# Asset Administration Shell Digital Twin of 5G Communication System

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Keywords: Asset Administration Shell, 5G, Digital Twin, Industry 4.0.

Abstract: A fundamental element within Industry 4.0 is the digital twin, which allows the development of a virtual model of a facility, with the aim of monitoring, managing, and simulating its operation, thereby enhancing control in testing, analysis, prediction, and risk prevention for sensitive processes. The communication system is an important part of highly interconnected Industry 4.0 systems; in particular, that based on wireless transmission plays a very strategic role mainly due to the reduced complexity in installation and maintenance. If changes are necessary in the production system, the communication system should be adapted accordingly. Modelling a communication system by a digital twin has the advantage to quickly allow updating the communication parameters according to the changed needs of the production system. Among the available wireless communication systems, the use of 5G inside industrial production seems very promising. This paper proposes to represent 5G-based communication system elements using the Asset Administration Shell model, which is one of the existing standards for the digital representation of assets inside Industry 4.0.

## 1 INTRODUCTION

Among the main features of the Industry 4.0, there is the definition of increasingly flexible, interoperable, and innovative systems, focusing on a continuous evolution of technologies capable of shifting the management of an asset from the physical domain to the virtual domain (Xu et al., 2018; Cotrino et al., 2020). A fundamental architectural element within Industry 4.0 is the digital twin, which is a digital representation of a real asset. A digital twin allows replicating a facility, with the aim of monitoring, managing, and simulating its operation, thereby enhancing control in testing, analysis, prediction, and risk prevention for sensitive processes (Mihai et al., 2022; Javaid et al., 2023).

A digital twin includes all the information representative of the real system to be modeled; furthermore, functions/applications using the digital information collected from the real system may be defined inside a digital twin. The digital twin and the physical part can exchange data for real-time awareness, process control and decision making (Schroeder et al., 2016;Wei et al., 2019).

The Asset Administration Shell (AAS) was introduced by Plattform I4.0 (www.plattform-i40.de) in 2016 as a core element of the Reference Architectural Model for Industry 4.0 (RAMI 4.0) (DIN, 2016). The Industry 4.0 component has been described within RAMI 4.0 as the combination of the asset and its digital representation (DIN, 2016; Wagner et al., 2017; Ye and Hong, 2019). The AAS is considered the official standard for the digital representation of components within the Industry 4.0 system.

The communication system is an important part of highly interconnected Industry 4.0 systems; in particular, that based on wireless transmission plays a very strategic role mainly due to the reduced complexity in installation and maintenance. If changes are necessary in the production system, the communication system should be adapted accordingly. Modelling a communication system by a digital twin has the advantage to quickly allow update of the communication parameters according to

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Cavalieri, S., Di Natale, R. and Gambadoro, S.
Asset Administration Shell Digital Twin of 5G Communication System.
DOI: 10.5220/0012914200003822

In *Proceedings of the 21st International Conference on Informatics in Control, Automation and Robotics (ICINCO 2024) - Volume 2*, pages 395-402
ISBN: 978-989-758-717-7; ISSN: 2184-2809

the changed needs of the production system. For this reason, the communication system and in particular a WCS, must be considered when realizing the digital twin of the production system.

Among the available wireless communication systems, the use of 5G network inside industrial production seems very interesting. Literature presents several papers pointing out the advantages of its use in Industry 4.0 contest (Ordonez-Lucena et al., 2019; Meira et al., 2023).

The aim of this work is to present a digital twin of the 5G-based WCS elements using the Asset Administration Shell. The paper will describe the AAS model defined by the authors and will provide an example of how the AAS model can be used in a real 5G communication scenario.

## 2 RELATED WORK

The current literature offers a huge set of papers about the use of the Asset Administration Shell for the digital representation of industrial assets. In (Inigo et al., 2020; Hu et al., 2023) the current state of the art about realizations of digital twins by the AAS metamodel is presented, proving the relevant feasibility of representing heterogeneous industrial assets. Among them, examples of use of AAS for modelling communication subsystems are present.

Considering the modelling of 5G communication systems by AAS, literature presents some publications. One of the available documents is a white paper written by 5G Alliance for Connected Industries and Automation (5G-ACIA, 2021). It points out the importance of integrating 5G into Industry 4.0 by defining a 5G AAS. The document does not present a detailed AAS model of the 5G communication system, but it points out the main features to be hold by a digital twin based on AAS, in order to properly represent a 5G communication system. A very general description of an AAS model is proposed, formulating only the main components that should be included in the model.

Another document available in the current literature about 5G modelling by AAS is given by (Cainelli et al., 2022). In the paper, the authors present a proposal of AAS model of 5G WCS, describing a communication submodel for a 5G-enabled device. Two AAS submodel elements were defined as the main relevant to a 5G device. The proposal does not take into account the general concepts given by (5G-ACIA, 2021).

As said in the Introduction, the aim of this paper is the proposal of a AAS digital twin of 5G communication system. On account of what written about the current state-of-the-art, it seems that the proposal here presented is original for two reasons. The first is that it gives a very detailed definition of the AAS model of 5G communication system, more than the other works present in the current literature; moreover, this proposal is fully based on the considerations and architecture drawn in (5G-ACIA, 2021). This last point is very important according to the authors' point of view; 5G-ACIA brings together widely varying 5G stakeholders and for this reason the authors believe that including the relevant considerations and vision of the AAS 5G model should be important.

## 3 ASSET ADMINISTRATION SHELL

The AAS is the implementation of the digital twin for Industry 4.0 from the perspective of Plattform I4.0 (Gowtham et al., 2021; ZVEI, 2022). It is under development by project 63278-1 of the International Electrotechnical Commission.

The AAS is composed of a passive part and an active part, as shown by Figure 1.

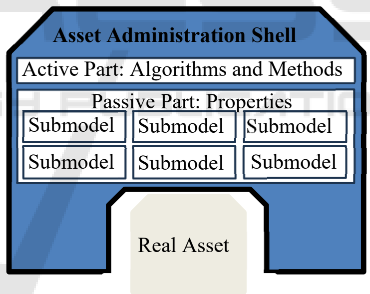


Figure 1: Asset Administration Shell.

The passive part contains the properties of the asset which are readable and/or modifiable. The active part consists of functions performed by the AAS; it incorporates decision-making functions and interaction mechanisms that enable peer-to-peer interaction.

The asset's information is described in the AAS as Submodels. Below the submodel level, there are the submodel elements (SubmodelElements), which store specific data related to the submodel. For example, a property, which is a submodel element type, can contain a value that represents a physical variable of the asset. The SubmodelElementCollection (SMC) plays a crucial role in this context, as it is defined as a set or list of SubmodelElements.

The AAS metamodel introduces an important referencing mechanism to establish relationships among the entities that make up the AAS. This mechanism relies on the ReferenceElement, through which structured navigation within the AAS becomes possible. For example, if one submodel refers to another through a ReferenceElement, it is possible to follow this link to access the related information. Navigation may be realized also among several AASs; a ReferenceElement of a particular AAS submodel may point to a different AAS.

One of the core entities of the AAS metamodel to achieve interoperability is ConceptDescription; it is used to define the semantics of entities inside the AAS metamodel. Every element in AAS may have its semantics described by a ConceptDescription.

In the Asset Administration Shell, Submodel Templates allow for establishing a standardized and consistent structure for submodels within an AAS (ZVEI, 2020).

# 4 THE 5G AAS MODEL

The 5G-ACIA proposes two Asset Administration Shell models called 5G Network AAS and 5G UE AAS (5G-ACIA, 2021).

The 5G Network AAS represents the enabling networking function, which includes all nodes and functions within the 5G RAN (Radio Access Network) and CN (Core Network) that do not belong to 5G-capable IIoT devices.

The 5G UE AAS describes the endpoint of the 5G link located on the device, which corresponds to the 5G UE (User Equipment), and analyzes its functionalities, capacities, and performances as defined by 3GPP (3GPP, 2020).

The white paper (5G-ACIA, 2021) outlines the main features of these two AASs, without specifying the structures of the various submodels. The authors have therefore undertaken further works to structure these models and then to implement them. In the following paragraphs, the details about the models defined by the authors will be given, focusing more on the 5G UE AAS, only for space reasons.

## 4.1 The 5G Network AAS

The 5G Network AAS presented in (5G-ACIA, 2021) has been defined and implemented by the Asset Administration Shell named AAS_5G_Network.

It was organized into the following submodels:

- Asset Service Registry. It registers the services offered by assets in the network and tracks them to facilitate access and management.
- 5G Network ID. It handles the management of a wide range of essential identifiers used for the identification and management of users and devices within the Radio Access Network and the Core Network.
- 5G Network Data Sheet. It contains detailed technical information about the 5G network, including equipment specifications, network configurations, and other crucial information for network design and maintenance.
- Physical & Logical Topology. It describes the physical and logical configuration of the 5G network, providing a comprehensive overview of the network structure and interconnections between its components.
- PDU Sessions/QoS Flows. It contains information about data transfer sessions and quality of service, ensuring that network traffic is efficiently managed and meets user needs.
- Performance. It contains metrics on the performance of the 5G network, allowing evaluation of network efficiency and reliability.

## 4.2 The 5G UE AAS

The 5G UE AAS presented in (5G-ACIA, 2021) has been defined and implemented by the Asset Administration Shell named AAS_5G_UE. In the following subsections the submodels defined and implemented by the authors, will be described.

### 4.2.1 Equipment Identifier Submodel

The Equipment Identifier Submodel maintains a wide range of essential identifiers for user and device identification and management within the network. These identifiers, such as the Subscription Permanent Identifier (SUPI), the Subscriber Concealed Identifier (SUCI), the 5G Globally Unique Temporary Identity (5G-GUTI), and others, play a fundamental role in managing connections and services within the network.

In addition to user and device identifiers, the submodel also includes information such as the name of the Access and Mobility Management Function (AMF), the Data Network Name (DNN), and network slice identifiers, which are needed for the proper delivery of services and efficient network resource management.

#### 4.2.2 Certification Status Submodel

The Certification Status Submodel represents the set of information related to the X.509 certificate associated with a UE device within a 5G network.

This submodel provides a detailed view of the various fields comprising the certificate, enabling efficient and secure management of security in the 5G environment. Among the fields included in this submodel there are fundamental pieces of information such as the certificate version, serial number, signature algorithm used, and the issuing authority. Additionally, details about the certificate's validity, including the validity period and associated policies, are also represented.

The structure of this submodel is designed using the SMC to define fields composed of multiple properties. For example, the Validity field, consisting of two properties - notBefore and notAfter, is implemented through a SMC.

Conversely, individual properties are represented using SubmodelElements of type Property. A key field is the Certificate field, represented through a SubmodelElement of type Blob, allowing for the retention of the actual certificate file. In addition to details about the issuer and subject of the certificate, the submodel also includes information about the public key associated with the certificate, as well as key usage restrictions and certificate extensions.

#### 4.2.3 Network Access Restrictions Submodel

The Network Access Restrictions Submodel is designed to manage network access restrictions within a specific system or environment. This Submodel is structured into two distinct SMCs: GeofenceArea and ListOfCGIs.

GeofenceArea contains information related to geographical areas defined as "geofences", which can be used to restrict or allow network access in specific geographical locations. Each element within this SubmodelElementCollection represents a precise geographical area defined by geographical coordinates. Geographical coordinates are represented through SubmodelElement of type Property.

On the other hand, ListOfCGIs contains a list of CGIs (Cell Global Identity), which are unique identifiers for cells within a mobile network. CGIs allow for the specific identification of a cell within a cellular network and can be used to apply access restrictions based on cell location. CGIs are formed by sub-identifiers such as PLMNID, LAC, and CI, and for this reason, each CGI is represented through a SMC.

#### 4.2.4 5G-UE Data Sheet Submodel

This submodel contains detailed specifications of the user equipment, e.g., hardware capabilities, supported 5G bands, throughput capacities.

To implement the 5G UE Data Sheet submodel, the Technical Data submodel template provided by Industrial Digital Twin Association (IDTA) was used (Industrial Digital Twin Association, 2024).

#### 4.2.5 Connectivity QoS Requirement Submodel

The submodel Connectivity QoS (Quality of Service) Requirement submodel defines the expected level of service quality that the network should provide to the device, which could include parameters like latency, bandwidth, and reliability.

The submodel was realized following the VDI/VDE 2192 (VDI/VDE, 2020). This submodel contains a main submodel collection called “Subscription” composed by ten submodel collections for supporting the quality-of-service-parameters, e.g., “Response Time”, “Trasmission Time”, “Update Time”. Each of these submodel collections describes a couple of requested value and guaranteed value parameters.

#### 4.2.6 QoS Monitoring Submodel

This submodel allows to monitor the device's actual performance against the QoS requirements, potentially for adaptive network management or SLA (Service Level Agreement) adherence.

In this submodel some characteristic parameters such as transmission time and update time are considered. As done for the previous submodel, it was modeled following the VDI/VDE 2192 (VDI/VDE, 2020).

#### 4.2.7 Positioning Data Submodel

The Positioning Data Submodel represents a crucial set of information for the precise localization of User Equipment (UE) devices within a 5G network. This submodel provides data regarding the geographical position of the UE, along with details about the received signal quality.

The geographical coordinates, collected through a SMC, include latitude and longitude, represented by a SubmodelElement of type Property. Through these coordinates, precise localization of the UE within the geographical context is achieved. This information is complemented by signal data, such as the Reference Signal Received Power (RSRP), the Signal-to-Noise

Ratio (SNR), and the Channel Quality Indicator (CQI), which are represented by SubmodelElements of type Property and are contained within a SMC called Signal Info. These properties provide indications of the quality and intensity of the signal received by the UE device.

## 5 CASE STUDY

The aim of this section is to present an example of application of the AAS-based modelling of the 5G UE-5G Network System, proposed in this paper.

The scenario considered for the case study features the use of a private 5G network to convey communications between Programmable Logic Controllers (PLCs) using the PROFINET communication protocol (Pigan and Metter, 2015).

Wired communication systems like PROFINET are widely used in industrial communication, mainly for their capability to guarantee a reliable, real-time deterministic data transmission. However, wired data transmission may not be feasible where non-stationary devices are involved; in this case, wireless technologies such as 5G can be applied. To combine wireless and wired transmission, suitable communication protocols that allow the integration of these technologies are needed.

Currently it is not possible to transmit PROFINET frames directly over 5G without using tunneling protocols; this because 5G communication system use the IP as layer 3 protocol, whilst the PROFINET protocol uses only layer 2 frames. A solution for this is the use of protocols like Virtual Extensible LAN (VxLAN) (Mahalingam et al., 2014) or Generic Routing Encapsulation (GRE) (Yegani et al., 2011). Tunnelling is commonly realized by the use of two devices - one wired and the other wireless. A wired Tunneling device is tailored to establish communication with the 5G core network via an Ethernet connection, and subsequently create a tunnel for the transfer of PROFINET packets, while ensuring that vital metadata and information related to the packet’s type of service is preserved. The wired Tunneling device establishes a transparent connection between a PLC and slave devices, while simultaneously informing the cellular network about the priority level of each packet and allocating distinct bearer channels for different types of traffic. A 5G-wireless router fulfils high-speed wireless connectivity requirements of industrial cabinets and mobile devices, offering the traffic prioritization and routing capabilities.

In the case study here considered, it has been assumed that a PLC featuring the PROFINET Controller role must communicate with one or more PLCs with PROFINET Device role, through a 5G network. For this reason, the PLC Controller is connected to a Tunneling device (through a switch) which is able to tunnel Layer 2 frames through Layer 3 protocol (assuming to use VxLAN protocol).

Figure 2 shows the case study here considered and based on the wired (Tunneling device) and wireless (5G-wireless router) devices just described. As shown by the Figure 2, a 5G-wireless router allows the data exchange between the PLC Controller and the PLC Devices, featuring the traffic prioritization and offering routing capabilities.

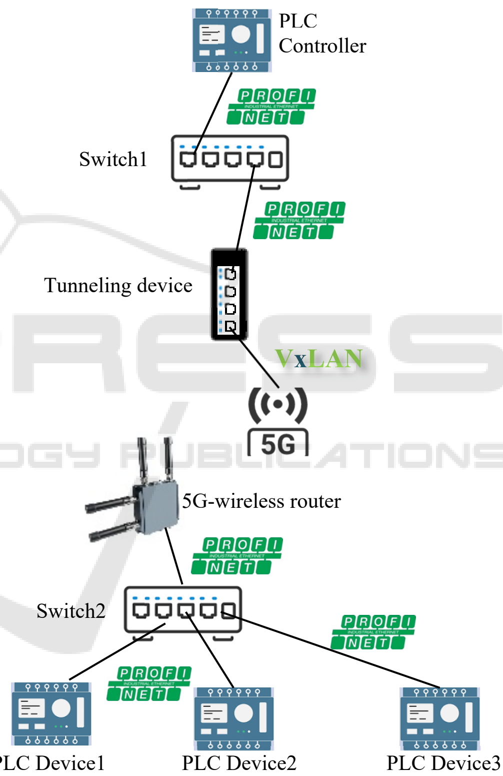


Figure 2: Case study scenario.

### 5.1 AAS Models

The scenario shown by Figure 2 includes the 5G network and the 5G user equipment, whose AAS models have been introduced in Section 4. But the scenario contains other components, whose relevant AAS models will be introduced in the following.

The AAS_ModularComputingSystem has been defined by the authors to allow the digital representation of modular computing systems such as

PLC, composed of interconnected modules with at least one possessing computing capabilities.

The AAS_CommunicationSystem has been designed to provide the digital representation of network communication devices, e.g. switches.

The AAS_CommunicationProtocol has been defined by the authors to represent each communication protocol used in the communication system. This AAS includes information about the configuration and parameters required to implement the protocol.

These AAS models have been introduced by the authors in another paper (Cavalieri and Gambadoro, 2024); the reader may refer to it to have more details.

## 5.2 Digital Twin of the Case Study

The aim of this sub-section is to present the AAS-based Digital Twin of the communication scenario shown by Figure 2. Figure 3 gives the graphical representation of the AAS-based Digital Twin.

The case study features a PLC with PROFINET Controller role and several PLCs with Device role. The AAS_ModularComputingSystem has been used to model each single PLC. Figure 3 shows the instance modelling the PLC Controller; for space reason, only one AAS model representing a PLC with Device role has been represented (PLC Device1). In each AAS modelling the PLC (both Device and Controller), the Submodel Modules includes the representation of the Ethernet port; a ReferenceElement points directly from the PLC Ethernet module to the AAS modelling the relevant switch, as shown by Figure 3.

To model each of the two switches, the AAS_CommunicationSystem model was used. Through the Connections submodel, the ReferenceElement Device allows to point to the AAS model of the devices to which each switch is connected. For example, considering the Switch1, the reference will point to the AAS models relevant to the PLC Controller and to the Tunneling device. In each instance of the AAS_CommunicationSystem that models a switch, the Connections submodel will include the ReferenceElement DeviceProtocol, which points to the AAS that models the communication protocol used for communication between the switch and each connected device. Considering both switches in our case study, this reference will point to the AAS model representing the PROFINET communication protocol (described in the following). In particular, Profinet1 is the AAS model of the PROFINET protocol relevant to the communication between the Switch1 and the PLC Controller; Profinet2 is the AAS model of the PROFINET protocol relevant to the communication between the Switch1 and the Tunneling device. Profinet3 and Profinet4 are the AAS models representing the PROFINET protocol relevant to the communications between Switch2 and 5G-wireless router and between Switch2 and PLC Device1, respectively.

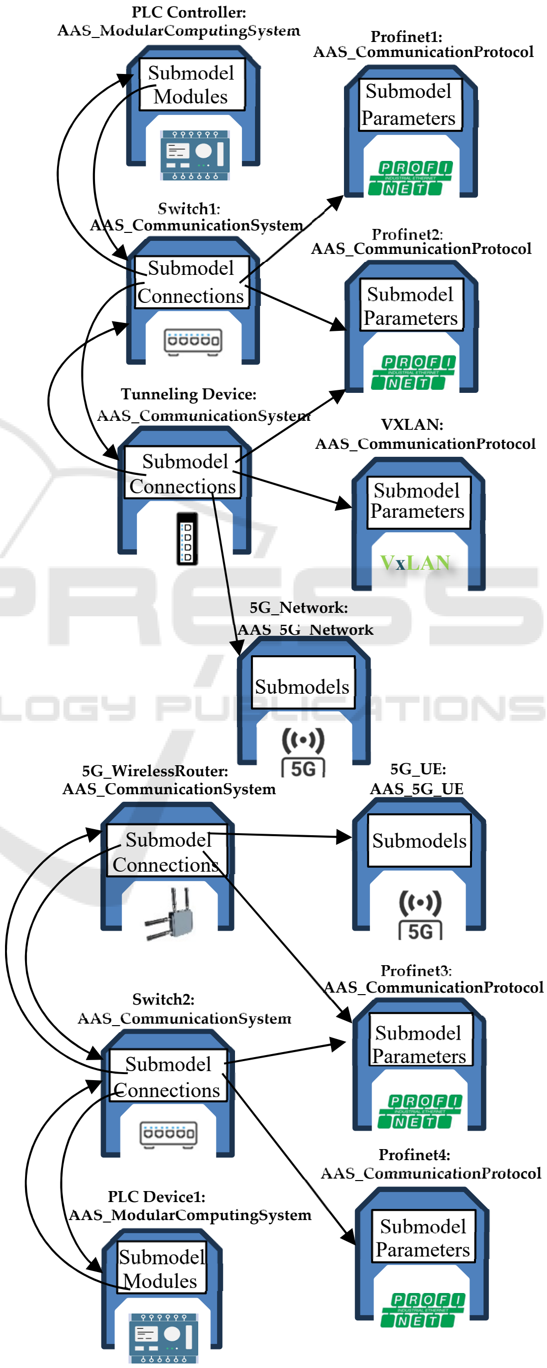


Figure 3: Digital Twin by AAS of the case study scenario.

The AAS model of the Tunneling Device has been realized as an instance of the AAS_CommunicationSystem type. Through the Connections submodel, the ReferenceElement Device allows to point to the AAS models of the devices to which the Tunneling device is connected, i.e. the Switch1 and the 5G network system. The ReferenceElement DeviceProtocol will point to the AAS modelling the communication protocol used for the communication between the Tunneling device and each device connected. In this scenario, a DeviceProtocol reference will point to the Profinet2 AAS modelling the PROFINET protocol used between the Tunneling device and the Switch1; another DeviceProtocol reference will point to the AAS describing the VxLAN protocol (described in the following) used between the Tunneling device and the 5G network.

The 5G network system has been represented using an instance of the AAS_5G_Network type, proposed in this paper. Through the AAS, a structured representation of the 5G network is provided, including all network nodes and their respective functions. The AAS's capability to provide details on the physical and logical topology of the network, along with PDU sessions and QoS flows, ensures excellent management of data traffic. Additionally, the 5G Network AAS constantly monitors network performance, allowing for continuous assessment of the efficiency and reliability of wireless communications in the production environment, thereby facilitating optimization of operations within the system.

The model of the 5G-wireless router device has been done considering the router as a communication system made up by an internal component realizing the 5G UE. Based on this assumption, instances of the AAS_CommunicationSystem and AAS_5G_UE types were considered. The instance of AAS_CommunicationSystem type (i.e. 5G_WirelessRouter in Figure 3) represents the router, whilst the other instance (i.e. 5G_UE) is the digital representation of the 5G UE component of the router. Through the Connections submodel, the ReferenceElement Device allows to create a reference from the AAS modelling the 5G-wireless router to the AAS 5G_UE. Another ReferenceElement Device is contained in the Submodel Connections, pointing to the AAS modelling the Switch2, as the 5G-wireless router is attached to the switch. In the AAS modelling the 5G-wireless router, the Connections submodel will also include the ReferenceElement DeviceProtocol, which points to the AAS modelling the PROFINET communication protocol used for communication between the 5G-wireless router and the Switch2 (i.e. Profinet3), as shown by Figure 3.

The AAS_CommunicationProtocol has been used to represent the PROFINET protocol. For each pair of devices connected by this protocol, an instance of the AAS_CommunicationProtocol have been considered to represent the main features of the PROFINET communication. Among the parameters that can be managed there are: IP address, SubnetMask, SendClock, and UpdateTime.

The AAS_CommunicationProtocol has been instantiated to represent the VxLAN protocol. This protocol is used in the communication between the Tunneling device and the 5G network system and between the 5G network system and the 5G Wireless Router. An instance of the AAS_CommunicationProtocol is referenced by DeviceProtocol ReferenceElement pointing from the Submodel Connections of the AAS representing the Tunneling device, as shown by Figure 3.

# 6 CONCLUSIONS

The paper pointed out the importance to realize a digital twin of a 5G wireless communication system. A solution based on the use of Asset Administration Shell metamodel has been presented in this paper. Originality of the proposed approach has been pointed out, considering the current state-of-the-art. A case study has been shown in order to better understand the AAS model and to demonstrate the feasibility of the proposal. The AAS model here proposed has been implemented using the AASX Package Explorer, that is a tool provided by the Industry 4.0 consortium.

# ACKNOWLEDGEMENTS

This work has been supported in part by the Research Grants from European Union – NextGenerationEU – PNRR within the project “RESearch and innovation on future Telecommunications systems and networks, to make Italy more smART” - RESTART, C.I. PE00000001, CUP E63C22002070006, and in part by the Research Grants from Fondo per la Crescita Sostenibile – Accordi per l'innovazione "Fabbrica Intelligente", within the project "Water 4.0", Prog n. F/160041/03/X41 - CUP: B69J24001170005.

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