DESIGN AND IMPLEMENTATION OF REQUIRED SUBMODELS, EXPOSURES AND INTERFACES

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Deliverable

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CONTRIBUTOR(S)	Ahmet Cihat Baktir

	Janina Knußmann Alberto Alonso Cañete David Martín-Sacristán

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Executive Summary

This document introduces the 5G Asset Administration Shell (AAS) design in TARGET-X. 5G AAS will be used for network automation & orchestration and the potential vertical use cases to be studied in the project. This document has a particular focus on the role of AAS in TARGET-X and a set of submodel definitions to enable the required capabilities.

The enterprises and the factory operators do not wish to concentrate on monitoring the low-level network performance metrics, configuration parameters and management functions. Instead, they demand a simplified and abstract view of the network with self-configuration capabilities under dynamic conditions to meet the production requirements. AAS, which is a common practice in the industrial ecosystem, can simplify the use of 5G system and the factory operators can interact with the 5G system through the uniform interface provided by AAS. Representing the 5G system via AAS supports the integration of 5G into the industrial domain and enhances the degree of automation. It is also useful in exchanging information across solutions provided by different vendors.

In order to fully benefit from the capabilities of AAS, the design phase should maintain the alignment with data and service capabilities exposed by the network and devices. In this direction, after introducing the background in AAS and its role in network automation & orchestration, this document introduces the common service exposure Application Programming Interfaces (APIs) and related capabilities provided by the network and industrial devices. The ways of interaction between AAS and exposure interfaces are also depicted.

Besides, this document describes the submodels to be integrated into 5G Network (NW) and 5G User Equipment (UE) AAS instances. These potential submodels will take part in exchanging knowledge among different AAS instances representing different assets, and collaboratively implementing a joint solution to automate the network management and orchestration processes. For each submodel, a list of submodel elements is also introduced. By using AAS as an integrator framework with digital twin (DT) capabilities, it can be used as an enabler for automated network management and asset orchestration processes.

In addition to the discussion on exposure interfaces and the 5G AAS submodels, this document presents the requirements for AAS interaction and common practices. Then, the next stages in TARGET-X regarding the AAS development are briefly defined and introduced.

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List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5G-ACIA	5G Alliance for Connected Industries and Automation
AAS	Asset Administration Shell
API	Application Programming Interface
APN	Access Point Name
CAPIF	Common API Framework
DL	Downlink
DNN	Data Network Name

DT	Digital Twin
EPS	Evolved Packet System
GMLC	Gateway Mobile Location Centre
I4.0	Industry 4.0
IMSI	International Mobile Subscriber Identity
IT	Information Technology
KPI	Key Performance Indicator
LCS	Location Services
MCC	Mobile Country Code
MNC	Mobile Network Code
NF	Network Function
NSA	Non-standalone
NW	Network
NWDAF	Network Data Analytics Function
OAM	Operations, Administration and Maintenance
OT	Operational Technology
PDU	Packet Data Unit
QoS	Quality of Service
RAMI4.0	Reference Architectural Model Industrie 4.0
RAN	Radio Access Network
REST	Representational State Transfer
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SA	Standalone
TS	Technical Specification
UE	User Equipment
UL	Uplink
UTDOA	Uplink Time Difference of Arrival
VNF	Virtual Network Function

1 Introduction

Within the scope of the digital transformation of the enterprises towards increased productivity with process optimization, we see an increasing demand for enhanced flexibility to be more competitive and align with how the products are manufactured and delivered [Eri23]. Industry 4.0 (I4.0) creates a transformation that requires enterprises to adapt themselves for new technologies by achieving higher levels of automation. This evolution through digitalization paves the road for industries to enhance the process efficiency, productivity, and agility. It is envisioned that all the participants of I4.0 deployments are interconnected at a large scale to collaborate.

5G networks are one of the important enablers for meeting connectivity requirements at Operational Technology (OT) domain. As we move from 4G to 5G and beyond technologies, the network implements relevant capabilities to provide desired performance for industrial use cases through ultra reliable, very low latency and energy efficient solutions. Leveraging always-on connectivity for the assets at the factory floor, 5G networks help enterprises to automate their processes at the factory floor.

However, as the industrial processes evolve and become more complex, the integration of 5G networks into industrial domain gets higher importance for both automation and flexibility. Considering the large industrial ecosystem consists of already complex subsystems with their own information and data model, it becomes more challenging to integrate them into the digital domain and maintain interoperability to minimize the manual human intervention in operations.

There are key requirements to achieve this smooth integration at various layers. To have a common understanding across different value chains and solutions from various vendors, there is a need to have a standardized mechanism and concept. To establish interaction among all participants and enable end-to-end interoperability at the factory floor, one promising solution is Asset Administration Shell (AAS), which creates the digital twin (DT) of the industrial assets. As proposed by Plattform Industrie 4.0, AAS principles are key to integrate physical assets (e.g., machines, products) into the digital world.

Since industrial 5G networks are also assets and part of the overall industrial system, AAS properties can be used to develop digital representation of the 5G system components: 5G Network (NW) AAS and 5G User Equipment (UE) AAS. Through the digital representation of 5G system and integration with the other systems via standardized interfaces and languages, we can achieve integration of 5G systems into OT (Operational Technology) and IT (Information Technology) processes and expand the automation. By using AAS as an integrator framework with DT capabilities, it can be used as an enabler for automated network management and asset orchestration processes.

This document introduces how 5G AAS can be designed to achieve this objective. By designing the 5G AAS and define the potential set of submodels to be integrated for automation purposes, this deliverable introduces the initial step towards 5G development.

1.1 Document structure

The document is structured as follows: Section 1 introduces the objectives of the deliverable. Section 2 introduces the background in AAS and its role in automation. In Section 3, this document presents the common data and service exposure capabilities provided by the network and devices. In Section 4, the relevant 5G NW AAS and 5G UE AAS submodels are introduced, which are envisioned to enable automation for network and asset management, along with the submodel elements that will populate the submodels. In Section 5, there is a detailed discussion on the next steps in AAS development. In Section 6, the document is concluded with a summary.

2 Background in Asset Administration Shell (AAS)

In TARGET-X, AAS will be used as an enabler of vertical use cases as well as a framework to realize the automation leveraging interoperability. The concept of AAS is one of the key pillars for accelerating the digitalization of the process industry and manufacturing. To grasp the AAS principles and its role in the digitalization process, it is important to define the requirements and characteristics of I4.0 services.

2.1 What is AAS?

Considering different aspects of industrial processes and the requirement of having a holistic view for the I4.0 deployments, German Electrical and Electronic Manufacturers' Association (ZVEI) proposed Reference Architecture Model Industrie 4.0 (RAMI 4.0). It is a service-oriented architecture which enables common understanding among all participants and components in I4.0 deployments. The 3D map proposed by RAMI 4.0 defines how I4.0 can be approached in a structured manner by focusing on the most important aspects. In one of these dimensions, the focus is on the properties of assets and its representation in the digital world. In this context, AAS plays an important role by integrating a physical asset into digitalized functions and processes.

AAS, as initially proposed by Plattform Industrie 4.0, is a DT implementation of an industrial asset such as machines, software, and products. It also implements relevant capabilities to maintain interoperability across different solutions from different vendors.

As introduced by 5G-ACIA (5G Alliance for Connected Industries and Automation) [5GA21b], AAS consists of two parts: (1) passive, and (2) active. In its passive part, AAS represents the capabilities, properties, and state of the corresponding physical asset. This set of information provided by the asset is structured as "submodels" in AAS, where each submodel represents a different aspect (e.g., lifecycle status, energy efficiency, security). The interaction among AAS instances is enabled via the active part, which is used to exchange knowledge and establish negotiation processes for a collaborative task via decision-making functionalities. So, we can design AAS in a way that incorporates these capabilities inherently.

The industrial ecosystem incorporates various systems that need to interact with other systems. In general, these systems composed of already-complex subsystems that implement their own communication and data models. Thus, there is a need for language that establishes a common understanding in the digital world. In this direction, VDI/VDE 2193 (VDI: Verein Deutscher Ingenieure – The Association of German Engineers, VDE: Verband der Elektrotechnik Elektronik Informationstechnik - Association of Electrical Engineering Electronics Information Technology) proposed I4.0 language with its vocabulary, structure, and interaction protocols [VDI20]. The proposed interaction model enables active part of AAS to have an interoperable communication across I4.0 components.

2.2 The Role of 5G AAS in Network Automation and Orchestration

Building on top of the AAS vision put forward by ZVEI and Plattform Industrie 4.0, 5G-ACIA proposes using AAS principles to build the DT of 5G system. Acknowledging industrial 5G network deployment and 5G UEs as assets at the factory floor, AAS can be used to represent them in the digital world along with other industrial assets.

Benefiting from the aforementioned capabilities, 5G AAS can be used to integrate industrial 5G network into OT/IT processes. Through its inherent properties enabling interoperability between solutions provided by various vendors, AAS can be deployed as a bridge between 3GPP (3rd Generation Partnership Project) and industry domains.

Enterprises may utilize 5G AAS to implement interoperability between different industrial systems as well as the 5G system. Within the scope of process industry and manufacturing, enterprises can make use of AAS as an enabler of different use cases leveraging digital transformation, such as process orchestration, condition monitoring, device onboarding and lifecycle management of I4.0 assets. The communication services with required connectivity for such use cases and enhanced automation degree for OT processes should be delivered at an abstract layer for smooth integration.

This integration is an enabler towards developing automation capabilities for the network management & orchestration functions. Existing network management solutions provide some automation capabilities. However, 5G integration into OT processes not only extends the scope to automate the asset management (i.e., OT management), but also enhances the degree of automation and orchestration for network management.

Realizing the smooth horizontal integration of 5G networks into OT processes via AAS paves the road for a holistic end-to-end automation view. For both network and asset management, AAS can provide knowledge and insights from other systems that can be useful to enhance the performance of management solutions. For example, the network management policies aim to optimize the resource allocation schemes for service assurance. However, the existing solutions are not able to benefit from external data (e.g., manufacturing processes, resource planning) provided by the industrial automation stack. AAS can be used to collect information and knowledge from different systems to have a further alignment between the network configurations and the requirements of industrial processes. Furthermore, the manufacturing processes can be enhanced to achieve higher performance by exposing the network capabilities and measurements that are aggregated at AAS. For instance, the cell-level performance measurements can be used to plan the manufacturing processes accordingly. In general, the factory operators expect not to focus on the internals of the industrial network. Therefore, it is important to enable the network management solutions to configure the network automatically in case the connectivity requirements of the production processes change. AAS in this environment with connected solutions is potentially a key enabler to implement the automation and self-configuration capabilities.

AAS, by aggregating data collected from different sources (e.g., 5G system, industrial applications), provides a uniform exposure and management interface. The standardized northbound interface of AAS representing the 5G system in digital world can hide all the complexities of the low-level network services and provide a consolidated interface for OT operators.

Therefore, this document introduces the 5G AAS design enhancing the automated network management and asset orchestration solutions. Since the 5G AAS design relies on the exposure capabilities provided by the 5G system and devices, the next section provides a view on the existing exposure capabilities in the literature.

3 Exposure Capabilities of the Network and Devices

The main value of representing 5G network and 5G-capable devices with AAS relies on the design and ways of interaction. Along with the potential decision-making capabilities, the submodels that are introduced in Section 4 are one of the key components of 5G AAS implementing the capabilities to qualify the degree of automation for network orchestration and asset management. However, there are some requirements to take full advantage of the envisioned submodels. To populate them with relevant information and events, and integrate the 5G system into the industrial ecosystem, the exposures provided by the assets (i.e., 5G network, 5G-capable devices) should be well-aligned and considered as the fundamental enabler. In this direction, this section discusses the overall idea of exposure interfaces provided by the 5G network and 5G UEs, and their role in the 5G AAS framework.

3.1 Network Services Exposure

The 5G NW AAS operations highly depend on the exposures provided by the industrial 5G network. Most of the submodels to be integrated into 5G NW AAS should be populated by the data and services exposed through the relevant network interfaces.

Exposing the 5G capabilities to the industrial domain is critical not just for AAS framework, but also for the industrial applications and processes. Network exposures, by making network data and services available for enterprises (e.g., monitoring device connectivity, provisioning of network functions - NFs) through Application Programming Interfaces (APIs), play an important role in driving innovation and integration of 5G capabilities into industries [Eri23b]. To benefit from the services provided by the 5G network in addition to the wireless connectivity, the exposures interfaces should be abstracted for ease of use.

The main exposure capabilities introduced by 3GPP are implemented by the Network Exposure Function (NEF) [3GP23-23501]. Monitoring, provisioning, reporting, charging and many other capabilities of 5G system can be exposed to the external applications via NEF. By using APIs, such as Representational State Transfer (REST) APIs, the 5G services and capabilities are securely exposed to the external consumers. The northbound interface of NEF enables the authenticated consumers (i.e., Application Functions - AFs) to monitor the network (e.g., UE location, loss of connectivity), retrieve the analytics, configure the network, and execute other related procedures.

On top of NEF, 3GPP also introduces the Common API Framework (CAPIF) architecture [3GP23-23222], which can be adopted by an exposure function providing 3GPP northbound APIs. NEF can use CAPIF for external applications by implementing the CAPIF core function, API exposing function, API publishing function and API management function. In addition, NEF can be integrated with a CAPIF core function by implementing the API exposing, publishing and management functions. In this overall CAPIF architecture independent of the functional model, CAPIF core function is responsible of acting as a gateway providing services to different AFs (i.e., API invokers).

3GPP also has a technical specification defining Service Enabler Architecture Layer for Verticals (SEAL) [3GP23-23434] to support vertical applications. The main objective is to deploy service enablers providing common services that various vertical applications can make use of. This CAPIF-compliant architecture introduces application-enabling services, such as group management, configuration management, location management, key management, identity management and network resource management. In this architecture, SEAL server implements the functionalities of

CAPIF API exposing function and provides them to a specific SEAL service. For different SEAL services, the SEAL server can interact with NEF to perform management procedures.

In addition to 3GPP, there are tailored exposure functions vertically deployed on top of existing low-level interfaces (e.g., NEF) to simplify the use of 5G network for industries. To enhance the automation, provide services beyond wireless connectivity, and increase the productivity for the enterprises, the exposures should be abstracted for factory and OT operators. Besides, the novel set of use cases for the factories of the future, such as industrial IoT and collaborative robots, defines different requirements to be met. Within this scope, service exposures and APIs can be the key building blocks for the solutions deployed by the enterprises [Eri19]. For implementing 5G exposure interfaces that are easy to use, modular, extensible, and service-oriented, 5G-ACIA defines the requirements in a whitepaper [5GA21a]. Correspondingly, different requirements are defined by this study with regards to device & network management as well as security. In practice, one of the studies with the objective of validating the 5G-ACIA exposure concept was realized by Ericsson collaborating with ABB [Eri22]. Within this scope, the proof-of-concept (PoC) activity enables an easy-to-use prototype 5G exposure interface for managing and monitoring the connectivity of devices.

Another practical implementation of the simplified exposure interfaces and APIs is provided by CAMARA project, which is an open-source project within Linux Foundation to define, develop and test APIs [CAM23]. The CAMARA project conducts activities to implement APIs within the scope of, but not limited to, device, edge cloud and network. While service and service management APIs are within the scope of CAMARA, operate APIs are not within the scope. On the other hand, for example, TM Forum defines more than 70 RESTful APIs as operate APIs, such as alarm management, product inventory management and resource catalog management.

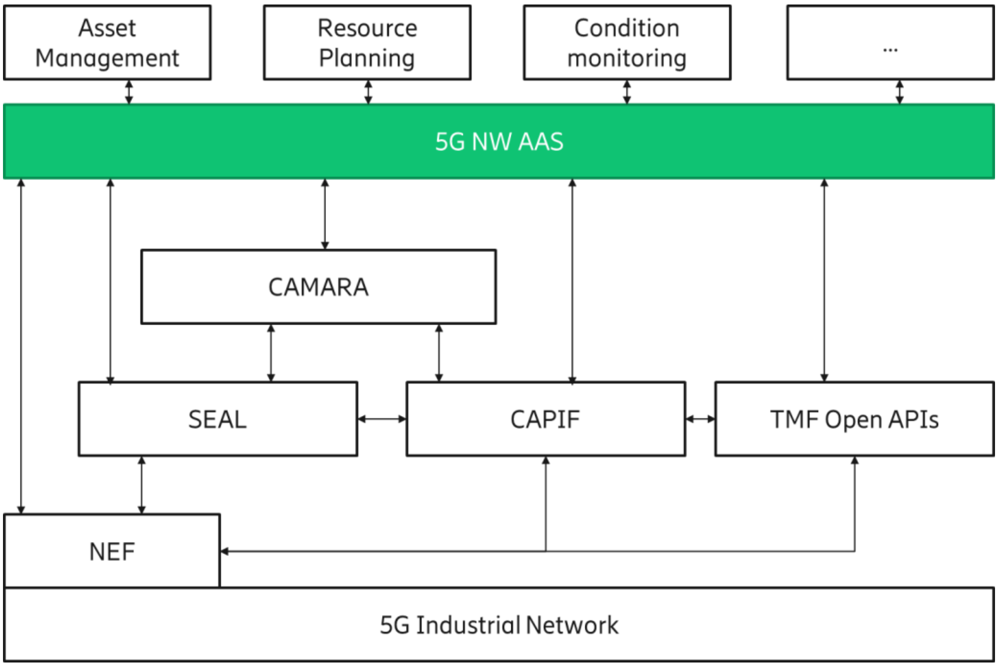

Figure 1: Exposures and 5G NW AAS alignment

When we consider all these initiatives and the different exposure related studies, their interaction with the 5G NW AAS, deployment models, and ways of use may differ. For this reason, it is important to achieve the big picture showing how AAS integrates the 5G networks and industrial applications.

In Figure 1, the exposure interfaces as an enabler of 5G NW AAS are depicted. As seen, 5G NW AAS not only provides a uniform interface for the enterprises, but also provides another level of encapsulation. Via standardized northbound interface, the factory operators can interact with the industrial 5G network through 5G NW AAS for monitoring and management purposes. Since the enterprises do not want to focus on the details of network and management systems, 5G NW AAS provides an abstract view by hiding the complexities.

In addition to the standardized service exposure APIs, some proprietary APIs could be used to enhance some of the submodels. Even though the northbound interface of AAS is standard, the southbound interface is being standardized but still have proprietary extensions due to commonality of the proprietary interfaces provided by the assets. The service providers can build proprietary APIs, and the AAS encapsulation can be used to hide these proprietary interfaces.

3.2 Device Exposures

Just as network exposures are needed for the operation of 5G NW AAS, UE exposures are needed for the operation of 5G UE AAS. This exposure includes the access to capabilities and configurations related to frequency bands, transmission parameters, antenna characteristics, among others.

First of all, it is crucial to note that the 5G network manages and operates not only the 5G Radio Access Network (RAN) and 5G Core, but also the 5G UEs. Therefore, the 5G network is aware of capabilities, configuration, and status of the UEs. That is the reason why the same network exposures presented in the previous section can also be used for device exposure, which are illustrated in Figure 2. This is the case, for example, for the NEF which also exposes the UE, indirectly through this 5G Core network function, to other parties. The use of these same network-based interfaces contributes to an efficient and uniform integration of the UEs into the AAS.

In addition to these exposures which are common to the network exposures, the 5G UEs can be exposed directly to the 5G UE AAS through dedicated services and interfaces. In fact, in TARGET-X we foresee an adaptation of standardized AAS REST API according to the submodels defined in the project. The REST API will be managed by a service which interacts at low level with the 5G UE. By low level interaction we refer usually to two mechanisms. The first one is the exchange of AT commands via serial interfaces with 5G modules as those of vendors such as Quectel, Telit and Sequans. The second one is the use of chipset specific interfaces such as Qualcomm's QMI (Qualcomm MSM Interface) protocol.

Both kinds of exposures, the network-based and the direct ones, can be combined and used at the same time. The network-based exposures depend usually on the developments of equipment vendors which could be less agile than the device vendors to adapt the APIs needed in a specific project. On the other hand, network-based exposures, although presumably not totally adapted to a project, will be likely available in early phases of the project.

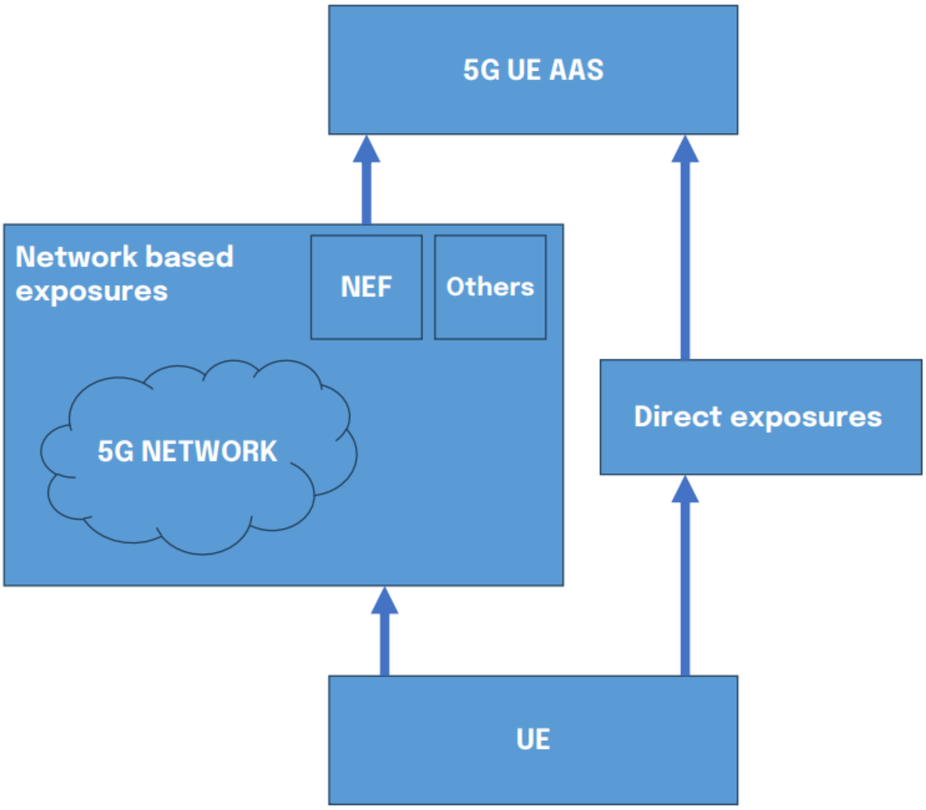

Figure 2: 5G UE AAS and exposures

4 5G AAS Design and Submodel Definitions

This section introduces the relevant submodels of 5G AAS representing 5G network and 5G-capable devices in the digital world. These submodels are defined and designed to define different aspects of 5G system components. The asset properties and related information, which are structured as submodels, will be used as knowledge that can be exchanged between AAS instances to enhance the degree of automation for network and asset orchestration procedures.

For each submodel, a set of submodel elements is introduced along with their associated data element category. Correspondingly, there are three different categories of data elements in AAS:

- Constant: Does not change over time
- Parameter: Once set, and then typically does not change over time
- Variable: Calculated during runtime

The submodels of the 5G AAS presented in this section are designed to aggregate a comprehensive set of information that might be used for management and orchestration purposes. Although a detailed review and study has been carried out in this deliverable to reveal the envisioned 5G AAS ecosystem in the future, TARGET-X project will implement a subset of these submodels in the following deliverables. It should be noted that the submodels introduced in this deliverable include the submodel elements at an abstract level. In practice, the submodels and submodel elements will include more information (e.g., idShort, semanticId, submodel element type)

4.1 5G Network AAS

The industrial 5G network is expected to provide services and support to meet the enterprise expectations. By enabling wireless connectivity for the industrial assets at the OT layer and exposing data and management capabilities to the industrial applications, 5G industrial networks can be integrated into enterprise management frameworks for end-to-end automation.

One of the important capabilities is to enhance the Key Performance Indicators (KPIs) that the verticals demand. 5G-ACIA defined a set of common use cases in the factory floor [5GA20]. Based on the characteristics of the use cases, 5G network is expected to provide a certain level of reliability, availability, data rate and latency. So, the management functions provide relevant capabilities to configure the network and network functions according to the expected KPIs under different conditions. Through continuous monitoring, the network can be configured and optimized for performance and fault management.

The main benefits that an intelligent management system provides for enterprises are improved customer experience and enhanced network performance in an automated manner [Eri23c]. In this direction, it is important to enable continuous monitoring and automated configuration of the network to address the requirements of industrial use cases (e.g., reliable connectivity for collaborative robots). AAS plays an important role in integrating 5G into industrial domain to address the needs of industrial applications and OT processes, implementing an abstraction layer for the factory operators to manage the network based on their expectations.

In this direction, this deliverable introduces the submodels to be integrated into 5G NW AAS. These submodels could be populated by either the exposures provided by the network (e.g., network functions, Operations, Administration and Maintenance - OAM) or other AAS instances. The information and knowledge stored in such submodels could be exchanged with the OT domain, so that the industrial applications can configure the network automatically via an abstraction layer provided by AAS.

Depending on the complexity of the 5G system and the requirements, the 5G NW AAS can be standalone or composition of multiple AAS instances. In this deliverable, 5G NW AAS is assumed as the single entity representing the industrial 5G network.

The submodels in 5G NW AAS consist of both static and dynamic information. In addition to the information that does not change over time, such as network identity, the 5G NW AAS is expected to provide data that is updated based on the events and measurements generated by the network.

The 5G NW AAS submodels introduced in this document could be accessed (e.g., read, write) by any other entity in the industrial domain through the standardized northbound API. For example, the measurements can be accessed by the industrial applications to evaluate whether the network provides the desired degree of performance for the manufacturing services.

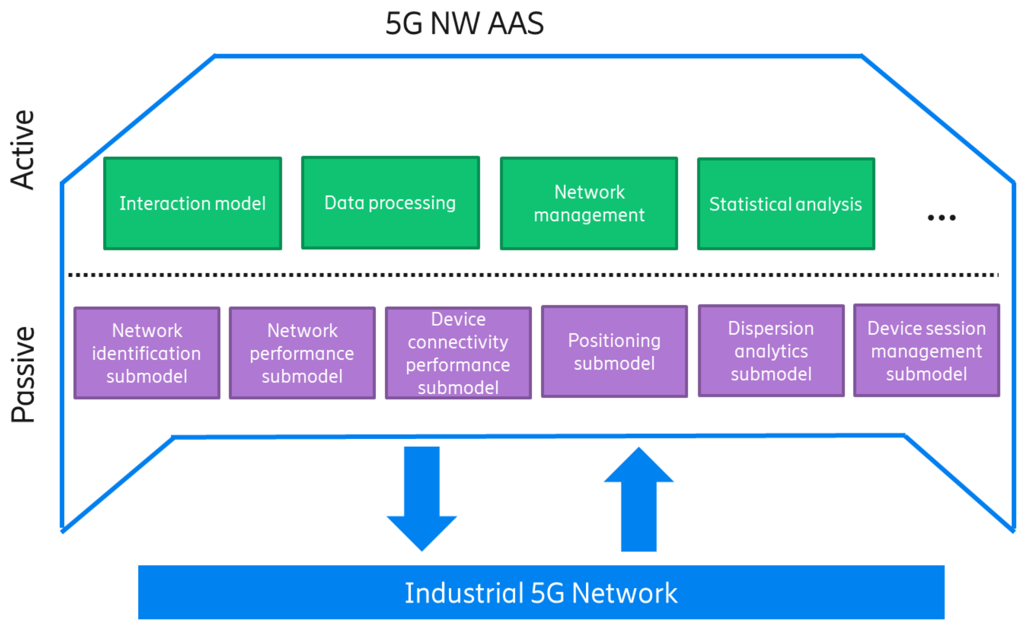

Figure 3: 5G NW AAS submodels

As illustrated in Figure 3, 5G NW AAS includes a set of submodels to represent the information and knowledge from the different aspects of management. It should be noted that the submodels discussed in this section constitute only a subset of the larger potential list of submodels. Besides the submodels, a set of candidate active part functions are also illustrated. The details of these potential active part functions are not within the scope of this document.

4.1.1 Network identification submodel

This submodel is used to aggregate relevant information that describes the network and its attributes. The network can be identified using Data Network Name (DNN). In 5G system, DNN is equivalent to an Access Point Name (APN) in Evolved Packet System (EPS) [3GP23-23003]. The network identity can be used to monitor the data streams at the factory and associated network. Besides, this submodel can be used for storing the system attributes that might be useful for the smooth functioning of the system such as supported frequency bands and their combinations. This information can be used by 5G NW AAS for troubleshooting when there is a failure in device connectivity. By comparing the frequency band used by the 5G UE, information of which can be provided by 5G UE AAS, and the supported frequency bands in the network, frequency configurations can be applied if an inconsistency is detected. Similar troubleshooting can be applied to the supported attach type by the network. The network identification submodel and relevant elements are summarized in Table 1. It should be noted that, APN is an option to describe the network for non-standalone (NSA) 5G deployments.

Table 1: Network identification submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
LIST OF DNNS	Parameter	APNs can be used in certain cases according to the network deployment
SUPPORTED FREQUENCY BANDS	Constant	-
SUPPORTED FREQUENCY BAND COMBINATIONS	Parameter	-
ATTACH TYPE	Constant	E.g., emergency attach, combined attach

4.1.2 Network performance submodel

This submodel will be populated by the performance data exposed by the network (e.g., RAN, core, OAM). It should be updated through continuous monitoring of the network to provide an up-to-date view of the network performance for the industrial applications, so that the factory operators can have a high-level view of the KPIs demanded by the applications.

As introduced by 3GPP Technical Specification (TS) 28.554 [3GP23-28554], there are many 5G end-to-end KPIs representing the performance of the network. Regarding accessibility, integrity, utilization, retainability, mobility, energy efficiency and reliability, there are various KPIs defined along with the formula definition and corresponding object instance where the measurement is made. Depending on whether these KPIs are exposed or not, the measurements can be stored in the network performance submodel and exchanged with any other entity.

When the novel set of manufacturing use cases are inspected and evaluated [5GS20], it is observed that the most common performance requirements are within the scope of following categories:

- Availability
- Latency
- Data rate
- Reliability

- Seamless mobility

Correspondingly, the common KPIs representing each performance requirement can be determined and stored in the network performance submodel [3GP23-28554]. A set of example KPIs, but not limited to, that can be represented as separate submodel elements in this particular submodel, are as follows:

- Availability: Ratio of available cells
- Latency: Downlink (DL) and uplink (UL) delay in RAN, end-to-end delay for a network slice
- Data rate: UL/DL RAN throughput, upstream/downstream throughput at N3 interface
- Reliability: UL/DL packet transmission success on Uu interface
- Seamless mobility: RAN handover success rate

For each KPIs, a "timestamp" field should be also added as a separate submodel element to keep track whether a measurement stored in the 5G NW AAS is up-to-date or not. The submodel elements representing the network performance is summarized in Table 2 along with the information about data element category and descriptions of the KPIs.

Table 2: Network performance submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
RATIO OF AVAILABLE CELLS	Variable	Available cell / Total number of cells
DL DELAY IN RAN	Variable	Downlink latency, in milliseconds
UL DELAY IN RAN	Variable	Uplink latency, in milliseconds
END-TO-END DELAY FOR A NETWORK SLICE	Variable	Latency including uplink, downlink, and processing in the network latencies
DL RAN THROUGHPUT	Variable	Data rate in downlink, in Mbit/s
UL RAN THROUGHPUT	Variable	Data rate in uplink, in Mbit/s
DOWNSTREAM THROUGHPUT AT N3 INTERFACE	Variable	Data rate on N3 interface (downstream from UPF), in kbit/s
UPSTREAM THROUGHPUT AT N3 INTERFACE	Variable	Data rate on N3 interface (upstream at UPF), in kbit/s
DL PACKET TRANSMISSION SUCCESS ON UU	Variable	Packet success rate percentage (%) between gNB and UE, in the downlink

UL PACKET TRANSMISSION SUCCESS ON UU	Variable	Packet success rate percentage (%) between gNB and UE, in the uplink
RAN HANDOVER SUCCESS RATE	Variable	# Successful handovers / # total handovers (UE changes cell)
TIMESTAMP	Variable	Each submodel element in this submodel has its own timestamp, because the measurements can be provided by different sources

In addition to the above mentioned KPIs, there are other sets of KPIs that might give an insight about the network performance, such as the number of Packet Data Unit (PDU) sessions, session establishment time, registered subscribers, and virtual network function (VNF) energy consumption. However, this deliverable focuses on the most common performance requirements demanded by the smart manufacturing services. The factory operators can customize the 5G NW AAS submodels by adding the relevant properties based on the use cases and requirements accordingly. For example, if minimizing energy consumption is one of the expectations defined by a factory operator, energy consumption and related information can be aggregated as a separate submodel.

4.1.3 Device connectivity performance submodel

Along with the network performance that is exposed through relevant functions and interfaces, the factory operators would like to monitor the connectivity performance of each device attached to the network. In some cases, the average network behavior can be satisfactory. However, to maximize productivity and quality with higher automation degree, it is important to meet the requirements of each particular device in the value chain.

Therefore, this submodel aims to store the relevant information about the device connectivity, so that it can be continuously monitored on the factory floor. Within this scope, the first submodel element that should be integrated is an ID representing the device such as International Mobile Subscriber Identity (IMSI). It should be noted that IMSI is typically not exposed by industrial 5G network to external consumers. Instead, Generic Public Subscription Identifier (GPSI) can be exposed as a UE identifier outside of the 5G network. In this submodel, we assume that IMSI can be retrieved from the AAS of the corresponding device (i.e., 5G UE AAS). As an alternative approach, IP address or MAC address of the UE can be used to uniquely identify the UE, as proposed by 5G-ACIA [5GA21a]. Furthermore, since each device can establish multiple sessions, it is important to add another submodel element identifying the session itself.

For each active session of a given online 5G-capable device, the KPIs introduced in Section 4.1.2 can be monitored and stored in the device connectivity performance submodel. This set of information as performance measurements are updated periodically or in an event-based manner. In addition, information regarding the Quality of Service (QoS) fulfilment can be also stored in this submodel. For example, “Quality on Demand” service APIs provided by CAMARA project can be used to receive notification if the network cannot meet the required QoS. The QoS status (e.g., REQUESTED, AVAILABLE, UNAVAILABLE) of the corresponding session can be added as another submodel element to monitor the performance and negotiate on the QoS criteria when necessary. Similar to the network performance, timestamp should be added separately for each KPI to keep track whether the performance data is updated or not. The device connectivity performance submodel and incorporated submodel elements are summarized in Table 3.

Table 3: Device connectivity performance submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
IMSI	Constant	International Mobile Subscriber Identity, identifying the UE
SESSION ID	Constant	Identifier of the session in Universally Unique Identifier (UUID) format, which is obtained when session is created
• **RATIO OF AVAILABLE CELLS** • **DL DELAY IN RAN** • **UL DELAY IN RAN** • **END-TO-END DELAY FOR A NETWORK SLICE** • **DL RAN THROUGHPUT** • **UL RAN THROUGHPUT** • **DOWNSTREAM THROUGHPUT AT N3 INTERFACE** • **UPSTREAM THROUGHPUT AT N3 INTERFACE** • **DL PACKET TRANSMISSION SUCCESS ON UU** • **UL PACKET TRANSMISSION SUCCESS ON UU** • **RAN HANDOVER SUCCESS RATE**	Variable	Same list of performance indicators for an active session established by a device
QOS STATUS	Variable	E.g., REQUESTED, AVAILABLE, UNAVAILABLE
TIMESTAMP	Variable	Each submodel element in this submodel has its own timestamp, because the measurements can be provided by different sources

4.1.4 Positioning submodel

The positioning information of the devices/UEs also has an impact on the decision-making systems for network configuration. For example, the radio resource management functions can make use of the position information for each robot at the factory floor. Based on the position of the devices, the network resources can be configured accordingly, cells can be switched on/off for energy saving or new QoS parameters can be defined.

In order to plan the manufacturing tasks, monitor the tasks, execute the asset management functions and tracking the devices, the industrial applications should have the information of device positioning. Indoor positioning is a key technology to achieve novel industrial use cases. The positioning information can be provided by different sources. The devices are equipped with various sensors such as camera, Light Detection and Ranging (LIDAR) and Inertial Measurement Unit (IMU), which are useful for performing accurate positioning information in the factory environment. In addition to the positioning techniques adopted by the industries, 5G system is integrated with location services (LCS) [3GP23-23273], which is capable of providing positioning information for a given UE based on a request by LCS client. In this regard, 5G LCS implements various positioning methods [3GP23-38305]. While some of these positioning methods are useful in outdoor scenarios, there are solutions that are used for indoor and industrial scenarios such as uplink time difference of arrival (UTDOA) and carrier phase positioning. The support for 5G positioning services, positioning techniques that can be enabled by 5G network, and relevant operations depend on the UE capabilities. In TARGET-X, device agnostic positioning methodologies and services will be used.

5G NW AAS is envisioned to accommodate a positioning submodel that stores the most recent positioning information for each device. For the devices that are already attached to the 5G network, this submodel can be populated by the data provided by LCS and exposed through the Gateway Mobile Location Centre (GMLC). For the devices which are not connected, the industry level positioning techniques can be applied the location of the device can be determined. This information can be relayed to the 5G NW AAS via AAS interaction. So, the positioning information from different sources can be aggregated in the corresponding submodel designed in 5G NW AAS. It should be noted that a LCS client or an external application may not be allowed to retrieve UE location information. UE LCS privacy is a feature defined by 3GPP. Privacy preferences of a UE is stored in the corresponding privacy profile, which is used to determine whether external location requests are allowed or not. This procedure applies to the 5G NW AAS too, if the location for UE is not allowed for any external application, the corresponding positioning information cannot be exposed to 5G NW AAS. The privacy classes defining whether a LCS client is allowed, conditionally allowed, or not allowed are summarized in 3GPP TS 23.271 [3GP21-23271].

In addition to the device identifier and location information, it is important to reflect the technique used for determining the location and the timestamp. Besides, the geographical area representing the device location can be in different shapes (e.g., polygon, ellipsoid) [3GP23-37355]. This type of information can also be stored in 5G NW AAS as a separate submodel element.

The high-level view of positioning submodel and the corresponding elements are summarized in Table 4.

Table 4: Positioning submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
IMSI	Constant	International Mobile Subscriber Identity, identifying the UE
POSITIONING TECHNIQUE	Variable	Positioning technique used by the location service
GEOGRAPHIC AREA TYPE	Variable	E.g., point, ellipsoid
POINT LIST (CONDITIONAL IF P-SME2 IS E.G., POLYGONAL)	Variable	Conditional, if geographic area type is e.g., polygonal
RADIUS (CONDITIONAL IF P-SME2 IS E.G., ELLIPSOID)	Variable	Conditional, if geographic area type is e.g., ellipsoid
OFFSET ANGLE (CONDITIONAL IF P-SME2 IS E.G., ELLIPSOID)	Variable	Conditional, if geographic area type is e.g., ellipsoid
INCLUDED ANGLE (CONDITIONAL IF P-SME2 IS E.G., ELLIPSOID)	Variable	Conditional, if geographic area type is e.g., ellipsoid
TIMESTAMP	Variable	-
ESTIMATED ACCURACY	Variable	-

4.1.5 Dispersion analytics submodel

The measurements provided and exposed by the network functions and OAM solutions are important for industrial applications to monitor how the network performs. Along with these data sets, the 5G network can provide statistical information and predictions. Network Data Analytics Function (NWDAF) is part of 5G core, providing such services to other network functions and OAM. The service consumers can subscribe to NWDAF analytics service by providing the identifiers of the demanded analytics. When the output becomes ready, NWDAF notifies the consumer on analytics information.

3GPP 23.288 [3GP23-23288] introduces that NWDAF can provide descriptive statistics based on the historical data and predictions in many different areas related to the network performance and UE behavior. These analytics may provide additional insights for the verticals.

As described in 3GPP 29.522 [3GP23-29522], the analytics information can be provided to any authenticated application function via NEF northbound interface. The application function can subscribe to the analytics exposure through sending a request to NEF, which then interacts with NWDAF to retrieve the analytics and send it to the consumer.

5G NW AAS can store the statistics and predictions provided by NWDAF by subscribing as an external function. In practice, the feasible approach is to design a separate submodel for analytics type so that each set of information can be easily accessed by the OT processes. In this section, an analytic type is introduced as a submodel to exemplify the idea of storing the analytics in 5G NW AAS. This example represents the dispersion provided by NWDAF. In 3GPP 23.288 [3GP23-23288], two different types of dispersion analytics are defined: (1) data volume dispersion, (2) transactions dispersion. For an industrial scenario, the information of data traffic volume provides more insight into the performance of the robots rather than the transactions. Data volume dispersion is defined as the *"percentage of data traffic volume that a UE, or a group of UEs, or any UE, generated at a location or in a slice during the period of interest".*

The data volume dispersion analytics is introduced in detail by defining the required data for subscription, the input data collected by NWDAF to generate the statistics and predictions, and the output information. A set of submodel elements that can be integrated into data volume dispersion analytics submodel in 5G NW AAS are depicted in Table 5. It should be noted that other types of analytics and information can be stored in separate submodels based on the needs. The detailed description of each output data type that can be modelled as a separate submodel element is available in 3GPP 23.288 [3GP23-23288].

Table 5: Data volume dispersion analytics submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
IDENTIFIER	Constant	E.g., IMSI if UE identifier, internal group ID if group of UEs
TIME SLOT START	Variable	-
DURATION OF THE TIME SLOT	Constant	-
OBSERVED UE LOCATION	Variable	Tracking area or cells
APPLICATION IDENTIFIER	Constant	Optional, if application identifier is used in the input data
DATA VOLUME DISPERSED AT THE LOCATION	Variable	Data volume dispersed at the observed locations
DATA MOBILITY CLASSIFICATION	Variable	E.g., fixed, camper, traveler
DATA USAGE RANKING OF UE	Variable	Ranking of UE data use at the observed locations
DATA USAGE PERCENTILE RANKING OF UE	Variable	Percentile ranking of the UE or UE group in the Cumulative Distribution Function

PERCENTAGE OF UES IN THE GROUP AT THE LOCATION	Variable	Conditional if multiple UEs or group of UEs
PREDICTIONS	Variable	Predictions of the same information in other submodel elements. Added as a single submodel element for simplicity purposes.

4.1.6 Device session management submodel

In order to fully reveal the potential of AAS in management automation, 5G NW AAS can accommodate information provided by the device as well.

The device capabilities can be reported by the device to its own AAS (i.e., 5G UE AAS). This information then can be exchanged with 5G NW AAS, so that the device management and network management procedures can be supported jointly. For example, group management and device onboarding operations can be executed by using data provided by both network and devices. Based on the supported frequency bands data provided by the associated network described with DNN, or APN, and the frequency band used by the device, failures in device onboarding or connection establishment can be assessed by 5G NW AAS. As an element supporting this process, a Boolean data describing whether the device is online or not can be incorporated too. As discussed in Section 4.1.3, IP address can be used to identify the UE too. If the device is already connected, its IP address can be represented by a separate submodel element. In this submodel, the use of IP address is introduced separately, along with the device identifier (e.g., IMSI).

In addition, this submodel is useful to list the activity sessions established by the corresponding device and the associated QoS class, such as assigned 5G QoS Identifier (5QI) value. In terms of connectivity management, active part of 5G NW AAS can potentially incorporate a function that automatically configures the QoS class of a session according to the requirements. Depending on the exposure capabilities and the use case attributes, it is also possible to store individual QoS parameters (e.g., priority, guaranteed bitrate - GBR) instead of a single QoS class identifier. While the submodel defined in Section 4.1.3 is used to monitor the performance of each particular session, this submodel is designed to store information that provides a general view about the device connectivity and session management.

To illustrate how such a device session management submodel can be designed in 5G NW AAS, a set of information that represents the capabilities of an industrial device is defined in Table 6.

Table 6: Device session management submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
IMSI	Constant	International Mobile Subscriber Identity, identifying the UE

DEVICE CONNECTED	Variable	Boolean value show device is connected or not
IP ADDRESS	Variable	IP address of the device, IPv4/IPv6
LIST OF SESSION IDS	Variable	Array consists of session IDs, identifying each session established by the corresponding device
FREQUENCY BAND USED BY THE DEVICE	Variable	-
QOS CLASS OF A SESSION	Variable	E.g., 5QI value of a given session
ASSOCIATED DNN FOR A SESSION	Constant	APN can be used instead for certain network deployment

4.2 5G UE AAS

The endpoint of the 5G link at the 5G UE is described by the 5G UE AAS, which accounts for functionalities, capabilities, and performance. This AAS essentially functions as a model of a 5G-capable device. While a 5G UE can be integrated into a manufactured product, detailing all its properties within the AAS, in this project, the decision has been made to separate the 5G UE from the sensor. Both components will have their individual connections to the 5G AAS network, even though they remain interconnected.

In the context of integrating a 5G network AAS in an industrial environment, both the UE and the 5G network necessitate distinct AAS. This requirement arises from the imperative to appropriately manage and represent the diverse devices and components that may originate from various manufacturers in an industrial setting. A primary rationale for this distinction lies in the diversity of devices and suppliers. Industrial environments witness an assortment of components such as sensors, actuators, and controllers sourced from different providers. Each supplier may possess its unique set of properties, functionalities, and specific characteristics. Consequently, the AAS employed to depict these devices must possess the capability to accommodate this diversity. Simultaneously, it is crucial to consider the varying configuration and management that equipment from different sources may entail, adapting to the specific intricacies of the 5G network and UE.

The 5G UE AAS model has been divided into the following submodels:

- Equipment submodel
- SIM submodel
- QoS submodel
- Positioning submodel
- Radio submodel

- Capabilities submodel

These submodels are introduced in more detail in the following sections.

4.2.1 Equipment submodel

First, the equipment submodel, which refers to device-specific data as shown in Table 7, shall be displayed. This submodel includes the type of communications module with the corresponding Qualcomm chipset. On the other hand, the transmission power at which the equipment operates is provided. In addition, hardware-related technical specifications of the device have been included such as the type of USB port and the ethernet.

Table 7: Equipment submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
IMEI	Constant	International Mobile Equipment Identity
VENDOR	Constant	E.g., Fivecomm
DEVICE MODEL	Constant	E.g., 5G Broad v2
MODULE	Constant	E.g., RG500Q
CHIPSET	Constant	E.g., X55
CHIPSET INTERFACES	Constant	E.g., AT Commands
TRANSMISSION POWER	Variable	
POWER CONSUMPTION	Constant	
USB PORT	Constant	
ETHERNET PORT	Constant	

4.2.2 SIM submodel

The parameters related to the SIM module are specified in Table 8. These include the APN/DNN which is associated by the UE with the APN/DNN profile that is connected at any given time during the PDU establishment message.

Table 8: SIM submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
IMSI	Parameter	International Mobile Subscriber Identity
IP ADDRESS	Parameter	IP address that is currently in use
DNN	Parameter	APNs can be used in certain cases according to the network deployment

4.2.3 QoS submodel

Measuring QoS in a 5G network often involves assessing throughput (data transfer rate performance) and latency (time it takes for a data packet to travel from source to destination). Both metrics are critical to assessing the performance of a network, especially in latency-sensitive applications. Implementing these metrics allows to continuously monitor and optimize the network to meet QoS requirements. The relevant submodel elements of the QoS submodel is summarized in Table 9.

Table 9: QoS submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
THROUGHPUT	Variable	
LATENCY	Variable	
MAX. DATA UPLINK	Constant	e.g., 6.5 Mbps
MAX. DATA DOWNLINK	Constant	e.g., 2.5 Gbps

4.2.4 Positioning submodel

In this submodel, the longitude and latitude of the device shall be received. This data is essential for location awareness and tracking of other devices and many other applications. This set of information to be stored in the positioning submodel is depicted in Table 10.

Table 10: Positioning submodel in 5G UE AAS

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
LATITUDE	Parameter	
LONGITUDE	Parameter	

4.2.5 Radio submodel

In the radio submodel, several parameters related to the type of 5G technology being used will be measured. First, Reference Signal Received Power (RSRP) shall be measured to monitor the power of the reference signal received from the 5G base station. Then, measurements related to the same concept such as Received Signal Reference Quality (RSRQ) to represent the signal quality or the signal to noise ratio are added. The band and technology type indicate the frequencies and standard in each case; the Mobile Country Code (MCC) and Mobile Network Code (MNC) are numeric codes to identify the country and operator respectively; and the CellID is an identifier of the cell being used. The content of the radio submodel is shown in Table 11.

Table 11: Radio submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
RSRP_5G	Variable	5G NR Reference Signal Received Power (dBm)
RSRQ_5G	Variable	5G NR Reference Signal Received Quality (dBm)
SINR_5G	Variable	5G NR Signal-to-Interface plus Noise Ratio (dB)
TECHNOLOGY	Variable	5G-SA, NR5G-NSA, LTE, WCDMA
MCC	Variable	Mobile Country Code
MNC	Variable	Mobile Network Code
CELLID	Variable	

4.2.6 Capabilities submodel

Finally, the technical specifications of the network are shared in this submodel, where the bands of both 5G NSA and 5G standalone (SA) are specified as shown in Table 12.

Table 12: Capabilities submodel

SUBMODEL ELEMENT NAME	DATA ELEMENT CATEGORY	COMMENTS
BAND 5G NR NSA	Constant	Frequency band in 5G NR NSA network mode
BAND 5G NR SA	Constant	Frequency band in 5G NR SA network mode

5 What is next with 5G AAS?

The AAS submodels that are introduced in Section 4 constitute an example set of information that represent 5G network and 5G-capable devices from different aspects. As the next step, TARGET-X aims to develop these submodels. There are different open-source tools that provide an AAS development framework (e.g., Eclipse BaSyx, NOVAAS). TARGET-X aims to use an open-source AAS development framework based on the requirements and needs. It should be noted that during the AAS development, the submodels and associated submodel elements can be adjusted for adapting the content to the updated requirements. Based on the existing exposure capabilities provided by the assets and the requirements defined by the verticals, AAS development will be demonstrated, and details will be shared in a following deliverable.

Considering the different roles and responsibilities of AAS, there are three different AAS interaction pattern types: passive (Type 1), reactive (Type 2), and proactive (Type 3). In passive mode (Type 1), AAS can be used as a static file that provides read only access. On the one hand, AAS can be used to store information in the submodel and expose to industrial applications in a client-server manner, which makes AAS reactive (Type 2). Furthermore, proactive AAS instances can exchange knowledge by enabling peer-to-peer interaction (Type 3). In [ZVE20], the attributes of a submodel instance and a submodel element are introduced with relevant descriptions and examples. The end-to-end interoperable data exchange between AAS requires the standardized way of designing and creating submodels In TARGET-X, the main objective in AAS development is to address the vertical requirements and investigate the role in network management and asset orchestration. In these scenarios, it is envisioned that 5G NW AAS will interact with the AAS of different entities such as industrial devices. During the development phase, TARGET-X will further study on the ways of interaction between AAS instances for information and data exchange.

In this direction, the requirements of the vertical use cases will be taken into consideration. The main goal is to enable the integration of 5G systems into the I4.0 domain and AAS will be used as the main enabler through the exposures and common semantics. AAS is expected to be adopted for WP2 Manufacturing use cases such as wireless production monitoring and inline quality assurance.

After the AAS submodels are defined and implemented, AAS can be stored on a server as a file for further operations. The standardized package file format for AAS is AASX, which includes AAS structure, data, and related files [PI421]. The main use of AASX file format is to exchange information between partners and deploy AAS as a storage entity. Different open-source AASX package explorer solutions exist, which provide a graphical user interface for viewing and editing AAS content [YSH22].

In addition to the alignment with the exposure interfaces to populate any submodel integrated into 5G AAS, it is important to add functionalities in the active part of AAS. To enable future use cases of verticals, AAS implementation of network and 5G-capable devices can accommodate decision making functions as well. Through these functions integrated into AAS, the information represented in submodels can be used for management and orchestration purposes. Correspondingly, the knowledge exchanged between 5G AAS instances can be processed, and the outcomes can be used as an input for the network management and orchestration procedures. With interoperable operations in the AAS framework, the network becomes able to understand the device's capabilities and requirements, and so the resource management efficiency can be increased. TARGET-X will leverage relevant interfaces and AAS concepts to adapt the 5G network based on the dynamically changing requirements of the connected entities.

The overall end-to-end view of the AAS subsystem integrated into the large industrial ecosystem and corresponding management operations are illustrated in Figure 4. The information exchanged between different entities are shown for exemplary purposes.

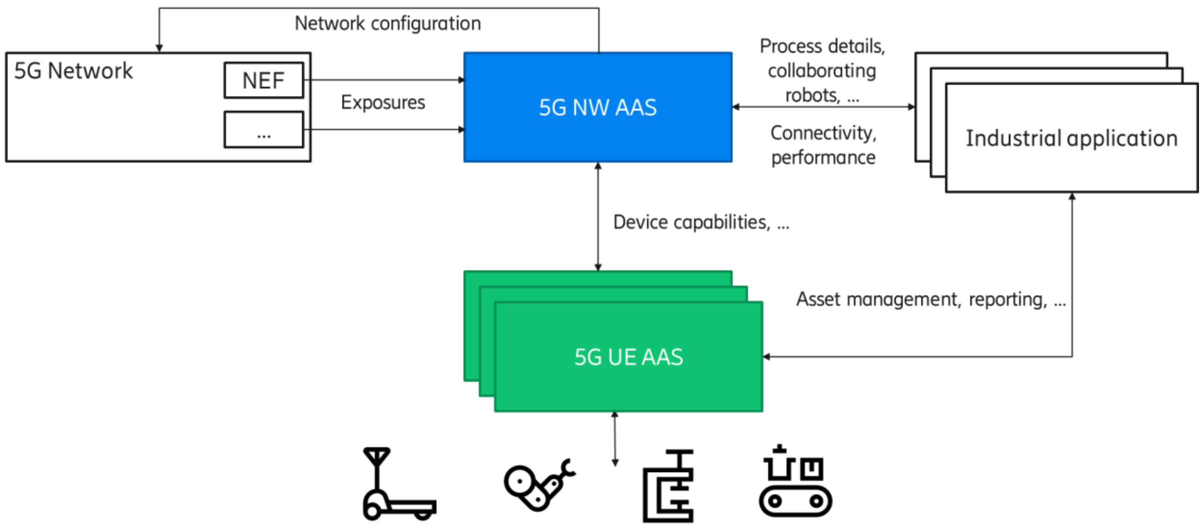

Figure 4: 5G AAS System in TARGET-X

6 Summary and conclusions

In this section, a summary of the deliverable is provided. AAS plays an important role in TARGET-X project by integrating 5G network into enterprises. In order to enhance the degree of automation for the network management and asset orchestration functions, the AAS representations of 5G network and 5G-capable devices can define relevant submodels and interaction models in the factory floor.

To make use of AAS to its full potential, the alignment with the exposure capabilities provided by the assets (e.g., 5G network, end devices) should be maintained. The data and service exposures are key ingredients of the AAS ecosystem in populating the submodels and configuring the assets based on the information exchanged between different systems.

The submodels of 5G NW AAS and 5G UE AAS introduced in this deliverable are provided as examples that are envisioned to be integrated. Based on the requirements of the verticals and use cases, necessary submodels that take role in providing valuable insights for the enterprises and the network will be explored and developed during the project.

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