

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

D3.3 - 5G AAS & digital twins

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List of Acronyms

3GPP	3rd Generation Partnership Project
AAS	Asset Administration Shell
CPS	Cyber-physical system
CPSoS	Cyber-physical system of Systems
CU	Centralized Unit
DT	Digital Twin
DS	Digital Shadow
DU	Distributed Unit
gNB	Next-Generation Node B
I4.0	Industry 4.0
I4.0MI	Industry 4.0 Maturity Index
IIoT	Industrial Internet of Things
IoT	Internet of Things
LTE	Long Term Evolution (4G)
RAN	Radio Access Network
RU	Radio Unit
UE	User Equipment

Executive Summary

5G is becoming an important part of the infrastructure of factories due to its performance, flexibility and tailored solutions for factory automation and connected industries. The industrial 5G system must be integrated within factories following the I4.0 principles. AAS is a key component of the I4.0 architecture to ensure integration across system boundaries and interoperability across the value chains. It supports the notion of working with “digital twins” of all assets of a factory. Two new types of digital twins/AAS were recently proposed by 5G-ACIA with respect to the 5G architecture called 5G network AAS comprising 5G RAN and 5G Core Network, and an independent AAS model for the 5G User Equipment (5G UE AAS). Built on top of that, this task will extend the specifications and will further refine the standards to ensure seamless integration and communication within the industrial 5G ecosystem, ultimately enhancing the efficiency and productivity of factories in the era of I4.0.

1 Introduction

In an era characterized by dynamic industrial progress, the convergence of advanced technologies and collaborative initiatives becomes paramount for transforming the manufacturing landscape. At its essence, this endeavour is fuelled by a shared vision: the seamless integration of 5G technology into factory environments, unwaveringly aligned with the principles of I4.0.

In the heart of this collaborative endeavour lies a multifaceted approach to introducing 5G technology into the field of factories and I4.0 principles. Here is a closer look at our key objectives:

1. Developing an open source 5G Network Asset Administration Shell (AAS) and 5G UE AAS
Our initiative is focused on creating an open-source AAS tailored specifically for 5G networks and user equipment. We embrace open standards and aim to establish a robust framework that not only promotes interoperability but also encourages innovation within the extensive 5G ecosystem.
2. Empowering real-time digital twins for sustainable production
I4.0 goes beyond just optimising operational efficiency; it strives for a future that is both sustainable and environmentally conscious. Our project is committed to advancing the development of real-time DTs, a technology that empowers environmentally conscious and ecologically sustainable production processes. Through digital twin capabilities, factories can optimize their operations while simultaneously minimizing their environmental footprint.
3. Forging interfaces between 3GPP 5G system and AAS repositories
Connecting the 3GPP's 5G system and AAS repositories is a critical step towards seamless integration; enabling factories to fully utilise the vast potential of 5G technology and advance their connectivity and automation capabilities. This interface will allow for uninterrupted data exchange, enabling factories to utilize the immense potential of 5G technology to enhance their connectivity and automation capabilities.

Together, these objectives form the cornerstone of our collaborative venture, which promises to redefine the future of manufacturing by combining the power of 5G technology with the sustainability and efficiency principles of I4.0.

1.1 Purpose of the Document

This document aims to examine the integration and implications of 5G AAS and digital twins in agile cyber-physical production systems. Against the backdrop of the fourth industrial revolution, it delves into foundational concepts, technological advancements, and the transformative potential of these innovations. The primary objective is to present a concise and clear explanation of how 5G AAS and digital twins contribute towards the next stage of industrial evolution, emphasizing their role in augmenting efficiency, nimbleness, and eco-friendly production. The document endeavours to provide guidance and insights for stakeholders navigating the fast-changing terrain via detailed discussions, specifications, and business model explorations.

1.2 Structure of the Document

To achieve these objectives, the paper includes the following sections: Section 1 introduces the topic. Following the introduction, Section 2 delves into the theoretical background, emphasizing how AAS

tools, digital twins, and 5G networks have impacted Industry 4.0. It gives background information and historical context, while examining the development of crucial industry metrics. Next, it reviews the conceptual framework and importance of digital representations of physical assets, as well as their position within modern industrial paradigms.

After establishing the foundations, Section 3 outlines the process of modelling 5G private networks in the AAS, summarising AAS types, modelling phases, and private 5G network implementation with monitoring. The section provides specifications on cutting-edge network technologies, highlighting their open-source characteristics and potential applications. Additionally, it thoroughly explores the practical aspects of implementing these specifications, uncovering insights into the challenges and solutions encountered in real-world scenarios.

Subsequently, Section 4 analyses the economic impact of AAS in private 5G networks, particularly on the digital green transformation within the industrial sector. It delves into the commercial consequences of these technological advancements. It outlines potential business opportunities by analyzing their market significance, potential revenue streams, and distinctive selling points.

Finally, Section 5 provides a preview of the forthcoming deliverable D3.7, which will delve further into the topics discussed in D3.3.

2 Background and Context

Exploring 5G AAS, digital twins and their integration into agile cyber-physical production systems requires foundational context. This section serves as a starting point, highlighting key concepts that form the foundation for the innovations discussed later. We examine the implications of the I4.0MI, clarify the role of AASs and highlight the transformative potential of DTs. Understanding the historical and conceptual background of these elements situates the content within a wider framework, facilitating the comprehension of nuanced discussions and implications outlined in the document.

2.1 Industry 4.0 Maturity Index

2.1.1 What is the Industry 4.0 Maturity Index?

The acatech I4.0MI is meticulously designed to guide companies through their transformation journey in the context of I4.0. Introduced to aid companies map their individual I4.0 development path, the maturity index prepares them for a gradual transformation into agile enterprises. The term “Industry 4.0” was coined in 2011, marking the profound fusion of information and communication technologies in the industrial area. However, there has been a tendency to misinterpret this term, often restricting its scope to technological aspects only. The true challenge for companies goes beyond technology – it involves reconfiguring their organisational structures and culture. The goal is to transform into a learning, agile organisation capable of flexibly adapting to a constantly evolving environment.

The maturity index outlines six stages of development for the four essential structural components, which are resources, information systems, organisational structure and culture. Each stage provides an additional benefit to the company, and the index can be used to create a tailored digital roadmap, facilitating the introduction of I4.0 across all company sectors. The maturity index underwent validation in early August 2016 at Harting AG & Co. KG in Espelkamp, Germany. Harting, a renowned manufacturer of industrial connectors, device connection technology, and network components,

leveraged the maturity index to assess and steer its journey towards I4.0 transformation. Figure 1 highlights the six major steps on the path to I4.0 maturity.

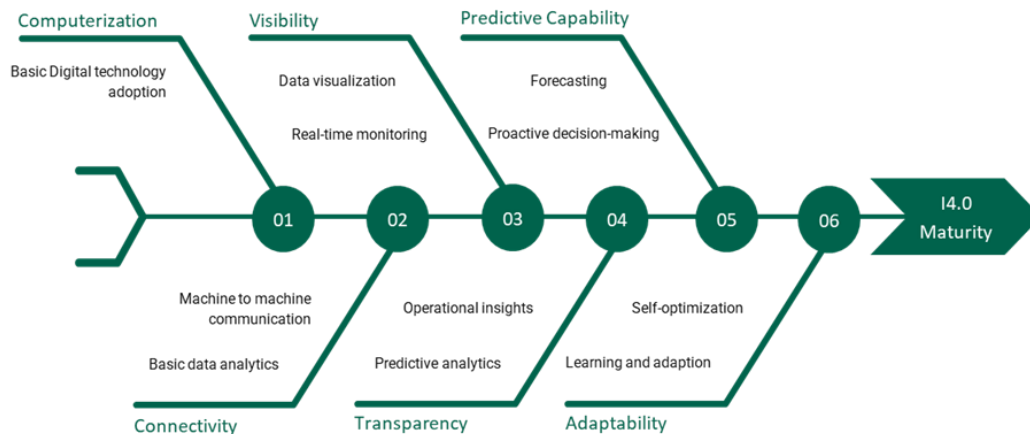


Figure 1 Path towards I4.0 Maturity

The application of the maturity index unfolds in three sequential phases. The initial phase involves determining the company's current I4.0 development stage by examining the existing I4.0 capabilities in various functional areas and design areas. Based on the company's strategy, the subsequent phase defines the desired development stage as the transformation process's target. A GAP analysis is then conducted to identify the capabilities that need to be cultivated, based on the current development stage and the desired end state. The final phase involves deriving measures and positioning them in a roadmap to develop the identified capabilities

Build upon the insights and the developed model, there is the opportunity to devise future tools to tangibly shape the transformation within companies. A domain-specific approach is recommended to furnish concrete recommendations, catering to the nuances and distinctions across various industries. In essence, the acatech I4.0MI is a robust instrument that provides a structured methodology for companies to gauge their current state, identify capability gaps, and draft a roadmap towards achieving I4.0 maturity, emphasizing the need for a holistic transformation that encompasses technological, organizational, and cultural dimensions. [8]

2.1.2 Where are the different aspects of 5G located in the I4.0MI?

In the context of the I4.0MI's six stages, different mobile communication technologies have specific roles. LTE-M (LTE for Machines) is particularly suited for the Computerization and Connectivity stages, offering a low-cost, low-power wide-area network solution that facilitates initial data collection and device communication. Narrowband IoT (NB-IoT) can similarly be used for these early stages but is optimized for applications requiring even lower power and deeper penetration, such as in underground or remote areas. As organizations move towards the Visibility and Transparency stages, 5G RedCap (Reduced Capability) can provide enhanced connectivity with more efficient power usage, ideal for non-time-critical applications. For the Predictive Capacity and Adaptability stages, 5G URLLC (Ultra-Reliable Low Latency Communications) offers ultra-reliable, low-latency links crucial for real-time analytics and automation. Meanwhile, 5G MEC (Multi-access Edge Computing) can enable data processing closer to the data source, enhancing real-time analytics and decision-making capabilities. Lastly, 5G zero-touch services can automate network configuration and management, directly contributing to the Adaptability stage by enabling dynamic resource allocation and thus a more agile infrastructure. These technologies collectively underline the critical role of advanced, reliable, and

agile connectivity in realizing the full potential of I4.0. The relation between the different technology aspects and I4.0MI are illustrated in Figure 2.

The I4.0MI outlines the complexities of manufacturing and production strategies, where 5G could serve as a transformative force. With its capabilities for high data transfer rates and ultra-low latency, 5G could enable real-time data processing and analytics, which are crucial for modern manufacturing. For instance, it could facilitate real-time monitoring of machinery and production lines, allowing for immediate adjustments to optimize performance, thereby leading to increased efficiency, reduced waste, and significant cost savings. Moreover, 5G could enable more effective predictive maintenance by allowing for the continuous monitoring of equipment health, thereby reducing downtime, and extending the lifespan of machinery.

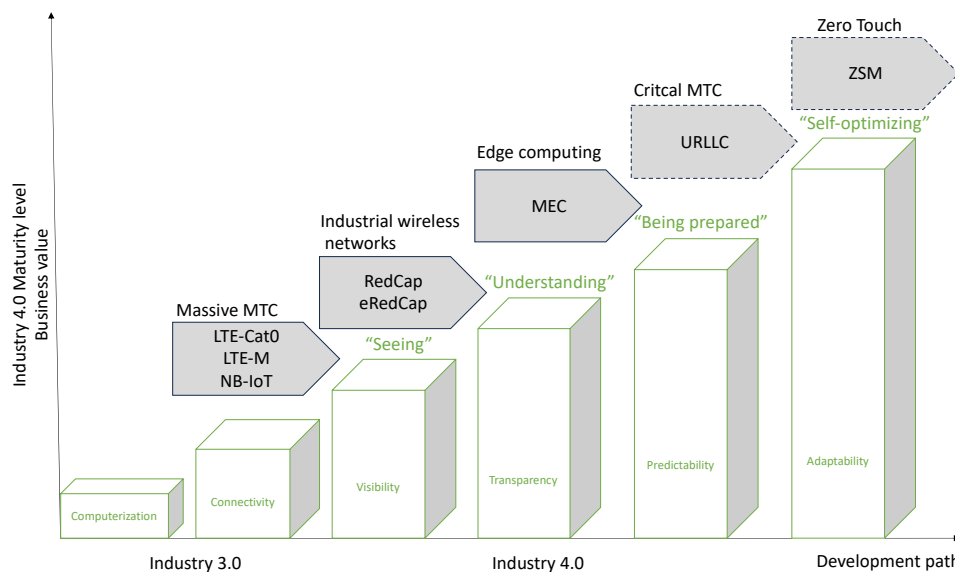


Figure 2 Location of the different aspects of 5G in the I4.0MI

The I4.0MI also delves into logistics, including supply chain management, transportation, and distribution. In this field, 5G could revolutionize logistics by enabling real-time data collection and analytics, which are vital for efficient operations. For example, 5G could allow for real-time tracking of shipments and inventory, leading to improved inventory management, reduced lead times, and more accurate delivery estimates. The technology could also facilitate better coordination among various logistics partners, thereby streamlining the entire supply chain.

The importance of innovation in product and process development is emphasized within the I4.0MI. In this context, 5G could significantly accelerate development cycles by enabling faster and more reliable data transfer. This would facilitate more effective collaboration between geographically distributed teams, allowing fast iterations and refinements. Additionally, 5G could support advanced simulation techniques, enabling real-time prototyping and testing, which would not only reduce time-to-market for new products but also enhance the quality and reliability of the end-product.

Customer service and relationship management are another focus within the I4.0MI. In the service sector, 5G could dramatically enhance the customer experience. For example, real-time customer support could be provided through high-definition video calls, enabled by 5G's high data speeds and low latency. This would allow for faster resolution of customer issues, potentially even in real-time. Moreover, 5G could enable more advanced customer service solutions, such as augmented-reality-

based troubleshooting or virtual customer service agents, leading to a bleeding-edge user experience and ultimately higher customer satisfaction rates.

Finally, the principles of applying the maturity index involve assessing a company's current capabilities and identifying gaps. In this regard, 5G could emerge as a key technological capability that needs to be implemented. The low latency and high data speeds that 5G offers could be crucial factors in achieving operational efficiency, a key metric in the I4.0MI. For instance, the integration of 5G could streamline data flow across globally distributed sites, enabling better coordination and faster decision-making. This could be particularly beneficial for companies looking to mature, as it would provide them with the technological infrastructure needed to support more advanced I4.0 applications.

After thorough analysis, the technological features of 5G networks align with the goals outlined in the presented framework. Hence, integrating 5G technology is a crucial factor for an organisation's progress in the I4.0MI. This integration can significantly enhance various aspects of an organisation, including but not limited to manufacturing processes, logistics, innovation, and customer relations.

2.2 Asset Administration Shells

The AAS has surfaced as an essential breakthrough in the domain of I4.0, acting as a digital representation of physical and non-physical assets. The AAS embodies a complete array of facts and details regarding an asset, comprising of its traits, attributes, qualities, conditions, parameters, measurement data and abilities. This representation is not simply a fixed compilation of the asset's characteristics, but instead reflects a dynamic and constantly updatable interface that mirrors the asset's current state and condition.

Within the context of I4.0, the AAS plays a crucial role in connecting the physical domain to its digital counterpart. This is achieved by providing a standardised framework for data exchange, which ensures seamless interoperability across multiple systems and platforms. The AAS's structure undergoes meticulous definition via a technology-agnostic meta-model, which then receives further elaboration through technology-specific serialization mappings. These mappings encompass formats such as XML, JSON, and OPC UA. The overall structural organization is augmented by sub-model templates that relate precisely to the domains they represent, strictly dictating what can be included within the AAS. One key feature of the AAS is its provision of various communication channels and applications, highlighting its adaptability to diverse operational scenarios and requirements. It functions as an intermediary point between tangible objects and the modern, interconnected, and dispersed realm of I4.0, with a critical role in driving the digital evolution of industrial processes.

Furthermore, the interaction mechanisms with the AAS are not uniform but can adapt to different patterns, each with its specific technical requirements. These interaction patterns encompass conventional file exchanges and more elaborate server-client and peer-to-peer interactions, offering a versatile approach to data exchange and communication procedures.

In summary, the AAS serves as a crucial element in the I4.0 terrain. It offers a systematic, uniform, and adaptable approach to asset representation in the digital realm. Its execution fosters improved interoperability and data coherence across industrial ecosystems, hence bolstering the realization of intelligent manufacturing and the broader goal of a fully integrated and interconnected industrial landscape. [9]

2.2.1 Role of AAS in Industry 4.0

The AAS is a crucial foundation within the digital transformation landscape, especially under the revolutionary frameworks brought about by I4.0. This transformation signals a shift in modern industrial practices, where the AAS serves as an essential link connecting the physical manifestations of machinery, equipment, and environments to their digital representations. It is in the digital world where the AAS takes an active role in shaping, defining, and enabling assets' digital identities. They create a comprehensive digital footprint from the shop floor to higher-level industrial management. In the complex system of I4.0, conventional industrial methods are quickly being replaced by more connected, data-driven paradigms. The AAS plays a vital role in this transformative journey, acting as the foundation upon which DTs are conceptualised, developed, and integrated. Its meticulous structure, standardisation and universality make it an excellent format for data representation, allowing the AAS to transcend its role as a digital mirror. It develops into a comprehensive platform that provides various features, ranging from up-to-the-minute operational data to anticipatory analytics, from performance measurements to prognosis for maintenance, and from life-cycle administration to incessant enhancement systems.

The AAS architecture is a remarkable example of well-thought-out design, ideal for future industrial operations centred on adaptability, scalability, and integration. Its meta-model, which is not tied to any specific technology, reflects this foresight. This innovative framework facilitates the smooth fusion of different communication protocols, data formats, and application scenarios, thus strengthening the AAS's role as a versatile connector in the presence of varied industrial communication demands. The adaptability of the AAS guarantees its relevance and applicability across the spectrum of industrial activity, spanning various sectors, technologies, and processes.

The AAS facilitates diverse interaction patterns, taking interoperability to new heights. These models, customised to suit the distinct features of industrial operations, span from the simplicity of sharing files to the intricacy of real-time, bi-directional communication flows that naturally exist in client-server and peer-to-peer frameworks. As a result, the AAS serves not only as a facilitator but also as an enabler of a novel industrial language accentuating efficiency, lucidity, and the unhindered transmission of digital discourse.

In surpassing convention, the AAS becomes a forerunner and cornerstone of a new era in industry. It embodies the ethos of I4.0, where the merging of the physical and digital realms is not happenstance, but rather a strategic necessity. Through AAS, industries are not only integrating systems and technologies, but also crafting a digital story that highlights the interconnectedness of assets, the interdependence of processes, and the integrated nature of industrial ecosystems.

Therefore, the AAS functions not only as a component within this digital tale, but also as the script, narrative arc, and denouement. It facilitates a broad digital transformation – a transformation that enables sectors to move with confidence and foresight through the intricacies and possibilities of the digital era, outlining routes through uncharted domains, and creating stories of advancement, progression, and everlasting commercial traditions. [9]

2.2.2 Location of AAS within I4.0MI

In the context of I4.0, the AAS is a vital facilitator for digital transformation. Although the I4.0MI does not mention AAS directly, it offers useful perspectives on the operational domains in an organization where AAS might be implemented. These domains encompass development, production, logistics, service, marketing, and sales.

The I4.0MI stresses the role of sensing and embedded systems in cyber-physical systems. It outlines the notion of a “digital shadow” which acts as a digital portrayal of physical operations and objects. Choosing suitable sensor technology is crucial for inspecting physical processes and generating the DS. This concept is similar to AAS, as both strive to build a DT or portrayal of physical assets. Therefore, one could deduce that AAS could be employed in locations where there is already widespread or planned deployment of sensor technology.

The I4.0MI also addresses the importance of digital transformation in different functional areas of an organisation. For example, in the manufacturing sector, the index recognizes the necessity for real-time data analysis and anticipatory maintenance. AAS could make a significant contribution to these areas by establishing a standardised framework for asset description. This would facilitate improved data analytics and predictive maintenance capabilities. Additionally, the I4.0MI emphasises the importance of real-time tracking and inventory management in logistics. Here, AAS could provide substantial benefits by facilitating seamless data exchange between various systems, which would enable efficient real-time tracking and inventory management. The I4.0MI defines a “maturity index”, which acts as a roadmap for businesses seeking to move towards I4.0. The index incorporates multiple dimensions, including resources, information systems, and organisational structure. Utilizing AAS could act as a transitional tool for firms aspiring to advance their maturity index, as it will furnish them with the technological framework required to support more sophisticated I4.0 applications.

In essence, the I4.0MI, with its focus on digital advancement, cutting-edge sensor applications, and the notion of a digital reflection, provides valuable insights into the incorporation of AAS within an organisation. By coordinating the implementation of AAS with these perspectives, enterprises can enhance their operational efficiency and advance towards achieving the benchmarks of I4.0. Figure 3 highlights the location of AAS within the Industry 4.0 Maturity Index framework and demonstrates its influence on the associated aspects.

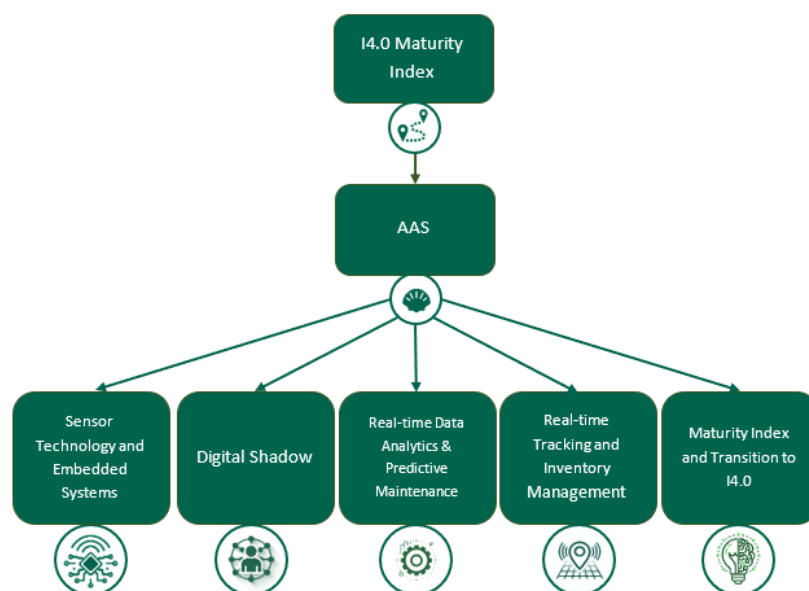


Figure 3 Positioning and Impact of AAS within the Industry 4.0 Maturity Index Framework

2.2.3 What are the AAS enablers?

In the context of I4.0, the AAS is a crucial development, carefully crafted to serve as a virtual identity for tangible assets. It serves as a comprehensive depiction, encapsulating the complex interplay of relevant information and functions linked to these entities. The digital infrastructure, which is a hallmark of I4.0 elements, adheres to a strict set of prerequisites. These requirements establish a strong foundation for supporting the intricate connections and increased levels of compatibility essential for a completely integrated, industry-wide network.

The structural stability and safeguarding of the AAS constitute the cornerstone of its framework. The header and body sections of the AAS consist of identifying information about the shell and represented assets, and sub-models that characterise assets in a nuanced, specific fashion. Maintaining the integrity of the AAS requires strict cybersecurity and encryption protocols, especially in situations where information is confidential or highly sought.

The AAS not only fulfils its structural requisites, but it also acts as an all-inclusive data hub, accommodating a broad range of information. This data encompasses real-time operational insights and historical retrospectives, guaranteeing that the DT replicates the physical entity with exceptional precision. The resultant digital copy provides a comprehensive reflection of reality that is both dependable and illuminating.

Interoperability is a vital aspect of the AAS, which is achieved through rigorous standardisation processes. This functional imperative ensures seamless communication and integration between different systems and components. By adhering to standardized data models and communication protocols, the AAS ensures effortless interaction within a diverse industrial environment. By effecting harmonisation in the areas of identifying information, data formatting, and interaction patterns, an ecosystem is established where diverse systems can coexist and interoperate without encountering compatibility issues.

The AAS's design allows for different interaction modes including real-time data exchange, event-triggered communication, and traditional request-response models. Such dynamism ensures efficient operations across various contexts including real-time monitoring and control, strategic optimisation, and predictive maintenance. Accessibility remains a top priority, with the AAS easily accessible to all stakeholders in the value creation network. However, it is subjected to stringent security and access control protocols.

The AAS's architecture is designed to facilitate scalability and flexibility, which are crucial in an industrial landscape that is continually evolving. The flexible design of the AAS demonstrates its resilience in accommodating the constant evolution of technology whilst maintaining operational stability. The system can easily be updated, expanded, or modified, highlighting its adaptable nature. The alignment of these essential prerequisites within the AAS represents the essence of I4.0's vision. It drives the digital revolution of traditional sectors towards connected intelligent, and productivity-enhancing digital corporations. The AAS exceeds its role of being a mere data repository and evolves into an active, responsive stage that inspires creativity, efficacy, and expansion within the industrial domain. [10]

2.3 Digital Twins

In current discussions within the rapidly evolving domain of digital technology, the DT concept has become a key point of interest. This interest is mainly due to the DT's significant potential to reshape the interface between the digital and physical realms. Amidst diverse interpretations of this term, a

new and pioneering definition arises, advocating for a thorough and intentional use of DTs, extending beyond their traditional applications. Significantly, a DT surpasses the simplistic idea of a static digital representation of a physical entity. Instead, it embodies a dynamic software construct that maintains a continuous interaction with its real-world counterpart throughout their life-cycle together. This partnership is complex; the DT ingests data and provides relevant insights about the system's operations, while also imposing specific control imperatives. This synergistic relationship highlights the DT's innate capacity as an analytical tool, adept at reflecting and offering strategic interventions based on real-time data analytics.

The core of a DT lies in its two key components: a set of models that precisely depict the system, and a collection of digital replicas which are constantly updated to reflect the current state of the system. These elements combine to create a platform focused on providing services, which allows the DT to be utilised effectively for obtaining insights or effecting changes in the original system. This definition recognises the active collaboration between the DT and the physical system, forming a partnership that continues beyond development stages to an ongoing operational alliance.

The term “original system” is used broadly, acknowledging the variety of potential applications. DTs are not limited to physical entities that are engineered; they are essential in natural ecosystems, biological entities, societal infrastructures, and even abstract processes carried out by different agents. Acknowledging this extensive scope emphasizes the DT's potential role in numerous scenarios, including those exclusive to software systems.

Interestingly, the idea of a “digital companion” aligns with the intended purpose of DTs, especially within healthcare settings. Nevertheless, DTs' scope goes beyond just companionship and requires a profound comprehension of the physical twin, derived from engineering documents and development models. These foundational models are essential, as they provide context for data interpretation and guide the interactive processes of the DT.

The interactive, evolving nature of DTs distinguishes them from models and emphasizes their dynamic characteristics. Although both constructs represent a certain reality, DTs are capable of learning, adapting and potentially predicting changes in the original system, rather than being simply representations.

The flexibility of both the physical system and its DT over time is critical. The DT mirrors and records these changes, producing a versioned history of the physical system's evolution. Additionally, it may participate in this evolution by providing valuable insights that could affect subsequent adaptations.

DS, as extensions of the DT, store real-time or near-real-time data that is updated through event-driven or periodic synchronization. This continuous data flow, although delayed, is crucial for the DT's accuracy and responsiveness. The updates' nature, whether manual or automated, and their frequency highlight the DT's dependence on current data for its operations.

The communication aspect of DTs is both two-way and varied. They are not passive receivers of information; they can transmit diverse data, such as contextual insights about surrounding systems, to their physical twin. This capacity extends to transmitting control commands, from simple configuration adjustments to complex, real-time operational directives.

To conclude, the present-day definition of a DT represents a considerable shift in paradigm. The construct's active, dynamic, and interactive capabilities are acknowledged, marking a departure from a traditional passive and static model. This redefinition opens the door for more nuanced and

expansive applications, positioning DTs as crucial components in the digital transformation journey across multiple domains. [4]

2.3.1 Role of digital twins in industry 4.0

The emergence of I4.0 signals a revolutionary phase in manufacturing, with DTs being a crucial technological breakthrough. In this context, DTs embody a cohesive amalgamation of physical and cyber systems, typified by a harmonious integration that is increasingly acknowledged in academic and industrial domains. This integration is not merely superficial but represents a significant interlinking of physical and virtual worlds, creating a dynamic and interconnected model of a physical object or system.

The implementation of DT technology has been highly successful in various industries and encompasses diverse applications such as product design, production, prognostics, and health management. These practical applications emphasise the substantial impact that DTs have on industrial development, signifying a move towards more technologically integrated and intelligent manufacturing methods.

One crucial function of DTs within I4.0 is the implementation of cyber-physical production systems. DTs act as a cornerstone in enabling real-time data acquisition in production systems. This real-time ability extends beyond data gathering and incorporates instantaneous computations, adjustments, and decision-making processes that considerably increase production efficiency and adaptability.

Moreover, the concept of “experimentable” DTs is enhancing simulation-based systems engineering, especially for I4.0. These innovative DTs permit more accurate and effective analysis, adjustment, and supervision of production systems, empowering industries to simulate various situations and make data-driven decisions with lessened risk and uncertainty.

The implementation of DTs extends beyond abstract systems to encompass tangible aspects of the production line. In I4.0, their practicality is exemplified in industrial production lines through the improved monitoring, analysis, and adaptation of production processes. Consequently, this results in optimized manufacturing outcomes and more agile production environments.

In conclusion, DTs are proving to be a revolutionary asset to modern industry, bridging the divide between physical and digital systems and promoting more efficient and adaptive production environments. Their capacity to simulate real-world situations in a virtual realm provides unparalleled operational insight and foresight, representing an incredible step forward in industrial innovation and productivity. [11]

2.3.2 Location of the Digital Twin within Industry 4.0 Maturity Index

The role of DTs could be highly instrumental at multiple junctures of an organisation’s maturity path. The maturity index itself serves as a comprehensive framework, providing the six-stage model that assesses a company’s capabilities across various dimensions such as resources, information systems, culture, and organisational structure. Each stage of this model offers specific benefits that manufacturing companies can leverage to enhance their operational efficiency and competitive advantage.

Next, consider the concept of DSs, which can be seen as a precursor or foundational element of a full-fledged DT. DSs primarily focus on capturing and storing data that provides a historical context for an asset. They serve as a digital footprint, offering a snapshot of the asset’s past and current states. In the

initial stages of a company's journey towards I4.0 maturity, where the emphasis is on the digitisation of assets and their basic monitoring, DSs can act as the first significant step. They provide a rudimentary level of digital representation that can be used for basic data analytics and monitoring, thereby aligning with the early stages of the I4.0MI where the focus is on resource and information system optimisation. As the organisation moves up the maturity ladder, the transition from DSs to DTs becomes not only possible but also highly beneficial. Unlike DSs, DTs offer a dynamic, real-time digital replica of the physical asset. They go beyond basic monitoring and data capture; they provide actionable insights derived from advanced analytics. These insights can be used to optimise various operational processes, including but not limited to, production cycles, logistics operations, and customer service protocols. This capability is particularly relevant to the middle stages of the maturity index, where the emphasis shifts towards more data-driven decision-making and the integration of advanced analytics into the operational workflow.

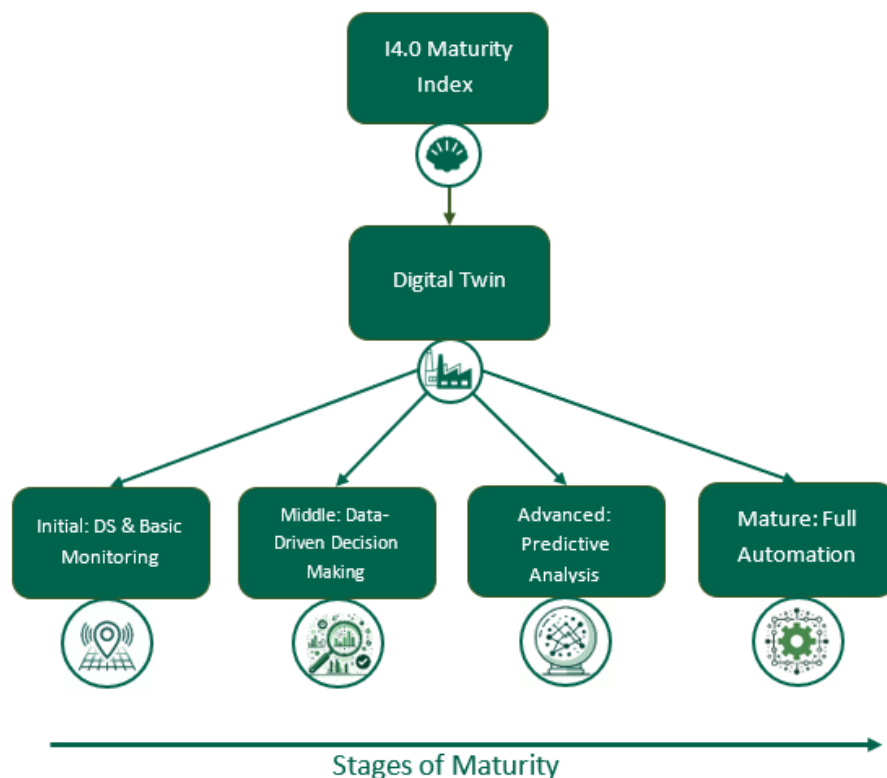


Figure 4 Digital Twin Progression: From Monitoring to Automation in I4.0

When the organisation reaches the more advanced stages of I4.0 maturity, the role of DTs becomes even more pivotal. Here, the focus is on predictive analytics, proactive decision-making, and the automation of complex processes. DTs can analyse real-time data in conjunction with historical data to predict when a machine is likely to fail or when a production bottleneck is likely to occur. This predictive capability can significantly reduce operational downtime, enhance resource efficiency, and increase overall productivity. These benefits are directly aligned with the advanced stages of the maturity index, where the objective is to achieve a high level of automation and optimisation.

In the most mature stages of the maturity index, DTs can serve as the cornerstone for a fully automated and optimised operational ecosystem. They can simulate different operational scenarios, analyse the potential outcomes, and even make real-time decisions without human intervention by integrating

with other advanced technologies like artificial intelligence and machine learning. This level of advanced capability is in sync with the ultimate goals of the I4.MI, which aims for full-scale automation, seamless cross-functional integration, and continuous improvement.

In summary, the concept of DTs, starting from their foundational DSs, offers a multi-faceted range of capabilities that are highly synergistic with the objectives and stages outlined in the I4.0MI. From the initial stages focused on resource optimisation to the most advanced stages aimed at full-scale automation and continuous improvement, DTs can play a transformative role in enhancing a company's I4.0 maturity journey. Their capabilities range from basic data capture and monitoring to advanced predictive analytics and real-time decision-making, offering a holistic solution that can drive significant improvements in operational efficiency, resource utilisation, and overall business competitiveness. Figure 4 illustrates the DT in the I4.0 Maturity Index, which progresses through four stages from basic monitoring to full automation.

2.3.3 What is the difference between the Digital Shadow and the Digital Twin?

In the ever-evolving realm of engineering and production, DTs have solidified their position as foundational elements. The term “digital twin”, though widely used, often lacks a unified definition, with interpretations ranging from the overly narrow to the exceedingly broad. To address this, a more encompassing definition has been put forth, aiming to encapsulate the multifaceted nature of DTs, making it relevant across diverse functionalities and use cases.

The refined definition of a DT portrays it as a fusion of models that illustrate a system's structure and behaviour, intertwined with “digital shadows”. These elements are dynamic, undergoing regular updates to reflect the real-world system they emulate. More than a mere representation, the DT provides an array of services tailored for two-way interaction with its physical counterpart. This interaction enables the DT to extract contextual data from the system while also having the capability to send control commands to influence its operations. The inception of a DT relies on the existence of elements in the tangible world that are not only observable and monitorable but also controllable.

Distinguishing itself from the DT, the DS consists of intentional data traces, either in their raw form or aggregated and abstracted, all related to the original system. While DTs are proactive entities, DSs adopt a more passive stance, acting as data reservoirs that record a system's current state and its historical progression. Facilitating human interaction with the DT is the DT cockpit, an interactive interface that presents data from DSs and models in a clear and concise visual format. It is more than a display; it grants users the ability to access, amend, and even control the represented physical system to some extent. An advanced version of this interface, the Process-Aware DT Cockpit (PADTC), focuses on the specific processes tied to the physical entity, enabling a range of automation opportunities.

The redefined concepts of DTs and DSs highlight their significance in driving operational efficiency, enabling informed decisions, and fostering automation, especially in sectors like engineering and production. They promise real-time monitoring and predictive maintenance capabilities. The research landscape for DTs is vast, covering areas from model-driven development to the integration challenges of DT systems within larger frameworks. In essence, while both DTs and DSs play pivotal roles in the digital representation domain, they serve different purposes. Figure 5 emphasises the importance of the digital shadow as a fundamental element of the digital twin framework. The DT is an active amalgamation of models and DSs, while the DS acts as a data repository, each tailored to specific objectives related to the original system. [4]

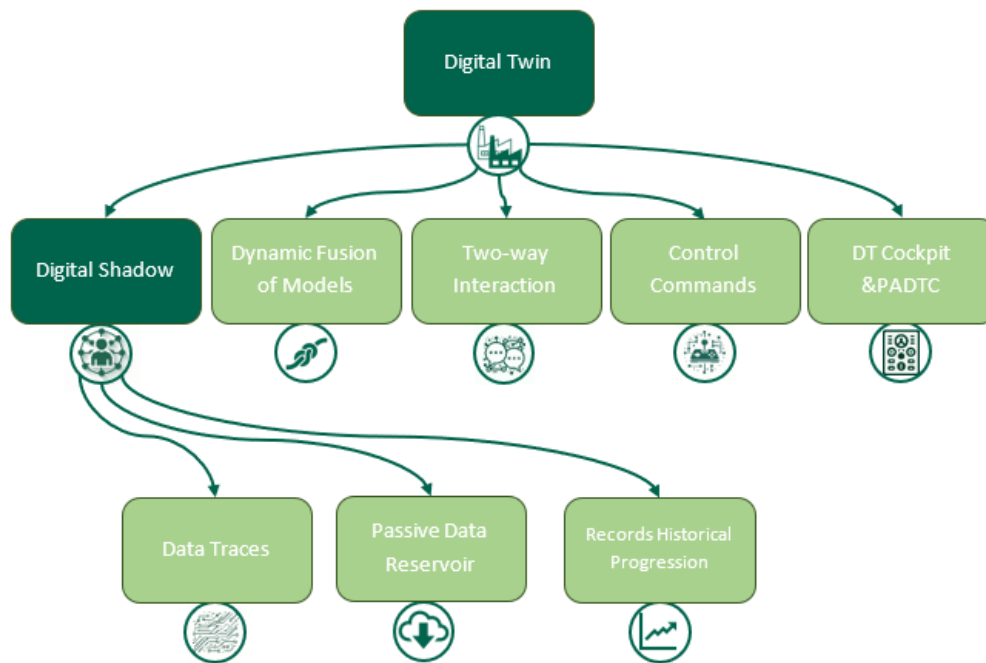


Figure 5 Emphasizing the Role of Digital Shadow within the Digital Twin Ecosystem

2.3.4 AAS as a Digital Twin enabler

The advent of DTs in the industrial domain, particularly with the integration of 5G technology, marks a transformative approach in contemporary manufacturing and industrial practices. This integration is predicated on several foundational enablers that contribute to the system's robustness and efficiency. Central to this paradigm is the concept of AASs, which serve as pivotal digital facsimiles for physical entities, facilitating a seamless information continuum and enabling sophisticated operational management within diverse industrial frameworks.

The evolution from conventional AASs to more dynamic active variants denotes a significant advancement within the digital industrial landscape. These active AASs transcend the role of mere digital reflections of physical entities; they embody versatility and are imbued with capabilities for intelligent interaction, autonomous learning, and adaptive processes. Such adaptability is indispensable in navigating the complexities inherent in modern industrial environments characterized by rapid shifts, necessitating real-time systemic adjustments to sustain operational efficiency and productivity.

Concurrently, the architectural nuances and comprehensive functional domains of 5G technology emerge as substantial enablers. The 5G infrastructure, characterized by its promise of ultra-reliable, low-latency communication, and the capacity for network slicing, provides a formidable backbone capable of supporting the extensive data exigencies and operational intricacies of DTs. This framework ensures high-speed and reliable data interchange, foundational to the real-time operational efficacy of DTs, thereby guaranteeing their status as precise digital replications capable of facilitating informed decision-making processes.

Furthermore, the intricate process of formulating a 5G AAS underscores the detailed methodology requisite for efficacious harnessing of 5G capabilities within the DTs' sphere. This elemental construct encapsulates the technical and operational specifics intrinsic to 5G communication modalities, thereby

ensuring that the DT paradigm is buttressed by a communication layer that guarantees data fidelity, security, and congruence with industrial operational demands.

Moreover, the structural delineation of the 5G UE AAS, typified by its bifurcation into active and passive components and the incorporation of a specialized message interface, enhances the reliability of communication exchanges between DTs and industrial control apparatuses. This system configuration conforms to I4.0 industry standards and integrates these benchmarks into the system's architecture, promoting the operational efficiency and reliability essential for today's industrial environments.

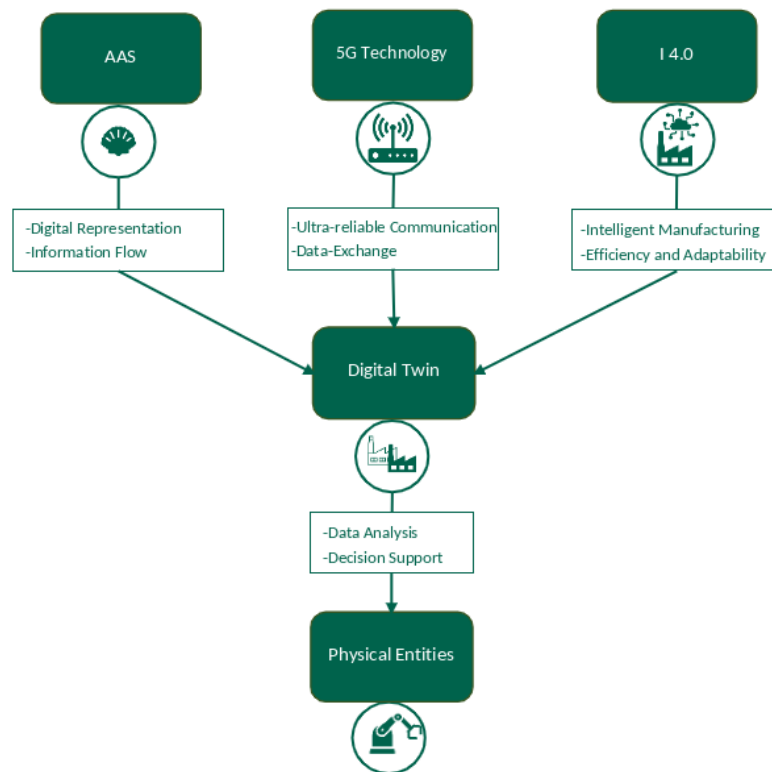


Figure 6 The enabling role of AAS for the Digital Twin

The functionality of AASs extends beyond the role of communication conduits; they are instrumental in engendering a cohesive operational ecosystem within industrial complexes. This is achieved through their capacity for providing a unified, flexible depiction of networks, ensuring unimpeded interoperability and integration across diverse factory functionalities and life-cycle phases. Such flexibility is paramount for contemporary production facilities reliant on a multitude of interconnected components operating in concert within a dynamic industrial milieu. Figure 6 demonstrates how AAS facilitates DT, subsequently integrating with 5G Technology and Advanced Industrial Practices.

In summation, these enablers collectively precipitate a seismic shift in industrial methodologies, heralding an era of intelligent manufacturing wherein DTs, propelled by 5G technology, catalyse unprecedented levels of efficiency, adaptability, and precision. The confluence of these avant-garde technologies signifies a monumental stride forward, presaging an innovative future sculpted by the synergistic interplay between digital acumen and human ingenuity. [6]

2.4 Relation with the Zero-SWARM reference architecture and requirements

The work done in D3.3 is mapped to the connectivity layer of the Zero-SWARM architecture presented in D2.2 as presented in Figure 7. It proposes some new interfaces and novel solutions on the access domain, in particular, mobile radio system (radio access network and user equipment), the mobile data domain (5G user plan function) and the control domain (mobile system control and synch). It also proposes a delta on the network management and orchestration, in particular, telemetry and APIs. The details of novelties introduced by D3.3 could be found on a table at the end of section 2. The solution presented in D3.3 paves the way to realize 5G AAS and to realize a real time update on 5G related information on the OT AAS format (if needed).

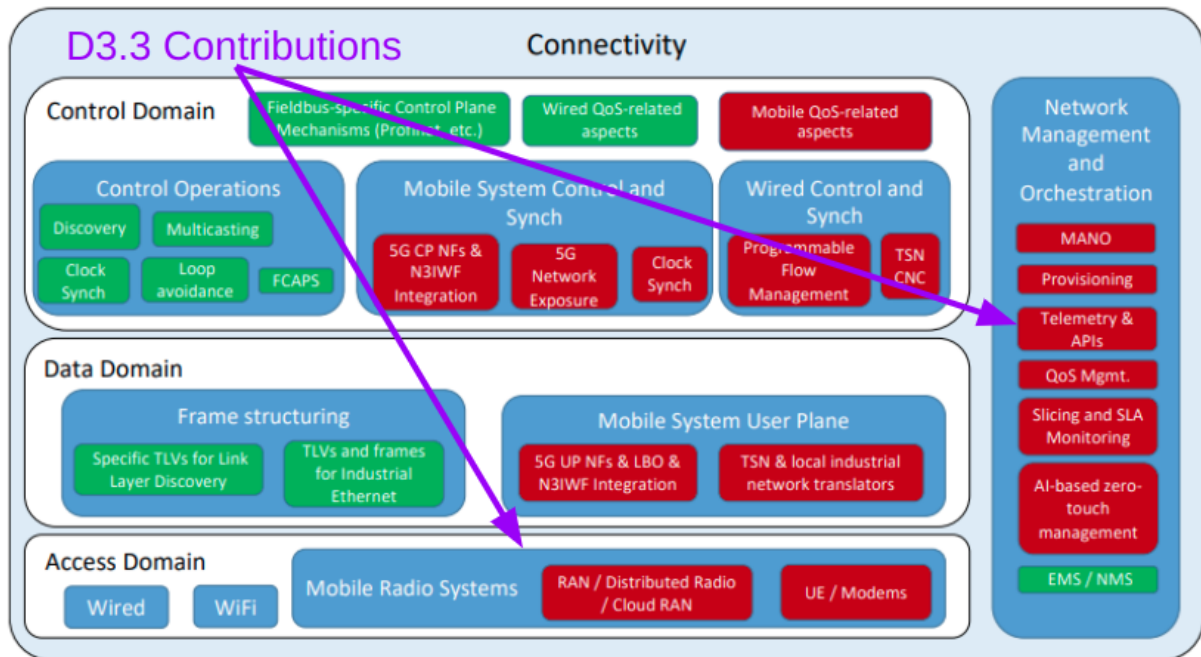


Figure 7 Connectivity Layer

This work answers to the following requirements presented in D2.1.

Industrial automation application layer	Digital twin representations	1	Data and information about devices participant to an industrial automation system must be available offline remotely and on-site	There are so much types of data needed about devices: e.g. asset information, structure of the cabinets, types of wires used, but also operational information, like last status of devices, security related setups (e.g. firewall rules) etc.
Connectivity layer	Management and Orchestration	1	It should be possible to achieve a flexible frontend and strong backend mechanisms & platforms that are making it possible to 1) define business specific SLAs, 2) set technical KPIs per SLAs and 3) monitor the SLAs continuously via predefined rules.	Though there are some known and generic business measures / requirements on shop floor (i.e. MTBF), there are various other measures that are specific from business to business. Thus, the solution should lay the conceptual foundation to let manufacturing customers define their business requirements on friendly user interfaces, and the system should be able to convert these requirements into KPIs and monitor them accordingly. This capability will give the option to future service providers to meet the expectations (SLAs) of their customers.

3 Specifications for first open source 5G Network AAS and 5G UE AAS to support real time DTs towards green production

3.1 Considerations of Open-Source Implementations of 5G AAS

In the developing landscape of I4.0, the implementation of the AAS becomes critical, especially given its role as the digital representation of physical assets. This transition emphasizes the requirement for a thorough appraisal system for open-source AAS implementations, ensuring their compliance with the intricate needs of DTs and the wider industrial ecosystem.

Evaluating open-source AAS implementations requires a comprehensive approach. Initially, it is crucial to examine general criteria that reflect the broader open-source environment. These include the backgrounds of primary contributors, specific licensing underpinning the distribution of software, the diversity of programming languages used, and versatility in terms of usage modes. This assessment ensures that the implementation is not only strong but also adaptable to accommodate different user preferences and operational requirements.

The technical proficiency of AAS implementations is crucial. It requires a thorough assessment of how these implementations align with AAS-specific standards, particularly their accuracy with the AAS specifications. Compatibility with supported versions of the AAS meta-model and the capability to operate with different serialization formats remains a critical aspect. The AAS relies on these technical standards to ensure precision and reliability in the DT's representation, a critical factor in maintaining their integrity. Additionally, executing these standards practically is fundamental.

The feasibility of AAS is contingent on optimal asset synchronization, encompassing vital interaction patterns that DTs must adhere to. These interactions, from simple read/write operations to more complicated execute and subscribe functions, are critical to the dynamic and real-time nature of asset management in I4.0.

In addition, to ensure objectivity, the evaluation process must be based on a structured analysis and testing regime. By consistently applying test cases in a standardized test environment, it becomes possible to assess various AAS implementations on a fair basis. This thorough methodology highlights both the strengths and weaknesses of each implementation whilst guaranteeing that evaluations stay current and flexible as new features and functionality emerge in future iterations.

To recap, critically analysing open source AAS implementations through a lens that balances both general and specific criteria is essential for steering the direction of I4.0. By ensuring that these digital platforms are strong, meet regulations, and can work with future technology, industries can confidently move towards a future where DTs are the foundation of operational excellence and innovation. [7]

3.2 AAS Types

The AAS type highlights the ways in which information is exchanged. Essentially, there exist three AAS types. Figure 8 gives a brief overview what functions each type fulfils.

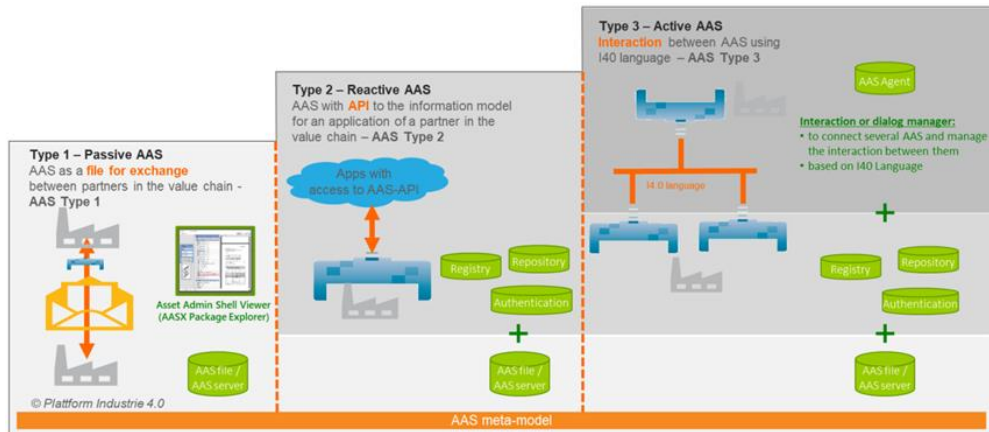


Figure 8 AAS types

3.2.1 Type 1

Type 1 are passive AAS operating as a file exchange mode between value chain partners. Serialized files (XML, JSON, etc.) bearing static information are shared as files. The data model for this type is specified by the AAS meta model.

3.2.2 Type 2

Reactive AAS with APIs to the information model of a partner's application in the value chain are of type 2. The servers host runtime instances that contain both static and motion data. Type 2 provides properties and operations, and is capable of signalling changing conditions through events. The AAS meta model defines the data model, and AAS API can be used to create server applications. AAS server applications may offer a REST API and an OPC UA API, according to the ASS OPC UA model I4AAS.

3.2.3 Type 3

Type 3 facilitates proactive interaction between AAS using I4.0 language and extends type 2 with active behaviour. Abbreviations will be explained when first used. Passive tone and impersonal construction will be employed, and first-person perspectives will be avoided unless necessary. Bias will be avoided, and precise word choice will be prioritised. Citation and footnote style will be consistent. Quotations will be clearly marked. VDI/VDE 2139 provides a language specification for type 3 AAS. A logical flow of information with causal connections between statements will be ensured, necessitating clear structure and concise, necessary language. The AAS are capable of independent communication and negotiation. The AAS I4.0 language describes interaction patterns and sub-models that communicate proactively via defined interfaces using REST, OPC UA, or MQTT. Regular author and institution formatting will be maintained in accordance with the appropriate style guide. The language will remain value-neutral and avoid figurative or ornamental language. The I4.0 language intends to unify and standardise interactions between I4.0 components. The text will adhere to grammatical correctness, conventional structure, and clear, objective language. Contractions, colloquial words, informal expressions, and unnecessary jargon will be eliminated to keep the language formal. It can be noted that the I4.0 language is a representation of linguistic aspects that describe communication methods without adhering to a formal definition of a communication protocol. The language is viewed as a control system, which comprises of three levels:

1. Vocabulary (VDI/VDE 2193-1): features, feature lists or other form of annotation of data elements used in the messages (word syntax). The vocabulary of the I4.0 language consists of features that describe both properties and functionalities. The characteristics are to be described in the format of IEC 61360. Each feature must be clearly identified by an ID. They appear both as a type and as an instance. The characteristics are stored in the administration shell in a structured way in sub-models.
2. Message structure (VDI/VDE 2193-2): organizes the arrangements of the contents and the elements necessary for their mutual classification (sentence structure). The structure of the I4.0 language is a set of rules with which the vocabulary of the I4.0 language is embedded in the messages. This is intended to create the conditions for a common understanding of the messages. Message contain the identification of the participants in the conversation and a data area including 'purpose' which defines the intention of the message and 'data items' which can be data elements, references, or other relevant information
3. Interaction protocols (VDI/VDE 2193-3): processes in the dialogues between I4.0 components that organize the tasks to be performed. (dialogue process). A semantic interaction protocol defines the sequence of messages exchanged between I4.0 components for a specific application. It is a set of rules where conversations take place between speakers to get a meaning dialogue: limited, constructive, ordered, in context, uniform and standardized. The interacting components are divided into two groups:
 - The requesting component (customer): splits the task to be solved into subtasks and looks for other components that can complete these subtasks. Based on the offers received, the requesting I4.0 component can decide whether the next iteration is final and whether part of the offers will be accepted and the rest rejected.
 - The requested components (contractors, usually the providers of services) take on the subtasks or become components to be requested themselves and further break down the subtasks to delegate them to other I4.0 components.

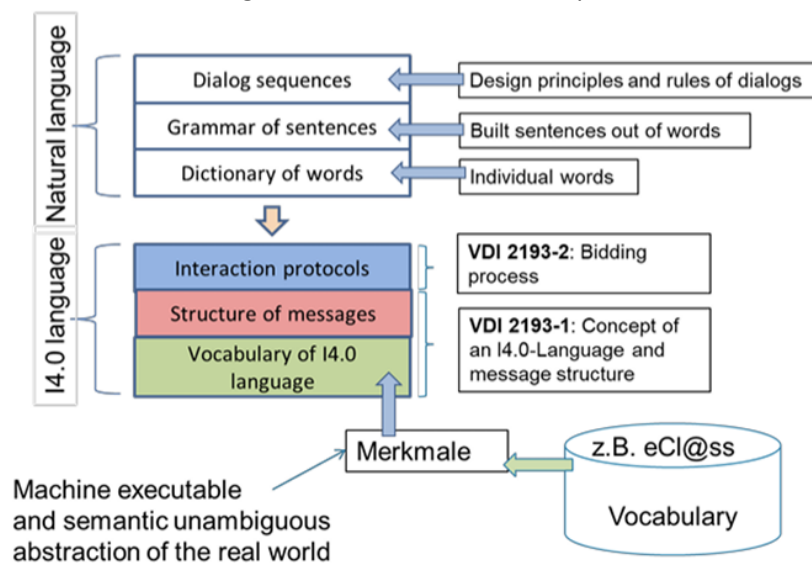


Figure 9 Industry 4.0 language

3.3 AAS modelling

The phases for modelling an AAS are defined as follows. The outcome of this procedure, from an I4.0 standpoint, is supposed to be an 'aasx' file.

3.2.1 Phase 0

Phase 0 defines and studies the asset information. This stage entails examining the asset and its architecture to determine the essential data to incorporate in the AAS. In the AAS architecture, if the asset is complex, its components can be considered independent I4.0 components and incorporated into their own AAS. This phase consists of identifying and defining AAS information. To effectively digitize an asset within the AAS framework, the following key attributes are meticulously defined and classified:

- Functional purpose of the asset
- Source of the data
- Identification of data at rest (static) or in motion (dynamic)
- Capabilities of the asset
- What are the services provided by the asset?

3.3.2 Phase 1

Phase 1 involves defining the AAS structure based on the previously gathered information from Phase 0. This is a critical step in ensuring the AAS delivers comprehensive information about an asset throughout its life-cycle. The structure is crafted in line with the AAS meta-model standard, which serves as a guideline for detailing the architecture. Within this structure, the asset's data is organized into sub-models, each with a specific domain. These sub-models are developed to include all necessary information required by any applicable domain-specific standard. However, the sub-models created at this stage of the AAS modelling do not purport to be technically complete or accurate, indicating an openness to further development.

3.3.3 Phase 2

Phase 2 aims to establish communication protocols between the AAS and external entities. Based on its information exchange and interaction capabilities, the asset can function as either an active AAS (type 2) or a proactive AAS (type 3). The key question is: Does the asset exchange information? If not, it is classified as type 1. If information exchange occurs, phase 2 specifies the parameters of this exchange. Is the asset engaged in interactions with other assets? However, if it does engage in interactions, it belongs to type 3, with proactive interaction capabilities. If not, the asset belongs to type 2, with reactive capabilities.

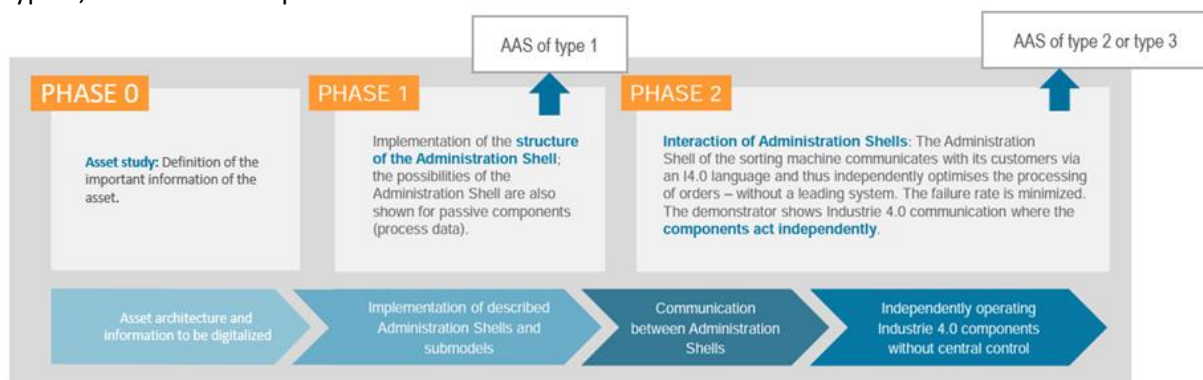


Figure 10 AAS modelling

What has been explained here is why that AAS has been introduced and progressed in I4.0 community. There are tools like AASX Package Explorer that can be used to develop AAS as presented in this subsection. As mentioned above 5G-ACIA has explored the possibility of introducing 5G UE AAS and 5G Network AAS based on AASX files in the white paper “Using Digital Twins to Integrate 5G into Production Networks”.

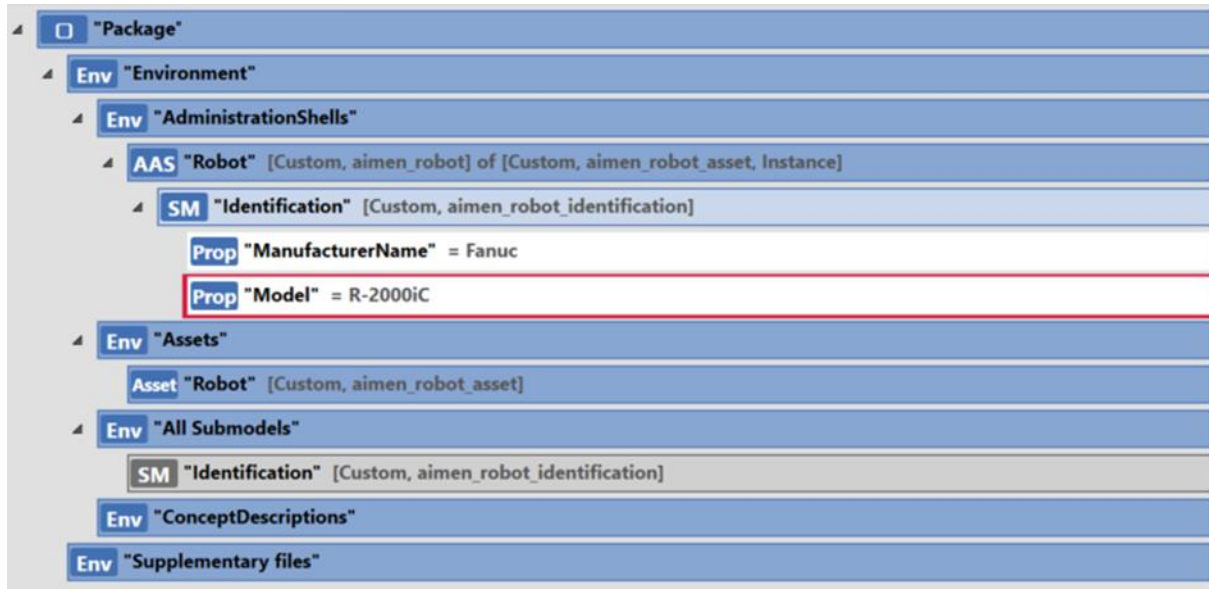


Figure 11 An example of AASX file for AAS

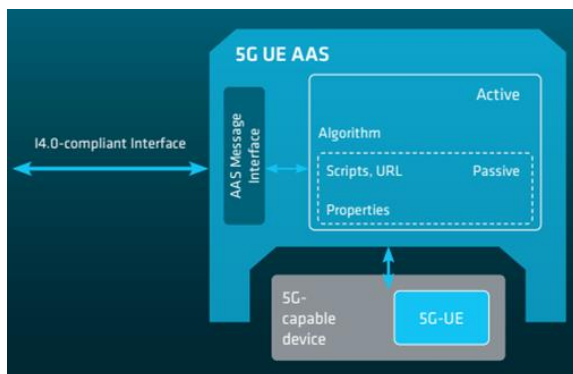


Figure 12 Internal structure of the 5G UE AAS

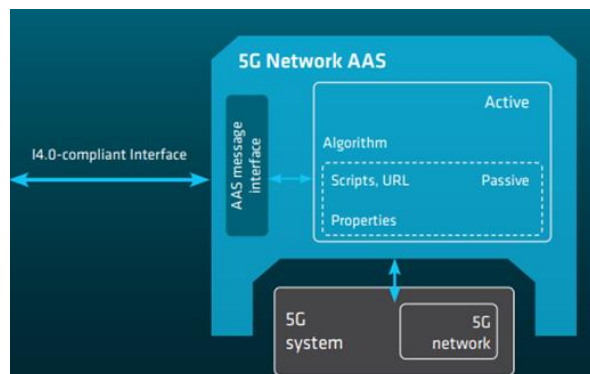


Figure 13 Breakdown of the 5G network AAS

The targeted AAS type here is type 0 where 5G UE and 5G network could expose some information via the AAS. Of course, one way to approach the problem of open source 5G Network AAS and 5G UE AAS is to extend the AASX files and see if it is possible to introduce some items from 5G world in the AAS of I4.0. However, this approach might not be necessarily the best way to processed. 5G systems have their own life-cycle of activities and they have their own monitoring and exposor functionalize. It might not be necessarily very beneficial to turn today I4.0 AAS into 5G management and monitoring system besides the other huge responsibilities it needs to deliver in the realm of I4.0.

Probably a more pragmatic approach is to have two side by side easy to use system in the factory monitoring facility where an operator could see both information of factory assets (e.g. machinery in the shop floor) and connectivity information on a single screen. This is the main focus that D3.3 tries to highlight. It means in and Figure 13 instead of focusing on the realization of AASX file as proposed by 5G-ACIA, D3.3 focuses on the arrow coming out of the 5G UE and 5G network towards traditional AAS model. Then we will explore if it makes sense really to merge everything under a single umbrella system or it is better to keep them two separate side by side systems next to each other.

To do so let us start reviewing our open source 5G monitoring solution below.

3.4 Private 5G Network

There are different solutions for NPN 5G networks which consider multiple vendors for each network component. Figure 14 shows the general architecture of a private 5G network.

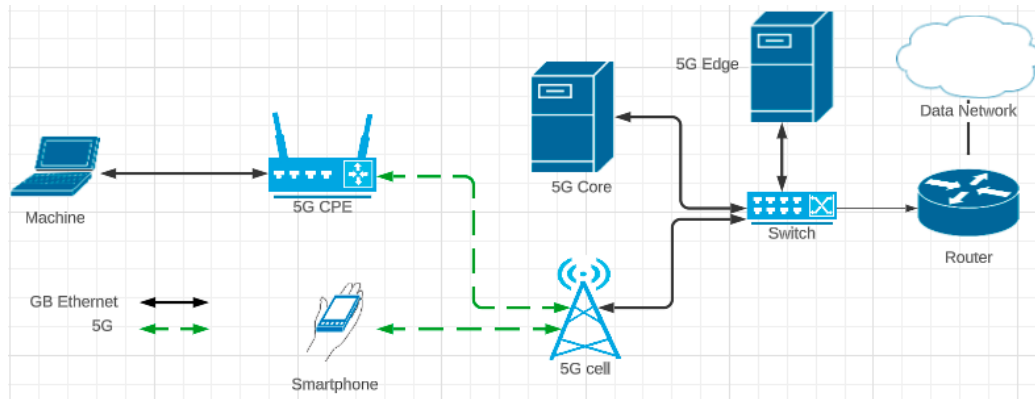


Figure 14 General block diagram of NPN 5G network

The 5G cell component in Figure 15 represents the RAN that is commonly composed by a set of gNBs. There are multiple gNB types and vendors, but two general types can be identified: virtual RAN (vRAN) and Open RAN (O-RAN) implementations.

In the vRAN implementation, three main components can be found: radio unit (RU), distributed unit (DU) and centralized unit. The RU contains the antennas and executes the radio frequency functionalities. On the other hand, the DU and CU implements the baseband functionalities of the 5G RAN protocol stack. The distribution of the functionalities between the DU and CU depends on the considered functional split, mostly a division in the physical layer (7.2 split option) is considered. Figure 15 shows the interfaces of the 5G RAN or NG-RAN with CU/DU split.

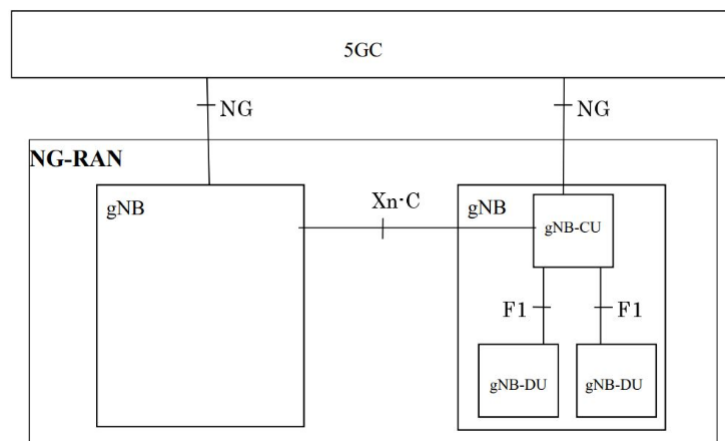


Figure 15 5G radio access network with CU/DU split [REF_Ref148716497 \r \h11]

The core network component on Figure 15 executes the 5G core functionalities, its required function and configuration depends on the specific solution. There are many commercial 5GC software available in the market supporting the use cases of interest. There are also open-source software solutions that have shown enormous flexibility and stability.

Open5Gs being one of those. It is a C language-based 5G core that complies with 3GPP Release 17, It is used by a large research community and therefore has a rich documentation describing different use cases. The general architecture of Open5GS with the network functions can be found in [2].

However, there are plenty of commercial 5G cores that can be also considered as tentative solutions such as Raemis Druid and Athonet Core.

Additionally, it is possible to see on Figure 14 the 5G Edge which represents the mobile edge computing server. It takes a significant role in the context of private networks for OT domains due to the low latency demand of multiple applications as well as the required adaptation to the industrial protocols. In general, mobile edge computing provides computational resources as close as possible to the data source, which commonly results in a latency improvement. In the last few years, there have been multiple efforts to study the impact of edge computing on 5G networks. Furthermore, it has a vast impact in the OT domain where latency and data protection play a significant role.

3.2.1 Network monitoring

Network monitoring function plays an important role for network management and optimization. It is even more fundamental in the industrial domain and private network context where everything should be controlled in a detailed approach. For this reason, the 5G network monitoring component is utilized not only in the network management, control, and optimization but also in providing a digital description of the network to the industrial owners.

In the industrial domain, each element of the factory floor is an asset. These assets are digitally described as a DT using an AAS tool. In general terms, each component of a factory has a digital model in the AAS. It centralizes the management and control of the elements in the manufacturing floor, increasing flexibility and remote control.

The private 5G network in a factory must be seen as an additional asset, which should be modelled inside the AAS to generate a DT of the network. This will guarantee a seamless integration of the 5G network in the industrial domain. Figure 16 shows a block diagram that integrates the 5G private network in the industrial domain.

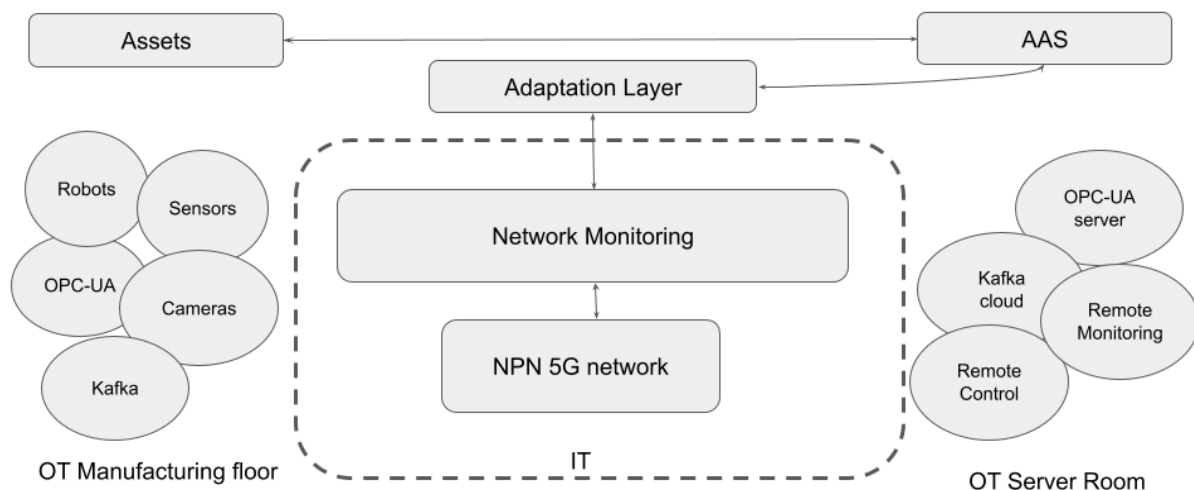


Figure 16 General scheme of the private network integrated in the industrial domain and in the AAS

In this case, the private 5G interconnects the manufacturing floor with a server room in the OT domain. In the manufacturing floor, it is possible to find multiple devices such as: cameras, simple or collaborative robots, and sensors. These devices currently exchange control information by using industrial protocols and tools: Profinet, EtherCat, OPC-UA, Kafka, etc. However, the 5G network is not natively designed to support these protocols. For this reason, in the context of this project the private

5G network should be adapted to operate with some industrial protocol, for instance OPC-UA and Kafka, which operate at MAC layers instead of the IP layer.

On the other side of Figure 16, it is possible to find the OT server room, which contains the servers of the different tools in the factory and has remote control and monitoring of the manufacturing floor. On this side of the factory, the AAS provides the remote control and monitoring of the different assets. Figure 16. also shows how the private 5G network can be seen as an additional asset of the OT domain. However, modelling the 5G network in the AAS to create a DT of the network is not an easy task. From the telecommunication perspective, there are a huge number of parameters that need to be analysed but not all these parameters are significant in the industrial domain. For this reason, the adaptation layer in Figure 16 filters the huge amounts of data (see Appendix A to see the RAN metrics) provided by the network monitoring layer to obtain the set of parameters that feed the AAS 5G network model. Due to the above description, the network monitoring function should be carefully designed not only to extract the network parameters but also to be synchronized with the AAS. For this reason, this section focuses on the description of the network monitoring strategy.

In this sense, Prometheus is often used as a tool with powerful features in monitoring. Figure 17 shows the general architecture of a Prometheus server. A detailed description can be found in the official documentation [3].

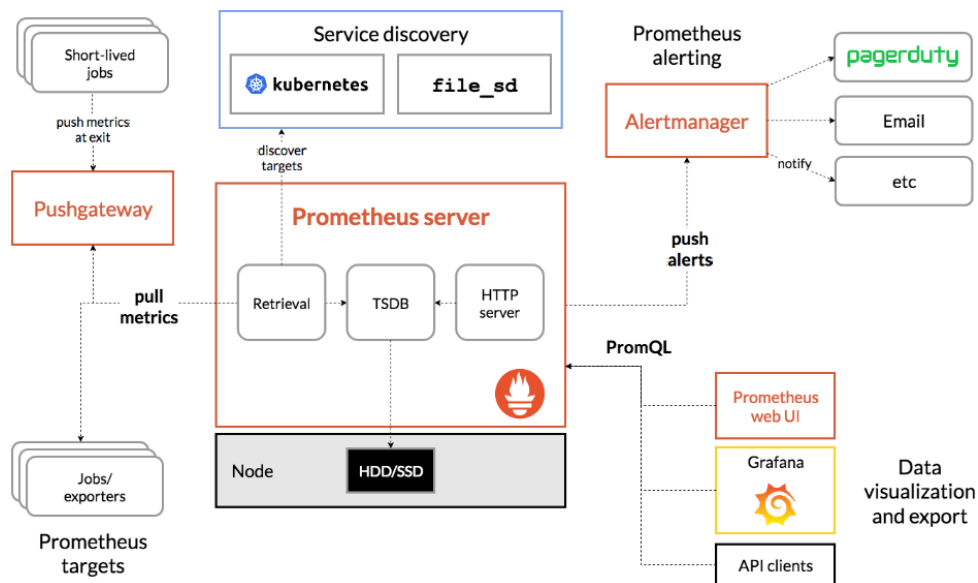


Figure 17 General architecture of a Prometheus server [3]

Prometheus can be used to monitor each component of the 5G network, this monitoring data should feed the adaptation layer for the AAS and should be used for network diagnostic and alarm monitoring. In general terms, the main components of Prometheus are the Prometheus server, the Prometheus targets, data visualization module and the alert manager block.

First, the Prometheus server is the core function of Prometheus, it has storage to temporarily save the obtained metrics, an HTTP server, and a retrieval function. In general terms the Prometheus server pulls the metrics with a periodic time from different targets.

The Prometheus targets depict any entity that exposes metrics and can be monitored. In our particular case, the targets are each component of the private 5G network: CPE, 5G cells, core network, edge computing servers and networking elements such as switches and routers.

It is important to mention that, in order to be a Prometheus target the network components should expose the metrics in Prometheus format. Otherwise, an exporter for the component should be defined as an adaptation layer between the component and the Prometheus server.

As shown in Figure 18, NodeH and Open5GS are being considered as 5G cell and 5G core, respectively. Open5GS exposes its metrics in a Prometheus format, but NodeH needs an exporter that has been defined and created to extract the radio access network metrics. Annex A presents the set of possible metrics and parameters that NodeH exposes and are available to be monitored in the RAN part.

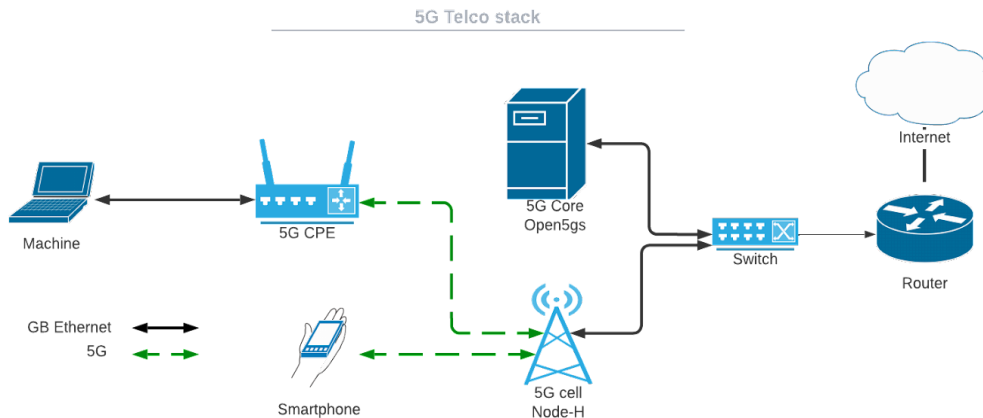


Figure 18 Considered 5G network stack for being modelled in the AAS

On the other hand, Prometheus provides a visualization layer through a web user Interface, API clients and also can be integrated with Grafana tool for better understanding and visualization of the data.

Another component of Prometheus is the Alert Manager block, it is possible to define in the Prometheus server a set of rules to set an alarm. Once the rule holds the Prometheus server pushes the alarm to the alert manager that is responsible for processing the alarm in the predefined manner, for instance sending the alarm by email.

In the context of this project, the network deployment has been configured and deployed. Moreover, the monitoring strategy has been defined using a Prometheus server to analyze each network component. However, to create a DT of the network there is still work pending. Further discussion and research should be performed to identify the set of significant metrics of the network for the industrial domain. This will help to define an AAS model of a private 5G network and consequently an adaptation layer to feed the model.

3.2.2 Network diagnostic and alarms of 5G NPN

As previously mentioned, the integration of 5G NPN in the OT domain represents a significant challenge. In particular, it is important to mention the lack of telecommunication engineers in factories or manufacturing floors. For this reason, it is fundamental to design a 5G NPN system that includes diagnostic features to simplify the human intervention and the network support periods.

As the initial stage to pave the road, it is crucial to identify common errors that could appear not only during the configuration process but also in the operational phase of the 5G network. It is also worthy to identify possible solutions or troubleshooting procedures to solve the mentioned issues. Some examples of common issues are listed as follows:

1. The radio access network is not registered to the core network.
2. The UEs are not able to see the 5G network.
3. The UEs cannot register to the 5G network.

4. The UE is registered in the network, but it does not have a data session.
5. There are crashes or serious alarm and/or performance issues in the RAN or core.

These failures can be caused by multiple errors not only on the provisioning or configuration phase but also during the network operation. The solutions are often high time demanding, because they require an expert troubleshooting process. Especially, it may reduce the productivity and performance of the device on the OT domain. For this reason, the zero-touch diagnostic has a significant role, which means to introduce automatic capacity to analyse the possible causes of the network failures and providing an advanced monitoring system. In order to accomplish this task, a self-monitoring system will have a huge impact because it has the goal of analysing the performance of the network in order to detect the possible failures. Such telemetry capabilities are normally available in current RAN and core implementations; interested readers can find typical RAN and gNB parameters in Appendix A, where Node-B parameters are provided as an example.

After failure detection, an alarm should be sent to the AAS. Multiple solutions can be proposed to process the network status in order to provide alarms and suggest the possible cause of the failures, reducing the recovery time and the human interaction.

3.2.3 Preliminary context for the AAS model of the wireless technologies

This section describes the preliminary version of the AAS model of the wireless connectivity components of factory floors. As it has been previously mentioned, the wireless path employs three major functional blocks. Figure 19 shows a general scheme that contains components of the wireless connectivity service. First, the CPE block provides 5G and/or Wi-Fi capabilities to elements in the production lines such as: robots, cameras, and multiple sensors. Secondly, the wireless network functional block considers the networking assets of 5G and Wi-Fi: 5G core, 5G RAN, and Wi-Fi access points. It is worthy to mention that each of these elements must have a dedicated AAS model.

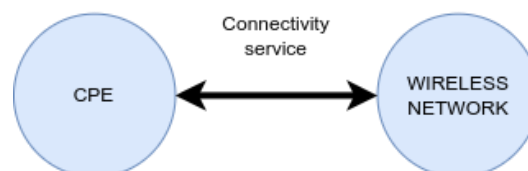


Figure 19 General architecture of the wireless technologies' wireless assets

Due to the integration of the industrial protocols with 5G and Wi-Fi demands additional features and tools such as: i) multipath TCP for load balancing and steering over 5G and Wi-Fi, and ii) Virtual eXtensible Local-Area Network (VXLAN) to ensure the layer 2 communication; the connectivity service itself is considered as an abstract functional block.

As a summary, the *CPEObj* contains all the relevant attributes related to each CPE on the factory floor. The *WirelessNetworkObj* contains the relevant attributes related to the wireless network. As it has been mentioned above, this block must contain different sub-modules to consider 5G and Wi-Fi elements. Finally, the *ConnectivityServiceObj* describes the connectivity services deployed between the CPEs and the wireless network. Table 1 shows an example of the structure of these components.

Table 1 Example of the AAS model of the network elements

Asset blocks	Object	Values
CPE	<i>CPEObj</i>	• ObjectName: • Location: • Interfaces: ○ InterfaceName ○ InterfaceType [5G/Wi-Fi/Ethernet] ○ InterfaceStatus [UP/DOWN] ○ NetworkPlane [Management/Data]
Connectivity Service	<i>ConnectivityServiceObj</i>	• ConnectivityType: [L2/L3] • ConnectivityConfiguration: [VLAN, VXLAN, routing, etc.] • ConnectivityStatus: [RUNNING, DISABLED] • AccessTechnologies: ○ TechnologyType: [5G/Wi-Fi] ○ ConnectionDetails • KPIs:
Wi-Fi Access Point	<i>WirelessNetworkObj:</i> <i>WiFiAPObj</i>	• AP_Name: • AP_Version: • AP_FreqBand: • AP_Bandwidth: • AP_Security:
5G Core	<i>WirelessNetworkObj:</i> <i>5GcoreObj</i>	• 5GC_type: [Open5GS] • BuildType: [BareMetal] • PLMN_id: [value] • RegisterCPEs: [list]
gNB	<i>WirelessNetworkObj:</i> <i>gNB_Obj</i>	• gNB_Name: • gNB_Location: • gNB_Vendor: • gNB_Bandwidth: • gNB_FreqBand:

3.2.4 Summary of delta introduced by Zero-SWARM

In this sub section we summarized the deltas (foreground items) introduced by the Zero-SWARM project:

Table 2 Summary of foreground items introduced by the Zero-SWARM project

Title	Short description	Related background
Network monitoring layer to feed OT AAS	A network monitoring layer has been introduced during the executing of this project. Especially, this layer is able to extract metrics from each element of the private 5G network: CPE, RAN, 5G Core and 5G Edge server. It is a fundamental component because the obtained metrics and network status will be used to feed the AAS model of the private 5G network.	The proposed solutions is based on Prometheus server, Prometheus exporters, and Grafana tools.
Extension of Prometheus	The Prometheus server pulls the metrics from different targets. These targets are classified as Prometheus exporters, which expose the metrics of a network entity in Prometheus format. The exporter of the considered gNB were not available and it has been created by Neutroon.	Prometheus open source monitoring tool and its available exporters: open5Gs exporter and node exporter (to monitor ubuntu servers).
5G private network	A complete private 5G network stack has been designed and implemented by Neutroon. As it was explained in Figure 18, the 5G deployment considers two bare metal servers, for the core network and for the mobile edge computing, a gNB from the Node-H provider, and additional networking elements: router, switch and cabling. These elements have been integrated in a compact solution call Neutroon Nomad5G. Additionally, in order to guarantee E2E connectivity the CPE has been provided and configured by i2Cat.	N/A
Preliminar AAS models for 5G network elements – listed on Table 1	Based on the proposed 5G private network, three main entities have been identified as assets in the E2E services connectivity: the CPE module, the abstract connectivity service module and the wireless network module. A preliminar AAS model for these modules has been proposed.	N/A

3.3 Meta-model Specifications

In the realm of digital systems, the concept of extensions is introduced as a mechanism to allow custom modifications to be integrated into specific elements. Each extension is defined by a unique name, a specific data type, and a value. These extensions can be linked to multiple system elements, thereby enhancing them with added information or functionality. The attributes of these extensions include the 'valueType', which determines the data type of the extension's value; the 'value', which holds the actual data associated with the extension; and 'refersTo', which signifies a reference to an element within the system that the extension pertains to. It is possible for multiple references to be associated with a single extension. This meta-model provides a structured framework for extending elements within a system, emphasizing that while extensions offer flexibility, they are inherently system-specific and might not be universally interoperable.

The digital framework also categorizes elements based on their identifiability and referability. Identifiable elements have a unique identifier, ensuring uniqueness within a specific namespace. The 'Referable' class represents elements that can be identified by a short name within a particular namespace. This class inherits properties that allow for extensions and carries attributes that provide additional metadata about the element's class, a short name for the element, and a display name.

The 'Identifiable' class encapsulates elements with a globally unique identifier. This class not only provides a global ID but also offers administrative details, such as version histories and other metadata.

The 'Qualifiable' class is introduced to cater to elements that require further context or specificity. This class allows these elements to be enhanced using qualifiers, which can be thought of as additional attributes or information pieces that provide a richer context to the base value of the element.

The 'AssetAdministrationShell' class is highlighted as a fundamental entity within the framework. It inherits properties from the 'Identifiable' and 'HasDataSpecification' classes. This class serves as a foundational entity for representing assets, with attributes like 'derivedFrom', which establishes a relationship between two AASs; 'assetInformation', which holds meta information about the asset; and 'submodel', which references one or more sub-models associated with the AAS.

Asset Information is further detailed with attributes such as 'globalAssetId', which represents the global identifier of the asset; 'specificAssetId', which provides additional domain-specific identifiers for the asset; and 'defaultThumbnail', which represents a thumbnail image of the asset.

The document also touches upon time and date representations, with various data types like 'xs:date' for dates, 'xs:time' for times, and 'xs:dateTime' for combined date and time. There are also specific data types for recurring and partial dates, as well as durations of time. Figure 20 illustrates the importance of "AssetAdministrationShell" in a well-organized system of asset-related entities and their connections.

Central to this framework is the emphasis on extensions, which allow for custom modifications tailored to specific system elements. The framework also prioritizes the categorization of elements, distinguishing them based on their identifiability and referability. This categorization ensures that each element is uniquely traceable, either within a specific domain or globally. Lastly, the framework underscores the importance of precise matching, especially when correlating or finding similarities between elements. All these facets work in tandem to ensure that digital operations within the system are both efficient and effective. [45]

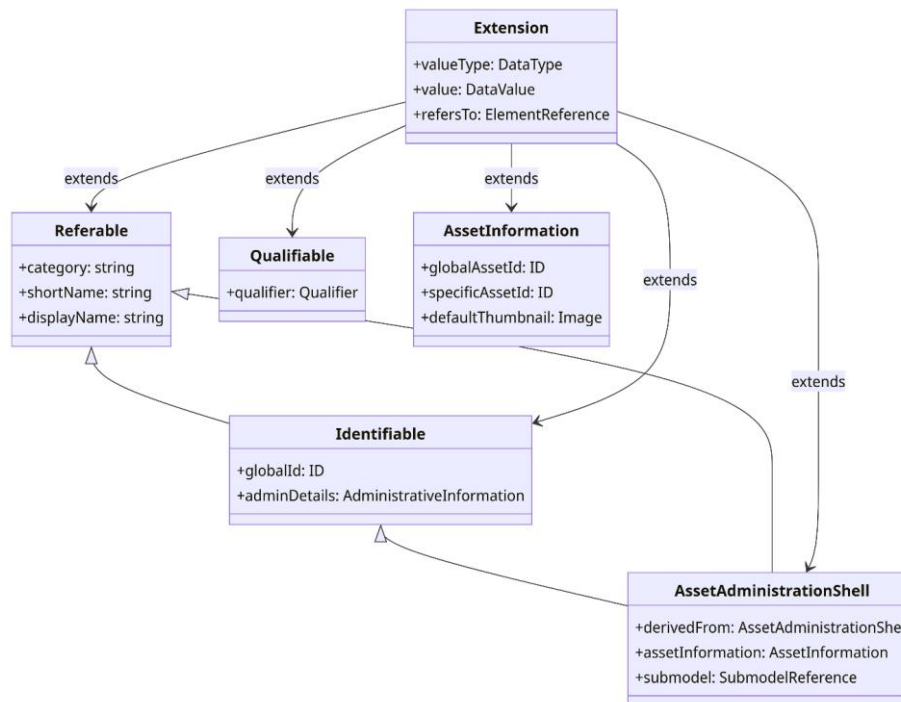


Figure 20 Meta-model Specifications

4 Economic Impact

This section explains the economic potential that implementing AAS for 5G has. As these considerations are specific to this task, it was decided that the points are made here to emphasize the existing connection.

4.1 Considerations of Market Influences for 5G

The challenges in implementing 5G for enterprise and industrial use-cases are compounded by the traditional focus of Mobile Network Operators (MNOs) on mass-market needs, given their control over most of the spectrum. This MNO-centric approach influences Modem Vendors, who implement new 5G features only if there is sufficient market demand, delaying the rollout of specialized functions like Ultra-Reliable Low Latency Communications (URLLC). Spectrum allocation inconsistencies across countries add another layer of complexity for global operations. Technical challenges include the need for specialized expertise in 5G network configuration and its integration into existing automation systems. The solution landscape is diverse, involving multiple key players. Telecommunication Operators bring the network infrastructure; Network Equipment Providers focus on the hardware requirements; Cloud Providers offer edge computing capabilities; System Integrators handle the complex task of merging 5G with existing systems; and Software Providers work on optimizing applications for 5G. These solutions must be secure, value-adding, and cost-effective to gain enterprise adoption. Amidst these considerations, an emergent concern is the environmental impact, specifically CO₂ emissions. As 5G networks require denser arrays of base stations and other hardware, there is a growing need to make these energy-efficient to mitigate their carbon footprint. Enterprises are increasingly under pressure not just to adopt technologies for operational efficiency but also to meet sustainability goals, making low-carbon 5G solutions an essential part of the enterprise technology roadmap.

In the ever-evolving landscape of business, models like the CPSoS Framework Provider, Digital & Green Transformation Consultancy, 5G-Enabled CPSoS Platform-as-a-Service (PaaS), Zero-Touch 5G Network Management Services, and 5G Carbon Footprint Analytics and Green Certification are emerging as pivotal blueprints for addressing the 5G market challenges. These models, influenced by technological shifts, sustainability imperatives, and market demands, offer organizations a structured pathway to deliver unparalleled value. As we delve deeper, we'll explore how each of these models is uniquely positioned to address specific market gaps, ensuring that businesses not only thrive but also lead in their respective domains.

4.2 CPSoS Framework Provider

In the fast-paced world of Industry 4.0, transitioning from traditional CPS to the more complex CPSoS has become a critical step for organizations striving for greater automation, efficiency, and data-driven decision-making. This transition is further complicated by the integration of 5G technologies, which offer unparalleled speed and connectivity but also introduce new challenges in system design, data management, and security. Given these complexities, there is a clear market need for a comprehensive, customizable framework to guide organizations through this intricate transition. This is where the economic impact of an AAS-enabled CPSoS framework becomes particularly relevant.

4.2.1 Market Need

The necessity for an AAS-enabled CPSoS framework becomes evident when considering the intricacies involved in moving from CPS to CPSoS. Traditional CPS are often limited in scope and functionality, designed to perform specific tasks in isolation. In contrast, CPSoS involves the integration of multiple such systems, each with its unique functionalities and requirements, into a unified, interconnected entity. The inclusion of 5G technologies adds another layer of complexity, presenting both challenges and opportunities in data management, real-time analytics, and system interoperability. Organizations are increasingly recognizing the need for specialized guidance and customizable solutions in this domain, creating a significant market gap that is ripe for filling.

4.2.2 Economic Potential

The primary economic impact for an AAS-enabled CPSoS framework lies in the deployment and utilization of its specialized framework. This framework would be designed to be highly adaptable, enabling organizations to tailor it to their specific needs and challenges. Given the high demand for such solutions, licensing fees could constitute a significant source of revenue. Moreover, economic benefits can be derived from customization services offered in collaboration with organizations to tailor the framework to their distinct requirements. These services could be billed separately, providing an additional, steady revenue stream. Historically, licensing and customization services have been reliable revenue generators, especially for solutions that meet clear market needs.

4.2.3 Unique Value Proposition

The unique value proposition of an AAS-enabled CPSoS framework lies in its comprehensive, customizable nature. Unlike generic, one-size-fits-all solutions, this framework would be designed to adapt to the specific challenges and opportunities each organization faces in its transition from CPS to

CPSoS. This adaptability is particularly crucial given the added complexities introduced by 5G integration. The framework would offer a range of features to address these challenges, from data management tools capable of handling the increased volume and speed of 5G data, to security protocols designed to protect against the vulnerabilities introduced by these more complex systems. By offering a seamless, customizable transition framework, organizations can not only navigate the complexities of CPSoS and 5G integration but also unlock the full range of benefits that these advanced technologies offer.

The economic impact of an AAS-enabled CPSoS framework offers a timely, valuable solution to a clear and present market need. By providing a customizable, comprehensive framework for the transition from CPS to CPSoS, especially in the context of 5G integration, this kind of economical orientation stands to gain a significant competitive edge. The potential for steady, lucrative revenue streams from both licensing and customization services further underscores the viability and promise of this innovative business model.

4.3 Digital & Green Transformation Consultancy

In today's rapidly evolving business landscape, the dual imperatives of digital transformation and sustainability are driving change across multiple industries. From manufacturing and logistics to healthcare and retail, organizations are under increasing pressure to modernize their operations and reduce their environmental impact. However, achieving these goals is far from straightforward, requiring specialized knowledge and expertise in both digital technologies and sustainable practices. Leveraging the transformative capabilities of AAS for 5G can uniquely address these challenges, positioning an AAS-enabled digital and green transformation consultancy as a pivotal enabler for additional economic impact.

4.3.1 Market Need

The market need for a digital and green transformation consultancy is both timely and significant. On the one hand, the digital revolution is compelling organizations to adopt new technologies, from cloud computing and artificial intelligence to the internet of things and blockchain. These technologies offer the promise of greater efficiency, agility, and competitiveness but also bring challenges in terms of implementation, data security, and workforce training. On the other hand, the growing urgency of climate change, coupled with increasing regulatory scrutiny and consumer demand for sustainability, is forcing organizations to rethink their environmental footprint. This involves everything from energy use and waste management to supply chain practices and product design. The intersection of these two transformative trends creates a complex landscape that many organizations find difficult to navigate without specialized help, thus creating a ripe market for consultancies that can offer expertise in both areas.

4.3.2 Economic Potential

The revenue model for a digital and green transformation consultancy is primarily based on the provision of specialized consulting services harnessing the capabilities of AAS for 5G. Given the complexity and high stakes involved in both digital and green transformation, organizations are willing to invest substantially in expert guidance. This allows the consultancy to command substantial fees for

its services, which could range from initial assessments and strategy development to full-scale implementation support. Additionally, the consultancy could offer ongoing monitoring and optimization services, creating opportunities for recurring revenue. The consultancy could also develop proprietary tools or frameworks to facilitate digital and green transformation, which could be licensed to clients for additional income.

4.3.3 Unique Value Proposition

The unique value proposition of a digital and green transformation consultancy lies in its ability to offer integrated, tailored solutions that address the specific needs and challenges of each client. Unlike consultancies that specialize in either digital transformation or sustainability, a consultancy that combines expertise in both areas can offer a more holistic, effective approach. For example, when helping a manufacturing client implement IoT technologies for real-time monitoring of factory operations, the consultancy could also advise on how to optimize energy use to reduce carbon emissions. Similarly, when assisting a retail client in developing an e-commerce strategy, the consultancy could also provide guidance on sustainable packaging and shipping practices. This dual focus not only enhances the consultancy's value to clients but also positions it as a leader in a niche but growing market.

The AAS-enabled digital and green transformation consultancy introduces a compelling answer to a complex, urgent market need. By integrating AAS capabilities for 5G with expertise in digital technologies and sustainable practices, the consultancy can help organizations navigate the challenges and opportunities of the modern business landscape. The potential for substantial, diversified revenue streams—combined with the consultancy's unique value proposition—makes this an exceptionally promising enabler for additional economic impact in the current era.

4.4 5G-Enabled CPSoS Platform-as-a-Service

In the age of I4.0, the integration of 5G technology into CPSoS is becoming increasingly important with AAS as a key enabler. The promise of 5G – ultra-fast data transfer, low latency, and the ability to connect a multitude of devices – offers unprecedented opportunities for enhancing the capabilities of CPSoS. However, the technical challenges involved in this integration are substantial, and many organizations lack the specialized expertise required for in-house development. This scenario presents a compelling market opportunity for a 5G-enabled CPSoS PaaS.

4.4.1 Market Need

The market need for a 5G-enabled CPSoS PaaS is both immediate and expanding. As industries ranging from manufacturing and healthcare to transportation and smart cities look to leverage the benefits of 5G, the complexities of integrating this technology into existing or new CPSoS become apparent. These complexities can include issues related to data security, real-time analytics, and the seamless orchestration of multiple systems and devices. The AAS approach positions itself as a vital solution to navigate these complexities, thus addressing a critical market demand.

4.4.2 Economic Potential

The primary avenue for economic impact for a 5G-enabled CPSoS PaaS would be a subscription-based model, capitalizing on the growing adoption of 5G technology across various sectors. Organizations would pay a recurring fee to access the platform, which would provide them with the tools, frameworks, and support services needed to integrate 5G into their CPSoS. This recurring revenue model is particularly promising given the long-term nature of most CPSoS projects, which often involve ongoing optimization and scaling. Additionally, potential revenue streams may include tiered pricing plans based on usage levels, as well as premium services such as advanced analytics, custom integrations, and dedicated support, offering flexibility and adaptability for additional income.

4.4.3 Unique Value Proposition

The unique value proposition of a 5G-Enabled CPSoS PaaS lies in its ability to offer a scalable and flexible solution that negates the need for in-house development. Unlike traditional methods that require substantial upfront investment in hardware and software, as well as the hiring or training of specialized staff, the PaaS model allows organizations to get up and running quickly with minimal initial outlay. The platform would offer a range of pre-built modules and APIs that clients can use to customize their CPSoS according to their specific needs. This not only speeds up the time-to-market but also allows for easy scaling as the organization's needs evolve. Moreover, by providing a standardized framework for 5G integration, the PaaS ensures that clients are following best practices, thereby reducing the risks associated with such complex projects.

The 5G-enabled CPSoS PaaS approach emerges as a transformative force, driving economic impact in response to the escalating demand for 5G integration. By offering a scalable, flexible, and risk-mitigated pathway to 5G integration, the platform stands to attract a wide range of clients across multiple industries. The recurring revenue model, coupled with the potential for additional income streams through premium services, makes this a highly sustainable and potentially lucrative business venture. As organizations continue to seek ways to leverage the transformative power of 5G in their CPSoS, the demand for specialized services like this PaaS is only likely to grow.

4.5 Zero-Touch 5G Network Management Services

The advent of 5G technology is revolutionizing various industries by offering unprecedented data speeds, low latency, and the ability to connect a multitude of devices. However, the management of these advanced 5G networks is a complex task that requires specialized expertise. Many organizations, particularly those in sectors like manufacturing, healthcare, and transportation, are keen to adopt 5G but lack the in-house capabilities to manage these networks optimally. This scenario creates a significant market opportunity for leveraging AAS technology to enable Zero-Touch 5G Network Management Services.

4.5.1 Market Need

The market need for Zero-Touch 5G Network Management Services is both immediate and likely to grow exponentially in the coming years. As more industries adopt 5G to enable smart factories, telemedicine, autonomous vehicles, and other advanced applications, the complexity of managing these networks increases. Traditional network management approaches that require manual intervention are not scalable and are prone to errors, leading to inefficiencies and security risks.

Therefore, there is a pressing need for automated, AAS-backed zero-touch solutions that can manage these networks efficiently and securely.

4.5.2 Economic Potential

The highest economic potential for Zero-Touch 5G Network Management Services would be a subscription-based model, where clients pay a recurring fee for continuous network monitoring, management, and optimization. Given the specialized expertise required for 5G network management, it's likely that the service will attract a consistent and loyal client base. Organizations would find it more cost-effective and less risky to outsource this function rather than attempt to build in-house capabilities. Additional revenue could be generated through tiered pricing models that offer basic monitoring in lower tiers and more advanced analytics and optimization features in higher tiers. One-time setup fees and charges for additional services, such as security audits or custom configurations, could also contribute to the revenue.

4.5.3 Unique Value Proposition

The unique value proposition of Zero-Touch 5G Network Management Services lies in its focus on operational efficiency through automated, AAS-backed zero-touch operations. By employing advanced algorithms, machine learning models, and real-time analytics, the service can automatically detect issues, implement fixes, and optimize network performance without human intervention. This not only reduces the likelihood of errors but also frees up valuable human resources to focus on more strategic tasks. Moreover, the AAS-enabled zero-touch approach – once set up – significantly enhances security by minimizing the potential for human error or unauthorized access.

In addition, the service could offer a dashboard that provides clients with real-time insights into network performance, as well as alerts and reports that help them make informed decisions. This level of transparency and control would be particularly appealing to organizations that are new to 5G technology and are concerned about the complexities involved in managing such networks.

Zero-Touch 5G Network Management Services offer a compelling solution to a critical and growing market need. The service not only promises to improve operational efficiency but also provides peace of mind by ensuring that 5G networks are managed securely and optimally. The likely consistency of the client base, coupled with multiple avenues for revenue generation, makes this a sustainable and potentially lucrative business model. As 5G technology continues to proliferate across various industries, the demand for specialized network management services like this is set to soar.

4.6 5G Carbon Footprint Analytics and Green Certification

In an era where sustainability is not just a buzzword but a business imperative, the intersection of emerging technologies like 5G and environmental responsibility presents a unique challenge. As industries increasingly adopt 5G for its transformative capabilities, there's a growing concern about the environmental impact of this technology. While 5G promises to revolutionize everything from manufacturing to healthcare, its energy consumption and subsequent carbon footprint cannot be ignored. This creates a significant market need for specialized services that can analyse and certify the carbon footprint specific to 5G infrastructures, giving rise to the potential economic benefit associated with AAS integration for 5G.

4.6.1 Market Need

The urgency to address climate change has led to a focus on sustainability across all sectors. Companies are under pressure from both consumers and regulators to reduce their carbon footprint and demonstrate their commitment to environmental stewardship. However, as these companies adopt 5G to improve operational efficiencies or enable new services, they face a dilemma. How can they reconcile the benefits of 5G with its environmental impact? AAS integration for 5G addresses this challenge by offering a comprehensive solution enabling 5G carbon footprint analytics and green certification services. These services fill a critical gap by providing companies with the tools they need to measure, analyze, and reduce the carbon footprint of their 5G operations.

4.6.2 Economic Potential

Given the increasing focus on sustainability and the rapid adoption of 5G, a high demand for these specialized analytics and certification services is expected. The primary revenue stream would likely be a consultancy-based model, where companies pay for a comprehensive analysis of their 5G infrastructure's carbon footprint. This could include everything from energy consumption metrics to recommendations for reducing environmental impact.

Another significant revenue stream could be the green certification process. Companies that meet specific sustainability criteria in their 5G operations could be awarded a green certification, which they can use in their marketing to demonstrate their environmental responsibility. This certification could require periodic audits to ensure ongoing compliance, providing an additional recurring revenue stream.

4.6.3 Unique Value Proposition

The unique value proposition of this business model lies in its comprehensive approach to 5G sustainability. Unlike generic environmental consultancy services, this model offers analytics and certification specifically tailored to 5G infrastructures. Companies would not only gain insights into their 5G operations' carbon footprint but also receive actionable recommendations for improvement. The green certification adds another layer of value by providing companies with a tangible marker of their sustainability efforts, which could be particularly appealing to eco-conscious consumers and stakeholders. Moreover, the service could leverage advanced data analytics, machine learning algorithms, and IoT sensors to provide real-time monitoring and predictive analytics. This would enable companies to make data-driven decisions quickly, optimizing both operational efficiency and environmental sustainability.

In summary, the AAS-enabled 5G carbon footprint analytics and green certification addresses a pressing and growing market need. It offers companies a way to balance the operational benefits of 5G with their sustainability goals. As sustainability continues to be a significant focus for industries and as 5G adoption accelerates, the demand for such specialized services is poised to grow exponentially. This aligns not only with timely business considerations but also with social responsibility, aligning perfectly with the current global priorities of technological advancement and environmental sustainability.

4.7 Conclusion

To conclude, as we stand at the crossroads of technological innovation and environmental responsibility, the AAS integration for 5G presents a cohesive fusion of progress and sustainability. From the intricate transition of systems in the CPSoS framework to the green initiatives of the 5G carbon footprint analytics, each approach underscores the importance of adapting to the evolving demands of the modern world. They not only highlight the potential for growth and profitability but also emphasize the significance of responsible business practices in today's interconnected global landscape. As industries continue to evolve, these serve as beacons, guiding organizations towards a future that is both technologically advanced and environmentally conscious.

5 Outlook (D3.7)

Moving on from the theoretical constructs outlined in Deliverable D3.3, the following Deliverable D3.7 will apply these concepts to a practical context. The Asset Administration Shell (AAS) remains core to our research, highlighting its significance in modern asset management. This progression will delve into the subtleties of asset types and instances, including the challenges of handling composite Industry 4.0 components.

Our upcoming work in D3.7 will comprehensively investigate the identification processes in the AAS and the mechanisms for event handling. The document will address the challenges that arise when these processes are implemented in practice, and the solutions that can be applied.

Additionally, with evolving security demands in the digital landscape, the report will evaluate how these concerns are addressed in asset management strategies. The findings will be presented with illustrative resources to clarify the use of AAS in asset management.

D3.7 aims to shift to a practical approach, demonstrating how AAS can transform asset management through digitalization. This deliverable exemplifies the practicality and adaptability of the previously discussed concepts, bridging the gap between theory and application.

References

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Appendix A: RAN, NodeH, gNB parameters

Object Name	Parameter Name	Read/Write	Description
FaultMgmt	FaultMgmt	R	This object contains parameters relating to Fault/Alarm Management.
FaultMgmt	SupportedAlarmNumberOfEntries	R	The number of entries in the SupportedAlarm table.
FaultMgmt	MaxCurrentAlarmEntries	R	The maximum number of entries allowed in the FaultMgmt.CurrentAlarm.[i] table.
FaultMgmt	CurrentAlarmNumberOfEntries	R	The number of entries in the CurrentAlarm table.
FaultMgmt	HistoryEventNumberOfEntries	R	The number of entries in the HistoryEvent table.
FaultMgmt	ExpeditedEventNumberOfEntries	R	The number of entries in the ExpeditedEvent table.
FaultMgmt	QueuedEventNumberOfEntries	R	The number of entries in the QueuedEvent table.
SupportedAlarm	SupportedAlarm	R	Supported Alarm Entries which can be raised by the device.
SupportedAlarm	EventType	R	Indicates the type of event.
SupportedAlarm	ProbableCause	R	Qualifies the alarm and provides further information than EventType.
SupportedAlarm	SpecificProblem	R	Provides further qualification on the alarm beyond EventType and ProbableCause.
SupportedAlarm	PerceivedSeverity	R	Indicates the relative level of urgency for operator attention, see [ITU-X.733].
SupportedAlarm	ReportingMechanism	RW	Indicates the reporting mechanism setting of the alarm.
CurrentAlarm	CurrentAlarm	R	Contains all currently active alarms.
CurrentAlarm	AlarmIdentifier	R	Identifies one Alarm Entry in the Alarm List.
CurrentAlarm	AlarmRaisedTime	R	Indicates the date and time when the alarm was first raised by the device.
CurrentAlarm	AlarmChangedTime	R	Indicates the date and time when the alarm was last changed by the device.
CurrentAlarm	EventType	R	Indicates the type of event.
CurrentAlarm	ProbableCause	R	Qualifies the alarm and provides further information than EventType.
CurrentAlarm	SpecificProblem	R	Provides further qualification on the alarm beyond EventType and ProbableCause.
CurrentAlarm	PerceivedSeverity	R	Indicates the relative level of urgency for operator attention, see [ITU-X.733].
CurrentAlarm	AdditionalText	R	This provides a textual string which is vendor defined.
CurrentAlarm	AdditionalInformation	R	This contains additional information about the alarm and is vendor defined.
HistoryEvent	HistoryEvent	R	Alarm events added or updated in FaultMgmt.CurrentAlarm.[i] are simultaneously entered into this table.
HistoryEvent	EventTime	R	Indicates the date and time when the alarm event occurs.
HistoryEvent	AlarmIdentifier	R	Identifies one Alarm Entry in the Alarm List.
HistoryEvent	NotificationType	R	Indicates the reason for the specific alarm notification event.
HistoryEvent	ManagedObjectInstance	R	Specifies the instance of the Informational Object Class in which the alarm occurred.
HistoryEvent	EventType	R	Indicates the type of event.
HistoryEvent	ProbableCause	R	Qualifies the alarm and provides further information than EventType.
HistoryEvent	SpecificProblem	R	Provides further qualification on the alarm beyond EventType and ProbableCause.
HistoryEvent	PerceivedSeverity	R	Indicates the relative level of urgency for operator attention, see [ITU-X.733].
HistoryEvent	AdditionalText	R	This provides a textual string which is vendor defined.
HistoryEvent	AdditionalInformation	R	This contains additional information about the alarm and is vendor defined.

Object Name	Parameter Name	Read/Write	Description
RAN	RAN	R	This object contains parameters relating to configuring the 5G FAP.
RAN	CUNumberOfEntries	R	The number of entries in the CU table.
RAN	CUUPNumberOfEntries	R	The number of entries in the CUUP table.
RAN	DUNumberOfEntries	R	The number of entries in the DU table.
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.	CU	RW	This object contains a table of all tunnel instances configured for the LTE FAP.
CU	Valid	RW	Denote if CU is configured
CU	CuOwnIPAddress	RW	IP address of the CU
CU	AmfIPAddresses	RW	IP address strings for AMF. Comma-separated list of strings , maximum length 6
CU	CuupIPAddresses	RW	IP address strings for CUUP. Comma-separated list of strings , maximum length 6
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.GlobalGnblid.	GlobalGnblid	RW	This object contains the GNB identity params for CU
GlobalGnblid	PmnidIdentity	RW	PLMN ID consists of Mobile Country Code (MCC) and Mobile Network Code (MNC).
GlobalGnblid	GnblidBitsUsed	RW	GNB identity number of bits used, this can be configured to use between 22 bits to 32 bits
GlobalGnblid	Gnblid	RW	GNB identity, this can be configured to use between 22 bits to 32 bits
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.Security.	Security	RW	This object contains the security params for CU
Security	SecurityAlgo	RW	Security algorithm
Security	CipherEnable	RW	Ciphering enable
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.Mobility.	Mobility	RW	This object contains the security params for CU
Mobility	ANRThresholdRSRP	RW	Threshold to enter and leave ANR Mode
Mobility	IntraNRThresholdRSRP	RW	Threshold to enter IntraNR Mode
Mobility	InterNRThresholdRSRP	RW	Threshold to enter InterNR Mode
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.Mobility.Reselection	Reselection	RW	This object contains the security params for CU
Reselection	SNonIntraSearchP	RW	Signalled Value in SIB2, actual value = signalled value * 2, value 32 = don't broadcast
Reselection	SNonIntraSearchQ	RW	Signalled Value in SIB2, value 32 = don't broadcast
Reselection	ThreshServingLowP	RW	Signalled Value in SIB2, actual value = signalled value * 2
Reselection	ThreshServingLowQ	RW	Signalled Value in SIB2, value 32 = don't broadcast
Reselection	CellReselectionPriority	RW	Signalled Value in SIB2
Reselection	QRxLevMin	RW	Signalled Value in SIB2, actual value = signalled value * 2, value
Reselection	QRxLevMinSUL	RW	Signalled Value in SIB2, actual value = signalled value * 2, value value -71 = don't broadcast
Reselection	QQualMin	RW	Signalled Value in SIB2, value -44 = don't broadcast
Reselection	SIntraSearchP	RW	Signalled Value in SIB2, actual value = signalled value * 2
Reselection	SIntraSearchQ	RW	Signalled Value in SIB2, value 32 = don't broadcast
Reselection	Pmax	RW	Signalled Value in SIB2, value 34 = don't broadcast
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.CarrierList.	ListCarrier	R	This object contains parameters relating to the neighbor list.
ListCarrier	NRCellNumberOfEntries	RW	The number of entries in the NRCell table.
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.CarrierList.NR	NRCarrier	RW	Table containing the LTE EUTRA (i.e. Intra-RAT) cell list.
NRCarrier	SsbArfcn	RW	SsbArfcn of NRCarrier
NRCarrier	Scs	RW	Sub-Carrier Spacing in khz (15,30,60,120,240)
NRCarrier	QRxLevMin	RW	Signalled Value in SIB4, actual value = signalled value * 2, value
NRCarrier	QRxLevMinSUL	RW	Signalled Value in SIB4, actual value = signalled value * 2, value value -71 = don't broadcast
NRCarrier	QQualMin	RW	Signalled Value in SIB4, value -44 = don't broadcast

Object Name	Parameter Name	Read/Write	Description
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.CarrierList	ListCarrier	R	This object contains parameters relating to the neighbor list.
ListCarrier	NRCellNumberOfEntries	RW	The number of entries in the NRCell table.
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.CarrierList.NR	NRCarrier	RW	Table containing the LTE EUTRA (i.e. intra-RAT) cell list.
NRCarrier	SsbArfcn	RW	SsbArfcn of NRCarrier
NRCarrier	Scs	RW	Sub-Carrier Spacing in khz (15,30,60,120,240).
NRCarrier	QrxLevMin	RW	Signalled Value in SIB4, actual value = signalled value * 2, value
NRCarrier	QrxLevMinSUL	RW	Signalled Value in SIB4, actual value = signalled value * 2, value value -71 = don't broadcast
NRCarrier	QQualMin	RW	Signalled Value in SIB4, value -44 = don't broadcast
NRCarrier	Pmax	RW	Signalled Value in SIB4, value 34 = don't broadcast
NRCarrier	ThreshXHighP	RW	Signalled Value in SIB4, actual value = signalled value * 2
NRCarrier	ThreshXLowP	RW	Signalled Value in SIB4, actual value = signalled value * 2
NRCarrier	ThreshXHighQ	RW	Signalled Value in SIB4, value 32 = don't broadcast
NRCarrier	ThreshXLowQ	RW	Signalled Value in SIB4, value 32 = don't broadcast
NRCarrier	CellReselectionPriority	RW	Signalled Value in SIB4 value 8 = don't broadcast
NRCarrier	QOffsetFreq	RW	To offset the ranking of this neighbour frequency by that amount.
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.NeighborList	NeighborList	R	This object contains parameters relating to the neighbor list.
NeighborList	NRCellNumberOfEntries	RW	The number of entries in the NRCell table.
InternetGatewayDevice.Services.FAPService.1.CellConfig.NR.RAN.CU.1.NeighborList.N	NRCell	RW	Table containing the LTE EUTRA (i.e. intra-RAT) cell list.
NRCell	SsbArfcn	RW	SsbArfcn or NRCell
NRCell	Scs	RW	Sub-Carrier Spacing in khz (15,30,60,120,240).
NRCell	OperatingBand	RW	Band Definition
NRCell	PlmnIdentity	RW	PLMN ID consists of Mobile Country Code (MCC) and Mobile Network Code (MNC).
NRCell	TrackingAreaCode	RW	Tracking Area Code. Corresponds to TrackingAreaCode 3 Bytes as specified in [3GPP-TS.38.331].
NRCell	CellIdentity	RW	Contains the 36-bit NR Cell Global Identity (NCI).
NRCell	GnbdBitsUsed	RW	GNB identity number of bits used
NRCell	PhyCellId	RW	Physical cell ID, as specified in [Section 7.4.2.1/3GPP-TS.38.211].
NRCell	QOffsetCell	RW	To offset the ranking of this neighbour cell by that amount.
NRCell	QrxLevMinOffsetCell	RW	Signalled Value in SIB3 actual value = signalled value * 2, value 0 = don't broadcast
NRCell	QrxLevMinOffsetCellSUL	RW	Signalled Value in SIB3 actual value = signalled value * 2, value 0 = don't broadcast
NRCell	QQualMinOffsetCell	RW	Signalled Value in SIB3, value 0 = don't broadcast

Object Name	Parameter Name	Read/Write	Description
DU	DU	RW	This object contains the DU config params
DU.General	General	RW	This object contains the general config params for DU
General	Enable	RW	Enables or disables this entry.
General	CellIdx	RW	Cell Index
General	NrMode	RW	Currently only TDD supported
General	PhyCellId	RW	Physical cell ID, as specified in [Section 7.4.2.1/3GPP-TS.38.211].
General	ChannelNrArfcn	RW	ARFCN points at center RE of channel
General	ChannelBwRb	RW	Width of channel in terms of RB
General	OperatingBandsDL	RW	Comma-separated list of strings. Band Definition Downlink
General	OperatingBandsUL	RW	Band Definition Uplink
General	MaxMimoLayers	RW	Max number of downlink MIMO Layers
General	MaxUlmimoLayers	RW	Max number of uplink MIMO Layers
General	TxPowerPerPathDBmX10	RW	Tx power per path in 0.1dB
General	DuOwnlPAddress	RW	IP address of the DU
General	SyncSource	RW	Sync Source Selected
General	FreqSyncTimeout	RW	Timer value for supervisory of the Frequency Sync duration. 0 meas disabled.On expiry Alarm is raised.
DU.MAC	MAC	RW	This object contains the MAC related config params of DU
MAC	SearchSpace0	RW	Width of channel in terms of RB
MAC	BwpDlNumberOfEntries	R	The number of entries in the BwpDL table.
MAC	BwpUlNumberOfEntries	R	The number of entries in the BwpUL table.
MAC	NmacTestMode	RW	Test modes for NMAC
DU.MAC.TDD	TDD	RW	This object contains the TDD relevant parameters of DU / MAC
TDD	TDDSlotsPeriod	RW	The number of slots in a single TDD Period
TDD	TDDSlotsDL	RW	The number of downlink slots in a single TDD Period
TDD	TDDSlotsUL	RW	The number of uplink slots in a single TDD period
BwpDL	BwpDL	RW	This object contains the MAC related BWP-DL config params of DU
BwpDL	Nrb	RW	Width of channel in terms of RB
BwpDL	Scs	RW	Sub-Carrier Spacing in khz (15,30,60,120,240)
BwpDL	OffsetToCrb0	RW	Offset to Control Resource Block 0
BwpUL	BwpUL	RW	This object contains the MAC related BWP-UL config params of DU
BwpUL	Nrb	RW	Width of channel in terms of RB
BwpUL	Scs	RW	Sub-Carrier Spacing in khz (15,30,60,120,240).
BwpUL	OffsetToCrb0	RW	Offset to Control Resource Block 0

Measurement Name	Description
Memory Usage	Number of memory bytes that are used or free.
NR.Memory.TotalUsed	The total number of kilobytes that are currently used in the on-board RAM memory
NR.Memory.TotalFree	The total number of kilobytes that are currently free (unused) in the on-board RAM memory
Flash Usage	Number of FLASH bytes that are used or free in the measurement period.
NR.Flash.TotalUsed	The total number of kilobytes that are currently used in the non-volatile FLASH memory
NR.Flash.TotalFree	The total number of kilobytes that are currently free (unused) in the non-volatile FLASH memory
CPU Usage	Percentage of CPU usage
NR.CPU.AverageLoad	The CPU load in percent
Data Interface	Data transmitted and received on the LAN/Ethernet interfaces.
NR.Interface.TotalBytesTx	The total number of kilobytes that have been transmitted (in the uplink direction).
NR.Interface.TotalBytesRx	The total number of kilobytes that have been received (in the downlink direction).
NR.Interface.DataRateTx	The average data rate for bytes transmitted (in the uplink direction).
NR.Interface.DataRateRx	The average data rate for bytes received (in the downlink direction).
Connectivity and Availability Time	Various system timers accumulated during the measurement period.
NR.SystemTime.TotalUpTime	The number of seconds that the device has been running for since the last reboot.
NR.SystemTime.Total5GAvailabilityTime	The total number of seconds that the 5G has been transmitted
NR.SystemTime.Total5GOutageTime	The total number of seconds that the 5G has not been transmitted
Radio resource utilization	
DL Total PRB Usage	Total usage (in percentage) of physical resource blocks (PRBs) on the downlink for any purpose.
RRU.PrbTotDL	Total usage (in percentage) of physical resource blocks (PRBs) on the downlink for any purpose.
UL Total PRB Usage	Total usage (in percentage) of physical resource blocks (PRBs) on the uplink for any purpose.
RRU.PrbTotUL	Total usage (in percentage) of physical resource blocks (PRBs) on the uplink for any purpose.
PDU Session Management	
Number of PDU Sessions requested to setup	Number of PDU Sessions by the gNB.
SM.PDUSessionSetupReq	Split into subcounters per S-NSSAI.
Number of PDU Sessions successfully setup	Number of PDU Sessions successfully setup by the gNB from AMF.
SM.PDUSessionSetupSucc	Split into subcounters per S-NSSAI.
Number of PDU Sessions failed to setup	Number of PDU Sessions failed to setup by the gNB.
SM.PDUSessionSetupFail.Sum	Sum of all failure causes
SM.PDUSessionSetupFail.RadioNetworkUnspecified	Failure cause RadioNetworkUnspecified
SM.PDUSessionSetupFail.RadioNetworkSliceNotSupported	Failure cause RadioNetworkSliceNotSupported
SM.PDUSessionSetupFail.MultiplePduSessionIdInstances	Failure cause MultiplePduSessionIdInstances
Mobility Management	
Inter-gNB handovers	
Number of successful legacy handover executions	Provides the number of successful legacy handover executions received by the source gNB.
MM.HoExeInterSucc	Number of successful legacy handover executions received by the source gNB.
Number of failed legacy handover executions	Provides the number of failed legacy handover executions for asource gNB.
MM.HoExeInterFail.UeCxtRelCmd.Sum	Sum of number of failed legacy handover executions for all causes
MM.HoExeInterFail.UeCxtRelCmd.UeCxtRelCmdAllCauses	Number of failed legacy handover executions for asource gNB for all causes due to UeCxtRelCmd
MM.HoExeInterFail.UeCxtRelCmd.RrcReestabReq	Number of failed legacy handover executions for asource gNB with cause RrcReestabReq
MM.HoExeInterFail.UeCxtRelCmd.HoExeSupTimer	Number of failed legacy handover executions for asource gNB with cause HoExeSupTimer
MM.HoExeInterFail.UeCxtRelCmd.RetrUeTbtReq	Number of failed legacy handover executions for asource gNB with cause RetrUeTbtReq

Measurement Name	Description
RRC connection establishment related measurements	
Attempted RRC connection establishments	Number of RRC connection establishment attempts for each establishment cause.
RRC.ConnEstabAtt.Sum	Total number of RRC connection establishment attempts
RRC.ConnEstabAtt.Emergency	Number of RRC connection establishment attempts for establishment cause Emergency
RRC.ConnEstabAtt.HighPriorityAccess	Number of RRC connection establishment attempts for establishment cause HighPriorityAccess
RRC.ConnEstabAtt.MtAccess	Number of RRC connection establishment attempts for establishment cause MtAccess
RRC.ConnEstabAtt.MoSignalling	Number of RRC connection establishment attempts for establishment cause MoSignalling
RRC.ConnEstabAtt.MoData	Number of RRC connection establishment attempts for establishment cause MoData
RRC.ConnEstabAtt.MoVoiceCall	Number of RRC connection establishment attempts for establishment cause mo-VoiceCall
RRC.ConnEstabAtt.MoVideoCall	Number of RRC connection establishment attempts for establishment cause mo-VideoCall
RRC.ConnEstabAtt.MoSms	Number of RRC connection establishment attempts for establishment cause mo-SMS
RRC.ConnEstabAtt.MpsPriorityAccess	Number of RRC connection establishment attempts for establishment cause mps-PriorityAccess
RRC.ConnEstabAtt.McsPriorityAccess	Number of RRC connection establishment attempts for establishment cause mcs-PriorityAccess
RRC.ConnEstabAtt.Spare	Number of RRC connection establishment attempts for establishment cause spare
Successful RRC connection establishments	Number of successful RRC establishments for each establishment cause.
RRC.ConnEstabSucc.Sum	Total number of successful RRC connection establishments
RRC.ConnEstabSucc.Emergency	Number of successful RRC connection establishments for establishment cause Emergency
RRC.ConnEstabSucc.HighPriorityAccess	Number of successful RRC connection establishments for establishment cause HighPriorityAccess
RRC.ConnEstabSucc.MtAccess	Number of successful RRC connection establishments for establishment cause MtAccess
RRC.ConnEstabSucc.MoSignalling	Number of successful RRC connection establishments for establishment cause MoSignalling
RRC.ConnEstabSucc.MoData	Number of successful RRC connection establishments for establishment cause MoData
RRC.ConnEstabSucc.MoVoiceCall	Number of successful RRC connection establishments for establishment cause mo-VoiceCall
RRC.ConnEstabSucc.MoVideoCall	Number of successful RRC connection establishments for establishment cause mo-VideoCall
RRC.ConnEstabSucc.MoSms	Number of successful RRC connection establishments for establishment cause mo-SMS
RRC.ConnEstabSucc.MpsPriorityAccess	Number of successful RRC connection establishments for establishment cause mps-PriorityAccess
RRC.ConnEstabSucc.McsPriorityAccess	Number of successful RRC connection establishments for establishment cause mcs-PriorityAccess
RRC.ConnEstabSucc.Spare	Number of successful RRC connection establishments for establishment cause spare.
Failed RRC connection establishments	Number of failed RRC establishments, this measurmenet is split into subcounters per failure cause.
RRC.ConnEstabFailCause.Sum	Total number of RRC establishment failures
RRC.ConnEstabFailCause.NetworkReject	Number of RRC establishment failures for establishment cause NetworkReject
RRC.ConnEstabFailCause.NoReply	Number of RRC establishment failures for establishment cause NoReply
RRC.ConnEstabFailCause.Other	Number of RRC establishment failures for establishment cause Other
RRC Connection Re-establishment	
Number of RRC connection re-establishment attempts	Number of RRC connection re-establishment attempts.
RRC.ReEstabAtt	Number of RRC connection re-establishment attempts.
Successful RRC connection re-establishment with UE context	Successful number of RRC connection re-establishment when UE context can be retrieved.
RRC.ReEstabSuccWithUeContext	Successful number of RRC connection re-establishment when UE context can be retrieved.
Successful RRC connection re-establishment without UE context	Successful number of RRC connection re-establishment when UE context can not be retrieved.
RRC.ReEstabSuccWithoutUeContext	Successful number of RRC connection re-establishment when UE context can not be retrieved.

Measurement Name	Description
Number of Active Ues	
Mean number of Active UEs in the DL per cell	Mean number of active DRBs for UEs in an NRCellIDU.
DRB.MeanActiveUeDI	Calculated per PLMN ID, per QoS level and per supported S-NSSAI.
Maximum number of Active UEs in the DL per cell	Maximum number of active DRBs for UEs in an NRCellIDU.
DRB.MaxActiveUeDI	Calculated per PLMN ID, per QoS level, and per supported S-NSSAI.
Mean number of Active UEs in the UL per cell	Mean number of active DRBs for UEs in an NRCellIDU.
DRB.MeanActiveUeUI	Calculated per PLMN ID, per QoS level, and per supported S-NSSAI.
Max number of Active UEs in the UL per cell	Maximum number of active DRBs for UEs in an NRCellIDU.
DRB.MaxActiveUeUI	Split into subcounters per QoS level, and subcounters per S-NSSAI.
DL PDCP SDU Data Volume Measurements	
DL Cell PDCP SDU Data Volume	Data Volume (amount of PDCP SDU bits) in the downlink delivered to PDCP layer.
DRB.PdcpSduVolumeDL	Calculated per PLMN ID and per QoS level (mapped 5QI) and per S-NSSAI. The unit is Mbit.
UL PDCP SDU Data Volume Measurements	
UL Cell PDCP SDU Data Volume	Data Volume (amount of PDCP SDU bits) in the uplink delivered from PDCP layer to higher layers.
DRB.PdcpSduVolumeUL	Calculated per PLMN ID and per QoS level (mapped 5QI) and per S-NSSAI. The unit is Mbit.
IP Latency measurements	
General information	
Average IP Latency DL in gNB-DU	Average IP Latency in DL (arithmetic mean) within the gNB-DU.
DRB.RlcSduLatencyDI	Split into subcounters per QoS level and subcounters per S-NSSAI.