DESCRIPTION OF THE TESTBED CAPABILITIES AND ENVISIONED EVOLUTION WITHIN THE PROJECT

Deliverable D6.1

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Deliverable

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SHORT ABSTRACT	This deliverable introduces the testbeds of TARGET-X and their planned evolution within the project.
KEYWORDS	Testbed, evolution, 5G, QoS, positioning, real-time, manufacturing, automotive, robotics, energy, mmWave, AAS
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Executive Summary

This document describes the different testbeds used in TARGET-X by first explaining the individual testbed setups as they exist at the start of the project. The testbeds for the four verticals in TARGET-X are spread across two locations, with four testbeds being part of the 5G-Industry Campus Europe (5G-ICE). The fifth testbed is located on the automotive testing grounds of IDIADA in Spain.

The testbed for the energy vertical is a distributed testbed, where phasor measurement units (PMUs) are installed at different locations across the 5G-Industry Campus Europe to collect data for further processing at a central location. The robotics and cloud-native production testbeds represent the manufacturing vertical in TARGET-X and are located in the WZL, respectively, Fraunhofer IPT machines halls. The construction testbed completes the testbeds at the 5G-ICE site. The four testbeds have access to the 5G (N)SA infrastructure, a standalone non-public network.

The automotive testbed, located at IDIADA, has different test tracks to cover many different road conditions. The whole area is covered by cellular technology from 2G to 5G. Its infrastructure is part of an MNO public network, using a dedicated PLMN to route data to an on-premises cloud infrastructure.

Furthermore, this document expands on the technology elements chosen as relevant elements in the evolution of the 5G technology towards 6G. QoS and other methods to manage the growing number of services are handled in 'Service differentiation and network convergence'. Exploring the mmWave spectrum for industrial use defines the second selected technical element. The Asset Administration Shell (AAS) models the different aspects of a 5G network and their interaction with a factory cloud. Positioning with 5G covers the applicability of positioning for the verticals in TARGET-X. The fifth element in focus is the real-time ecosystem, where the real-time capabilities of 5G combined with Time Sensitive Networking and DetNet are explored.

Besides the description of these technical elements, an indication is given in which of the TARGET-X testbeds these technologies shall be explored during the project.

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List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
5G-ACIA	5G Alliance for Connected Industries and Automation
5G-ICE	5G-Industry Campus Europe
AAS	Asset Administration Shell
AI	Artificial Intelligence
AMR	Autonomous Mobile Robot
API	Application Programming Interface
APN	Access Point Name
CCR	Center for Construction Robotics
CN	Core Network
DNN	Data Network Name
FIR	Forschungsinstitut für Rationalisierung (German)

FSTP	Financial Support for Third Parties
GHz	Gigahertz
GNSS	global navigation satellite system
GPS	Global Positioning System
HW	Hardware
IPT	Fraunhofer Institute for Production Technology IPT
JCAS	Joint Communication and Sensing
KPI	Key Performance Indicator
KVI	Key Value Indicator
LIDAR	Light Detection and Ranging
LTE	Long Term Evolution
LV	Low Voltage
ML	Machine Learning
MNO	Mobile Network Operator
MV	Medium Voltage
NR	New Radio
NSA	Non-standalone Architecture
NW	Network
PLMN	Public Land Mobile Network
PMU	Phasor measurement unit
RAMI	Reference Architecture Model Industry 4.0
RAN	Radio Access Network
ROS	Robot Operating System
RTK	Real-time Kinematic
RWTH	Rheinisch-Westfälische Technische Hochschule (German)
SA	Standalone Architecture
SIM	Subscriber Identity Module
SNPN	Standalone non-public network
SW	Software
TDD	Time Division Duplex
TSN	Time Sensitive Networking
TTFF	Time To First Fix

UE	User Equipment
UPF	User Plane Function
URLLC	Ultra Reliable Low Latency Communication
VDE	Verband Deutscher Elektrotechniker (German)
VDI	Verein Deutscher Ingenieure (German)
WZL	Werkzeugmaschinenlabor (German)

1 Introduction

The deliverable describes the testbeds in TARGET-X and their evolution within the project.

TARGET-X introduces and evaluates use cases from four different verticals. Each of these verticals provides a testbed for the project. This document gives an overview of these testbeds and the relevant infrastructure, tools, and equipment of each testbed contributing to the project.

The evolution of 5G towards 6G is the subject of WP6, and TARGET-X has chosen some technology enablers that are considered relevant in this evolution.

The document describes these technology enablers and proposes an introduction strategy for integrating them into the testbeds, as it is assumed that the different verticals have varying requirements for the selected features.

During the runtime of TARGET-X, two further reports will be published. The current report sets the starting point for the evolution of the testbeds. The subsequent reports will further focus on implementing and validating the planned features.

1.1 Document structure

The document is structured as follows: Section 1 briefly introduces the deliverable. Section 2 describes the testbeds within the project. Section 3 elaborates on the identified technology elements in the evolution beyond 5G. A view on the expected introduction in the testbeds is also covered in this section. Section 4 summarizes the document and presents conclusions.

2 Testbeds in TARGET-X

TARGET-X explores use cases from four different verticals on two geographical sites. One 5G site is located in Aachen, Germany, and the second is near Barcelona, Spain. Both test sites bring unique testing possibilities to TARGET-X, offering a broad spectrum of available technologies and infrastructure, 5G network architectures, and layouts.

2.1 5G-Industry Campus Europe (5G-ICE)

The 5G-Industry Campus Europe (5G-ICE) [5GI23] is one of the German government's official 5G model regions and, at the time of the application, the largest industrial 5G testbed in Europe. It is a large-scale research infrastructure to validate 5G in production. The 5G-ICE is located on the Melaten Campus of RWTH Aachen University, a university of excellence famous for engineering sciences.

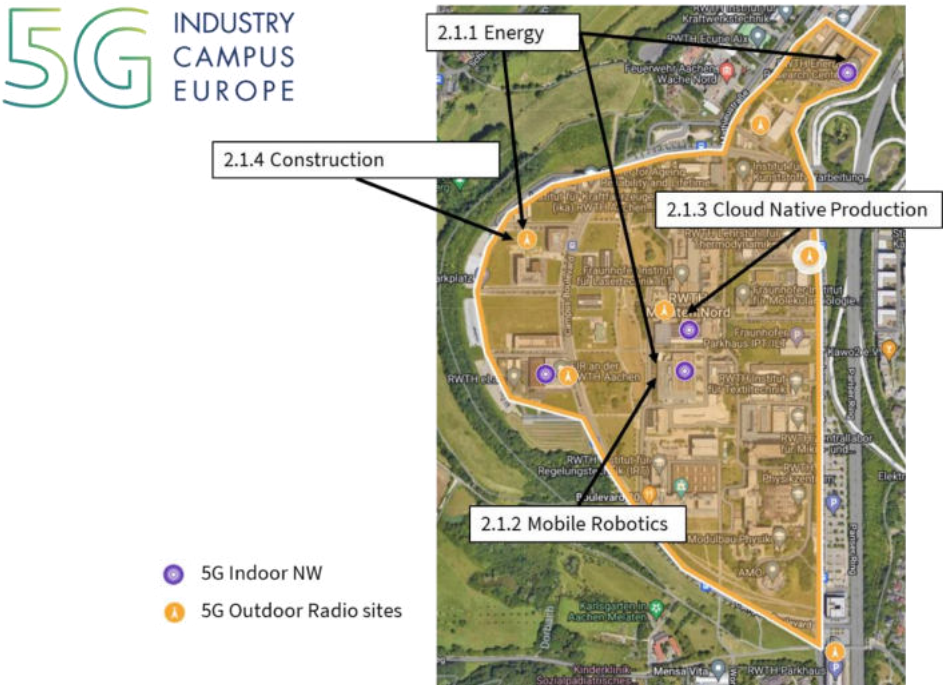


Figure 1: Representation of 5G-Industry Campus Europe and the TARGET-X testbeds
Courtesy: Google Maps

Two factors contribute to the uniqueness of 5G-ICE, being a complete 5G infrastructure and the cooperation of three production research institutes:

- the Fraunhofer Institute for Production Technology IPT
- the Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University
- the Institute for Industrial Management (FIR) at the RWTH Aachen University.

All three institutes are equipped with 5G indoor networks covering a total of 8.000 m^2 of shopfloor with multiple state-of-the-art machines and robots. Additionally, the Melaten Campus is covered with a 5G outdoor network of approximately 1 km^2. All sites have a local breakout via dedicated user plane functions (UPFs) with independent tenant configurations to have the entire network capacity for the use cases on each site. 5G-ICE is operated as a standalone non-public network (SNPN) with a central core network hosted at Fraunhofer IPT, the central coordinator of the 5G-ICE. The 5G network is based on Ericsson's 3GPP Rel. 15 compliant network equipment. It runs on a dual-mode core, with 5G NR in the spectrum at 3.7-3.8 GHz and an LTE anchor band at 2.3-2.32 GHz.

The 5G-Industry Campus Europe hosts several research projects and attracts significant interest from academia and industry across Europe, both digitally on its LinkedIn pages and physically, by rendering the research in the industrial 5G field tangible to visitors with several demonstrators.

Within TARGET-X, the 5G-Industry Campus Europe integrates four testbeds for manufacturing and robotics, construction, and energy verticals. Each testbed is tailored for exploring and developing use cases of the respective verticals.

2.1.1 Energy monitoring testbed

The energy pilots cover different verticals, focusing on

- measurement for energy awareness,
- carbon and lifecycle emission assessment,
- data-driven energy decision-making enablers,
- optimization and monetization possibilities

in a cross-vertical approach. The energy monitoring testbed's realization uses a multi-site set-up, reflecting the cross-vertical approach. The monitoring setups used to sample data on the three subsites will be connected to the existing 5G-ICE infrastructure. Both the indoor as well as the outdoor 5G networks will be used. The three subsites used in TARGET-X are described in the following paragraphs.

Energy Subsite 1: Campus distribution grid

This trial will be built in the RWTH Campus Melaten in Aachen and showcase Smart Grid technology in a live setting. RWTH Aachen has been developing this new campus in the last few years, and new buildings are added regularly. This creates a dynamic setting with various electrical load characteristics, offering an excellent environment for Grid Automation Services. The RWTH Campus Melaten private grid is a mix of medium voltage (MV) and low voltage (LV) infrastructure connected to the main public grid at two different points, each with two substations. The grid is equipped with local generation capacity based on classical generation and renewables, even if it is not equipped to operate as an island. It is organized into four main feeders in MV with numerous reconfiguration options. In addition, charging points for electric vehicles are also connected to the grid. In the H2020 project SOGNO, early versions of a phasor measurement unit (PMU) implementation [3GP21-22867] are already available in the grid, as shown in Figure 2, and are updated and integrated into the monitoring system for use in TARGET-X.

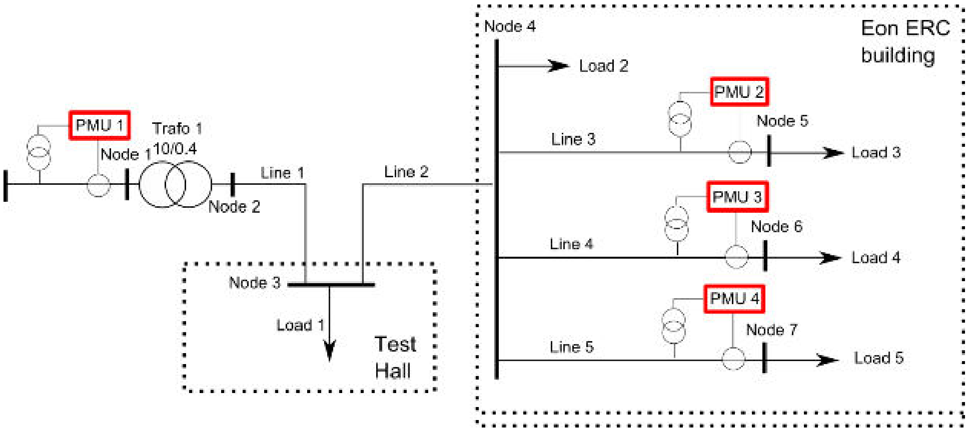


Figure 2: Campus distribution grid monitoring setup

Energy Subsite 2: WZL line-less mobile assembly laboratory

A selection of machines on the WZL shopfloor will be equipped with energy measurement capabilities. The energy measurement devices will be connected to the existing 5G indoor network to report the continuously captured samples to the backend servers for further processing. The installation of edge devices in the in-building electrical grid and machines enables the development of use cases related to consumption, power requirements in the process, and forecasting of energy needs in this vertical.

Energy Subsite 3: CCR reference construction site

On this subsite, TARGET-X aims to deploy the infrastructure on the premises necessary to measure the power consumption of the overall construction site and a selection of individual machines. The learnings and collected data will be interesting for enhancing energy awareness and process automation capabilities. The measurement activities aim to understand better how to increase efficiency, sustainability, and energy management, specifically for the construction domain.

The impacts of connecting the measurement units to the 5G network at the different subsites are expected to be in two main areas: devices and network configuration. A suitable mounting method must be found on the device side, as electrical installations are typically well shielded and/or in technical spaces. On the network side, transmitting the measurement data samples needs to happen with high reliability, raising the need for proper QoS handling.

2.1.2 Mobile robotics testbed

The assembly and mobile robotic use cases are conducted in WZL's line-less mobile assembly laboratory. The lab consists of multiple robots, real industrial product cases, large-scale metrology systems, and a 5G indoor network as part of the 5G-Industry Campus Europe. The robot fleet is very heterogenous and can be controlled by open-source control architecture based on ROS. Available robots are autonomous mobile robots (AMR), like an Imetron Donkey-Motion, BÄR-AGV, and Festo Robotinos, several mobile manipulators (2x Robotnik Kairos UR10 & 1x KUKA KR120), multiple semi-stationary industrial robots (1x ABB IRB 4600 on linear-axis & 2x ABB IRB 4600 on movable platforms).

Regarding large-scale metrology systems, WZL has a variety of measurement systems suitable for ground-truth benchmarking of 5G localization setups in 25 x 5 m². Dependent on the required measurement uncertainty, the indoor GPS (0,2 mm multi-target tracking), motion-capturing system OptiTrack (0,4 mm dynamic multi-target tracking), or a Lasertracker system (0.1 mm one-on-one tracking) can be utilized. Additionally, the URLLC-testbed located at Fraunhofer IPT can also be moved to the neighboring shopfloor of the WZL. This testbed allows for the exploration of URLLC-demanding robotics applications. The existing infrastructure, an indoor NSA-based 5G network, can be utilized for development, testing, and validation experiments.

The laboratory represents a simulated (close to real-space) environment of modern industrial shopfloors. Industrial products for testing real industrial processes are provided from automotive/truck or aerospace assembly from previous research projects. Thus, the transferability of results to the industry can be assured.

2.1.3 Cloud Native Production testbed

At the Fraunhofer IPT, a shopfloor of 2.700 m² is covered with a 5G indoor network as part of the 5G-Industry Campus Europe. At the IPT trial site, manufacturing applications are addressed. IPT possesses a comprehensive set of machine tools for manufacturing, including multiple 5-axis and 3-axis milling machines, combined milling and turning centers, production metrology like coordinate measuring machines and optical sensors, injection molding, embossing machines, and laser material processing machines. The IPT trial site provides an ideal playground for testing 5G and 6G technology in a realistic environment. In addition to the production and mobile communication equipment, the Fraunhofer IPT also has an on-premises Kubernetes Cluster from German Edge Cloud, a VMware vCenter Server, and a TSN testbed, which is used for real-time communication and computation for cloud-in-the-loop applications. Furthermore, IPT owns extensive measurement and diagnostic equipment from Rohde & Schwarz and Keysight to carry out performance and diagnostic measurements in the 5G and the production network.

2.1.4 Construction testbed

The Reference Construction Site is a trial site for research and development in construction operated by the Center Construction Robotics (CCR) GmbH. The site provides RWTH University institutes and industry partners with a living lab of more than 4.000m².

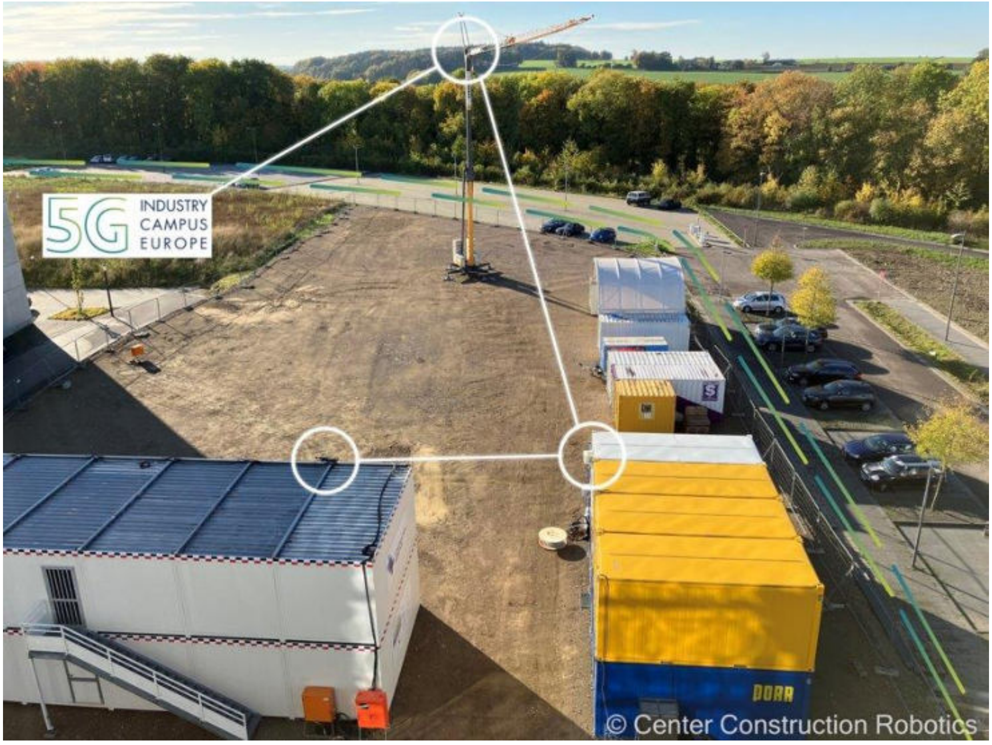


Figure 3: Reference Construction Site

In this environment, innovative processes, products, and concepts can be tested and evaluated under real-life conditions. Current research topics do not only include networked construction machines, the implementation of robots into construction processes, or software solutions, but also the proof of new working, communication, and teaching concepts. Within the project 5G.NAMICO, the Reference Construction Site, is connected to the 5G Industry Campus Europe's 5G NSA outdoor network. A unique approach of mounting a 5G radio node on the highest vantage point of the construction site, a tower crane, was chosen.

Consequently, it also provides a testbed for research and development of 5G technology within construction use cases. The application of 5G technology in construction has the potential to automate processes and reduce the workload of personnel. Yet, this transformation requires enhanced safety concepts to protect humans in partially and fully automated processes while at the same time advancing digital transformation.

2.2 Automotive testbed

The test site in Tarragona (near Barcelona), Spain, hosts the testbed for the automotive use cases within TARGET-X (see Figure 4). The testbed is located on the IDIADA proving grounds [IDI23].

The proving ground spans an area of 350 hectares, gathering 15 multi-purpose test tracks with a unique controlled environment capable of reproducing worldwide network configurations and conditions to develop and validate connected vehicle solutions.

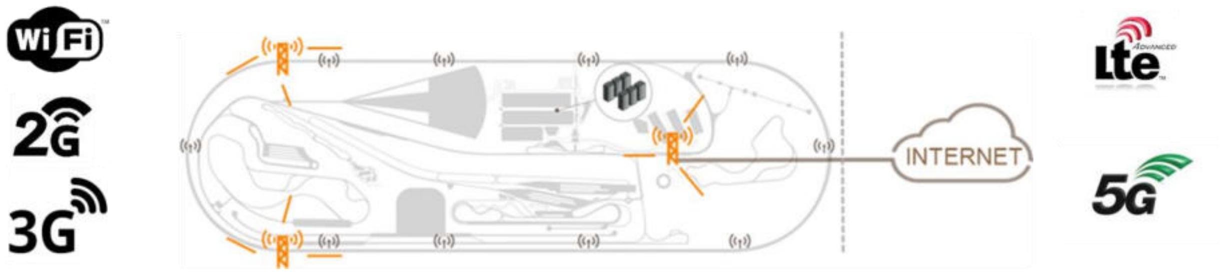


Figure 4: IDIADA proving grounds

One of the main objectives of the test tracks on the proving ground is to recreate conditions and situations as they can occur on the roads across countries. These capabilities are also reflected in the available mobile communication technologies, as the proving ground is, on the one hand, part of a commercial network. On the other hand, it offers possibilities to realize scenarios or situations that could occur during daily road use. Examples of such scenarios could be loss of coverage and frequent handovers at high vehicle speeds.

To accommodate these testing requirements, the testing ground has an operational network, supporting mobile communication generations from 2G to 5G NSA, with bandwidths as they can be found in public networks.

A dedicated PLMN ID is allocated to testbed users, allowing data from and to the vehicles to be routed efficiently to the on-premises infrastructures and platforms to integrate third-party HW and SW testing.

3 Technologies beyond 5G

3.1 Outline

In TARGET-X, four different verticals are contributing to individual use cases. All these use cases focus on different aspects of 5G technology and how this technology can enhance or improve their use cases. The project intends to ensure the evolution of the testbeds, as described in Chapter 2, by gradually introducing new technology elements from the technology clusters described below. The effects on the use cases will be evaluated with the help of the Key Performance Indicator (KPI) and Key Value Indicator (KVI) framework developed in WP1.

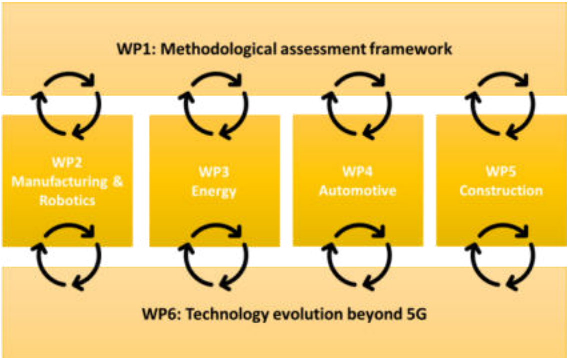


Figure 5: TARGET-X work package collaboration

This framework is also expected to offer guidance in assessing the usefulness and effectiveness of the introduced enhancements. To evaluate the relevance of the introduced enhancements, a close collaboration between the KPI / KVI framework, technology platform, and the vertical is needed and embedded in the project setup, as depicted in the figure above.

The approach in WP6 is as follows: Technology evolution beyond 5G is to create and maintain a diverse platform for exploring the technology drivers towards 6G [Eri22] [Hex21-D11]. The TARGET-X testbeds are already operational networks today. Introducing new functionalities must be aligned closely with the operators and/or owners of the networks, considering potential impacts of availability or reliability.

The elements identified for further detailed study and evaluation are listed in Table 1 below and described in more detail in the following sections.

Table 1: Elements of technology evolution beyond 5G

TECHNOLOGY ELEMENT	VISION
Service differentiation and network convergence	Service types in B5G networks are expected to be more diverse as in today's 5G networks, while at the same time, single networks are converging into larger and more complex networks.

mmWave spectrum	The need for bandwidth increases continuously and learnings can be drawn for future allocated spectrum by analyzing the currently available spectrum.
Asset Administration Shell (AAS) and network orchestration	With the growing complexity of networks and increasing numbers of devices, a model is needed to describe networks and UE and how they interact with each other.
Positioning with 5G NR	Positioning information for devices in the network is a key enabler for 5G use cases, such as autonomous vehicles [3GP18-22872].
Real-time ecosystem	Aspects such as bounded latency, reliable communication, and precise time synchronization are key in establishing a real-time ecosystem for industrial automation.

3.2 Service differentiation and network convergence

3.2.1 Definition

Service differentiation in 5G describes the ability of 5G networks to provide different types of services with varying levels of performance and quality tailored to specific applications and user requirements. This is made possible by introducing new network architectures, technologies, and capabilities that enable flexible, scalable, and efficient service delivery across a wide range of use cases.

Network convergence refers to merging different types of networks, technologies, and services into a single converged network. Network convergence aims to provide a unified and seamless user experience while reducing costs and simplifying network management. This can be achieved by using common network infrastructure and protocols and integrating different types of services.

With the convergence of networks expected to increase with the broader introduction of 5G in the industry, the ability to differentiate the different services in these networks becomes increasingly important to ensure the proper operation of the applications using the services. The vision of 6G to realize the cyber-physical continuum is expected to introduce more network service types [Eri22].

3.2.2 Key elements

One of the most widespread networking principles is using QoS. The network traffic for the services using the network gets assigned different QoS classes [3GP23-23501], allowing the prioritization of high-priority traffic over traffic types with lower priority. In the evolution towards 6G, traffic is expected to increase with the trend of convergence of wired and wireless networks, and with that, a more diverse pattern of traffic types will be observed in those networks. QoS classes are expected to continue contributing to service differentiation in the evolving networks. However, an excellent end-to-end QoS strategy must be implemented to properly classify the increasingly diverse traffic flows [5GA21b].

RAN slicing with radio resource partitioning is another technology that allows the simultaneous handling of different services sharing the spectrum. With radio resource partitioning, parts of the available spectrum can be granted exclusively for services with higher priority when required, yet allowing the usage of the entire available spectrum for lower prioritized service types in the absence of higher prioritized service traffic.

With the move towards 6G, new spectrum ranges are expected to be introduced to achieve higher transmission rates. Traffic steering methods will enable a controlled allocation of traffic from the various services in an optimized way towards the most suitable available spectrum, considering the characteristics of the available spectrum ranges and the needs of services and applications.

A final important aspect in the convergence of networks and the associated need to differentiate the services on the networks are insights into the performance and condition of those networks. A common practice today is monitoring key indicators of the networks to determine the health and performance of the network. As the networks become more diverse and complex, manually executed optimizations will likely become resource inefficient in the evolution toward 6G networks. Observability possibilities as an instrument to collect the performance and conditional indicators are identified as an enabler for cognitive networks. In these networks, AI / ML algorithms will acquire knowledge of the networks and initiate needed optimization actions.

3.2.3 Network convergence and service differentiation in testbeds

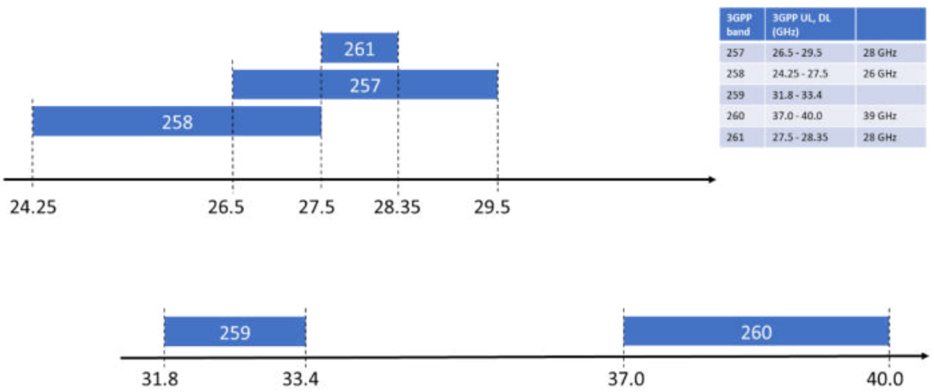
The convergence of networks and the need for service differentiation already play a significant role today in the 5G networks. However, with the transition towards 6G, the challenges in this area are expected to increase. Implementing all the elements mentioned above in a network implies complete control over all the involved infrastructure. In reality, having complete control over all of the infrastructure is not always given. The TARGET-X testbeds reflect reality as the IDIADA testbed uses infrastructure owned and controlled by an MNO. In contrast, the testbeds at the 5G-Industry Campus Europe are established in a 5G network where complete control of and access to the entire infrastructure is given. An extensive set of means exists to identify the data traffic to receive prioritized treatment. This can be per SIM, per Access Point Name (APN) / Data Network Name (DNN), based on IP addressed and ports, and, with 5G Stand Alone (SA), based on Network Slices [5GC22]. Furthermore, the configuration can be static or dynamic through network exposure APIs. The project intends to use this variety to determine requirements for the different deployment types of 5G networks.

The testbeds in the verticals will host different types of services, varying numbers, and types of devices. They will be operated under changing surrounding conditions, influencing the behavior of the networks. All this information is relevant to establish a proper QoS strategy. Experimenting with different strategies to establish QoS and service differentiation requires a platform to recreate these network patterns. The intent is to implement such a platform as part of the project. In an evolution towards the cognitive networks, this platform can also be employed to train AI/ML models to take actions towards optimization of network parameters.

3.3 mmWave spectrum

3.3.1 Definition

3GPP defines two frequency ranges for use with 5G NR. Frequency range 1 (FR1) covers a frequency spectrum between 410 MHz to 7125 MHz, with the licensed spectrum below the 6 GHz marker. Hence, this frequency range is called 'sub 6'. Frequency range 2 (FR2) defines the spectrum from 24 GHz to 71 GHz, with today's 5G technology using parts up to 40 GHz. In Europe, the range between 24 and 28 GHz is allocated for 5G networks. As most spectrum range has wavelengths in the millimeter range, the range is also commonly referred to as 'mmWave'. Figure 6 shows to bands currently used in the mmWave spectrum.



3GPP band	3GPP UL, DL (GHz)	
257	26.5 - 29.5	28 GHz
258	24.25 - 27.5	26 GHz
259	31.8 - 33.4	
260	37.0 - 40.0	39 GHz
261	27.5 - 28.35	28 GHz

Figure 6: mmWave band definitions

3.3.2 Key aspects

Coverage and throughput are two aspects that are closely interlinked and need consideration when planning and utilizing wireless networks. It is, therefore, essential to study and understand the advantages and disadvantages of this spectrum. Learnings and experiences that can be gathered in these large-scale trials, such as TARGET-X, will provide valuable input to the evolution of networks for industrial deployments.

The empirical study of the propagation of mmWave radio waves in industrial settings and for use cases in different verticals enables the best spectrum use by choosing optimal deployment strategies. In cluttered indoor environments, with many different materials blocking the line of sight between transmitter and receiver, understanding the effects of mmWave reflections will further enhance the deployment models.

Beamforming is a technique to improve wireless transmission quality by directing the radio frequency energy in a specific direction (see Figure 7). This focused beam, directed towards the receiver, assists in minimizing interferences and improves the overall signal quality. A higher signal quality allows the use of better modulation and coding schemes, thus increasing the achievable data rates while, at the same time, decreasing the number of retransmissions, resulting in lower latency.

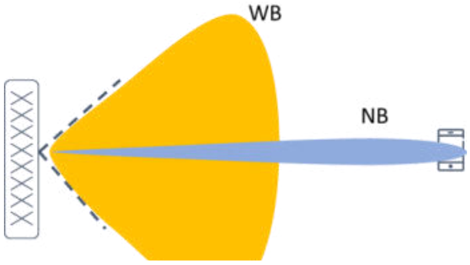


Figure 7: mmWave beamforming example

The probability of mmWave transmissions originating inside buildings or other massive structures leaking outside these enclosures is very unlikely. While this has a negative effect on the reach of mmWave transmissions, it creates opportunities for more flexibility in the configuration of indoor mmWave cells as the risk of interference with outdoor mmWave transmissions is significantly reduced. Flexible utilization of Time Division Duplex (TDD) patterns is one of the aspects that will be explored within the project.

3.3.3 Evolution and evaluation in testbeds

The mmWave spectrum will be introduced in one of the indoor testbeds in TARGET-X to have more flexibility in the experimentation with this additional spectrum. The objective is to introduce mmWave first for the manufacturing verticals testbed. Two activity phases: technology introduction and validation, are considered for mmWave.

In the first phase, the technology introduction, mmWave will be introduced into the existing testbed. The introduction of mmWave can be subdivided further into several steps:

- Configuration and integration of the new components into the existing infrastructure
- Identify suitable UEs and perform baseline tests with the chosen setup
- Execute coverage and performance measurements with baseline configuration
- Identify coverage and/or performance optimization opportunities and validate against an established baseline

During the second phase, a more use case-oriented focus is chosen by applying mmWave to use cases of the vertical from the pilot introduction. The use cases are the enablers to assess our KPI and KVI framework and determine the effectiveness of mmWave for industrial settings. The experimentation with the technology towards the creation of service differentiation or real-time ecosystem shall also be executed in this phase.

The introduction of further mmWave cells into the testbeds will be evaluated within the consortium, and a deployment strategy will be chosen accordingly.

3.4 Asset Administration Shell (AAS) and network orchestration

3.4.1 Definition

The Asset Administration Shell (AAS) concept is proposed by Plattform Industrie 4.0 [PI422] as a key outcome of RAMI 4.0 (Reference Architectural Model Industry 4.0), which is a three-dimensional and service-oriented model ensuring the Industry 4.0 (I4.0) components to understand each other. AAS is this architecture's primary methodology for connecting assets to the digital world. It can be considered as the digital twin (DT) of industrial applications, as it digitally represents all the information relevant to an asset consisting of valuable components to the factory floor, including hardware/software, services, and operators. AAS performs as an administration interface that is available in the I4.0 network. This interface can be reachable by external application services to interact and share information and can be used between the physical and digital world assets. This interaction is realized via a common semantic language that provides seamless interoperability among different value chains through standardized northbound exposure interfaces. Hence, AAS is used for identifying the information's structure, management, and security aspects, along with adapting various formats and protocols to ease communication. Moreover, the purpose of AAS is to exchange relevant data among industrial assets and between assets and production orchestration systems through a common semantic.

A 5G network combines various sets of devices and network functions. For seamless integration of 5G networks into industrial applications and processes, AAS can also describe 5G networks as an industrial asset. The explanation of the 5G network in terms of an AAS should consider the complexity of the 5G networks to build well-structured AAS submodels. While modeling the AAS for complex 5G network systems, it is crucial to consider a model that fits the functional aim of 5G networks to be deployed in the future factory. In addition, separate 5G AASs from different operational perspectives and lifecycle aspects should be considered. For this aim, 5G-ACIA introduced two primary AASs called 5G UE AAS (5G enabled user equipment) and 5G NW AAS (5G Network).

5G UE AAS describes the endpoint in 5G UE devices of which the functionalities, capabilities, and performance of those devices are identified in 3GPP. According to 5G-ACIA, some submodels spotted in 5G-capable devices AAS contains information related to UE identity, UE attach and connection status, permanent equipment identifier, connectivity QoS monitoring, and location event subscriptions, results, and events. In addition, the 5G Network AAS covers required nodes and functions in the 5G radio access network (RAN) and core network (CN). The submodel related to the 5G NW AAS covers the structured information and logical function of a 5G link on the network endpoint. In a 5G system, the User Plane Function (UPF), a fundamental component of a 3GPP 5G core infrastructure, provides the factory data network (DN). According to 3GPP [3GP23-23501], the UPF provides packet routing and forwarding, packet inspection, TSN support, etc. All the relevant assessments and configurations can be passed to the 5G network AASs through the integrated deployed computing hardware or orchestrated edge computing node.

According to Plattform Industrie 4.0, considering the interaction scheme, there are three types of AAS: passive, reactive, and proactive. The passive scheme contains static documents and information from assets stored in read-only and uniform data format in the AAS. This file-based AAS can be disseminated digitally or physically through all value-chain partners. The reactive scheme points out the information exchange between various AASs and software applications through Application Programming Interfaces (APIs). A client-server-based decision-making functionality in a service-oriented manner can be used in the reactive pattern. Moreover, the proactive scheme indicates the autonomous interaction of AASs by adopting common semantics and syntaxes (i.e., such as VDI/VDE 2193 that defines a common language for I4.0 components) through standardized interfaces. This schema can be implemented by peer-to-peer interaction based in a protocol-oriented manner.

3.4.2 Key aspects

AAS is one of the key technologies to be developed in this project toward the verticals (e.g., manufacturing). One of the key objectives of this project is to enable self-adaptive networks for enabling future use cases in the industrial domain. Correspondingly, AAS is expected to automate network and asset management.

As described and introduced by 5G-ACIA, the 5G network can be described through an AAS and 5G UEs. By eliminating vendor dependency in a heterogeneous setting, the AAS framework enables interoperable communication in the digital world where the 5G network can understand the capabilities of, e.g., the machines and their network requirements through standardized interfaces. Within this scope, AAS plays a significant role since it can provide dynamic interaction and zero-touch orchestration of 5G/6G communication among the network resources, (virtual) services, and physical equipment (e.g., machines, sensors, robots). Maintaining interoperability between various subsystems brings promising capabilities to realize the vision of a 'system of systems' and provides seamless integration of 5G NPN into IT/OT processes.

In this direction, necessary AAS submodels of all relevant assets (i.e., 5G-capable devices, 5G Network AAS, and Industry Automation Management Entities (IA-ME)) will be designed and implemented. These submodels represent the relevant information about the assets, which will be exchanged among different processes to realize and automate network/asset orchestration on the factory floor. The value-added information exchange is achieved by using standardized interaction mechanisms (VDI/VDE 2193 Part 2).

Another key aspect of this project is validating the proposed solutions. The AAS-related technologies developed in the project will be tested inside the manufacturing testbed. AAS solutions will be validated for industrial use cases to provide full zero-touch automation and increase resource management efficiencies by enabling the network to understand the device's capabilities and requirements. Besides asset and network management in an automated manner, TARGET-X will also validate how AAS plays a role in positioning services. It is expected that AAS will be used as a bridge between industrial processes and positioning services. By storing the positioning information in AAS, it will be shared throughout the factory cloud to enhance the monitoring capabilities on the factory floor. Here, the concept of submodel can be leveraged, as it provides the structured view of data populated in AAS. As an intersection point between the 5G network and industrial processes, the positioning information stored in AAS can be exchanged via standardized northbound interfaces.

3.4.3 View on evolution in testbeds

The main objective in TARGET-X regarding the validation of Asset Administration Shell (AAS) is to apply it in an industrial context. Correspondingly, the implementation of AAS for mobile communication systems and industrial 5G devices will be tested in manufacturing and robotics testbeds and validated in industrial use cases in the 5G-Industry Campus Europe (5G-ICE) facilities.

5G-ICE is deployed with a standalone non-public network (SNPN), where the functionalities are on-premises. Whether integrated with a central cloud or not, in this project, a factory edge/cloud will be developed on-premises to provide communication between industrial applications and devices with low latency and high reliability. To efficiently integrate different subsystems at the factory floor in an interoperable manner and achieve automated asset & network management, AAS should be able to meet certain KPIs. Based on the requirements of performance expectations provided by manufacturing use cases and the role of AAS, we envision that device and network AAS instances are deployed over the factory cloud. The physical asset and its digital representation AAS communicate via a proprietary interface in the industrial domain. In addition to AAS, the factory edge provides different latency-critical applications. For example, positioning service is key for enabling efficient and flexible monitoring and production control. To store the positioning information in AAS and share it with other industrial applications, on-premise edge deployment is required for low latency and high reliability. Therefore, seamless integration of the 5G system into IT/OT processes can be realized.

An alternative deployment model focuses on distributed factory clouds. In this option, distributed edge infrastructure is realized by deploying standalone edge datacenters in different buildings. For example, even though they reside in the same facility, manufacturing and robotics testbeds are in different buildings. One primary motivation for distributing the edge servers is maintaining privacy, especially data related to the devices. To enable isolated edge environments to keep the device data locally, distributed edge deployments in 5G-ICE may be a feasible alternative. Deploying device AAS in the same building and replicating the network AAS for multiple sites can achieve the above objectives of isolation and privacy.

The operations of AAS and ways of communication highly depend on the exposures provided by the network and the devices. The functionalities, capabilities, and related information of an asset (e.g., robot, network) are represented in the AAS through the exposures. To realize automated network and asset management & orchestration, necessary submodels will be created for device and network AAS. To populate these submodels, relevant exposures should be available (e.g., performance). Therefore, if necessary, the already-existing exposures (i.e., data and 5G capabilities) provided in the 5G-ICE facility will be extended to support the target use cases in this project to be realized by AAS, e.g., the automated provisioning of industrial 5G devices. Besides, by encapsulating the information provided by the assets and stored in the submodels, AAS provides another layer of exposure services for other Industry 4.0 applications.

As depicted in Figure 8, the 5G network and devices frequently expose data and functions to the factory edge where AAS instances reside. The AAS instances can exchange the value-added information with other industrial applications in the same domain to achieve integration of the 5G system with OT/IT processes.

In summary, our vision towards the evolution of testbeds in this project is twofold: (1) factory edge/cloud setup in the testbeds, (2) extended exposure capabilities of the SNPN in the 5G-ICE facility.

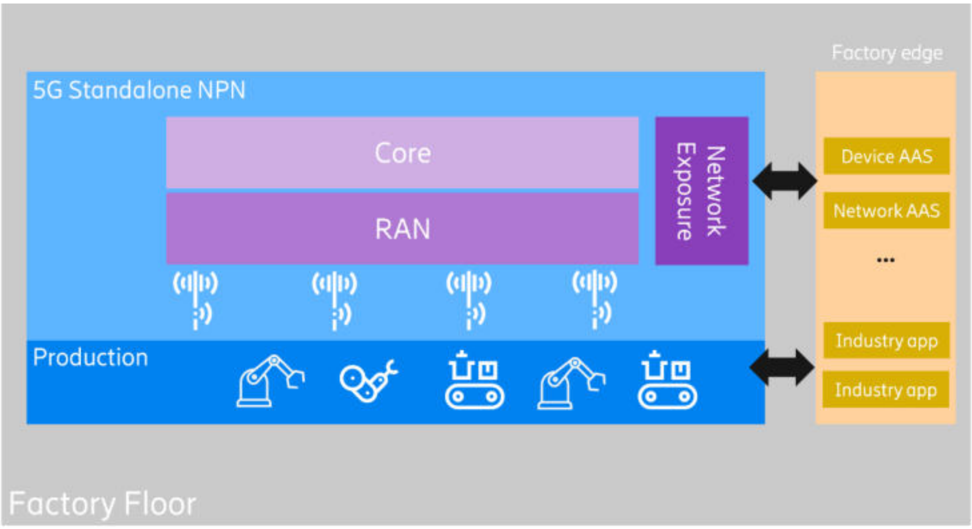


Figure 8: AAS deployment in factory cloud

3.5 Positioning with 5G NR

3.5.1 Definition

Positioning with 5G NR in TARGET-X focuses on indoor positioning methods and challenges as the industry sees this area as a key differentiator. As a starting point for the positioning with 5G NR in TARGET-X, the project concentrates on position estimates based solely on calculations with signals in the 5G network between 5G UE and 5G gNodeB.

3GPP has standardized several procedures in its Release 16. Within TARGET-X, one of the methods is chosen for implementation and used in use cases from the verticals for evaluation. In particular, accurate positioning information is vital for path planning and safety reasons for mobile robotics applications. These robots host a variety of sensors, such as gyroscopes, accelerometers, and LIDAR scanners, to provide the operating system with information. TARGET-X aims to explore methods of combining already available sensor data with the 5G NR acquired position estimates to optimize accuracy and precision further.

3.5.2 Key aspects

The following paragraphs describe factors that impact the usefulness of a 5G positioning system for applications within the TARGET-X verticals.

Accuracy in positioning refers to the degree of deviation between an object's measured or estimated position and its actual position. In general, higher accuracy in positioning is desirable, particularly in applications where the location of an object needs to be known with high precision, such as in path planning for mobile robotics and asset tracking. However, achieving high accuracy can be challenging, and different positioning methods may have different levels of accuracy. The cost of processing time in relation to the accuracy and availability of positioning information is essential to understand and are item for exploration.

Closely connected to accuracy is the precision of the positioning. Precision is essential in many applications, such as robotics, where objects must be moved consistently and accurately. In cluttered and dynamic environments, many factors can influence the precision of 5G (indoor) positioning results. Therefore it is essential to understand these factors and to propose mitigation strategies.

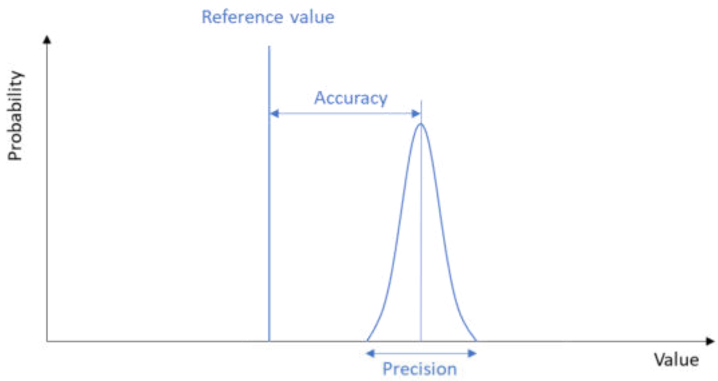


Figure 9: Illustration on the definition of accuracy and precision

Time to First Fix (TTFF) is a metric used to measure the time it takes for a positioning system to determine an object's or user's initial location. In other words, it is the time it takes for a system to calculate and provide the first accurate position fix after a request for location information is made. TTFF is an essential metric for applications that need to know the location quickly. Shorter TTFF values mean that the application can start using the positioning system more quickly, which can be critical in time-sensitive situations.

As such, calibration of a positioning system is required to retrieve and improve its accuracy and precision. The frequency in which calibration actions are required, and the time needed for these calibration procedures, directly impact the system's availability for use in manufacturing flows. The unavailability of the system would impact several shopfloor processes and need to be reduced as much as possible to achieve higher productivity.

3.5.3 Positioning technology in the testbeds

Introducing positioning into the project follows a similar approach as with mmWave. The testbeds for robotics within the manufacturing vertical is the prime candidate for the work on positioning with 5G. The robotics testbed already hosts a set of positioning solutions. The positioning setups use various technologies, such as indoor GPS, laser, or optical tracking of objects. Next to the availability of these solutions, the testbed facilities offer a mix of open and cluttered floor spaces. This mix of different environments makes the location an ideal candidate for validating 5G indoor positioning.

Again, two phases are defined here: a technology implementation and a technology validation phase.

The main focus of the activities is indoor positioning with 5G to understand and improve its capabilities towards 6G and its evolution towards Joint Communication and Sensing (JCAS).

Some of the TARGET-X verticals, such as construction and automotive, are working with 5G in an outdoor environment. A common assumption about positioning in an outdoor environment is that this can always be done with the help of GPS/GNSS. We assume that there are cases where this approach is impossible, either due to environmental influences (dense high-rise buildings, thick foliage, etc.) or malicious activities such as spoofing or jamming attacks. We also intend to look for opportunities to introduce positioning with 5G or supported by 5G in an outdoor testbed, e.g., with 3GPP GNSS Real-time Kinematic (RTK). 3GPP has standardized means to distribute Real-time Kinematic (RTK) information over cellular networks [3GP21-36305]. Different information is needed at different locations, but the network has a sufficiently good understanding of where a user requesting RTK information is located.

3.6 Real-time Ecosystem

3.6.1 Definition

An enabler for further introducing 5G and beyond in the automation field is the creation of a real-time ecosystem. Real-time capabilities of the 5G system open up possibilities for cellular technology used for applications where systems such as motion control or collaborative robots must be tightly synchronized. Furthermore, field bus communication, which today is cable-bound, can flexibly be used via a real-time capable wireless link. As such, the real-time ecosystem is not restricted to industrial automation. The cornerstones for the real-time ecosystem also find applications outside the industrial automation domain. Applications such as multi-user XR will significantly benefit from advancements in this area.

3.6.2 Key aspects

In TARGET-X, the cornerstones for establishing a real-time ecosystem are bounded latency, reliability, precise time-synchronization, and availability.

Bounded latency can be seen as a known and guaranteed sum of all latencies incurred on the transmission path between sender and receiver, regardless of the medium for the transmission. Ideally, the upper and lower latency boundaries move towards a single point, and the associated guaranteed latency is low. Several approaches will be used and validated to achieve this goal of bounded latency. Time Sensitive Networking (TSN) toolbox as the L2 ethernet layer extension or DetNet on L3, intending to bring deterministic communication capabilities into the networks [5GA21a].

Reliability is seen as the ability of all entities in the real-time ecosystem to deliver and process data without interruption and failure.

Time synchronization assures that all entities in the real-time system have the same time information for synchronizing their internal clocks to one master clock signal. The mechanism ensures that no unnecessary delays occur in the scheduling of data transmissions.

Availability in a real-time ecosystem can be seen as the capability to process data by each entity within the system at any given time. Methods such as CPU pinning, overallocation of resources, or redundant transmission paths can be applied to meet a high availability rate. Different entity types or classes can be seen in the ecosystem: devices, networks, compute resources, and applications [5GA23]. Only when all the entity classes contribute work towards the ecosystem's cornerstones can a successful implementation be realized. The project will evaluate all entity classes and strives to create a model for a real-time ecosystem supported by empirical evaluations of reference ecosystem implementations.

3.6.3 Real-time ecosystem in TARGET-X

The real-time ecosystem is a broad definition, and each of the testbeds within the project has its more specific or prioritized demand towards a real-time ecosystem.

In TARGET-X, the ambition is to explore the real-time ecosystem in a diverse manner, and thus it is crucial to bring enablers of a real-time ecosystem to each of the testbeds.

TARGET-X must explore real-time ecosystem approaches from different angles (cellular network, devices, or infrastructure) and evaluate how these parts contribute to an end-to-end ecosystem. TARGET-X testbeds' diversity in architecture and management models allows to see how an evolution towards real-time systems can be realized in different verticals.

Experimentation with TSN or DetNet can either be executed in a dedicated testbed, running prototype software based on 3GPP R16 and later, or the regular testbeds are extended with network elements that are identified to bring a positive contribution to a real-time ecosystem.

3.7 Deployment intents

The testbeds in TARGET-X represent four different verticals, and each presents different challenges and priorities for deploying the described technical elements. A mapping, shown in Table 2, was performed to reflect the current assumptions of the deployment priorities for the different testbeds. Changes to selected deployments can occur as the owner of the networks will need to agree.

Table 2: Intended deployment priority per testbed

	Energy	Mobile robotics	Cloud-native production	Construction	Automotive
Service differentiation	2	1	1	2	1
mmWave spectrum			1		2
Asset Admin. Shell			1		
Positioning		1	2	2	1
Real-time ecosystem		1	1		2

4 Summary and conclusions

Summarizing the deliverable, TARGET-X establishes a diverse set of testbeds representing four verticals with a high impact on the 5G evolution. Each testbed shall focus on a particular vertical. Yet, within the overall project, synergies and similar requirements between the different verticals will become clear as the project is executed.

A diverse testbed setup offers unique opportunities to explore 5G and beyond in various verticals, both for the consortium and the numerous FSTP partners that will be onboarded during the project. Establishing such a diverse setup brings risks to the project, which will be tracked during the project runtime to mitigate as early as possible.

Overall, the setup of the testbeds and technology elements bring valuable insights into the evolution of the four verticals toward 6G ecosystems.

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