perform automatic transport of packaging materials, food products, tools and spare parts for maintenance activities. Moreover, these mobile agents will be equipped with intelligent sensors, including vision systems, automatic tool change systems enabling the multi-purpose functionalities for different products and operations.

Compared to the current market state-of-the-art the proposed application is introducing the possibility to automatically load fresh or cooked food using robotic handling which is very complex because of the need to softly manipulate and precisely dose the product together with high production performance capability. The other components of the line are available on the market as they are; the objective here is to use them together as typical industrial application to start with and to validate the Zero-SWARM developments in real industrial environments.

The Adaptable Dispatching Algorithm.

One of the core elements for Scenario 1 is the development of a flexible algorithm to dynamically reschedule AGVs (or Robots) jobs (or tasks). If we consider a general real-application scenario, Reepack production lines are served by a fleet of multiple AGVs.

Such AGVs could or not have similar capabilities. That is, an AGV could be able to perform a certain type of task with certain productivities, while other AGVs could be suitable to accomplish different tasks and /or have different productivity.

Moreover, the single AGV can have a dynamic configuration over time; that is, it could be equipped with different tools, making the Robot suitable for different types of tasks.

The algorithm must be able to manage such a dynamic scenario to be adaptable to the various

situations that a single installation of the production line might require.

The layout where the robots move is also dynamic in the sense that it could change over time for different reasons (reconfigurability).

We use the term "mission" to identify a sequence of jobs assigned to an AGV

There are two structures of mission: mono-job and multi-jobs.

An example of a mono-job mission is: "go to pick up a component C1 & come back." An example of a multi-jobs mission is: "go pick up components C1, and C2, and bring C1+C2 to station S2". Such a composed job mission can be created by a superior-level algorithm or be automatically composed and optimized by the dispatching algorithm.

The algorithm receives the list of jobs, that is, missions to accomplish, and based on the status of each AGV and their suitability to perform the specific jobs. The status of the AGV includes its position, if it is busy or idle, the battery-charge level, the fact that it is not in failure or at a "degraded-performance status," the velocity, and the remaining estimated time to complete the current job.

The algorithm assigns the jobs to the fleet of robots based on optimization objective function and respecting a series of operation constraints that could vary installation by installation or situation by situation. Indeed, the algorithm optimizes the usage of the fleet, that is, increases productivity. The dispatching algorithm creates an optimal sequence of jobs for each Robot to maximize overall productivity.

The Algorithms run based on a predefined cycle (e.g. 15 secs), or in case an external run request force a new calculation (for example, if new jobs arrive or a robot has a failure). The Algorithms pass the list of jobs for each Robot. In case of a new run, such a list is updated apart from the jobs under execution. In addition, via parameters, it will be possible to block an additional number of jobs for each Robot, so the algorithm will not change part of the previously calculated sequence).

The objective function could be selected between two options:

- minimization of average missions time (for the list of jobs)
- maximization of transporters utilization

Follows some additional remarks.

Job/ Mission time estimation:

The algorithm calculates the expected time to accomplish jobs and a sequence of jobs. Such calculation is based on the distances, the parameters (velocity, acceleration, and deceleration) of each AGV, and the parameters characterizing the eventual activities the Robot must accomplish when visiting the stations.

Failure and battery recharge:

The algorithms consider the state of each AGV in terms of availability, failure, and battery level. The battery level is managed by parameters, which permit the management of the recharging policy.

The Layout

The layout is modelled in terms of stations and links.

Station and links have a set of characteristics that might influence the jobs dispatching policy. For example, a station, "Sx" can be accessed only by specific robots. A Station can be linked (dynamically) with one or more elements (e.g. products, workstations etc.) so that the algorithms can accept higher-level commands such as "pick up the product P" instead of "go to the station S".

The layout can be reconfigured dynamically.

AGVs & Stations priority

AGV could prioritize, in terms of preference, related to a specific type of job. This parameter influences their selections in the job's assignment. For example, a faster AGV or smaller AGV could be preferable in the case of specific jobs. The same concepts are valid for the locations to visit.

Traffic logics

Traffics is considered by the algorithm in the sense that, for example, the schedule tries to limit possible future congestion on specific zone and paths. A zone or a path can also be constrained to the presence, for example, of a single AGV. Obviously, such types of constraints require to be managed by the AGV navigation logic (not included in the use case), but the algorithm tries to assign the job avoiding, limiting waiting time to access constrained zone (like, for example, in the case, the AGV is required to get a lift).

The algorithm can be interfaced with both the real-time control system and a digital twin.

The algorithm logs a series of data to permit the invoking system to monitor its status.

Prediction of charge level

The system logs a series of data to feed a machine-learning online algorithm which provides the dispatching algorithm estimation of the battery level for each Robot. This feature enables a better plan for recharging, especially in case of picks of work.

Scenario 2

The *Scenario 2* Trials will be built over the same set of mechatronic equipment of *Scenario 1* consisting of a compact automatic packaging line, which targets a simplification of a typical industrial application for high production rates.

In this *Scenario 2* Trial a specific focus will be dedicated to ReeNEXT edge platform (e) which will be integrated to the packaging line and will be used updated with functionalities coming from Zero-SWARM developments.

Finally, for the usage of mobile agents, mounted over AGVs, to support high degree of line re-configurability and to perform automatic transport of packaging materials, food products, tools and spare parts for maintenance activities, New Modules will be developed and integrated into the original ReeNEXT Platform Architecture, AI algorithms for decision making in terms of Production and Maintenance Plannings.

6.1.2 Participants and roles

Reepack srl leads and defines the SN Trial Use-Case for the testing of Technology Providers Solutions, based on different Scenarios of typical Packaging production Line, with focus on IEC61499 Automation Architectures, AI and Machine Learning Algorithms, Virtual Commissioning.

nxtControl GmbH contributes with expertise on IEC61499 Standard for Distributed Systems, defining, improving and developing HW and SW Control Architectures, including OPC-UA Communication Protocol, for Machine and Stand-Alone Units integrated into Reepack Use-Case.

Research Wings (RWings) defines and develops algorithms related to the Supply Chain of the Packaging Production Line represented by Reepack Use-Case, with main focus on AGV Tasks depending by Production Scheduling and Re-scheduling, Maintenance Activities.

TTS - Technology Transfer System Srl works on Virtual Commissioning, developing Digital Twin and Simulation Solutions for Reepack Use-Case with integrated 3D Animation of Reepack Use-Case, with the possible to test the Tools in relation to IEC61499 Distributed Control System and Packaging Production Line (Machine, AGV, Additional Devices) Tasks.

6.1.3 Trial Present Scenario

The described production system is a new demonstration line specifically designed for ready meals packaging. The food-packaging processes are different according to the complexity of the production line directly depending on the food-product to be packed.

The most critical applications are due to:

- the handling of food-products: loose products compact or instable; products in containers (trays or bags) or on supports (flat carton or paper layers);
- the dosing of food-products: fresh or pre-cooked, solid or liquid, cold or warm;
- the packaging environment where machineries and operators are located.

The dimensions of the packaging line could be different but, in any case, each customer with a production based on industrial or artisanal processes has to identify its own proper solution: complete of equipment and complex as necessary, sustainable and efficient, with an adequate investment. The continuous technological development influences positively the transformation of production processes and plants but peculiar problems have not still a solution, mainly the handling and dosing of loose products.

Nowadays, according to the shape, the texture and the quality of the food-products, not all operations of portioning and dosing, or handling in general can be managed by means automatic systems, so that also sophisticated packaging lines often need handwork in addition to specialized technicians for skilled support and maintenance.

Always more frequently, where possible, robotic applications are integrated into fully automatic packaging lines for the loading of the food-product into containers or over special supports before to be packed (primary packaging), and/or for the handling of packed containers in carton (pre-formed or wrapped) boxes (secondary packaging), with the typical immediate and direct advantages achievable on repetitive processes. On contrary, in case of non-repetitive processes and with a great variability of food-products, which requests frequent and continuous reconfigurations of the packaging production line, the handwork, with all own well-known limitations and consequences in terms of management of human resources normally low-profile, cannot be reduced or replaced.

This is currently the way Reepack approaches the conceiving and building of this kind of automatic production lines: according to the product or the set of products the customer needs to handle the best balance between manual and automatic procedures is provided.

The IEC61499 standard is already tested from Reepack and a prototype of a tray sealer machine built with the control solution compliant to the standard is already running. On the contrary, the other topics and technologies proposed by Zero-SWARM are pretty new and their effectiveness have to be tested during the project.

Scenario 2

Packaging machineries are highly performing systems that process different type of packaging materials (trays and or films) and food-products with strong cycles and/or delicate dynamics.

Reepack's ambition is the realization of an advanced platform for automatic machines and packaging line, based on a unified and standard communication, able to satisfy main requirements of Industry 4.0, specifically about: forecast production plan, production batch management, real-time acquisition and storage of machine and processing data, cost evaluation, scheduled and predictive maintenance, according to real runtime behavior of packaging line normally integrated with additional devices. A proprietary environment for production and maintenance managers who need proper tools of condition-based planning at different levels with the guarantee of certain data, performances and consumptions.

ReeNEXT platform implements an advanced condition monitoring automation packaging machines – tray-sealers, thermoforming and flowpack or others; improves maintainability performance through digitalization of automation; applies predictive maintenance techniques with a direct impact on performance degradation in terms of production capacity and quality; provides a user-friendly and operative software instrument to improve maintenance procedures, including augmented reality.

The expected Impacts are: 1) increase the operating life of single component thanks to more advanced condition monitoring and continuous adaptation of performance; 2) reduce unforeseen breakage events thank to predictive techniques; 3) but in particular, a clear and real overview of all activities (running, alarms, general warning, pause, maintenance, cleaning) made by the operators on the packaging line according, or eventually in contrast, with the production batch.

This is the pathway that Reepack started with the development of its edge platform ReeNEXT and that is wishing to improve with Zero-SWARM project.

The following schema shows the logic blocks related to the interaction between the ReeNEXT layer and the logic of the dynamic rescheduling of the AGVs.

The AGVs job lists, generated based on the production schedule, are the main input for the dispatching algorithm. Other inputs are: the layout (that could change dynamically), the status of each AGV, the fleet configuration.

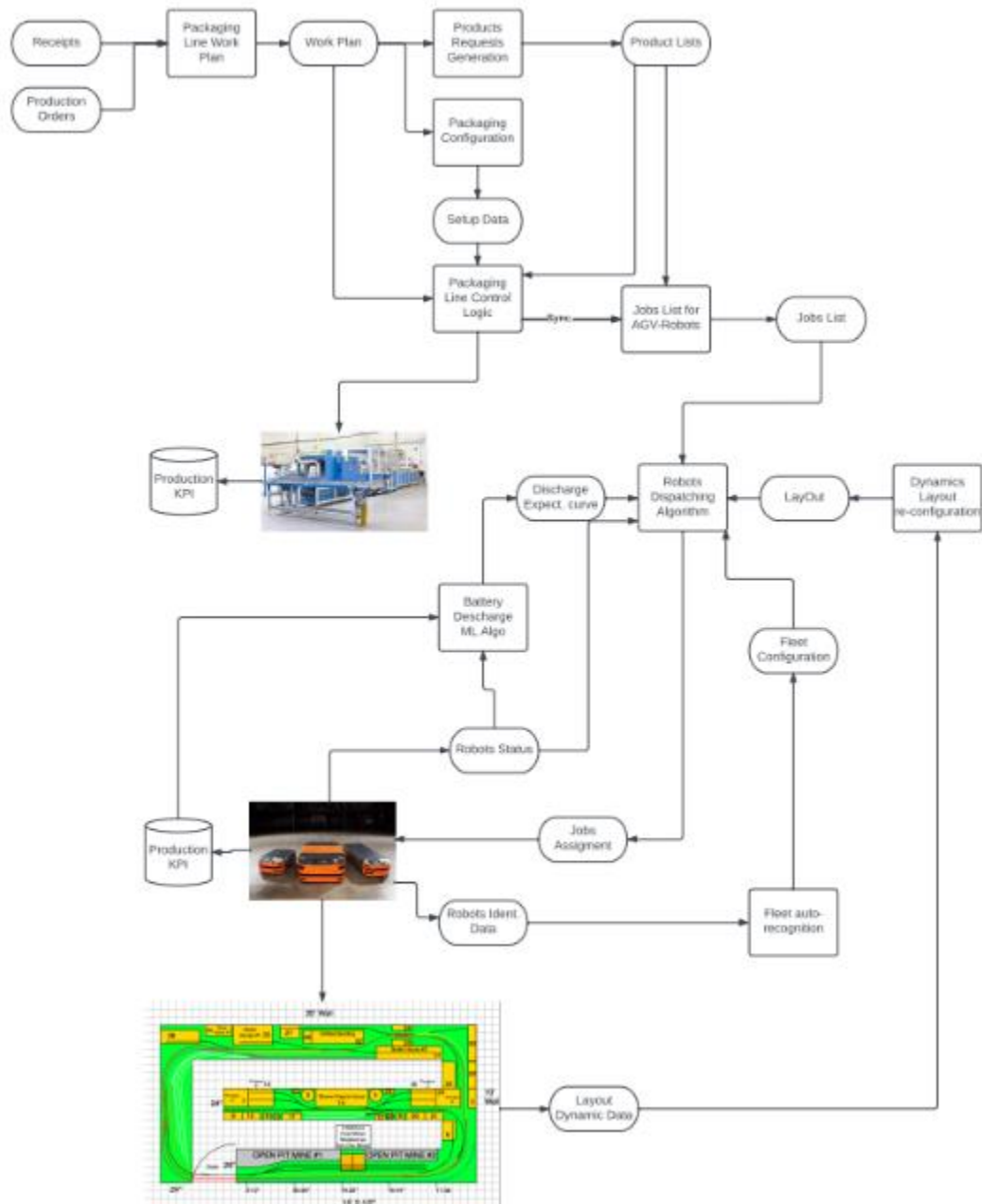


Figure 55 - Flow Diagram

6.1.4 Weaknesses and Bottlenecks

WEAKNESS & BOTTLENECKS	DESCRIPTION	AREA ¹	IMPACT IN THE COMPANY <i>At processes (manufacturing) level and business level</i>
Weakness	Nowadays the Industrial Production Layouts and Processes are not ready and organized to reorganize own Plants and adopt so advanced	Marketing, Sales, Customer Relationships	No direct and immediate impact at manufacturing process, maybe in business level taking time to create new needs for the Market and the Customers.

	methodologies and technologies. A long and strong process at Market and Social Levels will be necessary to define the New Factories of the Future.		
Bottlenecks	Choice of Proper AGV for Scenario1 and Real Production Plants fulfilling Market and Customer requirements of the New Factories of the Future.	Purchasing, Market	Delay in Scenario 1/2 for Trial Activities.
Bottlenecks	5G Network Communication at Industrial Level, need of necessary Authorizations	Technical Support, Purchasing, Management	Problems and/or Delay in Scenario 1/2 for Trial Activities.

Table 11 - Weaknesses and Bottlenecks addressed in SN03

6.1.5 Trial Future Scenario

The New Factories of the Future in Food Packaging Sector will be characterized by Production Processes based on the coexistence of Human Operators, CoBot and AGV in cooperation to guarantee the maximum and necessary efficiency.

The Layout of these New Production Plants will be reorganized, defining the New Roles of Human Operators trained and promoted to supervise the full Automated Production Processes, and redesigned to create the proper spaces for CoBot and AGV operations and integrations, respecting the essential safety conditions of work.

At Machine, Plant and Network Levels will be necessary HW and SW Architecture and Communications able to satisfy the necessary requirements of Plug&Produce, Flexible and Reconfigurable Technologies and Devices starting from a Unique Control Platform for Production Planning and Re-Planning, Predictive and Predictable Maintenance, Cost Analysis, integration of advance AI Algorithms to face the daily Production Requirements and Customer Demanding.

Thanks to the real-time acquisition of machine and processing data it is possible to maintain the Digital Twin of the plant synchronized with the real behavior of the packaging line. Digital Twins can then be used to simulate different scenarios both for line or cell reconfiguration but also to identify and optimize bottlenecks. In addition, it is possible to continuously monitor machine operation to identify any deviations from the expected behavior predicted by the simulation and intervene to resolve any identified problems in order to maintain optimal levels of production and quality.

It is expected that simulation tools will be used during different lifecycle of the production line: in the design phase to evaluate the optimal devices and their layout, for virtual commissioning during the development of the automation programs, during the normal operation to forecast the performance based on the actual shopfloor status and to monitor any deviations, optimization based on varying

production plan, reconfiguration when required by new process requirements.

The needs to be addressed are the following

- More Flexible and Reconfigurable Automation Solutions according to Real-Time Production Scheduling and Re-scheduling.
- Logistics based on AMR (Single or in a Fleet) and Food-Product Handling based on CoBot (Collaborative Robots) + 3D Vision System.
- Advanced Tools for Simulation and Validation of Control Solutions with reference to Overall Packaging Line.
- Integration in ReeNEXT of New Production Line Facilities according to New HW & SW Architecture, Communication and Network Protocols.

6.1.6 Expected Results and KPIs

The Trial Implementation will show an example of New Food Packaging Line based on Plug&Produce Technologies and Devices, advanced Robotics Solutions as CoBot and AGV, connected by Safe and Efficient 5G/Wi-Fi Network Protocols; ReeNEXT Platform will guarantee the HW and SW integrations for a Daily Data Acquisition and Management, an Instrument for a Proper Decision-Making Process at Production and Maintenance Levels based on AI Algorithms.

A possible evolution SN Reepack Trial could be the realization of more than one Packaging Line for testing the addition and simultaneous interactions between all involved Devices and Technologies, into the same Network and Physical Space.

KPI	Description	Technology Provider	Validation Scenario (1 or 2)
IEC61499 Application at Automation Level: [Timing TBD]	HW and SW Reconfigurability in case of Machine Set-Up and Maintenance	NXT Control LTU	1
IEC61499 Application at Communication Level: [Timing TBD and Data Reliability]	OPCUA Protocol Communication and ReeNEXT Production Line Data Management	NXT Control LTU	1, 2
IEC61499 Application at Communication Level: [Timing TBD and Data Reliability]	Wi-Fi Communication Protocol	NXT Control LTU	1, 2
Virtual Commissioning Application at Automation Level: [Tool Usability and Process Reliability]	Validation of HW and SW Architecture based on IEC61499	NXT Control LTU TTS	1
Virtual Commissioning Application at Automation Level: [Tool Usability and Process Reliability]	Simulation of Control Solution at PLC and HMI Levels	NXT Control TTS	1
Virtual Commissioning Application at Production Level: [Tool Usability and Process Reliability]	OEE of Packaging Line and Cost Analysis with reference to Production Batches Scheduling and Rescheduling	NXT Control TTS RWG	2
AGV Technology Application at Production Level:	Physical Interaction with Human Operators in Safety Conditions	NXT LTU	1, 2

[Device Usability; Process Reliability; Timing of Scheduling]	and according to Production Plan Scheduling and Re-Scheduling, Inputs Availability, Unexpected Interferences.	TTS RWG	
AGV Technology Application at Production Level based on AI Algorithms: [Timing of Re-Scheduling and Production Line Efficiency]	Scheduling and Re-Scheduling of AGV Tasks according to New Production Inputs and/or NO-Conformities of Production Outputs	RWG	1, 2

Table 12 - SN01 and SN02 KPI Table

6.1.7 GDPR Assessment

In this trial there will not be any kind of personal data management or treatment. Video cameras used in the trial shall frame only the equipment and will not capture any worker during the regular operation of the trial.

6.2 SN03. 5G Enabled Remote Quality Control for Zero Defect Resilient Manufacturing

Automated manufacturing cells are complex systems that allow for a more flexible factory layout, as they integrate all the required equipment on a single platform that can be easily moved through the workshop. Data aggregation, integration and communication for production and machine monitoring and control are key challenges to optimize the overall production process.

Since all the steps along the manufacturing process (engineering, manufacturing and quality control) are so interdependent, only by integrating data from all these stages the Zero-Defect Manufacturing paradigm can be achieved on these automated cells. This task may be difficult because these steps may occur in different geographical locations or even by different companies.

This trial addresses two different challenges in this sense for Automated Additive Manufacturing Cells: first, increasing the flexibility of the cells to be rearranged in the shopfloor by integrating 5G technologies, and second, optimizing the quality control process, enhancing the information that is shared with the engineering and manufacturing stages. Results obtained on this Additive Manufacturing use case can be extrapolated to any other type of manufacturing cell.

6.2.1 General Description

The trial focuses on the Additive Manufacturing (AM) and the Quality Control processes, and explores the benefits that 5G and other Industrie 4.0 technologies can bring in to each of them in terms of flexibility, improved data collection and sharing and seamless integration of the overall process.

First, by enabling 5G additive manufacturing cells (Figure 57), that will facilitate the deployment of monolithic robotic cells that can be easily moved through the factory while ensuring the communication with the cloud systems that allow monitoring and controlling of the process and the status of the cells, demonstrating the interoperability between 5G and Industrie 4.0 protocols like OPC-UA.



Second, by establishing a sovereign data-sharing environment that enables all the secure sharing of design, manufacturing and quality information among the ecosystem, connecting engineering, production and quality control to improve the production resources, capacity and quality.



Figure 57 - Quality Control equipment

6.2.2 Participants and roles

The activities of this trial related to adding 5G to Additive Manufacturing cells will take place in Aimen Laser Centre, one of the two main Aimen facilities located in the city of Porriño, in Galicia region (Spain) (see Figure 58).



Figure 58 - Aimen Laser Centre at Porriño (Spain).

Aimen Laser Centre contains part of the offices from AIMEN and two warehouses with different industrial cells and stations that enable AIMEN to replicate real manufacturing scenarios. Among other equipment, Aimen Laser Centre is equipped with several robotic manufacturing cells with different types of manufacturing technologies including laser sources of different types, arc welding machines, robotic claws and much more. Aimen Laser Centre concentrates most of AIMEN R&D activities.

In Zero-SWARM, one of the warehouses in Aimen Laser Centre will be installed with 5G connectivity to connect different manufacturing cells with the information systems and from there to a private cloud that collects manufacturing data in a centralized way. Figure 59 shows two robotic cells at AIMEN Laser Centre. AIMEN provides the proper test bed to study how 5G can be used in real manufacturing scenarios and mixed with most new I4.0 technologies, including new protocols, AI and cloud technology.



Figure 59. Robotic cells at Aimen Laser Centre, in Porriño, Spain.

The activities of this pilot related to Innovalia, mainly related to quality control, will take place at the Automotive Competence Center in Advanced Quality Control Services, within the **Automotive Intelligence Center (AIC)** in Amorebieta, Spain (see Figure 60). Innovalia, as end user of SN3 trial, will provide here a testing environment for testing 5G technologies in an industrial environment for time sensitive operations.



Figure 60 - The AIC in Amorebieta, Spain.

The AIC is a European center generating value for the automotive industry, based on the concept of open manufacturing production innovation in which companies improve their competitiveness through cooperation. The AIC-Automotive Intelligence Center is managed by ACICAE, the Basque Country Automotive Cluster (over 300 companies), and hosts 26 companies including OEMs (Daimler), Tier 1 and Tier 2 component providers such as GESTAMP (6.500 M€ & 100 locations), ZF Lemförder TVA (18.400 M€ & 230 locations), etc.

The Automotive Competence Centre in Advanced Quality Control Services (AQCS) – INNOVALIA Metrology's Lab (see Figure 62), placed in the AIC, is part of the INNOVALIA Zero Defect Manufacturing (ZDM) Digital Innovation Hub (DIH) with the vision that any local manufacturing industry should master manufacturing excellence through zero defect manufacturing products, processes and services. The DIH mission consists in ensuring that local industry can fully benefit from digital opportunities (technical support, access to experimental infrastructures, financing, skill development, market intelligence etc.) on the following competences: (1) Digital automation, Industrial IoT and CPPS (2), ZDM digital platforms (3) Factory 4.0 Big Data & 3D mobile data visualization, (4) Cybersecurity and digital trust.



Figure 62 - The Automotive Competence Center in Advanced Quality Services - Innovalia's Lab

i2CAT - Edge Orchestration and 5G user equipment developer

The i2CAT Foundation is a non-profit research and innovation centre. Its Mobile Wireless Internet (MWI) department has expertise in 5G networks, among others. MWI's work includes the physical design of embedded systems to driver level optimizations of broadband wireless technologies based on IEEE 802.11, software defined networking, and development of V2X applications.

In SN3 Trial, i2CAT will focus on extreme edge orchestration and computing capabilities for industrial domains, developing a smart industrial CPE that provides a policy-driven aggregation of 5G and Wi-Fi6 bandwidths.

Neutroon - 5G/Wi-Fi aggregation

Neutroon is a technology SME providing advanced telecommunication software solutions for the deployment, management, and operation of private 5G, 4G and Wi-Fi networks. Neutroon offers an end-to-end solution able to configure, monitor, and control all the components of a cellular private network, from the radios and the core network, up to simplifying the deployment of virtualised applications in the Edge servers.

Zero-SWARM is very well aligned with the company core business, and in SN3 Trial Neutroon will contribute in the Wi-Fi and 5G aggregation, and automation of the deployment of virtualised edge applications.

UMH – Industrial Communication Networks

The Ubiquitous Wireless Communications Research (UWICORE) laboratory at the Universidad Miguel Hernández de Elche (UMH) conducts research on the design of wireless networks applied to verticals, including industrial wireless networks. In this area, UWICORE's current research focuses on the design of 5G RAN protocols for deterministic URLLC service provisioning, the integration of 5G and TSN and other industrial protocols, and new AI-based mechanisms for proactively adapting the configuration of 5G RAN to industrial service demands. In SN3 Trial, the UMH team will develop solutions for monitoring, managing and proactively adapting the QoS and operation of local industrial networks based on the data and service demands and the status of local industrial controllers. UMH will also define the necessary interfaces and interaction processes for the effective and seamless coordination between the local industrial network controllers and the 5G NPN

S21Sec - Cybersecurity per Design

S21sec is a leading pure player cybersecurity provider. S21Sec was founded in 2000, becoming the first pure & professional cybersecurity company in Spain. In 2014, S21sec was acquired by Sonae IM - Investment Management Software and Technology. Since then, S21sec has strengthened its position as a European cybersecurity leader through the acquisition of Sysvalue in Portugal, Nextel S.A. in Spain and Excellium in Luxembourg and Belgium. More recently, in 2022, S21Sec has been acquired by Thales Group to reinforce its cyber-defence strategic business.

In SN3 Trial, S21Sec is responsible for providing cybersecurity to the project, defining the Cybersecurity methodology guidelines and templates and integration within the implementation level of functional architecture and development and operations platform of the project.

6.2.3 Trial Present Scenario

Additive manufacturing is a process to build three-dimensional objects by depositing layers of material, joined by melting each new layer with previous one and solidifying together. It can be used with multiple materials, like plastics, metals or composites, added in different formats like wires, powder or grains, and molten by different heat sources, like resistors, laser light or electrical arc. In this trial, Laser Metal Deposition (LMD) process will be used. In this process a cone of metal powder is projected to a point and molten by a laser source that travels inside the cone (see Figure 63).

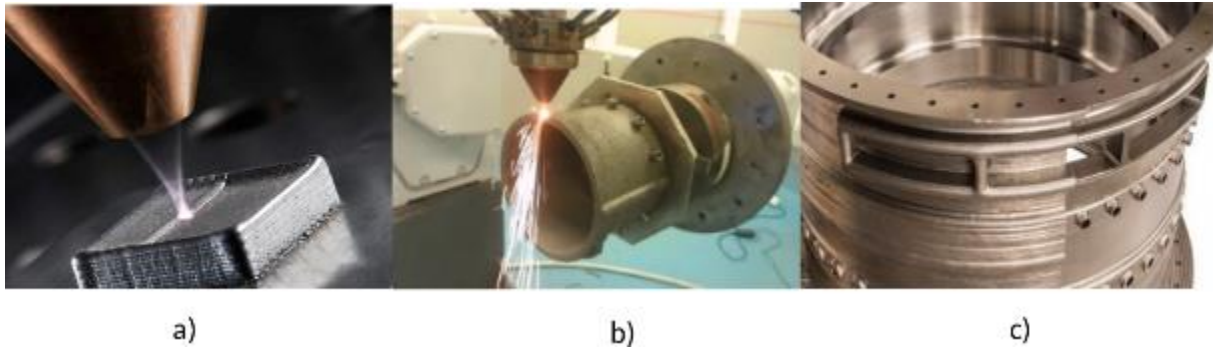


Figure 63 - LMD process detail showing powder cone (a), process manufacturing a big part (b) and finished LMD part partially machined to see the difference between raw and final product aspects

Due to the high-power concentration of heat and the complex thermo-mechanical effects, the appearance of defects like cracks or dimensional distortion are common. For this reason, the process is accurately monitored by different sensors and it is also common to apply real time control algorithms to maintain the process parameters into optimal values. Despite this, some final quality control process is needed to ensure the part is ok. Manufacturing data from sensors and quality control data is returned back to the design team to refine the part design and manufacturing programs (robot trajectories to avoid heat distortions, etc.)

When building a manufacturing plant with additive manufacturing cells it is common to install a big infrastructure for communication purposes, to connect a manufacturing cell to other parts of the factory or to data collection systems like ERP or Cloud. Nowadays it is also common to build monolithic robotic cells mounted on platforms that can be moved easily through the factory in case tomorrow a change in the factory layout is needed, due to changes in the production.

In most cases these manufacturing cells are connected to the OT network either by using network cable or, in some cases, via Wi-Fi. In the first case, flexibility is significantly reduced, as a network connection is needed where you want to install the cell, which implies new expenditures and time for rearranging the factory layout. In the second case, Wi-Fi cannot be always used. In many cases range and signal strength is not enough for the applications, especially in factories with a lot of metal, like automotive companies, that have metal cars moving through the factory over big metal structures. Given that 5G mobile communication could be considered as an alternative solution providing the required connectivity in a wider area able to guarantee an equal QoS.

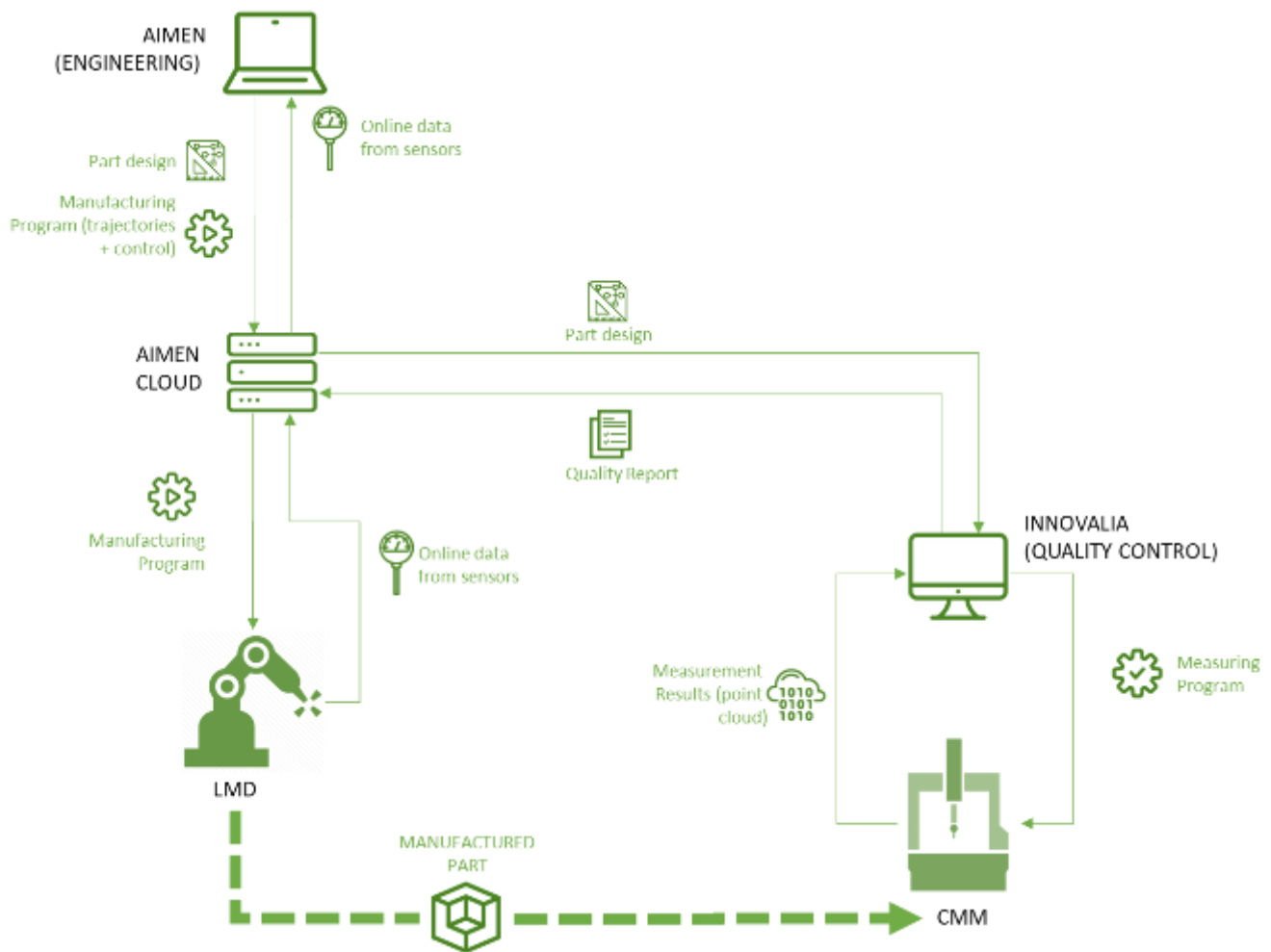


Figure 64 - Trial Present Scenario

Once the part is manufactured, as shown in Figure 64, it goes through the quality control, for which it is necessary, at least for the first time, to set up and calibrate the measuring equipment and define a measuring program that will identify the key sections and geometries of the part (based on its design data and CAD files). Both of these actions have to be performed by a metrology expert, that has to be physically present by the machine, what means that he/she has to travel to the client premises every time a part is designed or redesigned (even slight modifications require, often, a new measuring program).

6.2.4 Weaknesses and Bottlenecks

WEAKNESS & BOTTLENECKS	DESCRIPTION	AREA ¹	IMPACT IN THE COMPANY <i>At processes (manufacturing) level and business level</i>
Cable infrastructure needed to communicate cells to cloud	The lack of wireless technology with big range and high-speed forces cable infrastructure to be installed to ensure reliable cell-to-cloud reliable communication.	Manufacturing	It increases the costs of rearranging the shopfloor due to two causes: new cable infrastructure is needed to adapt to the new layout and the time that the factory is waiting for this infrastructure to be installed and tested.

Low speed of Edge-to-Cloud tools to ingest manufacturing data in real time	Low speed of current IoT frameworks, usually designed to ingest small data, cannot cope with images and high-speed sensor data in real-time, forcing high-speed data to be captured locally in a file and uploaded at the end of the process	Manufacturing	Workers get used to work locally with files and there is a discoordination between the local content and the cloud content, creating missing files and a delay on data arriving to the cloud. This also makes extra cloud time to convert compressed files captured locally to the cloud format, increasing computing infrastructure costs.
Unfeasibility to check production status from remote locations.	Previous problem makes it difficult to have the cloud unified information from all cells in the factory, preventing from having real-time information on how production is going.	Manufacturing	Makes it more difficult for production team to assess the status of production and the planification of production. This increases the probability to comply with deadlines with the costs associated (discoordination between transport and manufacturing, penalties due to delivery delays, etc.)
Data sharing risks	The part design as well as other manufacturing information that is shared between the manufacturer and the metrology company are in many cases not properly controlled.	Technical support	Part design is key for most industries, and it is very sensible information. Keeping control of the data is vital for those companies.
Physical access to the CMM required to update configuration and recalibration	Currently, when a CMM installed at the customer premises needs to be reconfigured or recalibrated, specialized personnel must travel to the client premises to perform these actions as they require physical access to the CMM.	Manufacturing	This sort of actions are performed at least once per year, or every time there is a slight modification of the piece. This weakness implies additional costs for the customer and, if not well planned, it can imply delays in the quality control process, that in the end mean delays in production.
Configuration and operation performed manually	The configuration, calibration and operation of the quality control process is currently mainly manual work, that require a specialised worker to be physically by the CMM, and manually overtake the different tasks by running specific commands.	Technical Support	Many of the configuration and calibration tasks, but also of the operational tasks, are repetitive and extremely time-consuming. Highly skilled metrology workers need to stay by the machines for long periods of time performing low-added-value actions to ensure the correct functioning of the CMM.
Lack of information regarding the status of the CMM and the health of the system	Currently, the maintenance of the CMM is done periodically, without taking into consideration the current status of the machine.	Manufacturing	Periodic maintenance force specialised workers to travel to the client's premises, and performing some actions that could not be necessary, just to avoid the risk of failure.

Table 13 - Weaknesses and bottlenecks addressed in SN03

6.2.5 Trial Future Scenario

The ambition of this pilot is to use 5G and other I4.0 technologies to connect all the stages of the product's life cycle, enabling and enhancing data exchange for the improvement of each of these stages (see Figure 65 and advance towards the Zero-Defect Manufacturing paradigm).

First, a data space based on the International Data Spaces Reference Architecture (IDS-RA) will be deployed so that AIMEN and INNOVALIA can share their data in a sovereign and secure way. Thanks to this data space, the detailed measurement results in the quality control step will be made available for the improvement of the part's design and the manufacturing program (Engineering phase).

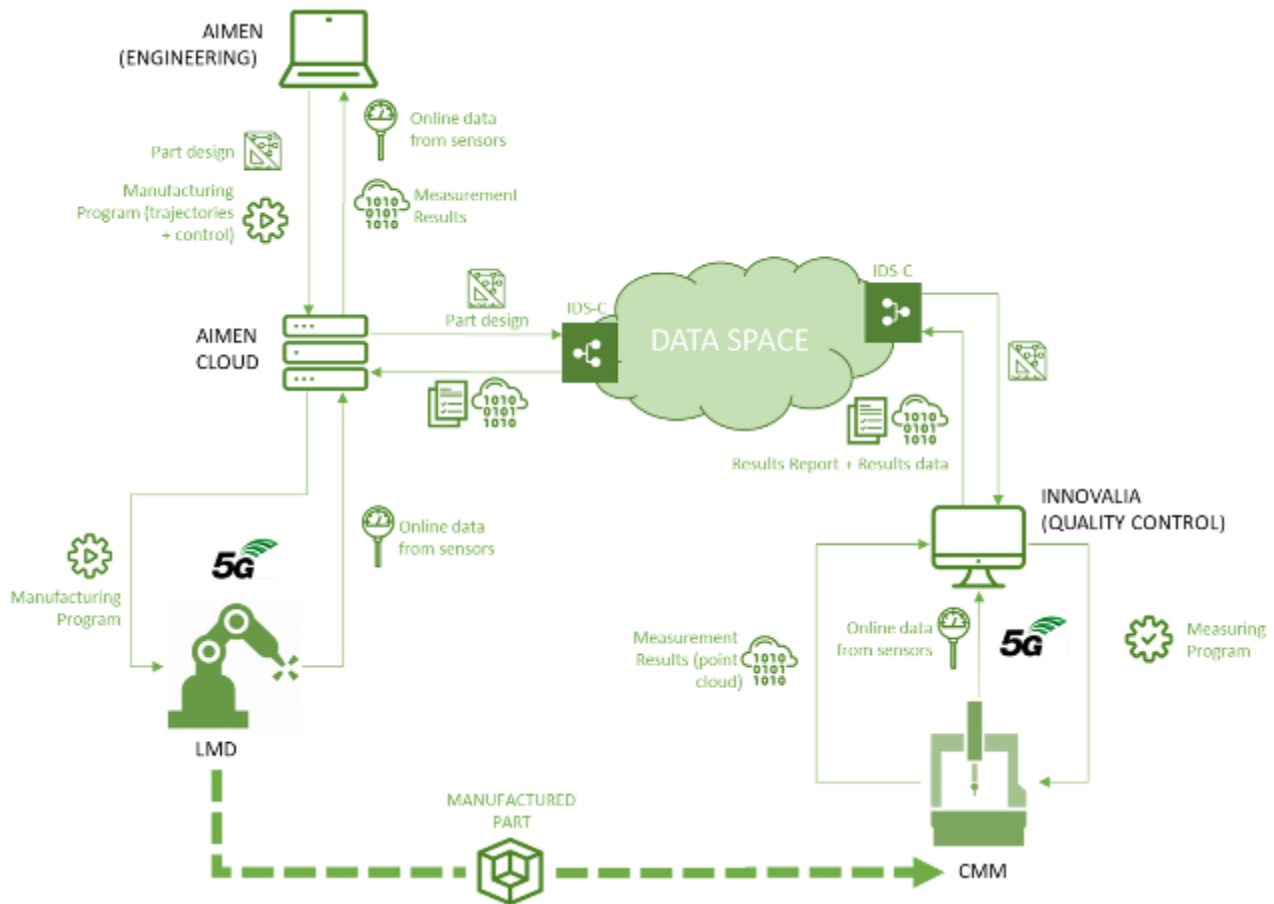


Figure 65 - Trial Future Scenario

In the shopfloor (production phase), robotic LMD cells at AIMEN Technology Centre will be connected via 5G to a Private Cloud that is used as central process data capture and visualization platform. The idea is to test 5G connectivity between the cells and the cloud to evaluate the possibility to have mobile additive manufacturing cells that can be easily deployed or moved inside the factory easier thanks to the 5G connectivity, that helps reducing cable deployment and enabling working in factories where Wi-Fi or other wireless technologies are not appropriate (i.e. factories with a lot of metal which blocks Wi-Fi coverage). These tests will use Industrial I4.0 protocols like OPC-UA and IoT protocols like Kafka together with 5G, evaluating the compatibility and performance obtained when combining these technologies together, helping to design future 5G products that comply with industrial requirements.

Finally, in the metrology process (quality control stage), the trial will address the automation of the configuration/calibration process, thanks to the 5G connectivity that will allow the remote operation of the machine, as well as the remote monitoring of the status of the Coordinate Measuring Machine (CMM) by adding sensors to the CMM and its environment.

The main innovative aspect of this trials is the connection of both an AM cell and CMM, for quality control, to a NPN 5G network to be operated remotely.

Regarding the CMM machine, from the business point of view, the possibility to operate them remotely provides a considerable agility to the in-line quality control process. It also contributes greatly to the digitalization of the manufacturing process and opens several business opportunities, such as the capacities to serve a greater number of customers, to adapt easily to change in production, to perform calibration or maintenance operations faster. These operations are currently performed by a qualified technician on the shop floor.

For a CMM machine to be operated remotely, we need to have a stable 5G connection, with a latency as lower as possible. Moreover, the overall system needs to guarantee the continuous flow of the information between the CMM machine and its control station, currently connected by an ethernet cable. The control station sends to the CMM the commands to move the mechanical arm and place the sensor in the desired position, while the CMM sends back to the control station real time information about its position, operational information about the machine, e.g. pressure, temperature (these data are key to evaluate the to assess the accuracy with which the machine is measuring), information about the environment. Independently by the connection, be it wired or wirelessly, this flow of information shall be ensured with great stability. When operating remotely, in addition to the data flow mentioned before it is important to add the video flow coming from two HD camera, one to show the status of the machine and another to show the environment and the contest. For as much as the video flow is needed, however, data from the machine, position and data from sensors need to be prioritized.

6.2.6 Expected Results and KPIs

ID	KPI Name	Description	Unit	Current value	Future expected value	Expected date of achievement**
1	Cells connected wirelessly	Number of cells connected via 5G wireless technology	-	0	3	End of implementation (September 2023)
2	Wireless process parameter transfer rate	Number of transfers per unit of time of the full set of (scalar) process parameters (20 parameters) through 5G wireless network to the cloud storage	Hz	0	20	before 4 months after implementation (January 2024)
3	Wireless transfer rate	Number of transfers per unit of time of the full set of (scalar) process parameters (20 parameters) plus thermal image through 5G wireless network to the cloud storage	Hz	0	20	before 4 months after implementation (January 2024)
4	Real time update in cloud	Number of updates per unit of time in the cloud visualization tools of the current process and cell status parameters (without image)	Hz	0	2	before 4 months after implementation (January 2024)
5	Increase production throughput	By having access to the metrology results, the engineering department will be able to optimize and improve the production program for the AM	-		+15%	Before 4 months after implementation

		system				
6	Reduce customer visits	Enabling the remote configuration of the CMM will allow to reduce the visits of metrology experts to the customers	-		-40%	Before 12 months after implementation
7	Reduce service response time	For all the services that can be provided remotely, much faster response time will be possible			-50%	Before 12 months after implementation

Table 14 - SN03 KPI Table

6.2.7 GDPR Assessment

In this trial, there will not be any kind of personal data management or treatment. Video cameras used in the trial shall frame only the equipment and will not capture any worker during the regular operation of the trial.

7 Requirements Engineering

7.1 Requirements engineering methodology

The methodology for requirements engineering in Zero-SWARM is based on the standard ISO/IEC/IEEE 29148:2018 Systems and software engineering — Life cycle processes — Requirements engineering. According to the concepts introduced by the standard, **requirements engineering is an interdisciplinary function that mediates between the domains of the acquirer and supplier to establish and maintain the requirements to be met by the system**, software or service of interest. The whole process requires different steps:

1. Identify stakeholders

In the scenario acquirer-supplier addressed by the abovementioned standard, the stakeholders are the users or the acquirer (who may not be the same) of the system. In the case of Zero-SWARM project we have 10 trials and ideally each of them requires its instantiation of the Zero-SWARM framework. In our case, stakeholders can be industrial players, academies, SMEs or industrial supplier. In fact, each trial is carried out by a team that combines multidisciplinary competences in ICT, operational technology and automation, as well as data technology. All the partners involved in trials have long history of engagement in 5G and I4.0 and include researchers with different seniority levels, from young PhD students to senior researchers with more than 20 years of experience, and expert industrial consultants. These competences cover know-how in system design, wireless communication systems, software development, service provisioning, experimental testing of I4.0 and 5G technologies. It is worth to highlight that while industrial companies and SMEs express their particular needs, suppliers, academic researches and consultants have a larger view and represent the needs of the sector in which they operate, see for example SMS-digital a big supplier for the steel sector, that is able report on the needs of this specific sector.

On average, the teams in charge of the trials are composed by 10-15 people, with a uniform distribution among expertise, sectors and years of experience, as showed in the following

pictures.

2. Recollection of needs

The collection of needs has been done for each trial together with the partner involved. A first iteration of needs has been extracted from the information presented in the previous sections. Needs have been refined and extended by the partners of the trial.

3. Definition of requirements

Needs are then converted in requirements and written according to the approach suggested by the standard¹²

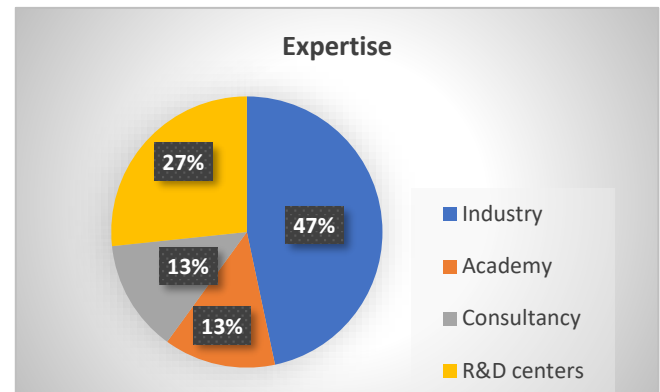


Figure 66 - Trial average team - Distribution of expertise

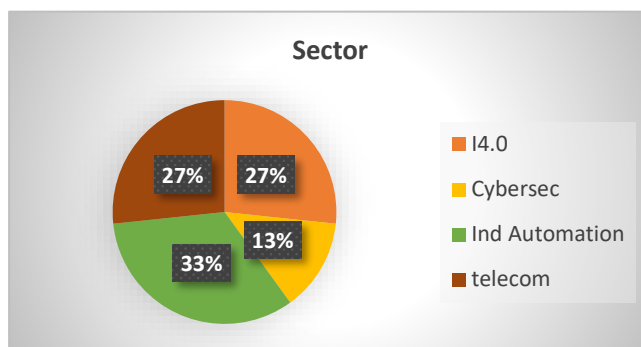


Figure 67 - Trial average team - Distribution of sector

Finally, requirements have been analysed together by stakeholders and solution providers to ensure their **consistency**, i.e. the set of requirements contains individual requirements that are unique, do not conflict with or overlap with other requirements in the set, **completeness**, i.e. the set of requirements¹³ stands alone such that it sufficiently describes the necessary capabilities, characteristics, constraints or

quality factors to meet entity needs without needing further information, and correctness.

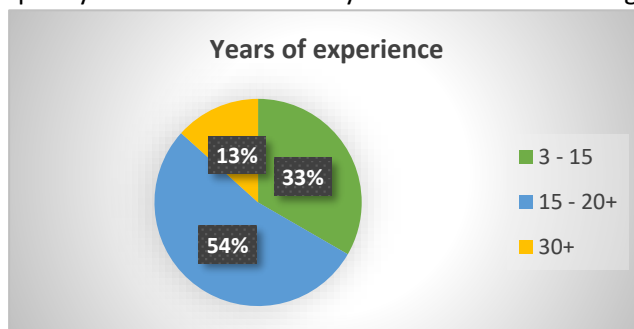


Figure 68 - Trial average team - Distribution of seniority

¹² ISO/IEC/IEEE 29148:2018(E) - 5.2.4 Requirements construct

¹³ We consider a set of requirements for each trial

7.2 Requirement Traceability matrix

The following list traces the requirements to the WP in which they will be fulfilled and, when possible, the technical component required is specified and declared as background or foreground.

7.2.1 North Node

TRIAL	Stakeholders	Suppliers	Industrial scenario	Needs	Business Requirements	WP or task	ID
NN1	ABB, as a big player in the field of industrial automation is representative of the needs of companies in the sector, as well as their customers.	Huawei, Aalto, ABB	Investigation of performances and capabilities of 5G-System deployment in relation to industrial automation systems.	Availability of cellular equipment following 3GPP standards	3GPP specifies the need for the UE to be able to send the 5G-System time	WP3	NN1-01
				Clock deviation measurements over 5G-System	The UE should have an Ethernet bridge interface	WP3	NN1-02
				QoS and traffic shaping capabilities of a 5G-System	Industrial automation traffic (e.g. OPC UA client-server and Profinet IO controller-device) should be guaranteed resources (i.e. bandwidth) over the 5G-System	WP4	NN1-03
				Challenges of traffic shaping capabilities of a 5G-System	Investigation of challenges in configuring and troubleshooting a 5G-System for the above needs of industrial automation	WP4	NN1-04
			Production of low voltage drive cabinets, devices used in industry e.g. to control industrial motors.	Security Aspects	Investigation of security configuration and monitoring needed for operation of an industrial automation system over a 5G-system	WP2	NN1-05
				Utilisation of smart tools in cabinet manufacturing using a wireless 5G System for their interconnection	Investigation of a system architecture for smart tools in cabinet creation	WP2	NN1-06
NN2	ABB, as use case definer and provider of industrial automation equipment. AALTO as provider of the physical and digital infrastructure	Acceleran, Visual Components, Huawei, ABB	Operation of a powertrain consisting of drives and motors controlled by a IEC 61499 PLC connected remotely, over a 5G-System	Remote PLC connectivity using a 5G-System	Getting rid of the complexity of configuring 5G-Systems and of plugging devices to them	WP3	NN2-01
				Advanced sensing	Remote expert services for configuration, optimisation and functionality shall be possible	WP5	NN2-02
				Distributed Intelligence	Wireless sensors for motor monitoring should be possible (e.g. ABB smart sensor)	WP4	NN2-03
				Secure connectivity	Security aspects to be included	WP5	NN2-04
				Plug & Play concept to add devices to a 5G-System	Control of a drive from a PLC over a 5G-System	WP3/WP4	NN2-05
				Commonly accepted industrial automation system architecture in relation to a 5G-System	Functional profiles of the motor should be remotely enabled over a 5G-System	WP3	NN2-06
				Reconfiguration use cases for the customer requested changes in the industrial automation system	Analytics and diagnostics build up in a distributed way (gateway and cloud)	WP4	NN2-07
				Optimisation of the whole system functionality (5G-System and industrial automation) using remote mechanisms	Remote expert services for configuration, optimisation and functionality shall be possible	WP3	NN2-08
NN4	LTU, as use case definer, provider of the physical and digital infrastructure.	LTU, AALTO, Acceleran, Huawei	Not a specific industrial trial, instead a 5G ready test bed (AIC3) for demonstration of I4.0 applications. It is equipped with PLC and embedded controlled device	Customizable and Distributed Production Systems with Plug-and-Play Capabilities	Agile Adaptability for Production Facilities: production facilities to swiftly adapt to evolving requirements without disrupting operations.	WP5	NN4-01
				Security of distributed industrial production systems	Safe reconfigure of production facilities	WP5	NN4-02
				Advanced Development Tools for Distributed Control Systems based on IEC-61499	Rapid and Dependable Development in Accordance with IEC 61499	WP5	NN4-03
				Data streaming from IEC 61499	Dependable Data Streaming in Accordance with IEC 61499	WP4	NN4-04

7.2.2 Central Node

CN1	SMS digital as provider of digital solutions in the metals industry Demo Factory Aachen as a manufacturer with AGVs for transport of goods within the factory's shopfloor. SICK as a provider for sensor systems, edge computing devices and automation services for industrial automation solutions.	SICK AG CCI RWTH	Safety in the use of AGV in the metal industry	Low network latency	Latency must be below 100ms (RTT control to AGV) to ensure emergency stops are in time.	WP3	CN1-01
				High link stability	Network outages can cause safety issues or reduce enhanced safety by advanced environmental awareness, fallback solutions are possible but this should be avoided.	WP3	CN1-02
				Data rates higher than 10MB/s	High data rates are needed to ensure the AGV gets all required data at all time. (Pre-)processing of data should take place on the edge and on the vehicle in a TDC which reduces data rates to more essential information.	WP4	CN1-03
				Easy access to local wireless network	TDCs, i.e. AGVs and sensors, should be easily integrable into the wireless network.	WP3	CN1-04
				Access to AGV path planning and limitation of its velocity	Easy and safe transport of goods in a warehouse using mobile platforms. The AGV must stop in dangerous situations, even if it cannot yet detect them itself. The AGV must adapt its speed to the actively (own sensors) and passively (other sensors) perceived environment.	WP4	CN1-05
				Access to sensor data, pre-processed data or acquired insights of the environment	The AGV should be aware of obstacles and objects that are out of sight but detected by other sensors or AGVs.	WP5	CN1-06
				Centralized control to coordinate distributed controls	For enhancement of coordination among various moving objects and AGVs, a centralized controller is required.	WP5	CN1-07
				Sustainability aspects	Avoidance of unnecessary stopping and accelerating by predictive velocity adaptation to safe energy and minimisation of wear.	WP4	CN1-08
CN2	Opticom as industrial solution provider nextControl GmbH as industrial solution provider	IPK HHI Opticom LTU	A small industrial robot arm mounted on an AGV to interact with its environment in a production facility.	New product variations need to be integrated on a short term through robot as a service solution	5G should enable a sufficient quality for wireless communication.	WP3	CN2-01
				A flexible and distributed automation platform that allows a fast integration of wireless equipment and sensors to shorten the setup or re-configuration time for production lines.	Wireless sensors should be easily integrated at existing machines delivering real-time data for process monitoring.	WP4	CN2-02

7.2.3 South Node

SN1	Reepack as industrial owner (PERK)	NX-SE, RWG TTS, LTU	Ready-Meals / Food Packaging in Trays and MAP (Modified Protective Atmosphere), Plastic Materials	More Flexible and Reconfigurable Automation Solutions according to Real-Time Production Scheduling and Re-scheduling.	Timing/Costs Saving for Machines Set-Up and Format Changes, according to Production Requirements: different Recipes vs. different Product References.	WP5	SN1-01
				Logistics based on AMR (Single or in a Fleet) and Food-Product Handling based on CoBot (Collaborative Robots) + 3D Vision System.	More Efficient Packaging Lines based on Advanced Automation Solutions especially for Logistics and Product, Food and Packaging Materials (Trays, Film, Spare Parts) Handling.	WP5	SN1-02
				Advanced Tools for Simulation and Validation of Control Solutions with reference to Overall Packaging Line.	Integration of AMR and CoBot in Traditional Food-Packaging Line	WP5	SN1-03
SN2	Reepack as industrial owner	NX-SE, RWG TTS, LTU	Edge Platform I4.0 Compliant (ReeNEXT) for Food-Packaging Processes	Integration in ReeNEXT of New Production Line Facilities according to New HW & SW Architecture, Communication and Network Protocols.	Edge Platform as User-Friendly and Reliable Instrument for Data Acquisition/Monitoring/Management, Production Planning and OEE/Cost Analysis, Predictive and Predictable Maintenance	WP5	SN2-01
SN3	AIMEN INNO/TRIMEK as industrial solution providers	i2cat Neutron UMH S21SEC	Remote quality control in AM, deployed with a support of a data space	5G connection shall allow remote control of the machine	Latency should be under 4 ms	WP3	SN3-01
				5G connection shall allow a clear visualization of the context and the operation all the time	The NPN 5G network shall be stable enough to guarantee continuous operation	WP3	SN3-02
				Data transmitted through the network have different priority	The traffic shall be prioritized according to the stakeholder's criteria	WP3	SN3-03
				Safety of operation: quick reaction to alarms and events	A system for automatic alarm should be included	WP5	SN3-04

8 Conclusions and next steps

This document has presented an overview of the trials of the project, including a state of the art of the most relevant technologies. According to the Trial Handbook Methodologies, the following have been reported in deliverables D2.2, D2.3, issued before the present, reviewed version of the current document:

- Definition of Business Scenarios, where the workflow and functional specification of the Trial components are detailed.
- Definition of technical Requirements and KPIs

Finally, Zero-SWARM will implement cyber security transversally in the architecture of the platform to be developed in the project in order to obtain a cybersecure by design CPSoS automation during the lifetime of the project. Specifically, the cybersecurity of the platform will be analysed with two approaches:

1. Cybersecurity policies will be implemented transversally in the deployment of the platform in the different trials. Specifically, it will be ensured that the platform complies with the system security requirements defined by IEC 62443-3-3¹⁴ (this standard is aimed to cover all situations that may occur during the life cycle of an industrial control system, from its implementation to its decommissioning), in each and every framework deployed in the trials of the project: *FR1. Identification and authentication control, FR2. Use control, FR3. System integrity, FR4. Data confidentiality, FR5. Restricted data flow, FR6. Timely response to events (Audit) and FR7. Resource availability.*

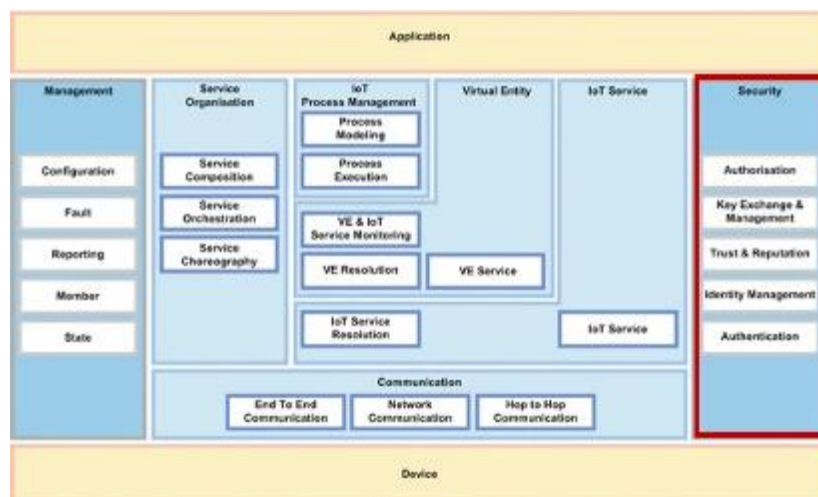


Figure 69 - Cybersecurity in the IIoT architecture

2. A DevSecOps technology approach will be defined and implemented with the intention that all developments made within the project will comply with the defined methodology. DevSecOps is a natural extension of DevOps that advocates for shifting security-left to security-by-design and

¹⁴ https://webstore.iec.ch/preview/info_iec62443-3-3%7Bed1.0%7Den.pdf

continuous security testing by making use of automated security controls in the DevOps workflow. The DevSecOps methodology will enable the activation of security controls using appropriate open-source tools to perform security assurance tasks along the DevSecOps workflow.

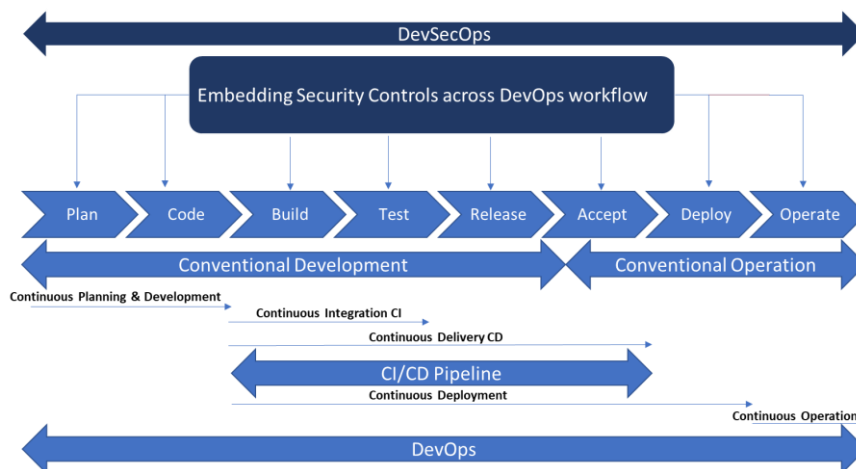


Figure 70 - DevSecOps implementation methodology

The implementation of cybersecurity in the project has been further elaborated in deliverable “D2.3 Cyber security implementation templates and methodological approach”.

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