
# D4.1

## Integration and validation plans and Open labs design

ERC

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## Abstract

The objective of deliverable 4.1 is to define the methodology of validation of the PREDICT-6G Proof of Concepts (PoC), as well as the design of the Open Labs. All these validations are oriented to prepare the integration of deterministic User Plane, provided by WP2, with the AI-Control Plane, provided by WP3, and to prepare the final demonstrations of PREDICT-6G project, where enhancements in deterministic will be showed for different use cases.

## Keywords

integration, open labs design, roadmap, use cases, test cases, verification, experimentation.

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**Document information**

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R: document, report (excluding periodic and final reports).

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# Acronyms and definitions

| | |
|---|---|
| 3GPP | 3rd Generation Partnership Project |
| AI | Artificial Intelligence |
| AICP | AI-driven Multi-stakeholder Inter-domain Control-Plane |
| API | Application Programming Interface |
| AF | Application Function |
| DetNet | Deterministic Networking |
| DS-TT | Device-Side Translator |
| DT | Digital Twin |
| DUG | Data Unit Group |
| E2E | End-to-End |
| IETF | Internet Engineering Task Force |

| | |
|---|---|
| KPI | Key Performance Indicator |
| MD | Management Domain |
| MDP | Multi-domain Data-Plane |
| MS | Management Service |
| ML | Machine Learning |
| NW-TT | Network-Side Translator |
| PoC | Proof of Concept |
| TD | Technology Domain |
| TSCTSF | Time Sensitive Communication Time Synchronization Function |
| TSN | Time-Sensitive Networking |
| WP | Work Package |

# Table of partners

| Short Name | Partner |
|---|---|
| UC3M | Universidad Carlos III de Madrid |
| NOK | Nokia Solutions and Networks KFT |
| ERC | Ericsson Espana SA |
| INT | Intel Deutschland GMBH |
| TID | Telefónica Investigación y Desarrollo SA |
| ATOS | ATOS IT Solutions and Services Iberia SL |
| GES | Gestamp Servicios SA |
| NXW | Nextworks |
| COG | Cognitive Innovations Private Company |
| SIM | Software Imagination & Vision SRL |
| AUSTRALO | AUSTRALO Alpha Lab MTU |
| POLITO | Politecnico di Torino |
| UPC | Universitat Politecnica de Catalunya |
| CNR | Consiglio Nazionale delle Ricerche |
| UNIPD | Universita degli Studi di Padova |
| IDE | InterDigital Europe Ltd |

# 1 Executive summary

The current report focuses on designing and planning of the integration activities in terms of methodology and activities breakdown.

The framework for integration testing was defined considering the internal project work package layout and the possible difference between the development of the technology domain specific modules and the development of the correspondent management domain modules. The proposed methodology is based on the definition of specific tests which shall be executed by a subset of partners at some point within the lifetime of the project. A specific design was drafted for Predict-6G use cases while all the use cases were presented in a similar manner. Moreover, a roadmap of activities for both data plane and control plane components was drafted alongside with anticipated cycles of delivery.

This integration methodology leverages the interfaces, and workflows defined in WP1 and is based on the definition two different level of tests: (i) infrastructure integration test in which the aim is to validate the correct implementation of a specific of the generic interface by the MDP functionality; (ii) E2E use case validation tests and activities focus on the KPIs and functional validation of the AICP platform. For this, within this task we have developed specific templates to convey the information of the different tests at different levels.

We define four demonstrations with the aim of showing the deterministic enhancements introduced by PREDICT-6G project. The design of the demonstrations, as well the design of the open laboratories that will host them, are detailed in this deliverable.

The key contributions of the deliverable are:

- Definition of the integration test methodology
- Initial design of the demonstration to be performed in the PREDICT-6G Open Labs
- Initial definition of verification tests.

# 2 Introduction

This document is the first deliverable of the PREDICT-6G Work Package 4. The main objective is to define the methodology of validation of the PREDICT-6G Proof of Concepts (PoC), as well as the design of the Open Labs. PREDICT-6G has defined four PoCs that will demonstrate the enhancements in the network determinism, that is, the enhancements in the reliability, time sensitiveness and predictability of the networks. The preparation and design of these PoCs implies to coordinate and integrate the work done in the other technical Work Packages.

The Work Package 1 described and analysed the PREDICT 6G use cases that will be demonstrated in the PoCs. Also, it defined the system requirements required for achieving the goals of the project. All this information is delivered in the PREDICT-6G D.1.1[1], Work Package 2 is devoted to enhancing the determinism (resilience and time sensitiveness) in the User Plane. Those enhancements are described in PREDICT-6G D2.1[2]. Finally, Work Package 3 is focused on the enhancement of network determinism from the control plane perspective. The first design of the Control Plane is described at PREDICT-6G D3.1[3].

In this document we will address the integration of the AI-Control Plane, defined by WP3, with the enhanced User Plane, defined by the WP2, by defining the methodology for testing it. We detail the Integration Points between Control and User plane, which use the WP2 APIs that follow the Open API guidelines on vendor-neutral interface description formats [4], and the test to check the integration.

Also, Open Lab design is included for the different demonstrations in the two open laboratories of the project. We define verification tests for the demonstrations by itself and for the end-to-end integration tests.

Finally, a roadmap with the proposed development cycle that coordinates the work of the three technical Work Packages of the project is included in this deliverable.

# 3 System integration methodology and planning

The PREDICT-6G project aims to deliver innovations at the infrastructure and management and control planes enabling deterministic E2E services over multiple technologies. In this sense, the project aims to design a fully automated framework for the life-cycle management and quality assurance for services with deterministic requirements. Within the scope of the project three main technologies, with their own set of characteristics, protocols and control and user plane frameworks, are targeted: 3GPP , IETF DetNet  and Wi-Fi 6/7  as specified in D1.1[1].

In order to provide E2E deterministic service lifecycle management and assurance capabilities the project has proposed an architecture (**Figure 1**), described in D1.2 (to be delivered) which defines the E2E and domain Management Function blocks which leverage the APIs exposed by the different domains.

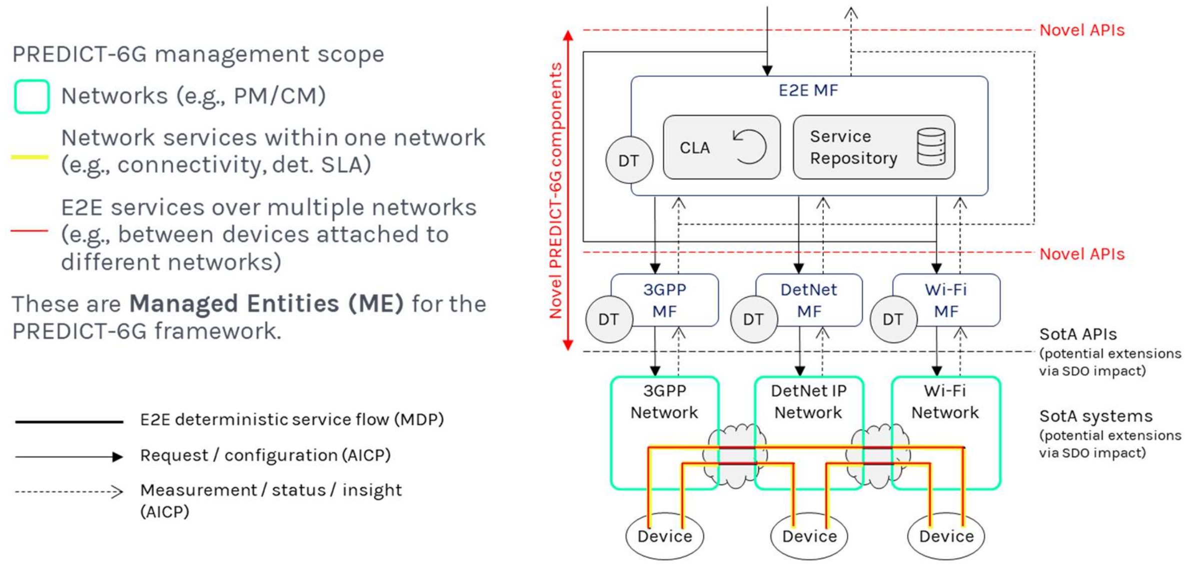


**Figure 1**: PREDICT-6G Reference Architecture (from D1.2)

The E2E management domains and per technology domain management services are further described in D1.2, to define the PREDICT-6G AI-driven multi-stakeholder inter-domain control plane (AICP) depicted in **Figure 2**. We refer to D1.2 for further details regarding the architectural blocks, and to D3.1 [3] for further details regarding the software blocks of each management service and initial lifecycle management and assurance workflows.

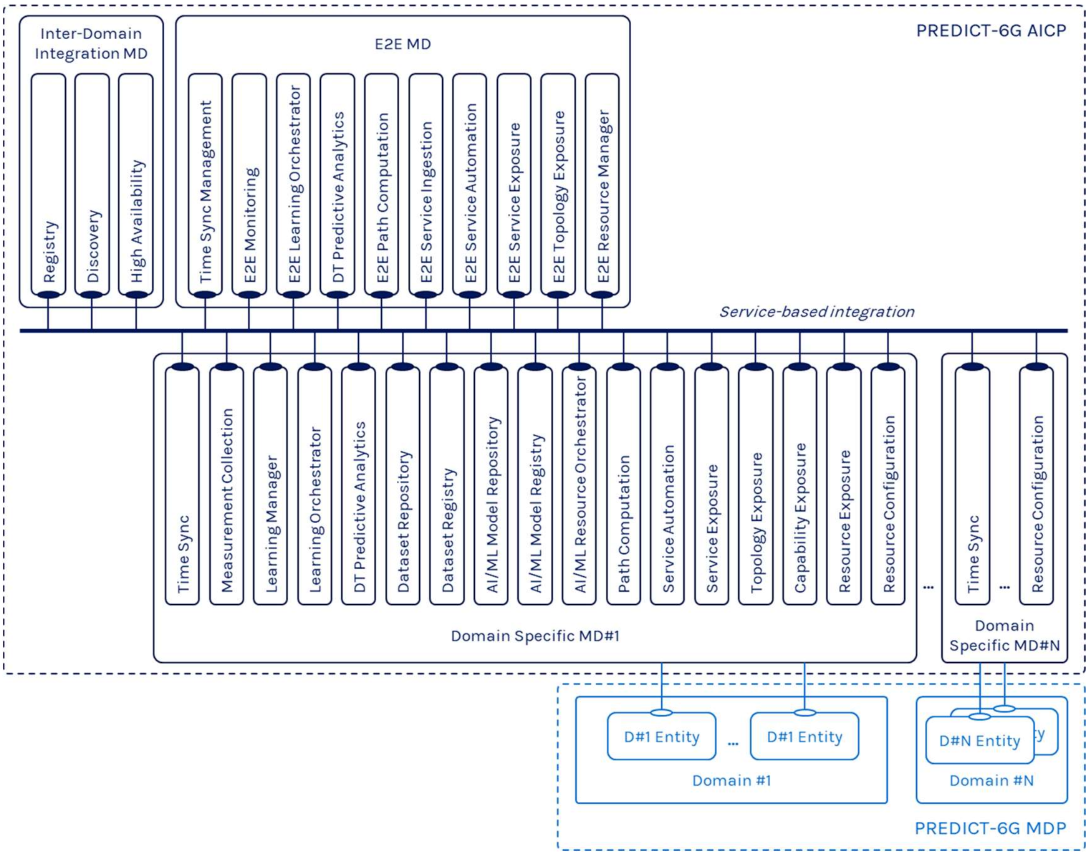


**Figure 2**: PREDICT-6G AICP Reference Architecture

Considering this architectural split between the technology specific domains and the E2E, the focus of the integration activities in PREDICT-6G are divided in two different categories with different scopes:

A. **AICP – Technology domain integration tests and activities:** These activities cover the tests performed to verify the integration between the domain specific management functions and the domain specific entities. The target is to validate the correct implementation of the APIs exposed by the domain functions and the proper consumption through the domain specific management service. By definition, these tests have a very specific objective and can be performed in the lab facilities or in emulated environments.
B. **E2E use case validation tests and activities:** The scope of these tests is to validate the KPIs of the use cases described in D1.1 [1] and the architecture functional and non-functional requirements established in D1.2. These tests and activities have a broader objective than the previous and are to be performed using the lab facilities of the project.

In the following subsections we further elaborate about the methodology established for (A), while for (B) in section 4.1 we define a reference validation test definition and report template to be used in sections 5 and 7.

## 3.1 Integration test methodology

In order to account for the internal project work package layout and the possible difference between the development of the technology domain specific modules and the development of the correspondent management domain modules, in PREDICT-6G we use an integration methodology based on the definition of specific tests which shall be executed by a subset of partners at some point within the lifetime of the project.

With the aim of providing a clear and unified understanding of the integration tests, and enable an initial roadmap of integration, in PREDICT-6G we defined two different templates which summarize the relevant information. For the definition of the *AICP – Technology domain integration tests and activities*, the most relevant information to convey refers to the domain management function, interface to be tested and verification mechanisms. In this section we formalize the reference template for the integration tests to describe the system integration activities. In **Table 1** we provide initial specifications of this template.

| Parameter | Description |
|---|---|
| **ID** | A unique internal identifier of the integration test |
| **Description** | One sentence describing the objectives of the integration test |
| **Management domain services** | List of the management modules to be used during the Integration Test. Reference software level workflows (D3.1) |
| **Technology domain (TD)** | Targeted technical domains during the integration test |
| **Specific TD Interfaces** | Reference to the TD specific interface, methods/features (See Sec. 3.2) |
| **Targeted period** | Period to run the Integration test (based on the release plan in D2.2 and D3.2) |

**Table 1**. Integration test reference template

In a similar manner the templates used to define *E2E use case validation tests and activities* focus on conveying the information regarding the KPIs and functional requirements to be validated, and the in-lab setup used for the validation. In we provide the formal definition of the template. Initial specifications of this template are provided in sections 5 and 7.

| Parameter | Description |
| --- | --- |
| **ID** | A unique internal identifier of the integration test |
| **Description** | Description of the objectives of the validation test in terms of KPIs and functional requirements |
| **E2E and MD specific MS involved** | Management modules to be used during the PoC. Reference software level workflows (D3.1, D1.2) |
| **Technology domains involved** | Targeted technical domains during the validation test |
| **Integration** | Reference to the integration tests which need to be validated before attempting this E2E validation. |
| **Targeted period** | Period to run the validation test |
| **Laboratory setup** | High-level description of the setup used for the validation. |
| **KPIs and validation** | Reference to the targeted KPIs and means of verification |

**Table 2**. Validation test reference template

## 3.2 Integration points

In **Figure 3** we represent one example integration point and the concept of integration test we use in PREDICT-6G. As described previously, and represented in the figure each technology specific MD is expected to expose unified APIs towards the E2E management system functions. In the figure we represent the Topology Exposure MS of the MD, which in the northbound interface exposed the unified API for the topology retrieval, and in the southbound it interacts with the domain specific interfaces to extract the required information.

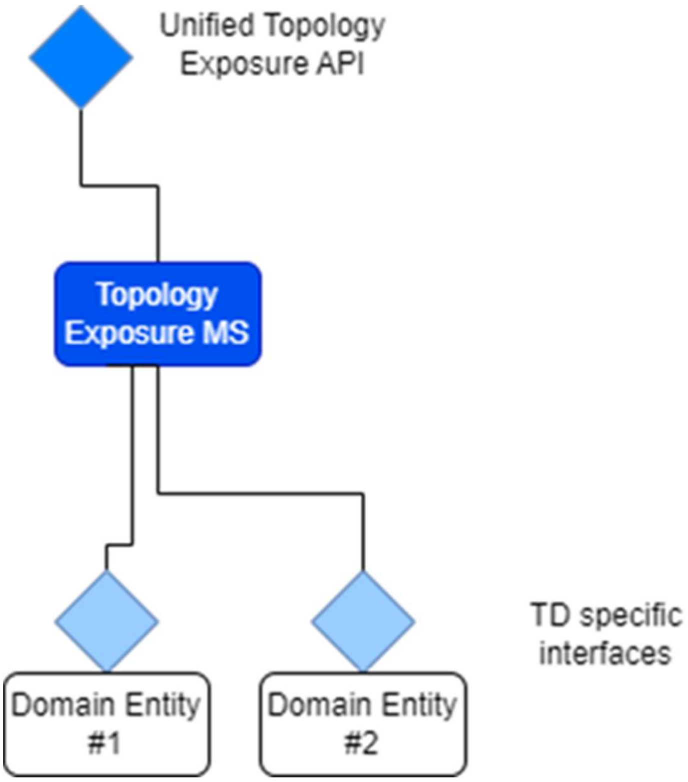


**Figure 3**. Topology exposure reference integration point

A reference example of this for the specific case of a 3GPP domain is represented in section 3.2.1, where we describe the Time Synchronization integration point. All the exposure and service automation MS follow the same design pattern (see D3.2). The domain monitoring MS follows a similar pattern, with the difference that functionalities a

In **Table 3** we provide the full list of unified interfaces (and associated domain management services) which will leverage underlying domain specific interfaces and will be therefore used during the integration tests. For convenience, we associate each interface with a reference point which will be used in the integration test definition templates.

| Interface / Domain MS | Functionalities (based on the functionalities described D1.2) | Reference Point Identifier |
|---|---|---|

| | | |
|---|---|---|
| Time Sync | Clock capability exposure | *time_sync.capabilities* |
| | Clock configuration management | *time_sync.configuration* |
| | Clock status reporting | *time_sync.reporting* |
| Service Exposure | Exposes Service Information | *service_exposure* |
| Service Automation | Service Lifecycle Management | service_automation.lcm |
| Topology Exposure | Expose Topology Information | *topology_exposure* |
| Capability Exposure | Expose deterministic capabilities | *capability_exposure* |
| Resource Exposure | Expose abstracted resource information | *resource_exposure* |
| Data collection and management | Data source configuration | *data_collection.configuration* |
| | Historical data retrieval | *data_collection.historial_data* |
| | Near-RT data retrieval | *data_collection.nrt_data* |

**Table 3**. MDP integration reference points

### 3.2.1 Reference example: Time Synchronization capabilities exposure

This section contains a reference example of integration point definition (**Figure 4**), where a AICP Time Synchronization Management Service integrates with the TSCTSF 3GPP function for Time Synchronization capabilities exposure.

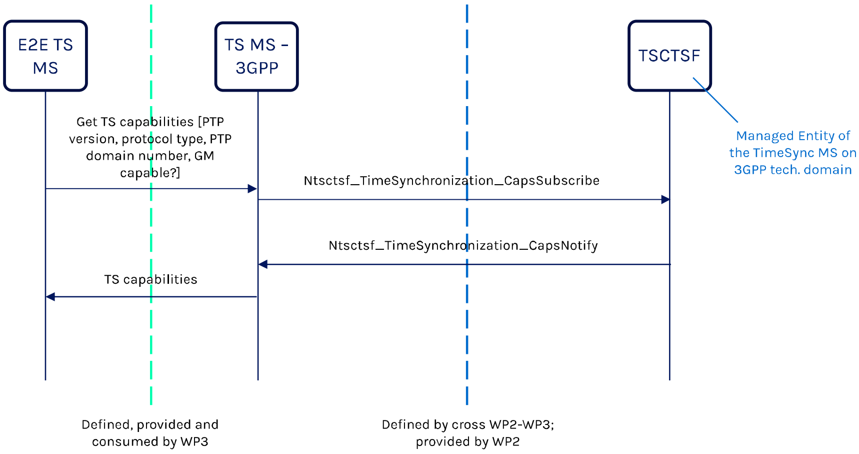


**Figure 4** Clock capability exposure for 3GPP domain.

The TSCTSF (Time Sensitive Communication Time Synchronization Function) function is in charge of managing the 3GPP domain in several aspects, including the Time Synchronization, and it exposes an Open API interface towards external Applications. This will be the integration point between AICP and the PREDICT-6G and the Integration Tests will be defined according to this interface.

## 3.3 Integration test

In tables **Table 4** we provide examples of the integration tests, related to the data collection and topology exposure, targeted to be executed in order to verify the integration of the AICP platform to a particular domain. In D4.2 we will report the complete set of tests defined together with the initial results

### 3.3.1 Data Collection

| **Parameter** | **Description** |
|---|---|
| **ID** | DATA_COLLECTION_CONFIGURATION_3GPP |
| **Description** | This test will verify the proper creation of the collector plugins to retrieve the monitoring data associated to a specific service from a 3GPP TD. Focus will be set on the collection of the aggregated latency for the service in that domain. The validation will be done using the internal catalogues and registries of the module, assessing if the information is arriving. |
| **Management domain services** | Data collection and management |
| **Technology domain (TD)** | 3GPP |
| **Specific MD Interface & methods** | *data_collection.configuration* |
| **Reference to TD interfaces** | Telegraf/Influx/MQTT will be used for this integration. |
| **Targeted period** | To be determined. |

**Table 4**. Data collection configuration test example

| **Parameter** | **Description** |
|---|---|
| **ID** | DATA_COLLECTION_RETRIEVAL_3GPP |
| **Description** | This test will verify that the data collector module of the MDP correctly exposes the near-real-time and historical data of the 3GPP TD associated with a service. Focus will be set on the retrieval of the aggregated latency for the service in that domain. The validation will be done using the external interfaces of the module |
| **Management domain services** | Data collection and management |
| **Technology domain (TD)** | 3GPP |
| **Specific MD Interface & methods** | *data_collection.historial_data*<br>*data_collection.nrt_data* |
| **Reference to TD interfaces** | Telegraf/Influx/MQTT will be used for this integration. |
| **Targeted period** | To be determined. |

**Table 5.** Data collection configuration test example

| **Parameter** | **Description** |
|---|---|
| **ID** | DATA_COLLECTION_RETRIEVAL_3GPP |
| **Description** | This test will verify that the data collector module of the MDP correctly exposes the near-real-time and historical data of the 3GPP TD associated with a service. Focus will be set on the retrieval of the aggregated latency for the service in that domain. The validation will be done using the external interfaces of the module |
| **Management domain services** | Data collection and management |

| | |
|---|---|
| **Technology domain (TD)** | 3GPP |
| **Specific MD Interface & methods** | *data_collection.historial_data*<br>*data_collection.nrt_data* |
| **Reference to TD interfaces** | Telegraf/Influx/MQTT will be used for this integration. |
| **Targeted period** | To be determined. |

**Table 6**. 3GPP Data collection retrieval test example

### 3.3.2 Topology Exposure

| **Parameter** | **Description** |
|---|---|
| **ID** | TOPOLOGY_RETRIEVAL_DETNET |
| **Description** | This test will verify the topology exposure module of the MDP correctly aggregates and translates the underlying DETNET topology |
| **Management domain services** | Topology Exposure |
| **Technology domain (TD)** | DETNET |
| **Specific MD Interface & methods** | *topology_exposure* |
| **Reference to TD interfaces** | To be determined |
| **Targeted period** | To be determined. |

**Table 7**. DETNET Topology retrieval test example

## 3.4 Integration test results

The results of the execution of an integration test shall be reported using a template depicted in **Table 8**. These reports will be integrated with bug/issue tracking mechanisms to facilitate the monitoring of the progress in terms of integration.

| **Parameter** | **Description** |
|---|---|
| **Test ID** | Reference to the integration test identifier |
| **Result** | A short statement with the results of the test execution (i.e. SUCCESSFUL/PARTIALLY SUCCESSFUL/NOT SUCESSFUL) |
| **Date** | Date of the execution of the integration test |
| **Observations and comments** | Details to aid the resolution of partially or not successful tests |

**Table 8**. Integration test report template

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# 4 Use case initial design for the integration phase.

In this section we detail the demonstrations of use cases planned in PREDICT-6G.

## 4.1 Multi-Technology Multi-Domain DetNet-Based Integration of MDP and AICP (5TONICc)

The objective of this use case is to test a complete end to end integration of selected data plane and control plane innovations. This section provides the initial design of the integration of the use case, highlighting the point which, at this stage, are not clear. **Figure 5** presents the physical deployment of the testbed being developed at 5TONIC.

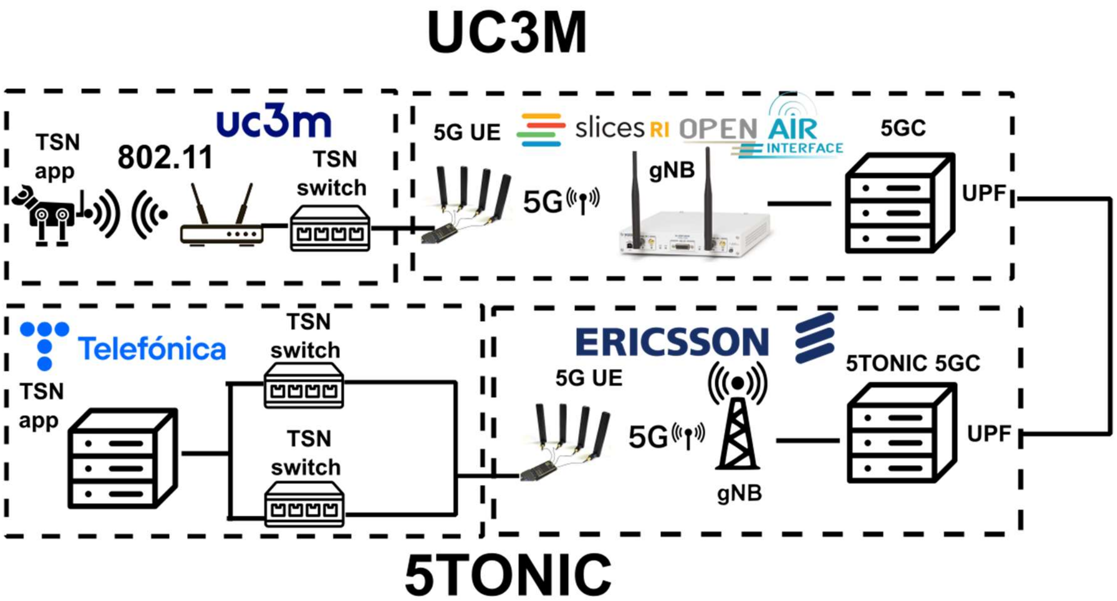



**Figure 5**: End to end MDP physical deployment as presented in D2.2

The final goal of the demonstration is to remotely control a robot dog from a digital twin connected at the other side of the MDP. The robot dog is a Unitree Go1 Edu[1], this robot has a configurable control loop of 1ms-20ms, which will be capable of stressing the deployed network in terms of latency and jitter. The digital twin is an in-house development in Coppelia SIM (see **Figure 6**). Through this application we will

[1] https://eu.robotshop.com/products/unitree-go1-edu-w-emlid-reach-m2?gad_source=1&gclid=CjwKCAiApaarBhB7EiwAYiMwqnQZ4VVsaSECfZxmPsUThs4J5Es6lbKtMzFjg0wJVDh0F4PYPaCm3xoCrlsQAvD_BwE (November 2023)

be able to visually assess (in addition to experimentally measure the KPIs), on the quality of the synchronization of data and the implications of the TSN requirements for different traffic loads.

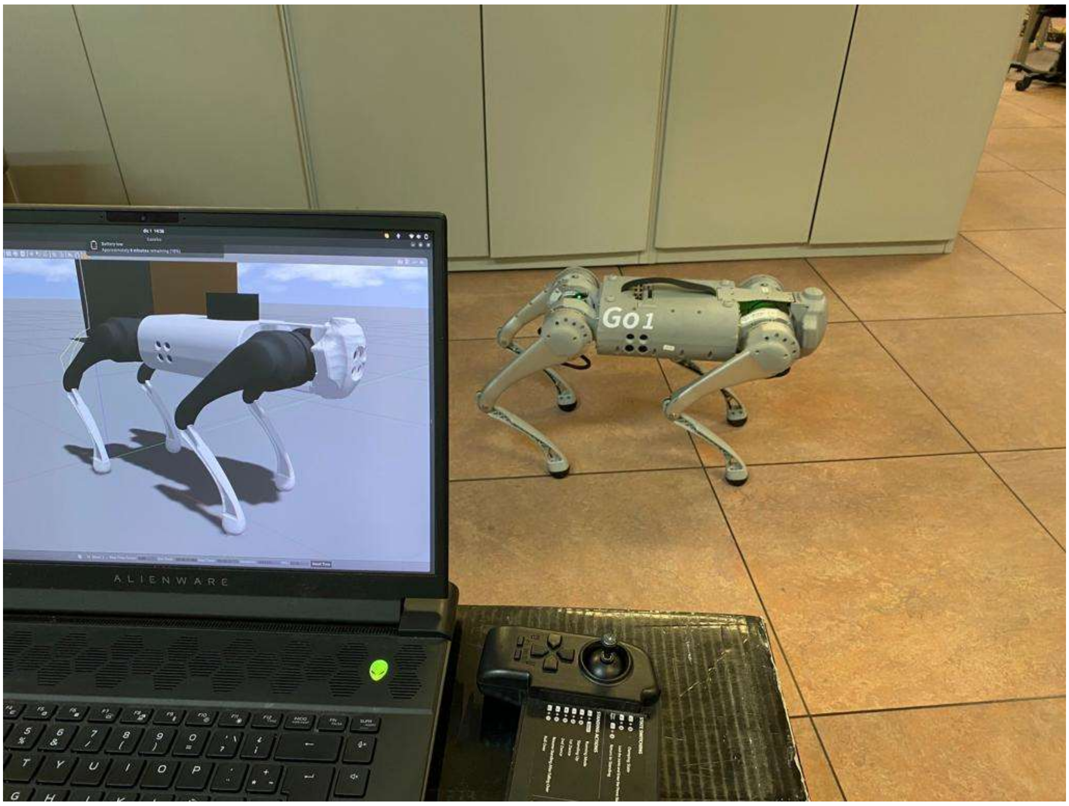



**Figure 6:** Digital Twin application

The current view of the data plane is presented in **Figure 7**.

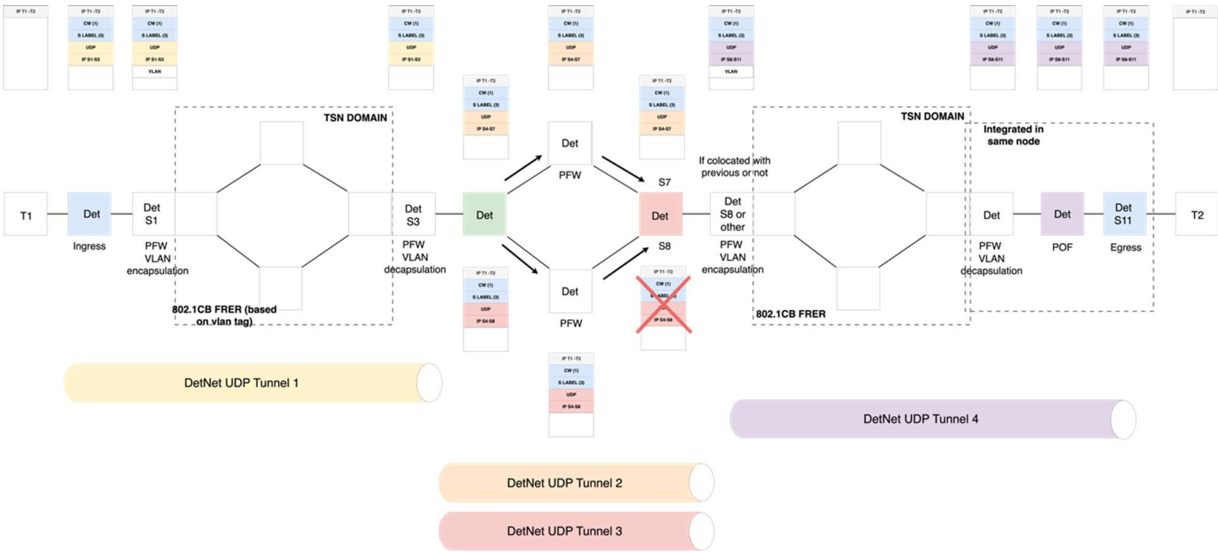



**Figure 7**: DetNet-based MDP design

The data plane is based on the latest draft for IP in IP encapsulation [5], also considering the PREDICT-6G contributed draft on multi-domain [6].

The data plane forwarding is based on a DetNet label (in blue), which is used for service continuity across all the different domains. Decision on replication and configuration of the L2 domains is based on the requirements of the flow indicated in the label and code word. This information should be provided by the E2E MS defined in PREDICT-6G across all the domains crossed by the packets. On each specific MD, an IP-on-IP tunnel between the DetNet end points of the domain is used to provide forwarding and PREOF.

The AICP is not shown in the figure, since it is currently being discussed how the interaction between the nodes occur. The current understanding of the project is that the control for each domain is performed by Open API interfaces between the DetNet nodes/PCE and the AICP.

At this stage of the project design there are still many open questions and decisions to be taken, in the following we briefly discuss the different friction points encountered and the current approach taken to solve them:

- IEEE 802.11 domain: we are currently in the process of obtaining TSN-enabled drivers for IEEE 802.11 from Intel. At this point we have not analysed how is the interface control of the drivers and how the interaction between the DetNet and the IEEE 802.11 can be integrated.

- TSN capabilities of the Open source 3GPP domain: the available implementation of the Open-Air Interface 3GPP domains does not cover deterministic networking, therefore we need to characterise the time characteristics of the domain and find solutions if the delay of the packets while crossing it does not meet the requirements of the application. The 5TONIC 5G commercial deployment is TSN capable, so this will not happen in the second domain.
- The connection between the Open Source 3GPP domains and the commercial one is based on a network which is not TSN. As in the previous case, we need to understand the impact of such a network. In the worst case, we will move the open source 3GPP domains to the IMDEA 5TONIC dependencies and connect both with TSN switches.
- There is no commercial DS-TT and NW-TT available. Ericsson is developing options to cover this aspect.
- DetNet nodes: current implementation developed by UC3M relays on P4 switches which cannot be integrated with IEEE 802.1Qcb due to the lack of management of queues. This requirement has been discovered later in the development process. We are ongoing a new implementation over OpenFlow/XDP to solve this issue.

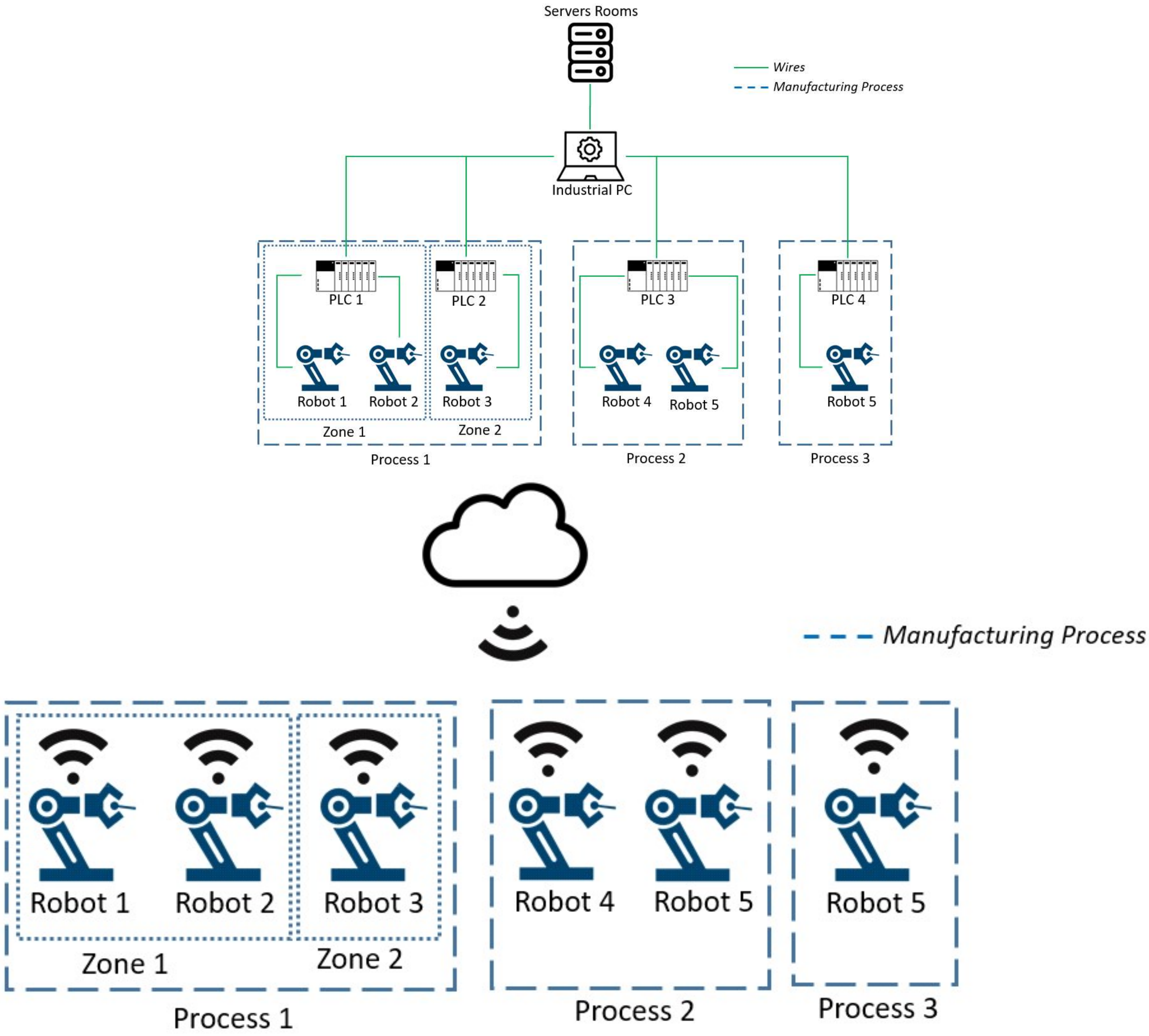
| Parameter | Description |
|---|---|
| **ID** | MULTIDOMAIN_5TONIC |
| **Title** | Multi-technology Multi-domain DetNet-based Integration of MDP and AICP |
| **Use Case** | Multi-domain deterministic communication |
| **Description** | The goal of this PoC is to demonstrate an integrated MDP across WLAN, TSN and 3GPP. The integration is performed over the DetNet data plane. The PoC will also integrate the relevant AICP MSs. |
| **MD & MS Involved** | The PoC is based on the idea of using DetNet as the entry point for the interaction to the different technologies. As such we will have multiple administrative domains which SAP is DetNet based. On each of the |

| | |
|---|---|
| | MDs a different technology will be used. Currently we are exploring IEEE 802.11, TSN and 3GPP domains for their integration in the PoC.<br><br>The key MSs to be implemented in the first phase of deployment, are (subject to further investigation):<br>- E2E monitoring<br>- E2E Service ingestion<br>- E2E Service automation<br>- E2E Path computation<br>- E2E Resource Manager<br>- E2E Topology Exposure<br>- E2E Service Exposure<br>- Measurement collection<br>- Service automation<br>- Path computation<br>- Resource Configuration<br>- Topology exposure<br>- Capability exposure<br>- Resource exposure |
| **TD Involved** | 3GPP, DetNet (Wi-Fi, TSN and 3GPP) |
| **Integration Tests** | To be completed |
| **Targeted period** | 2024-H2 |
| **Laboratory and setup** | The laboratory architecture and setup are described in the next section |
| **KPIs and validation** | Jitter, latency, packet ordering, reliability (packet loss) |
| **Team (INTERNAL)** | UC3M, TID, ERC |
| **PoC Leader (INTERNAL)** | David Rico |

**Table 9**.. Multidomain demonstration.

## 4.2 Smart Factory Demonstration (5TONIC)

Smart Factory demonstration will focus on the execution of the Smart Manufacturing use case using a 3GPP network enhanced with user plane improvements and the AICP. **Figure 8** shows the evolution of the use case, from the current state towards a full cloudified solution, where the controllers of the equipment are offloaded to a cloud environment (please refer to D1.1 [1] for more details)



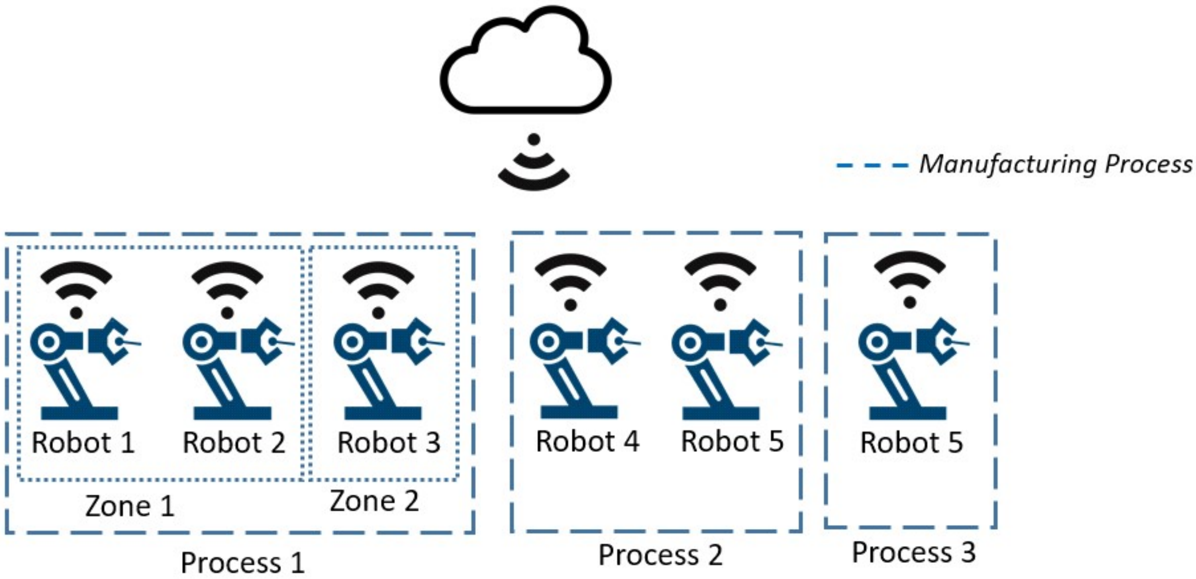



**Figure 8** Current architecture (top) and future cloud architecture (bottom) for Smart manufacturing use case

The demonstration of this use case will be performed at 5TONIC laboratory, using the 3GPP network of the open lab, as described in the **Figure** .

The demonstration includes an equipment from GESTAMP (robot) that is controlled by a virtual PLC located at the cloud. As communication network, we will use the 5TONIC's 5G network with the enhancements of PREDICT-6G project. As described in D1.1, the requirements for the communication network are demanding, especially considering the current state-of-art of 3GPP networks.

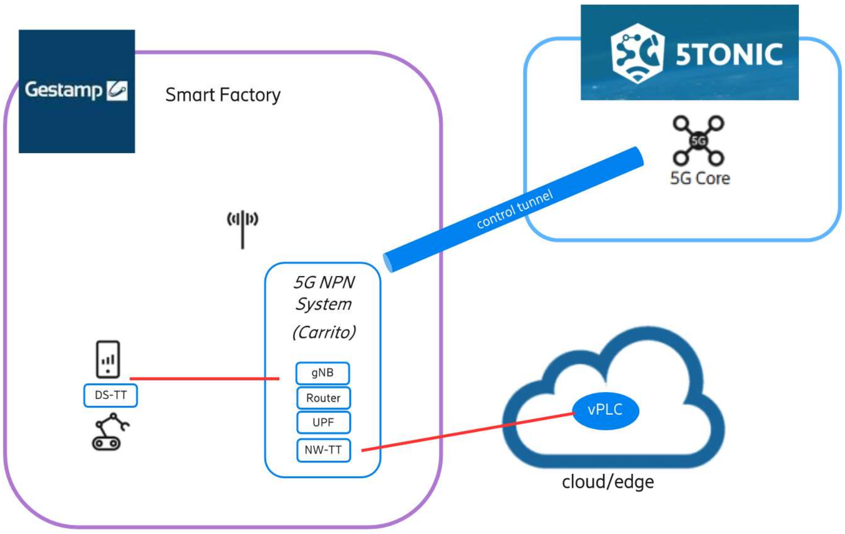



**Figure 9** Smart Factory demonstration setup at 5TONIC

The proposed setup tries to follow a real architecture of 5G deployment integrated as communication network in a manufacturing factory. For that reason, we use a Non-Public Network deployed on-premises, which is integrated with a Public Network (represented by 5TONIC network). This approach allows to have a dedicated user plane for the use case, with a Radio Access Network that can be shared for other purposes.

The demonstration will focus on show the improvements of time-based schedulers using 3GPP network and show the enhancement in Reliability using replication mechanisms.

| **Parameter** | **Description** |
|---|---|
| **ID** | SMART_FACTORY_GESTAMP |
| **Title** | Smart Factory |
| **Use Case** | Smart manufacturing |
| **Description** | Smart Factory use case aims to provide flexible deployments of manufacturing premises. For that, it requires a wireless network with deterministic capabilities in order to ensure the communication between factory elements with a high reliability and bounded latency. |
| **MD & MS Involved** | Measurement collection, Service Automation, more? |

| | |
|---|---|
| **TD Involved** | 3GPP |
| **Integration Tests** | TBC |
| **Targeted period** | 2024-H2 |
| **Laboratory and setup** | The laboratory architecture and setup are described in the next section |
| **KPIs and validation** | Reliability, Service latency, Jitter, Packet loss, Packet Order |
| **Team (INTERNAL)** | GESTAMP, ERC |
| **PoC Leader (INTERNAL)** | Marc Mollà (ERC) |

**Table 10.** Smart Factory demonstration

## 4.3 Localisation and Sensing (5TONIC)

..As described in full detail in D2.2 [7], the Localisation and Sensing testbed will be integrated at 5TONIC, aiming at representing a sensing-enabled 3GPP domain with TSN support. The testbed to be integrated is again illustrated in **Figure 10** for completion purpose and depicts various compute nodes representing a 3GPP domain with three UEs, a sensing-enabled Core Network which coordinates the collection of sensing data and the exposure of sensing results to the outside, i.e. the AICP.

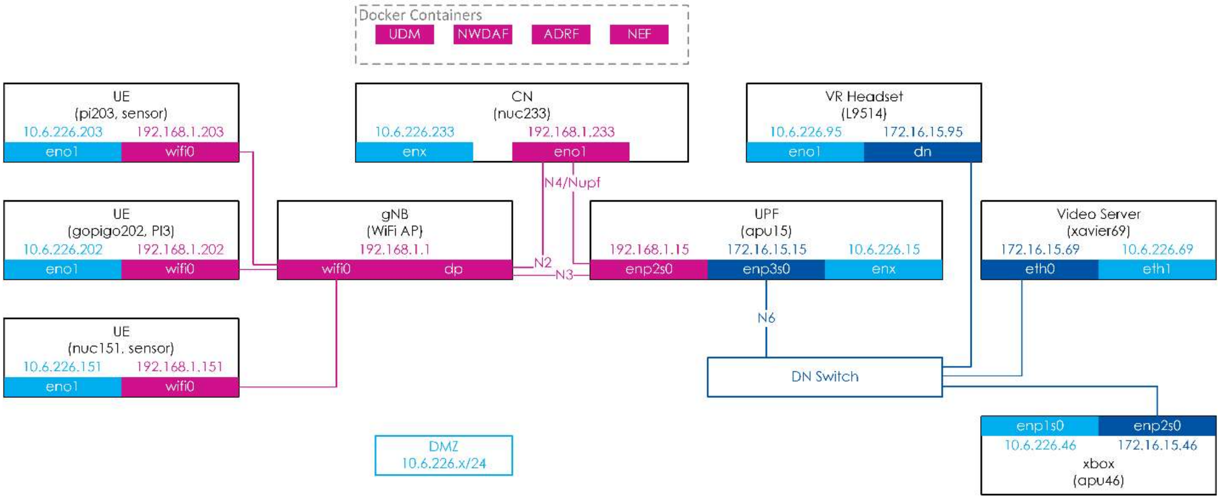



**Figure 10**. Localisation and Sensing Testbed to be Integrated in 5TONIC

**Table 11**, below lists the planned integration to be conducted including the MDs and MSs involved.

| Parameter | Description |
|---|---|
| **ID** | LOCALISATION_SENSING |
| **Title** | Localisation and Sensing |
| **Use Case** | Localisation and Sensing |
| **Description** | This PoC uses a range of sensor data to be processed in the network using AI/ML to generate meaningful sensing results. The use case also includes the remote control of a vehicular device using haptic gloves. |
| **MD & MS Involved** | - E2E Monitoring, E2E Path computation, E2E Resource Manager, E2E Topology Exposure, E2E Service Exposure<br>- Measurement collection, Path computation, Resource Configuration, Resource Exposure, Topology exposure, Capability exposure |
| **TD Involved** | DetNet (3GPP, TSN) |
| **Integration Tests** | - TSN software switch integration<br>- TSN-based packet switching using Data Unit Group IP header extension.<br>- TSN AF with AICP<br>- CNC with AICP |
| **Targeted period** | 2024-H2 |
| **Laboratory and setup** | The laboratory architecture and setup are described in the next section |
| **KPIs and validation** | Jitter, latency, packet ordering, reliability (packet loss) |
| **Team (INTERNAL)** | IDE, UC3M |
| **PoC Leader (INTERNAL)** | Sebastian Robitzsch (IDE) |

**Table 11**. Location and Sensing demonstration.

## 4.4 Deterministic services for critical communications (Budapest Open Lab)

The use case implemented in the Nokia Open Lab aims at providing deterministic services for critical communications. For the sake of better readability, the subsection will first give a high level overview of the use case (you may check Section 5.2 of D1.1 [1] for further details) and then provide implementation plans.

Devices requiring deterministic group communication over a distance, and potentially touching multiple intermediate cloud applications, is a pattern followed by scenarios such as cooperative cloud robotics, cyber-physical system automation or long-range vehicular communication. In these scenarios, devices may run local Application Functions (AF) connected to cloud applications (Network Application Functions, NW AF), where the operation of the AFs at both ends may impose deterministic requirements on the network that interconnects them (e.g., by generating periodic traffic to which a response is expected within a pre-defined time slot). Mobile devices may also engage in collaborative tasks executed in the physical space, which require that the network provides deterministic communication for a group of equipment where groups may dynamically evolve as devices are joining and leaving according to their interest or mobility. Cloud applications may be responsible for the monitoring and control of the devices and serving as rendezvous points to enable cloud-based group communication and data sharing across a large set of distributed devices that share a common task, physical or virtual environment or mission. In all these cases, it is important that the devices and the cloud applications participating in the same collaborative relation stay synchronized with regards to their shared application state and thus need to exchange information, data, commands, and contextual information through deterministic and reliable communication services.

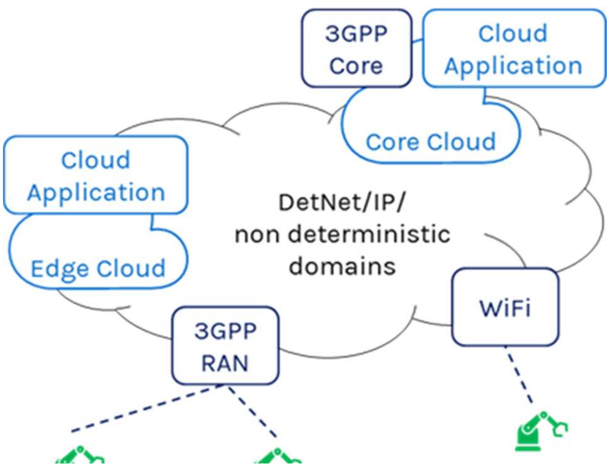



**Figure 11.** Planned network setup for deterministic services for critical communications use case

The use case demonstration in Budapest Open Lab will focus on the machine control scenario of the deterministic services for critical communications use case, e.g., real-time sync between physical robot states and robot DTs. The implementation of selected PREDICT-6G system components will enable the automated setup and management of deterministic services across technology domains both with deterministic capabilities and with no native deterministic capabilities (e.g., no TSN HW). The planned network setup is shown in **Figure 11**, the network domains and access technologies include 3GPP (5G), Wi-Fi, IP.

At current stage of the planning the following MDP components will be required for the desired operation. Time synchronization shall be available for all the devices that are participating in real-time communication, scheduling and traffic shaping shall implement time aware scheduling and the selection of communication paths, path reservations and fault-tolerance requires the implementation of PCE and reservations along selected path and the multi-path and packet duplication/elimination (PAREO) feature. Moreover, the integration of non-TSN/non-DetNet segments as part of e2e DetNet service requires profiling of intrinsic network capabilities (e.g., latency/error/jitter vs. load) and here requirements and considerations described in Section 4.7. of Predict-6G D2.1 [2] shall apply.

At current stage of the planning the AICP implementation shall focus on the following features. In case of the Network Digital Twin, it shall be able to expose and model the status, capabilities and behaviour of the network (including predictions) and support both analytics and control tasks for automated deterministic session management. The cross-domain path, resource and configuration management shall be able to carry out harmonized setup and provisioning of e2e deterministic services across multiple domains (builds on NDT capabilities). The autonomous e2e deterministic service management should implement dynamic service assurance based on resource/domain/network/service monitoring, analytics, and proactive actions.

| **Parameter** | **Description** |
|---|---|
| **ID** | DETERMINISTIC_SERVICES_CRITICAL_COMMUNICATIONS |
| **Title** | Deterministic services for critical communications |
| **Use Case** | Deterministic services for critical communications case |
| **Description** | The use case investigates deterministic group communication scenario where multiple devices and cloud applications share one or more states synchronized in real time. |
| **MD & MS Involved** | Management domains: |

| | |
|---|---|
| | E2E management domain, technology management domain<br>The key MSs to be implemented in the first phase of deployment, are (subject to further investigation):<br>E2E Time Sync, Time sync, E2E service automation, service automation, E2E monitoring, Measurement collection, E2E Service ingestion |
| **TD Involved** | 3GPP |
| **Integration Tests** | List of required integration tests |
| **Targeted period** | 2024-H2 |
| **Laboratory and setup** | Nokia Open Lap |
| **KPIs and validation** | E2E delay; jitter |
| **Team (INTERNAL)** | NOK |
| **PoC Leader (INTERNAL)** | Péter Szilágyi (NOK) |

**Table 12**. Deterministic services for critical communications

Funded by the European Union

# 5 Open Labs design introduction

PREDICT-6G relays in two open laboratories to perform the integration and testing of the innovations developed: i) the Madrid Open Lab (5TONIC) and ii) the Budapest Open Lab.

Both laboratories provide an open experimental platform based on commercial and non-commercial hardware, although each of the labs has a special focus.

5TONIC is composed of two main sites, the IMDEA Networks site provides access to a commercial R16 RAN and core by Ericsson. This infrastructure supports the most common 5G services: enhanced Mobile Broadband (eMBB), massive Machine Type Communication (mMTC) and Ultra-reliable Low Latency Communications (URLLC). Those services are supported by dedicated network slices to meet the requirements of each service. The lab provides access to below 6GHz and mmWave 5G variants.

In addition, the UC3M site in 5tonic provides a complete open-source alternative. It provides access to a full Open-Air deployment based on USRPs N310 with up to 100MHz of bandwidth. In addition, this site has deployed a commercial TSN network, based on RELYUM hardware switches.

The testing capabilities of the project are extended through the capabilities provided by the Budapest Open Lab. This lab is a private 5G standalone (SA) network deployed to develop, test, and validate industrial use cases supported by network and service automation technology. The network can be used as a sandbox for disruptive research due to no SLA or commercial operation obligations. The network can be integrated with any platform (e.g., traffic generators, AI/ML platforms), either hosted by its own local edge cloud, or connected to any cloud (e.g., other 5G Non-Public Network (NPN) or public cloud). A great advantage of the Open Lab in Budapest is the possibility to inject any kind of data, control and management-plane traffic, network and service management actions, configuration directly into the network itself, as it provides open access to every Network Function (NF) and interface. These attributes make the Open Lab ideal to research and validate network management automation innovations.

# 6 Verification at 5TONIC Open Lab

## 6.1 Open Laboratory Design

As mentioned above, 5TONIC Open Laboratory will host three demonstrations of end-to-end proof of concept of the PREDICT-6G framework. The approach for each demonstration is different: (1) with Smart Factory we aim to demonstrate enhancements in the user plane that improves the determinism of it to meet the use case requirements; (2) with Multidomain use case we will show the multi-technology, multi-domain capabilities provided by PREDICT-6G.

Within the Smart Factory use case the goal is to integrate a 3GPP mobile network in the factory communications for connecting the endpoints (robots, production lines, virtual PLCs). The approach used in the architecture is to deploy a Non-Public Network (NPN) that provides the wireless connectivity (5G NR) and the user plane connectivity (5G Core User Plane), which is connected to a Public Network (5G Core), provided by 5TONIC lab, through a dedicated transmission line.

We also deploy on-premises the TSN-Translators (DS-TT and NW-TT), which will provide the deterministic enhancements for the 3GPP network at Layer 2. With this approach, we will demonstrate that PREDICT-6G can provide a good level of determinism for the use case, according to the requirements exposed in D1.1

The setup for Multidomain use case proposes a multi-technology, multi-domain architecture that involves 3GPP, Wi-Fi and TSN domains interconnected for offering end-2-end deterministic connectivity between deterministic applications.

The aim of these demonstrations is to show as much PREDICT-6G capabilities as possible working in a cross-domain architecture, for the user plane and the control plane (AICP). For that, we interconnect UC3M laboratory, which provides Wi-Fi, TSN and 3GPP domains; with 5TONIC open laboratory, which provides 3GPP and TSN network.

**Figure** below illustrates the integration plan for the localisation and sensing demonstration. Three domains are depicted, i.e. plain TSN, TSN-enabled 3GPP and a general applications domain. The application domain on the left is comprised of various non-3GPP sensors (video, laser, radar) which periodically transmit sensing data with various QoS requirements to the Sensing Repository in the right Applications domain. The Sensing Repository uses AI/ML techniques to continuously provide meaningful sensing results to the user via a web-based VR frontend. Furthermore, the user situated in the Applications domain on the right in **Figure 12** remotely controls the vehicle through haptic gloves.

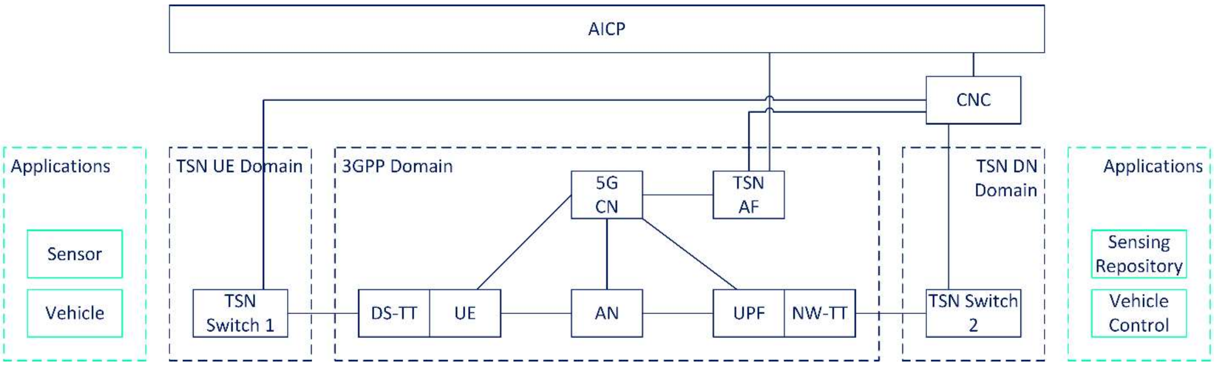



**Figure 12**: Integration Overview of Localisation and Sensing Demonstration

The User Plane in this demonstration utilises the described Data Unit Group (DUG) innovation in D2.2, which allows to perform deterministic packet delivery in TSN-enabled switching fabric using IP header fields and map this directly into the Release 19 feature PDU Sets. The DUG IP headers are written by a user space implementation in the Application domain allowing to transparently act upon an TCP connection initiated by any application.

Furthermore, the TSN domain is represented by hardware TSN switches at 5TONIC, controlled by a Centralised Network Controller (CNC). The TSN switches in the 3GPP network, i.e. Device-Side Translator (DS-TT) and Network-Side Translator (NW-TT), are realised by an PREDICT-6G-internal implementation of an TSN switch.

On the Control Plane, the CNC and TSN Application Function (AF) integrate with PREDICT-6G's AICP to establish, monitor, adjust and release end-to-end flows of DUG-enabled communication.

## 6.2 Verification tests

Following we describe the verification tests to be planned in the 5TONIC Open Lab

### 6.2.1 Demonstration Verification Tests

| **Parameter** | **Description** |
|---|---|
| **ID** | SMART_FACTORY_VERIFICATION |
| **Description** | The objective is to verify that all KPIs defined by Smart Manufacturing use case (please refer to [1]) are met. |

| | |
|---|---|
| **E2E and MD specific MS involved** | Measurement Collection, Service Automation |
| **Technology domains involved** | 3GPP |
| **Integration** | To be defined |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for Smart Factory demonstration |
| **KPIs and validation** | Smart Factory:<br>Latency <= 5 ms<br>Jitter <= 2 ms<br>Packet order == 100%<br>Packet lost == 0%<br>Resilience >= 99,9999% |

| **Parameter** | **Description** |
|---|---|
| **ID** | MULTI_DOMAIN_VERIFICATION |
| **Description** | The objective is to verify that all KPIs defined by Multi-domain use case [1] are met. |
| **E2E and MD specific MS involved** | Measurement Collection, Service Automation, Resource configuration |
| **Technology domains involved** | IEEE 802.11, 802.1 TSN, 3GPP |
| **Integration** | To be defined |
| **Targeted period** | 2024-H2 |

| | |
|---|---|
| **Laboratory setup** | The laboratory must be configured as described for multi-domain demonstration |
| **KPIs and validation** | KPIs are configurable on the application and depend on the control loop of the robot used. We can play with control loops from 100 to 10 ms. Jitter should be in the order of a 10% of the control loop delay. Bandwidth is low, lower than 100 Mbps. Regarding reliability, a high reliability in terms of control messages, of around 99.999% is required. Packets must be delivered in order. |

| **Parameter** | **Description** |
|---|---|
| **ID** | LOCALISATION_SENSING_VERIFICATION |
| **Description** | The objective is to verify that all KPIs defined by Multi-domain use case (please refer to [1]) are met. |
| **E2E and MD specific MS involved** | E2E Monitoring, E2E Path computation, E2E Resource Manager, E2E Topology Exposure, E2E Service Exposure<br>Measurement collection, Path computation, Resource Configuration, Resource Exposure, Topology exposure, Capability exposure |
| **Technology domains involved** | DetNet (3GPP, 802.1 TSN) |
| **Integration** | To be defined |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for the localisation and sensing demonstration |
| **KPIs and validation** | KPIs should be assessed for each sensing traffic type, i.e. video, distance measurements and haptic control. Following the KPIs presented in Deliverable D1.1 [Section 6.1, 8], the following service flow KPIs must be guaranteed for the best user (human) experience:<br>• Haptic: 20ms latency, < 2ms jitter<br>• Video: 100ms latency, <30ms jitter<br>• Audio: 80ms latency, <30ms jitter |

| | |
|---|---|
| | For inter-service flows, their jitters are as follows:<br>• Once haptic has arrived at user:<br>  ○ Audio must arrive within 25ms.<br>  ○ Video must arrive within 20ms.<br>• Once video is first at user:<br>  ○ Haptic must arrive within 30ms.<br>  ○ Audio must arrive within 20ms.<br>• Once audio is first:<br>  ○ Haptic must arrive within 12ms.<br>  ○ Video must arrive within 20ms |

### 6.2.2 Measurement Collection

The objective is to verify the integration of all domains involved in the demonstrations with the Measurement Collection Management Service.

| **Parameter** | **Description** |
|---|---|
| **ID** | MEASUREMENT-COLLECTION-3GPP-ERC-01<br>MEASUREMENT-COLLECTION-3GPP-UC3M-01<br>MEASUREMENT-COLLECTION-3GPP-IDE<br>MEASUREMENT-COLLECTION-TSN-TID-01<br>MEASUREMENT-COLLECTION-TSN-UC3M-01<br>MEASUREMENT-COLLECTION-TSN-IDE<br>MEASUREMENT-COLLECTION-Wi-Fi-UC3M-01 |
| **Description** | The objective is to verify that all relevant KPIs are generated in each of the domains, and they are published in the AICP. |
| **E2E and MD specific MS involved** | Measurement Collection |
| **Technology domains involved** | 3GPP, DetNet (Wi-Fi, TSN) |
| **Integration** | To be defined |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |

| | |
|---|---|
| **KPIs and validation** | Smart Factory: Latency, Jitter, Packet order, Packet lost, Reliability. |

### 6.2.3 Resource Configuration

| **Parameter** | **Description** |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-DETNET-UC3M-01<br>RESOURCE-CONFIGURATOR-3GPP-ERC-01<br>RESOURCE-CONFIGURATOR-3GPP-UC3M-01<br>RESOURCE-CONFIGURATOR-3GPP-IDE-01<br>RESOURCE-CONFIGURATOR-TSN-TID-01<br>RESOURCE-CONFIGURATOR-TSN-UC3M-01<br>RESOURCE-CONFIGURATOR-Wi-Fi-UC3M-01 |
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. The RESOURCE-CONFIGURATOR-DETNET-UC3M-01 acts as the Open API interface to control each technology domain. |
| **E2E and MD specific MS involved** | Resource Configurator |
| **Technology domains involved** | 3GPP, DetNet (3GPP, TSN, Wi-Fi), Wi-Fi, TSN |
| **Integration** | To be completed |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | Resource configuration across the multiple domains is performed according to the requirements of the application. |

| **Parameter** | **Description** |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-DETNET-UC3M-01 |

| | |
|---|---|
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. This first test validates the use of the Open API interface towards DETNET nodes to configure the resources across a DetNet domain. |
| **Technology domains involved** | DetNet (3GPP, TSN, Wi-Fi) |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | A resource configuration request is sent to entry point of DetNet domain. Communication across the DetNet domain is configured with the indicated resources.<br>KPIs: Latency, reliability, bandwidth |

| **Parameter** | **Description** |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-3GPP-ERC-01 |
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. This test validates the API to configure the 3GPP domain from a DetNet entry node. This validation test is performed over the Ericsson infrastructure. |
| **Technology domains involved** | 3GPP |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | A resource configuration request is sent from the DetNet entry point to the 3GPP system. A path across the 3GPP system according to the required resources is established and KPIs requested are met.<br>KPIs: Latency, reliability, bandwidth |

| Parameter | Description |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-3GPP-UC3M-01 |
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. This test validates the API to configure the 3GPP domain from a DetNet entry node. This validation test works over the OAI UC3M infrastructure |
| **Technology domains involved** | 3GPP |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | A resource configuration request is sent from the DetNet entry point to the 3GPP system. A path across the 3GPP system according to the required resources is established and KPIs requested are met.<br>KPIs: Latency, reliability, bandwidth |

| Parameter | Description |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-TSN-TID-01 |
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. This test validates the API to configure the TSN domain from a DetNet entry node. This validation test configures the TSN resources provided by TID. |
| **Technology domains involved** | TSN |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | A resource configuration request is sent from the DetNet entry point to the TSN system. A path across the TSN system according to the required resources is established and KPIs requested are met. |

| | |
|---|---|
| | KPIs: Latency, reliability, bandwidth |

| **Parameter** | **Description** |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-TSN-UC3M-01 |
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. This test validates the API to configure the TSN domain from a DetNet entry node. This validation test works on top of the TSN RELYUM infrastructure available at UC3M. Since this infrastructure has already a TSN configurator implemented, we will validate the integration of the later with the DetNet API. |
| **Technology domains involved** | TSN |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | A resource configuration request is sent from the DetNet entry point to the TSN system. A path across the TSN system according to the required resources is established and KPIs requested are met.<br>KPIs: Latency, reliability, bandwidth |

| **Parameter** | **Description** |
|---|---|
| **ID** | RESOURCE-CONFIGURATOR-Wi-Fi-UC3M-01 |
| **Description** | The objective is to verify that AICP is able to configure the resources for all the domains. This test validates the API to configure the 3GPP domain from a DetNet entry node. This validation test works over the WiFi infrastructure developed by Intel and deployed at UC3M. |
| **Technology domains involved** | IEEE 802.11 |
| **Targeted period** | 2024-H2 |

| | |
|---|---|
| **Laboratory setup** | The laboratory must be configured as described for each 5TONIC PoC |
| **KPIs and validation** | A resource configuration request is sent from the DetNet entry point to the IEEE 802.11 system. A path across the IEEE 802.11 system according to the required resources is established and KPIs requested are met.<br>KPIs: Latency, reliability, bandwidth |

[1] To be decided if there will be a direct integration or DetNet will wrap the measurement collection.

### 6.2.4 Other Verification Tests

A part of the verification tests described above, there are more integration points that must be verified end-to-end. These verification tests will be completed when the integration point is fully defined between AI-Control Plane and the User Plane.

#### 6.2.4.1 Resource Exposure

| Parameter | Description |
|---|---|
| **ID** | RESOURCE-EXPOSURE-WIFI-UC3M-01<br>RESOURCE-EXPOSURE-3GPP-UC3M-01<br>RESOURCE-EXPOSURE-TSN-TID-01<br>RESOURCE-EXPOSURE-3GPP-ERC-01 |
| **Description** | These verification tests are oriented to verify the Resource Exposure integration tests, focused on requirements for the Multi-Domain Demonstration. |
| **Technology domains involved** | DetNet (Wi-Fi) domain, DetNet (3GPP) domain, DetNet (TSN) domain |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | Multidomain 5TONIC setup as described in **Figure 7** |
| **KPIs and validation** | Resources are exposed as expected |

#### 6.2.4.2 Service Automation

| Parameter | Description |
|---|---|
| **ID** | SERVICE-AUTOMATION-WIFI-UC3M-01<br>SERVICE-AUTOMATION -3GPP-UC3M-01<br>SERVICE-AUTOMATION -TSN-TID-01<br>SERVICE-AUTOMATION -3GPP-ERC-01 |
| **Description** | These verification tests are oriented to verify the Service Automation integration tests, focused on requirements for the Multi-Domain Demonstration. |
| **Technology domains involved** | DetNet (Wi-Fi) domain, DetNet (3GPP) domain, DetNet (TSN) domain |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | Multidomain 5TONIC setup as described in **Figure 7** |
| **KPIs and validation** | Services can be provisioned into the different domains with the requirements from use case |

#### 6.2.4.3 Service Exposure

| Parameter | Description |
|---|---|
| **ID** | SERVICE-EXPOSURE-WIFI-UC3M-01<br>SERVICE -EXPOSURE-3GPP-UC3M-01<br>SERVICE -EXPOSURE-TSN-TID-01<br>SERVICE -EXPOSURE-3GPP-ERC-01 |
| **Description** | These verification tests are oriented to verify the Service Exposure integration tests, focused on requirements for the Multi-Domain Demonstration. |
| **Technology domains involved** | DetNet (Wi-Fi) domain, DetNet (3GPP) domain, DetNet (TSN) domain |

| | |
|---|---|
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | Multidomain 5TONIC setup as described in **Figure 7** |
| **KPIs and validation** | Services provisioned by Service Automation are exposed correctly. |

#### 6.2.4.4 Topology Exposure

| **Parameter** | **Description** |
|---|---|
| **ID** | TOPO-EXPOSURE-WIFI-UC3M-01<br>TOPO -EXPOSURE-3GPP-UC3M-01<br>TOPO -EXPOSURE-TSN-TID-01<br>TOPO -EXPOSURE-3GPP-ERC-01 |
| **Description** | These verification tests are oriented to verify the topology Exposure integration tests, focused on requirements for the Multi-Domain Demonstration. |
| **Technology domains involved** | DetNet (3GPP, TSN, Wi-Fi) |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | Multidomain 5TONIC setup as described in **Figure 7** |
| **KPIs and validation** | Topology of the different domains are exposed towards AICP |

#### 6.2.4.5 Capability Exposure

| **Parameter** | **Description** |
|---|---|
| **ID** | CAPABILITY-EXPOSURE-WIFI-UC3M-01<br>CAPABILITY -EXPOSURE-3GPP-UC3M-01<br>CAPABILITY -EXPOSURE-TSN-TID-01<br>CAPABILITY -EXPOSURE-3GPP-ERC-01 |

| | |
|---|---|
| **Description** | These verification tests are oriented to verify the CAPABILITY Exposure integration tests, focused on requirements for the Multi-Domain Demonstration. |
| **Technology domains involved** | DetNet (3GPP, TSN, Wi-Fi) |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | Multidomain 5TONIC setup as described in **Figure 7** |
| **KPIs and validation** | Capabilities are exposed as expected |

# 7 Verification at Nokia Open Lab

Nokia Open Lab located in Budapest, Hungary is a private 5G standalone (SA) network deployed to develop, test, and validate industrial use cases supported by network and service automation technology. The network can be used as a sandbox for disruptive research due to no SLA or commercial operation obligations. The network can be integrated with any platform (e.g., traffic generators, AI/ML platforms), either hosted by its own local edge cloud, or connected to any cloud (e.g., other 5G Non-Public Network (NPN) or public cloud). The Open Lab in Budapest leverages existing infrastructure including HW and SW assets (5G NPN radio, transport, and core network (CN), 5G NFs, edge cloud HW).

## 7.1 Open Laboratory design

**Figure 13** provides an overview about the Nokia Open lab in Budapest. The lab is comprised of a core cloud running the 5G core network and the relevant Predict 6G components. The 5G base stations and edge clouds are connected to the core network via a transport network. The figure also highlights the existing capabilities of the lab, the MDP components to be integrated into the network and the AICP components that are created in the Predict 6G project and will be implemented in the lab.

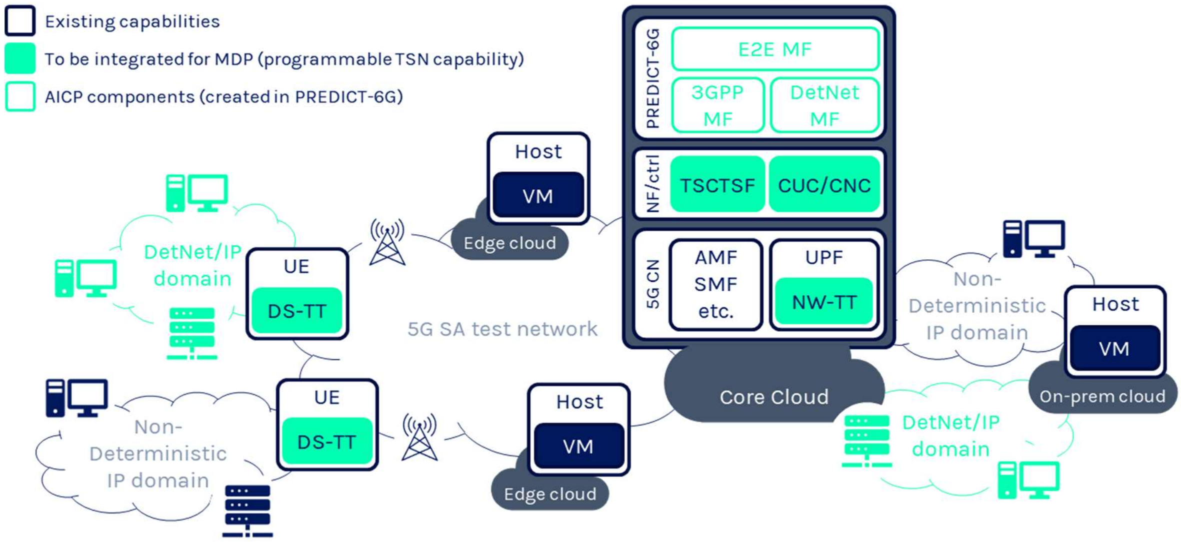



**Figure 13**. Nokia Open Lab overview

Besides the 5G core, 5G radio and transport network, the existing capabilities of the lab setup include a GPS based ToP solution, 5G devices, edge clouds (K8s/docker) for applications, server components and other SW modules and programmable traffic generation setup (support for virtual devices). The MDP components to be integrated are as follows: Device-Side and Network Side TSN Translator (DS/NW-TT), Time Sensitive Communications and Time Synch Function (TSCTSF), Virtual DetNet IP routers and hosts (Linux/DPDK), Flow monitoring and measurements (including non-deterministic domains). For the AICP the components to be implemented in the lab setup include management functions for 3GPP and non-deterministic IP domains and E2E management functions.

## 7.2 Verification tests

The verification tests will focus on validating that the PoC built in Nokia Open Lab fulfills the required KPIs of the Deterministic services for critical communications use case. Thus, the verification tests will focus on these two KPIs: E2E delay and jitter. The tables below describe the verification tests.

| **Parameter** | **Description** |
|---|---|
| **ID** | E2E-DELAY-NOK |
| **Description** | The objective is to verify that the created system fulfils the e2e delay threshold relevant for the use case. |
| **Technology domains involved** | 3GPP |
| **Targeted period** | 2024-H2 |
| **Laboratory setup** | As described Nokia Opel Lab design section, |
| **KPIs and validation** | KPIs: E2E delay<br>The E2E delay of the system is measured and compared to the given threshold. |

| **Parameter** | **Description** |
|---|---|
| **ID** | E2E-JITTER-NOK |
| **Description** | The objective is to verify that the created system fulfils the e2e jitter threshold relevant for the use case. |
| **Technology domains involved** | 3GPP |
| **Targeted period** | 2024-H2 |

| | |
|---|---|
| **Laboratory setup** | As described Nokia Opel Lab design section, |
| **KPIs and validation** | KPIs: E2E jitter.<br>The E2E jitter of the system is measured and compared to the given threshold. |

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# 8 Roadmap

Four 3-months cycles of release plus a 3-month contingency are provisioned to deploy PREDICT-6G starting from January 2024 (M13). During this 15-month period WPs 2, 3 & 4 will work closely to deliver, integrate, and deploy the functionalities of PREDICT-6G system.

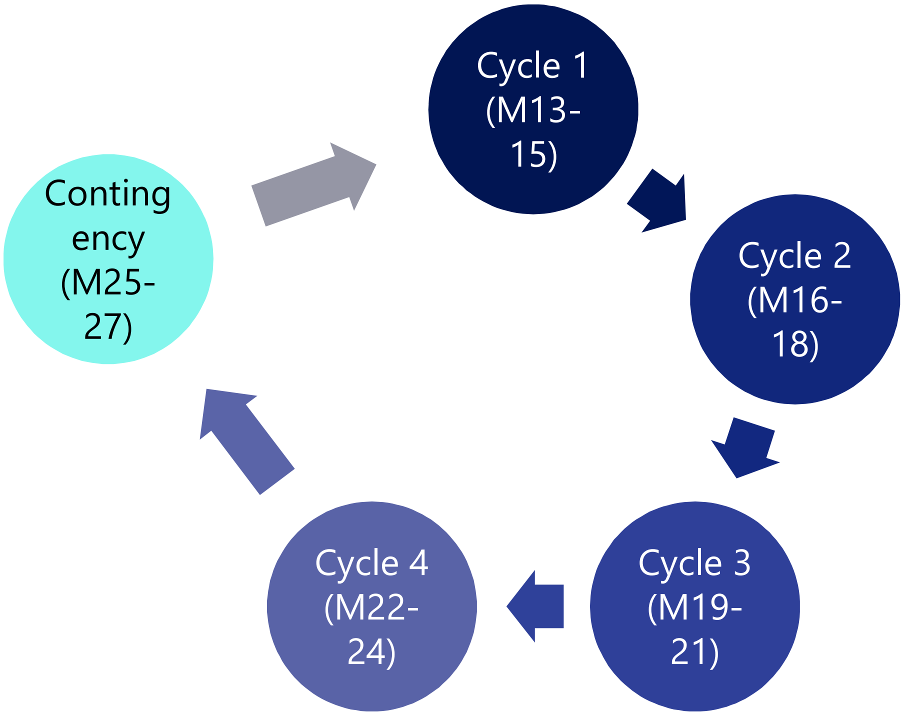


**Figure 14:** Roadmap

**Figure 14**, illustrates the proposed cycles and below a brief presentation of the scope of releases is provided:

- Release 1. Aims at detailing and validating the technical activities, scheduling of releases and agreeing on the analytical framework for the development, integration and deployment of PREDICT-6G system.
- Release 2. Aims at finalizing the test plan for all use cases and the release of the fist versions of data plane and control plane components.
- Release 3. Focuses on the integration tools both data plane and control please components.
- Release 4 Focuses on the delivery of the integrated prototype and on testing and validating it is components.
- Contingency is reserved to tackle any delays in the delivery of the integrated prototype.

Each Cycle will run in parallel with the development cycles described in D3.2 (delivered in parallel to this document) and have the same length and starting point in time.

The development cycles defined in D3.2 are represented in **Figure 15**:


**Figure 15:** One development cycle

.

Considering that the integration will be organized in parallel with the development, we are defining integration cycles of the same length as the development cycles but with different scope and activities. The integration in each cycle will refer to the components considered in the parallel development cycle.

A cycle will be divided in three main phases, as presented in **Figure 16**:

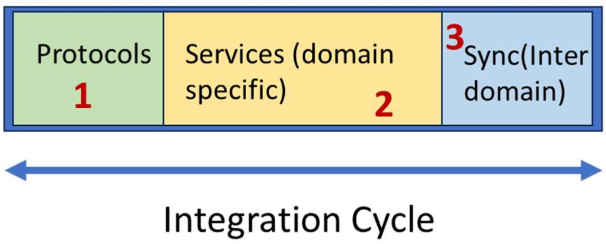


**Figure 16:** One integration cycle

- 1-Definition of protocols, standards for interfaces between components.
- 2-Definition of services and interfaces for integration at the domain level
- 3-Synchronization (Inter domain integration).

The definition of standards and protocols (Phase 1) is planned to take 1 to 3 weeks. In the first cycles this part will be longer (3 weeks), and in the last cycles, it will be shorter.

The definition will refer to the uniform way of communication between components, and will include the communication mechanisms, the data formats, the data validation means, the communication flows.

The creation of services for the integration at intra domain level (Phase 2) is planned to follow the development process, to verify if the implementation is in line with the defined standard and protocols, and if not, to employ the necessary corrections. The service-based integration will be created here, and the results verified and monitored. The monitoring and verification process will be based on the inspection of several checkpoints defined in the previous phase.

The synchronization phase (Phase 3) is planned to be in parallel and in close relation with the synchronization in the development process. The difference refers to the fact that for the integration activities, integration refers to the system, is realized at inter domain level and has a wider scope than the synchronization for the development activities. It is working at cross domain level.

The three phases for each cycle, can be mapped on the system architecture, and the result is schematically drawn in the next figure (**Figure 17**).

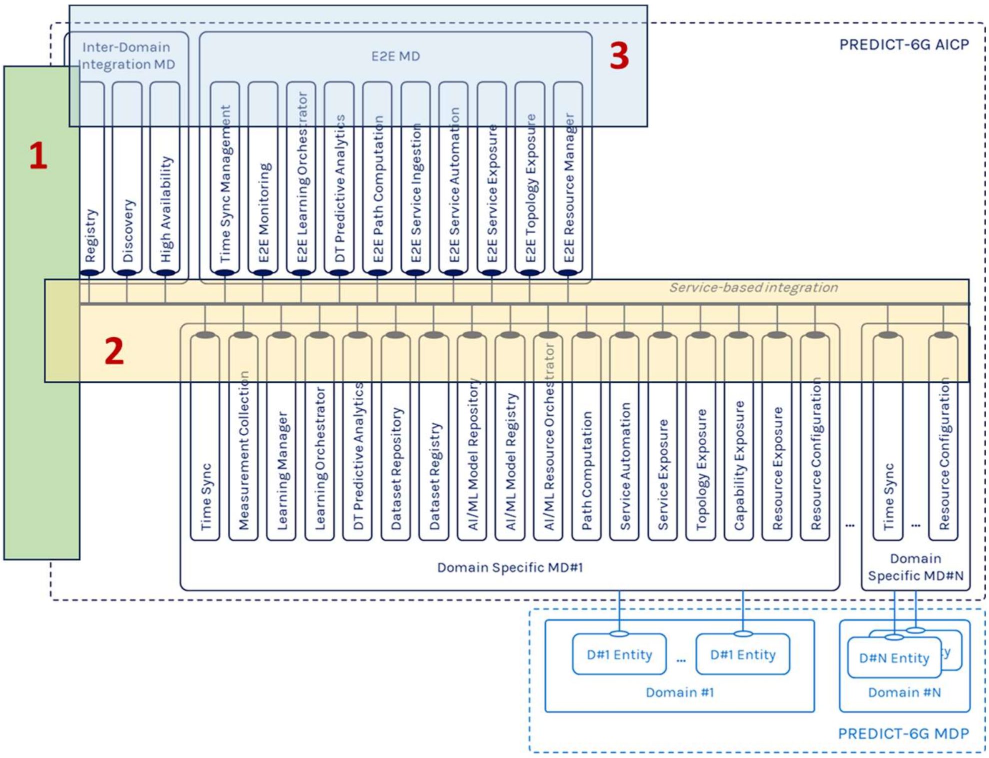


**Figure 17**. Integration cycles, mapped on the architecture.

Considering the definition of cycles, and the organization inside each cycle, now we are defining the detailed activities specific for each cycle and addressing both data plane and control plane components.

**Table 13** included the breakdown of activities for data plane and control pane components of PREDICT-6G system.

| **Component** | **Cycle 1**<br>**M13-M15** | **Cycle 2**<br>**M16-M18** | **Cycle 3**<br>**M19-M21** | **Cycle 4**<br>**M22-M24** |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Time Sync** | Initial interfaces and data models definition | Implementation of technology domain specific TS MS | Implementation of E2E time sync management | Integration with MDP. |
| **Service Ingestion** | Component skeleton with base NBI functions and base service parsing logic | **R1:** NBI for service Management, service management logic, initial integration with service automation via SBI | Base authentication logic design and early implementation. Possible changes in the information model to be integrated | **R2:** Full-fledged NBI and SBI. Integration with Service Automation and IAM platform under refinement |
| **Exposure Services** | Skeleton of MD level for Deterministic service. Data model analysis for mock modules | MD level Deterministic Service Exposure module. Mock for MD topologies. | Skeleton form E2E MD level modules. Mock to complete modules, if possible | Complete set of exposure modules in both MDs and E2E Md levels |
| **Service Automation** | Final definition of data model. Development of MD Service Automation and interfaces. | Implementation of E2E Service Automation functionalities and interfaces. | Fine-tuning MD and E2E functionalities, initial integration with the rest of modules. | Final integration and testing with other modules. |
| **Path Computation** | Initial interfaces and data models definition | Interfaces and data models consolidation<br>Preliminary path computation engine | Consolidated Path Computation engine both at domain and E2E level<br>Initial integration | Fully integration of the Path Computation module with the other modules |
| **Digital Twin** | Initial interfaces and data models definition | Preliminary Queuing models for deterministic services | KPIs composition for e2e estimation | Fully Integration with other models |

| | | | | |
|---|---|---|---|---|
| **Resource Configuration** | Initial manually configurable TSN module | Preliminary TSN configurator with DetNet Constrains focus | Integrable TSN configurator in DetNet with well-defined SBI endpoints | Fully autonomous configurator interoperable |
| **Data Collection and Management** | Integration with MDP available data collection technologies | Support for hierarchical deployment, Integration with MDP available data collection technologies | Support of IAM, integration with MDP available data collection technologies | Integration with MDP available data collection technologies |
| **AI/ML algorithmic framework** | | | | |
| **ML Architectural Framework** | Addition of dataset registry and repository capabilities. Support for Pytorch libraries. | Support for the deployment of Federated Learning algorithms. | Fine-tuning of functionalities, and release of first complete version of AI/ML architectural framework. Initial integration with other Management Services. | Final integration with the rest of Management Services. |
| **Assess TSN over Wi-Fi** | Enable and evaluate TSN redundancy and resiliency to interference/attacks and mobility | | | |
| | Leverage multi-radio/MLO (Wi-Fi 7 – available in 2024) towards seamless roaming | | | |
| | Deterministic channel access in Wi-Fi | | | |

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| | | | | |
|---|---|---|---|---|
| | Scheduling of TSN traffic based on rTWT | | | |
| **Dynamic re-configuration of TSN-based wired/wireless networks** | Use of different SDN controllers | | | |
| | Assessment of the TWT behaviour | | | |
| **Non-deterministic devices and networks** | Traffic management for non-deterministic domains | Programmable APIs for service automation | Programmable and intelligent management plane in TSN enabled RAN | |
| **Interfaces to AICP** | | | Implementation of XDP based IEEE 802.1Qub bridge | |
| **General TSN technologies** | | Scheduling techniques and queueing models with mixed traffic classes | Testing of XDP bridge on top of IEEE 802.11 and validate Intel deployment with and without XDP bridge | |
| | | Development the concept of slice in IETF for the support of determinism, reliability and predictability (e.g., including DetNet) | Cloudification of TSN reliability functions | |
| **Integration of MDP** | Implementation of DetNet transport | Integrate DetNeT control plane with L2 FRER techs | Integrate DetNet control plane with | |

| | | | | |
|---|---|---|---|---|
| | | | the 3GPP and Wi-Fi | |
| | | Development of multi-domain reliability | | |
| **3GPP TSN** | Design of dynamic scheduling algorithms for mixed traffic | | Linking PDU Sets with E2E DetNet Data Plane | |
| | Design of multi-cell coordinated scheduling strategies | System-level simulator for evaluation of scheduling and multi-cell coordination algorithms | | Enable programmable Data Unit Group-enabled IP headers and 3GPP User Plane with PDU Sets |
| | | Dynamic Scheduler Interface | Development of needed extensions for operation of 5GS as TSN bridge. Time-based schedulers on 3GPP networks | |

**Table 13**. Provisioned activities for both data plane and control plane components

# 9 Conclusions

In this document we detailed the methodology for building integration tests for the PREDICT-6G project. This is the basis for the integration efforts that will be performed during next year for testing the behaviour of the AICP and the enhanced user plane.

Also, we define the four demonstrations that will show the capabilities of the PREDICT-6G project in different angles. The demonstrations definitions include the Open Lab design as well as the verification tests required for their validation.

This work sets the foundations for starting the integration of the Work Package 2 and Work Package 3 deliveries in the Open Labs.

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