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Deliverable D1.3

D1.3 – Publishable Final Report | Final Periodic Report

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Revision history

Version	Issue Date	Changes	Contributor(s)
v0.1	28/08/2024	Drafting of periodic report structure	F. Davoli (CNIT), D. Klonidis (UBI)
v0.2	30/08/2024	Finalisation of structure and assignment of contributors	F. Davoli (CNIT)
v0.3	02/09/2024	WP6 related contributions	Diego San Cristobal (ERC)
v0.4	04/09/2024	WP5 related contributions	Thanos Xirofotos (UBI)
v0.5	09/09/2024	WP5 related contributions	Maurizio Giribaldi (INFO)
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v0.7	13/09/2024	Re-check of answers to reviewrs' comments raised in the 1st periodic project review held in Sept. 2022	D. Klonidis (UBI), F. Davoli (CNIT), R. Rapuzzi (CNIT)
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v1.0	18/09/2024	Final version to be submitted	F. Davoli (CNIT), R. Rapuzzi (CNIT)

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Glossary of terms and abbreviations used

Abbreviation / Term	Description
5G	Fifth Generation
AGV	Automated Guided Vehicles
AI	Artificial Intelligence
AMF	Access and Mobility Management Function
AMR	Adaptive Multi-Rate
API	Application Programming Interface
APN	Access Point Name
AUSF	Authentication Server Function
BG	Background
B2B2X	Business-to-Business-to-Any
CI/CD	Continuous Integration (CI) and Continuous Delivery (CD)
CPF	Control Plane Function
CPU	Central Processing Unit
DevOps	Software development (Dev) and IT operations (Ops)
EM	Emergency Maintenance
ER	Exploitable Result
ExFa	Experimentation Facility
FA-GN	Focus Group on Autonomous Networks
FG	Foreground
IMSI	International Mobile Subscriber Identity
IDS	Intrusion Detection System
IDPS	Intrusion and Detection
IoT	Internet of Things
IP	Internet Protocol
KER	Key Exploitable Results
KPI	Key Performance Indicator
MEC	Multi Edge Computing
ML	Machine Learning
MME	Mobility Management Entity
MNO	Mobile Network Operator
MP	Manual Preventive Maintenance

Abbreviation / Term	Description
MT	Mobile Testbed
NAO	Network Application Orchestrator
nApp	Network Application
NFV	Network functions virtualization
NFVCL	NFV Convergence Layer
NR	New Radio
NS	Network Service
NSD	Network Service Descriptors
OSS	Operation Support System
PGW	Packet Gateway
POTP	Packet optical transport network
QoS	Quality of Service
RAN	Radio Access Network
SBI	Service Based Interface
SDO	Software Development Outsourcing
SGW	Service Gateway
SIM	Subscriber Identity Module
SINR	Signal Interference Noise Ratio
SME	Small and Medium-sized Enterprise
SMF	Session Management Function
TSN	Time Sensitive Networking
TRL	Technology Readiness Level
UAV	Unmanned Aerial Vehicle
UC	Use Case
UDM	Unified Data Management
UE	User Equipment
UPF	User Plane Function
UL	Uplink
USV	Unmanned Surface Vehicles
VNF	Virtual Network Function
VR	Virtual Reality
WP	Work Package

1 Summary of the work within the reporting period [M18 – M42]

This section provides an overview of the work progress of the 5G-INDUCE project from the date of the Interim Periodic Report (D1.2, M18) till the end of the project (M42, following the 6-month extension), highlighting its main achievements for this reporting period, during which the objectives of the project were successfully accomplished. The progress is split according to the targeted innovation and development areas. Finally, a summary of the progress per WP activities is provided, highlighting the key achievements.

1.1 Main innovation and development areas

The prime goal of the 5G-INDUCE project has been **to develop an end-to-end service orchestration platform over enabling 5G experimentation infrastructures (with specific target in the Industry 4.0 vertical sector), able to provide the essential mechanisms for the onboarding of advanced 5G Network Applications (nApps) and the efficient management of the infrastructure resources, independently of the underlay network orchestration layer.** The aim was to provide the enabling interfacing layer between the vertical sector end-users and the infrastructure owner to select, deploy and also extend their 5G applications with the appropriate networking features that comply with the application requirements, in terms of physical network constraints (such as bandwidth and latency), as well as functional constraints (such as locality, resiliency, security). Moreover, the 5G-INDUCE platform enables nApp developers to have a common interface for the porting of nApps, either as complete services (in the form of linked application components) or individual extension components to existing services. An additional relevant goal of the project was **to demonstrate the effective application of the developed tools in 8 Industry 4.0 Use Cases, over 3 different Experimentation Facilities (ExFas).**

In order to achieve the targeted development goals and also demonstrate successfully the functionality of the 5G-INDUCE platform solution through a number of use cases and over real industrial experimentation facilities, the overall work has been split into the following development areas:

Development Area 1: **5G-INDUCE orchestration platform** (Implemented in **WP3**). This refers to the main innovation offered by 5G-INDUCE, which provides the end-user driven nApp onboarding and lifecycle management of the nApps over the southbound 5G infrastructures. The platform is composed by the **Network Applications Orchestrator (NAO)** and the **Operations Support System (OSS)** modules. The NAO deals with the nApp onboarding and deployment requests, allowing nApps to negotiate and obtain from the OSS both the needed computing resources at the edge facilities where to run nApp components, and connectivity among such resources and User Equipment (UE). The OSS deals with the tasks of analysing operational and performance (soft and hard) constraints expressed by the NAO slice request and consequently selecting the most suitable computing facilities and network services complying with the requirements. **Key innovative features** of the platform include:

- the automated translation of nApp micro-services into deployment requests for the OSS, annotated with QoS and operational requirements,
- the generation of end user- or policy-based requests by the NAO to the OSS for reconfiguration of the deployed resources at run-time (including resource scaling and/or relocation of involved VNFs),
- the capability of the OSS to select/deselect proper resources at edge facilities updating/creating/deleting network services,
- the dynamic reconfiguration of network slices to transparently/smoothly redirect UE incoming/outgoing traffic during the reconfiguration phases,
- the introduction of the NFV Convergence Layer (NFVCL), for driving NFV service orchestration along all the lifecycle phases over external network orchestrators (e.g., MANO) and through standard interfaces, thus adaptively exploiting the programmability level offered by the underlying network infrastructure(s).

Development Area 2: **Use case nApps** (Implemented in **WP4**). This area deals with the developments for the specific use cases envisioned in 5G-INDUCE and more specifically with the development of the essential nApp components, offered in the form of Kubernetes micro-services, for supporting the targeted use cases. All use case applications are decomposed in a series of linked micro-service components, complying with the nApp application graph approach defined for the NAO part of the platform. Besides the components developed in support of the use cases, the goal is to develop also general-purpose nApp components that can be directly added to the existing applications and update them, or be reused by other applications. The design of such nApps is critical, in order to fully utilise the platform capabilities and then demonstrate real case scenarios over the targeted infrastructures at the industrial sites.

Development Area 3: **Experimentation infrastructures** (Implemented in **T5.2, T6.1**). This area refers to the actual testing infrastructures of the project. Three main experimental infrastructures (**ExFas**) have been realized and are located in Spain, Italy and Greece. All ExFas relate to industrial sites and connect to the core network through operator-scale 5G infrastructures. The three sites have been designed to have different deployment characteristics complying with a diverse set of actual deployment scenarios and market directions, including independent industrial 5G infrastructures with 5G support by operators and full network programmability, operator owned 5G infrastructures with nApp level configuration capabilities, and hybrid schemes of operator-supported infrastructures with some programmable features at the industry level. In addition to the ExFas, a **DevOps testbed** has been developed to host the integration, testing and validation of the platform and the use cases prior to their deployment over the industrial ExFas. The role of the DevOps testbed is important for the proper integration of the development and the identification of development issues.

The work in all three development areas has been performed in parallel in view of the final integration and then demonstration activities that have been conducted during the second half of the project duration. An overview of the final status in all three development areas is presented in the next section.

1.2 Overall status per development area

According to the project workplan, the project phases listed below have been identified and followed by the related project activities. For each phase we present the performed actions, as well as the activities per development area.

Note 1: The overlap between consecutive phases is due to the logical overlap between the development and integration cycles; e.g., the integration of the early release is in the M19-M21 period, which overlaps with the M19-M24 final development cycle running in parallel.

Note 2: The testing cycles have been considered separately from the development and integration for a clearer management of the related activities that follow the integration cycles.

M18-M30 **Final release and integration over DevOps Testbed**:

- Actions for DA1 – Platform developments:
    - Complete NAO-OSS integration
- Actions for DA2 – nApps developments:
    - Verification of final version of Use Cases' nApps on the DevOps testbed
- Actions for DA3 – ExFa Developments:
    - Completion of ExFas' Infrastructure
    - Preliminary testing of some Use Cases on the ExFas' Infrastructure
    - Verification of ExFas' Infrastructure functionality

M31-M38 **Updated final release** (version c) **and integration over ExFas**:

- Actions for DA1:
    - Bug fixes following DevOps testbed testing activities
    - Slice update

- Actions for DA2:
  - No further actions required
- Actions for DA3:
  - Deployment of Use Cases' nApps over ExFas for final testing activities

M31-M42 **Final testing and demonstration activities**:

- UC1, UC2, UC3 tested on ExFa Spain (M35)
- UC5 tested on ExFa Greece (M36)
- UC4, UC7, UC8 tested under Option 1 on ExFa Italy (M38)
- UC6 tested under Option 1 on ExFa Italy (M41)
- UC7 and UC8 tested under Option 2 on ExFa Italy (M41)
- UC4 tested on ExFa Greece (M42)
- Demonstration material collected following each testing activity and publicly disseminated
- Final demonstration Workshop held online

1.3 Deviations to the overall planning

Issues with integration of the slice update mechanism that was completed, tested on the DevOps testbed, but not demonstrated in any of the Use Cases.

1.4 Summary of progress per WP activity

WP1 – Project Management

Overview: WP1 is the administrative work package, which is devoted to providing the financial and administrative coordination of the project and to managing the technical activities, assuring, thanks to the fruitful collaboration among all partners, the scientific quality of the activities and the achievement of projects goals.

Key achievements:

- Management of ordinary financial and administrative issues, along with leading technical and research activities.
- D1.2 - Interim Periodic Report submitted in M21 and re-submitted in M24 to further address comments raised in the project periodic review report.
- WP1 tasks T1.1 "Administrative Project Management & Quality Assurance" and T1.2 "Technical Coordination and risk management" led respectively by CNIT and UBITECH, proceeded and terminated without significant problems.
- In the frame of WP1, under CNIT coordination, all partners contributed to the creation and completion of two consortium requested Amendments, which have been accepted on 26 October 2022 and on 28 November 2023, respectively, by the European Commission.

WP2 – 5G Orchestration Platform Requirements, Use Cases, and Targeted KPIs

- WP2 ended in the first reporting period. Deliverable D2.3 was submitted in M19 and re-submitted in M24 to address comments raised in the interim review report.

WP3 – 5G Orchestration Platform Development

Overview: The scope of WP3 consists of developing the 5G-INDUCE Orchestration Platform, to be integrated with the Experimentation Facilities (ExFas) being set up within WP5 and to be utilized for the deployment and management of nApps in the validation, evaluation and showcasing activities that are part of WP6. The 5G-INDUCE Platform aims at:

- providing nApp developers with tools for the smooth deployment, orchestration and run-time management of nApps;

- flexibly exploiting the capabilities (in terms of exposed control/management interfaces and physical and virtual resources) of the different ExFas, in order to largely automate the deployment of nApps and the activation of supporting 5G Network Services.

Key achievements:

- Several significant updates were made to the NAO, focusing on enhancing the runtime functionalities of the 5G-INDUCE Platform. These updates primarily revolve around improving telemetry, runtime policy support, and the platform's front-end.
- Regarding the OSS: completion of the interface with the NAO and extension of the slice management and network orchestration operations supported by the 5G-INDUCE platform; integration of the platform in the ExFas.
- Platform fixings and enhancements during Use Case trials.

WP4 – nApp Use Cases development and Onboarding

Overview: The main goal of WP4 is to provide 8 fully functional and demonstrable nApp use cases to be developed, onboarded, tested, validated and evaluated over 5G-INDUCE ExFas. The major requirements and methodology for design and implementation of application graphs of each use case have been determined. The technical KPIs to be used for validation and evaluation of each use case have been also established. Moreover, the nApp application graphs have been designed and defined. The ultimate scope of each use case has been discussed and decided through regular telcos with different involved industries and required datasets are collected for AI-based use cases. The major VNFs of each use case have been also defined and the VNFs have been finalised. All functional and deployable versions of the Net Apps have been onboarded on the NAO platform and Use Case results and demos have been provided for showcasing.

Key achievements:

All the key objectives set for WP4 have been achieved successfully:

- WP4 provided the requirements and methodology for the design and implementation of the application graphs for 8 use cases.
- WP4, together with WP6, defined 51 technical KPIs for the use case nApps to be used for validation verification.
- WP4 developed 11 use case specific nApps, including 31 required network functions.
- WP4 provided the final validated nApp to the 5G platform experimentation facility
- WP4 supported the deployment of nApps from 3rd party developers, including a total of 4 diverse nApps from 2 ICT-41 projects and 2 commercial companies.

Overall, significant achievements have been made in terms of 8 high-TRL and innovative use cases developed for 5G.

WP5 – Integration over Experimentation Infrastructures

Overview: WP5 is responsible for managing the integration of the platform over the ExFas and the preparation of the ExFas in view of the planned use case testing scenarios. WP5 deals with the extraction of the overall integration workplan and later with the workplan for the experimental activities. For this reason, it undertakes also the planning and preparation work for the 3 ExFa deployments at industrial sites including the 5G system support. Finally, WP5 includes the major horizontal integration activity which follows a solid CI/CD process and provides the deployment of the 5G-INDUCE platform over the defined ExFas according to the use case requirements. Currently the integration procedures have been clearly defined and followed. A detailed implementation and evaluation workplan has been extracted, updating the one defined initially in the DoA. Finally, significant effort is conducted with respect to the Experimentation Facilities in the three targeted sites.

Key achievements:

- Unified Framework for Testing and Validation

- Dedicated CI Pipelines for testing software developments:
- Utilised for both Platform and nApps components at DevOps testbed
- Provides Automated testing, code reviews, and Kubernetes-based integration tests.
- Successful development of the Multi-Site Experimentation Framework
- Successful set-up and deployment over 3 industrial sites
- Integration of 5G-INDUCE platform over ExFas
- Integration of UC nApps over ExFas
- Planning-monitoring-refinement of integration process
- Monitoring of integration process led to early identification of potential experimentation issues
- Updated and detailed workplan extracted on time

WP6 – nApp Validation, Verification and Showcasing (ERC)

Overview: As the 5G-INDUCE platform evolution was completed and the network infrastructure at the ExFas was deployed during this period, this conformed the environment needed to achieve the goals of WP6: validating interoperability and lifecycle management simplicity of the nApps, verifying nApp functionalities, evaluating performance KPIs and showcasing the service capabilities. In the context of WP6, experimentation was done to onboard the nApps first on the DevOps platform and later on the ExFas. Besides experimentation in lab environments, the experimentation and showcasing of the use cases on the final ExFas was performed. All this experimentation allowed to detect and fix bugs and produced a big deal of performance metrics to be able to draw conclusions. Finally, the showcasing of the demos running on the ExFas was done with several events, like for example, the webinar broadcasted on July 23, 2024.

Key achievements:

- Onboarding of nApps via 5G-INDUCE platform achieved in all ExFas
- Demos of the use cases run on ExFas
- Webinar describing all three ExFas on July 23, 2024

WP7 – Dissemination, Communication and Exploitable Market Potentials

Overview: In terms of dissemination, during the reporting period 2 Whitepapers, 5 journal papers and 7 conference papers were produced in the framework of the project. A project booth was organized at the Exhibition connected with IEEE ICC 2023 in Rome, Italy, and a Special Session was set up at BalkanCom 2024 in Ljubljana, Slovenia. Communication activities continued to be actively pursued with participation in social media, in 5G PPP Steering Board, Technical Board and Working Groups. Regarding participation in SDOs, partner Ericsson was particularly active. Business and market studies were conducted, along with identification of Key Exploitable Resources, SWOT and Lean Canvas analyses. Videos of the Use Cases' experimentations were produced.

Key achievements:

- Over the whole project duration: 49 representations of 5G-INDUCE in form of press releases, webinars, workshops and exhibitions in major events hosted across Europe; 11 publications in conference/workshop proceedings; 11 journal articles
- Booth at the IEEE International Conference on Communications in Rome, Italy, in June 2023
- Special Session organized at IEEE Co-sponsored 7th International Balkan Conference on Communications and Networking (BalkanCom 2024), Ljubljana, Slovenia, in June 2024
- Contribution to 2 Whitepapers of the 5G-PPP organization
- Contributions to 3GPP standardization activities by partner Ericsson
- Leading coordination activities with other ICT-41 projects, which led to a common Whitepaper
- Identification of Key Exploitable Results (KERs) and related business analysis
- Comprehensive market analysis

2 Explanation of the work carried out per Work Package

This section provides a detailed description of the work per work package including the generic objectives, the progress towards the completion of the objectives, and any potential deviations to the initial plan. The following paragraphs provide in further detail the activities and main achievements per task within the reporting period.

2.1 WP1 – Project Management

WP1 is responsible for the project management and the coordination of the works.

The key objectives of WP1 are:

- To provide the financial and administrative coordination of the project;
- To manage the technical activities according to the work plan and assuring the project scientific quality;
- To identify potential risks and manage efficiently the contingency plans maintaining the overall quality;
- To establish and manage the activities of the Industry 4.0 and Service management advisory board member.

Task 1.1 – Administrative Project Management & Quality Assurance

Leader:	CNIT
Participants:	{ALL}
Duration:	M01 – M42
Description of activities:	During the second reporting period, the Coordinator managed the ordinary financial and administrative issues, along with leading technical and research activities. Partners having a leading role in WPs offered their support in the coordination of the corresponding research and management activities. Four plenary meetings have been organized during the reporting period. The third plenary meeting was held online, on 5-6 July 2022. The fourth plenary meeting was held in Athens, Greece, on 28-30 November 2022. The fifth plenary meeting was held in Rome, Italy, on the 30-31 May 2023 and the sixth plenary meeting in Varano Borghi, Italy, on the 20-21 May 2024. In addition to the plenary meetings, more than 60 virtual meetings have taken place, and some face-to-face meetings have been arranged between some partners for deeper discussions on joint collaboration activities. Excluding the first technical review, all the project reviews took place in the reporting period. The first project periodic review was held online, on 29 September 2022, the second and final project periodic review is scheduled to be held online, on 23 September 2024. The Coordinator led the organization of the review meetings, together with the technical coordinator, and supported partners in preparing required documents and presentations. D1.2 - Interim Periodic Report was submitted in M21 and re-submitted in M24 to further address comments raised in the first periodic project review meeting report. The Coordinator spent effort in organizing and managing the activities devoted to prepare the required financial and technical documents, both with regard to the first project periodic review, whose deadline for providing the documentation has fallen in the second reporting period, and to the second and final project periodic review. The Coordinator also offered support to partners in compiling their periodic reports, by providing dedicated and pre-filled template documents to each partner and by checking data for inconsistencies.

The amount received as interim payment by the European Commission has been distributed by the Coordinator without undue delay and in accordance with the relevant provisions of the Grant Agreement and of the Consortium Agreement. Some corrections in the payments have been applied to reflect the changes that have occurred with the approval of the second Amendment.
The following Table 1 shows the amounts distributed by the Coordinator to each partner as share of the interim payment and the necessary corrections.

Table 1 Interim payment distribution

Beneficiary	Share of the Interim payment	Corrections (amounts to be added to/deducted from the interim payment share)	Reasons for corrections
CNIT	€57,511.55		
OTE	€38,885.67		
WIND3	€21,064.12		
ERC	€42,225.12	-€3,986.72	To be deducted to take care of the transfer of costs from ERC to FORD as defined in the 2nd Amendment
UNIS+UNIS-EL	€62,305.45		
WHR	€-	-€124,841.25	Paid back to the Coordinator due to the partial takeover by WHMAN
FORD	€15,815.97	€3,986.72	To be added to take care of the transfer of costs from ERC to FORD as defined in the 2nd Amendment
PPC	€24,884.40		
UOP	€18,967.36		
UWS	€41,209.03		
UBITECH	€70,131.25		
ININ	€48,938.75		
5COMM	€55,997.81		
YBVR	€30,625.00		
ASTI+UBU	€44,095.09		
ILINK	€35,065.63		
INFOCOM	€42,920.94		
8BELLS	€48,234.38		
SUITE5	€48,234.38		
K3Y	€43,640.63		
OCULAVIS	€51,832.81		
WHMAN	€-	€141,469.87	Paid to the new partner as pre-financing share
Total	**€842,585.32**		

In the frame of WP1, under CNIT coordination, all partners contributed to the creation and completion of two consortium requested Amendments, which have been accepted on 26 October 2022 and on 28 November 2023, respectively, by the European Commission. The main reasons of the requested Amendments were as follows:

- To manage the partial takeover of Whirlpool EMEA S.p.A. (WHR) and Whirlpool Management Emea S.r.l. (WHMAN)
- To ask for an extension of the project duration from 36 to 42 months.

Deviations: Some deliverables were delayed with respect to the due date.

Task 1.2 – Technical Coordination and risk management

Leader:	UBITECH
Participants:	{ALL}
Duration:	M01 – M42
Description of activities:	The consortium has identified critical risks for properly achieving the remaining activities and provide the required reporting within the time framework of the project until M36. The risks were mainly associated with the proper integration of the final 5G-INDUCE platform version over the targeted Experimentation Infrastructures (ExFas) and the related validation and demonstration activities within the remaining time of the project. This occurred as the result of the delays encountered during the second development phase of the platform and related in particular to the interfacing between the NAO and OSS parts, for supporting the agreed features. It is noted that all the platform related development issues were successfully addressed by M28 of the project, while the final fully functional version of the integrated platform had been completed by M30 and deployed (in M31) over the ExFas without any issues, utilizing the flexible southbound OSS interface that is easily adaptable to various types of network orchestrators. The advanced features related to runtime nApp management were also addressed, finalized and integrated in the updated platform version by M33. However, the timing of the activities described above indicated a delay of about 6 months according to the original time plan of the project and with respect to the final platform version and integration, even though certain developments related to the project Use Cases and ExFa site preparation had progressed without critical delays, allowing for certain integration activities to be performed in parallel, and thus partially mitigating the effect of the platform development delay to the final ExFa site integration, testing and demonstration actions. Considering the high potentials of 5G-INDUCE for delivering significant and innovative outcomes in the field of advanced 5G-enabled services in the industrial sector, the Consortium decided to propose a 6-month extension, in order to allow the proper deployment and completion of the advance platform features and accommodate the related testing activities and, at the same time, to continue the demonstration actions for the promotion of the 5G-INDUCE platform and the enabled industrial nApp service deployments. The requested extension was accepted by the EU in Nov. 2023.
Deviations:	As described above, leading to the extension request.

Task 1.3 – Advisory Board Establishment and Operation

Leader:	UOP
Participants:	ERC, PPC, FORD, INTRA
Duration:	M01 – M42
Description of activities:	The Industrial Advisory Board was established with the following members: - Fotis Karonis (EVP, CapGemini; ex-CTIO, BT) - Andreas Mueller (General Chair of 5G-ACIA & Head of Communication and Network Technology at BOSCH) - Marios Nikolaou (5G Techritory Director; Ex-Bell Labs Consulting Strategy Expert) Significant feedback was received internally from participating industries on the usage of 5G applications and also from partner Ericsson through the related joint publication activities in 5GPPP.
Deviations:	A foreseen meeting with the members of the Advisory Board was not held.

2.2 WP2 – 5G Orchestration Platform Requirements, Use Cases, and Targeted KPIs

WP2 ended in the first reporting period.

2.3 WP3 – 5G Orchestration Platform Development

WP3 is responsible for the design, development and integration of the 5G-INDUCE Orchestration Platform.

According to the original plans, the 5G-INDUCE Platform has been developed as an evolution of the outcomes of the H2020 project MATILDA[1], from which the 5G-INDUCE project inherits the overall architectural design and some key components. -In fact, the MATILDA platform already fit the main architectural concepts which the 5G-INDUCE Platform is based on, and, primarily, the key notion about the 'separation of concerns' between the two administrative domains the Platform spans, namely, the Application Domain and the Telco Domain. According to this notion, the lifecycles of nApps and supporting network services have to be managed through the interworking of separated orchestration tools, which are owned and operated by different stakeholders, such as, for instance, a Vertical Industry or an Application Service Provider for the Application domain, and a 5G/B5G Network Operator for the Telco Domain. Hence, the 5G-INDUCE Platform functions are split over two distinct components, which interoperate through a well-defined interface: the nApp Orchestrator (NAO), which pertains to the application domain (developed on the basis of the MATILDA VAO – Vertical Application Orchestrator), and the Operation Support System (OSS), which pertains to the telco domain (based on the namesake module of the MATILDA platform).

The key objective of WP3 is, hence, evolving the Platform components inherited from the MATILDA project to develop, integrate in Experimentation Facilities (ExFas) – whose provision is dealt within WP5 – and make available for WP6 validation, evaluation and showcasing activities, the 5G-INDUCE Platform NAO and OSS building blocks, which:

- provide nApp developers with tools for the smooth deployment, orchestration and run-time management of nApps over the 5G-INDUCE ExFas;
- flexibly exploit the capabilities (in terms of exposed control/management interfaces and physical and virtual resources) of the underlying heterogeneous ExFas, in order to undertake the deployment of nApps and the activation of supporting 5G Network Services.

The following paragraphs provide in further detail the activities and main achievements per task.

Task 3.1 – 5G-INDUCE Network Application Orchestration Development

Leader:	UBITECH
Participants:	UNIS, CNIT, INFOCOM, UWS
Duration:	M04 – M24
Description of activities:	After M18, several significant updates were made to the Network Application Orchestrator (NAO), focusing on enhancing the runtime functionalities of the 5G-INDUCE Platform. These updates primarily revolve around improving telemetry, runtime policy support, and the platform's front-end. Specifically, • The telemetry feature was improved, enabling more complex monitoring and data collection processes. The enhanced telemetry capabilities now support the adaptive monitoring of the platform, allowing for dynamic re-configuration of various parameters that influence how metrics are extracted and collected from different sources.

[1] R. Bolla, R. Bruschi, F. Davoli, P. Gouvas, A. Zafeiropoulos, "Mobile edge vertical computing over 5G network sliced infrastructures: an insight into integration approaches", *IEEE Communications Magazine*, vol. 57, no. 7, pp. 78-84, July 2019.
R. Bruschi, F. Davoli, C. Lombardo, J. F. Pajo, "Managing 5G network slicing and edge computing with the MATILDA telecom layer platform", *Computer Networks*, vol. 194, pp. 1-14, July 2021.

Additionally, the updated system introduces the ability to load and manage different monitoring probes on demand. This added flexibility improves the platform's ability to monitor and manage its operational environment in real-time, ensuring that critical performance metrics are captured efficiently and accurately (D3.3, D3.6).

- The introduction of runtime policy support, which significantly extends the platform's automation and operational control capabilities. This feature empowers end-users to define policy rules for managing deployed applications. These policies dictate automatic actions, such as resource scaling or application mobility, triggered by specific conditions derived from the collected metrics. Both the NAO front-end and back-end modules have been upgraded to allow users to compose policy rules for managing these applications more effectively. These policies outline automated actions, such as resource scaling, which the 5G-INDUCE Platform executes when specific conditions are met. This automation extends to day-2 operations on deployed nApps, ensuring ongoing management and optimization post-deployment. (D3.3, D3.6).
- Finally, the platform's front-end was updated to integrate the newly introduced telemetry and policy management functionalities, providing users with enhanced monitoring and runtime policy control directly through the interface. Additionally, significant developments were made to expose these features in the interface between NAO and OSS, enabling the OSS to fully realize and support the day-2 operations and dynamic adjustments required for the efficient management of nApps.

Deviations: No deviations from the amended workplan have been identified. There have been small deviations from the activity schedule, which, because of the interdependency of the activities carried on in the three tasks included in the WP and of relevant deliverables, are summarized in the 'Deviations' section of Task 3.3.

Task 3.2 – 5G-INDUCE Operations Support System Orchestration development

Leader: CNIT

Participants: UNIS, UBITECH, INFOCOM, K3Y, 8BELLS, UOP

Duration: M04 – M24

Description of activities: The 5G-INDUCE Operations Support System is in charge of enabling advanced nApp deployment and operation mechanisms according to the nApp deployment requirements, constraints and management rules, as well as to the heterogeneous ExFas' capabilities.

While a complete prototype of the OSS was already released during the first reporting period (see D1.2), activities in the last stretch of the project mainly focused on *i*) completing the interface with the NAO and extending the plethora of slice management and network orchestration operations supported by the 5G-INDUCE platforms, and *ii*) integrating the platform in the ExFas. The former activity mainly regarded the extension of the slice management with the introduction of dynamic slice reconfigurations, while the latter represented most of the effort of this task in the last reporting period. Details on the deployment of the OSS over the ExFas can be found in Section 2.5.

Deviations: No major deviations from the task original technical scope and objectives have been registered.

There have been small deviations from the activity schedule, which, because of the interdependency of the activities carried on in the three tasks included in the WP and of relevant deliverables, are summarized in the 'Deviations' section of Task 3.3.

Task 3.3 – 5G-INDUCE open platform integration and interfacing

Leader:	INFOCOM
Participants:	CNIT, UBITECH, K3Y, 8BELLS, UOP
Duration:	M07 – M30
Description of activities:	The goal of the Task was releasing the 5G-INDUCE Platform demonstrator, along with the relevant documentation, moving from the outcomes of the design and development activities carried out on the Platform components (NAO and OSS) in the scope of T3.1 and T3.2. As per the original plan, the 5G-INDUCE Platform demonstrator has been released in three subsequent versions, with incremental features, namely, "Version a", "Version b" and "Version c", which correspond, respectively, to the project deliverables D3.1, D3.2 and D3.3. Platform releases have been accompanied by architectural documentation that provides details about the architectural solutions and technologies the demonstrators are based on; such documentation consists of the deliverable D3.4, which describes the basic architecture of the Platform and the features supported in its "Version a", and D3.5, which is an update of D3.4 and outlines the improvements introduced in the following Platform's "Version b" and "Version c". In addition, a further public document, namely the deliverable D3.6, has been issued, which provides a high-level, overall description of the 5G-INDUCE Platform, while skipping all the sensitive technical details included in the confidential deliverables D3.4 and D3.5. The integration of the Platform releases has largely relied on the CNIT's DevOps infrastructure, which has provided a suitable environment for testing NAO and OSS core functionality and interworking. Integration tests have also included the pre-deployment on the DevOps of trial versions of WP4 Use Cases, for an end-to-end check of the NAO-OSS toolchain. Furthermore, Platform's "Version b" and "Version c" integration has required activities to be executed on all the ExFas, to prove the different peculiar OSS control interfaces and interworking between the OSS itself and each ExFa, which varied depending on ExFa specific architecture and features. Throughout the whole progress of WP5 and WP6, T3.3 activities have also comprised the continuous monitoring of the evolving ExFas and Use Cases hardware/software features and development plans, as well as the capture of feedbacks following Platform-ExFas integration tests and Use Case deployments; this activity has allowed the WP3 team to capture the technical requirements for the NAO and OSS coming from ExFas and Use Cases, synchronize WP3 and WP5 plans with regards to Platform-ExFas integration and provide Platform fixings and enhancements during Use Case trials.
Deviations:	No deviations from the planned targets have been registered; all T3.3 and, in general, WP3 goals have been met. Some deviations from the T3.3 and WP3 deliverables schedule, defined in the amended Grant Agreement, occurred, as detailed herein: - D3.2 - planned delivery in M18; actual delivery in M19; - D3.6 - planned delivery in M36; actual delivery in M38.

2.4 WP4 – nApp Use Cases development and Onboarding

WP4 is responsible for designing and prototyping the nApps for the 8 use cases and onboarding these nApps over the 5G-INDUCE DevOps platform, thereby paving the way for WP5 integration and WP6 nApp validation, verification and showcasing over the 5G ExFas.

The key objectives of WP4 are:

- To provide the requirements and methodology for the design and implementation of the application graphs.
- To define the technical KPIs per use case nApp that are going to be used for validation verification.
- To develop the use case specific nApps, including the required network functions.
- To provide the final validated nApps to the 5G platform experimentation facility.
- To support the deployment of nApps from 3rd party developers.

The following paragraphs provide in further detail the activities and main achievements per task within the reporting period.

Task 4.1 – nApp development and interfacing requirements

Leader:	UNIS
Participants:	UBITECH, INFOCOM, UWS
Duration:	M04 – M15
Description of activities:	The main effort in this task focused on the outcomes from the first release of the nApp use cases' developments. The work followed the definitions of the use cases performed in WP2-T2.2 and the initial frontend framework development of the 5G-INDUCE NAO, reported in D2.2 and D3.4, respectively. The key outcomes of the studies include: a) the definition of the required nApp components; b) the initial developments and onboarding of component images in the form of containerised functions; c) the component operational parameters that are provided to the NAO frontend UI; d) the definition of the network parameters through the nApp graph composition; e) the initial definition of operating and application-related policies; and f) the definition of the full chain of the onboarding process. A common presentation structure was adopted and followed by all 8 use cases. This is expected to be updated once additions, modifications or new nApp use cases are introduced. The adopted structure assists in the proper collection of nApp operational, network, monitoring and policy requirements, in compliance with the onboarding methodology. It also provides a description of the nApp use case from the deployment point of view and the generation of the respective graph. The outcomes of the work in this task are reported in D4.1.
Deviations:	There were no deviations to the workplan.

Task 4.2 – Development of use case specific nApps

Leader:	UWS
Participants:	OCULAVIS, ININ, ASTI, YBVR, 5COMM, SUITE5, iLINK, PPC, WHR, FORD
Duration:	M04 – M30
Description of activities:	This task has been successfully completed. Its main outcome is the final releases of the 8 different use cases addressed by 5G-INDUCE. Following an agile DevOps approach with several iterations, the 8 use cases have produced 11 network applications with 31 associated essential components developed. The use cases have also produced the corresponding application onboarding graphs required to perform the deployment of the

use case, and then tested the onboarding of the nApps onto the 5G-INDUCE DevOps platform. Various validation tests have been conducted over the pre-DevOps and pre-ExFa labs and industrial premises wherever appropriate, to create the final validated version to be deployed in the 5G-INDUCE ExFas. Some initial showcasing has been performed too. Further analyses and considerations have been documented for additional network application components and the reusability of the network application components for each of the use cases. In summary, all the use cases have been successfully implemented and validated to be fully functional, providing the expected outcomes. Consequently, WP4 has provided all the technical artifacts that have been delivered to T6.1 for validation and T6.3 for showcasing purposes. The following table shows a summary of the major technical activities in this task per use case.

Table 2 Summary of major technical activities in Task 4.2 per use case.

Use case #	Number of nApps	Number of network functions (VNFs and non-VNFs)	Number of dockerised network functions (VNFs)	Newly developed network functions	Reused/adapted network functions (especially in relation to open source projects)	Notable hardware (UE etc.) and additional services	Number of KPIs defined	Pre-DevOps lab operation tested	Performance optimisation done	Onboarding tested over DevOps testbed	Final version validated (ready for ExFa)
UC1	2: 1) VSLAM; 2) AGV Coordination & Logistics Management	3	3	1) VSLAM Localisation; 2) AGV Coordinator; 3) Logistic Process Manager		AGVs; camera; edge	5	Burgos facilities with 5G, Spain	1) Reduced packet loss, with for nApp1, with capacity and protocol improved; 2) Reduced latency for nApp2, with communication/network optimised	Y	Y
UC2	1: Gesture Control of AGV	3	3	1) Gesture Recognition; 2) AGV Control	Video Encoder/Decoder based on H.264 codec	AGVs; 3D camera; edge	7	UPV testbed, Spain; 5TONIC testbed, Spain; Ford testbed, Spain	Reduced latency, with AGVs from ASTI optimised	Y	Y
UC3	1: Immersive Industrial Monitoring	4	2	1) 360 Video Server; 2) Graphic Overlay Generation; 3) VR headset client (non-VNF) and VR mobile client (non-VNF)	Monitoring Agent based on Prometheus+Grafana	AGVs; 5G modem; 360 camera; edge; VR headset; mobile/tablet	6	YBVR Labs testbed, Spain; 5TONIC testbed, Spain	Improved graphic overlay, with proxy-to-real-time database optimised	Y	Y
UC4	2: 1) Thermoforming Machine Maintenance; 2) Power Generator Maintenance	4	4	1) Edge Data Collector; 2) Edge Analytics Engine; 3) On-Prem Data Collector; 4) Visualisation Engine;	On-Prem Kafka Platform based on Kafka	Thermal camera; edge; PPC electric power generator	7	Suite5 testbed	Reduced processing time for current jobs for Edge Data Collector and the On-Prem Collector, with the messaging queues algorithm optimised	Y	Y
UC5	2: 1) Corrosion Detection; 2) Intruder Detection	4	4	1) Corrosion Detection; 2) Intruder Detection	1) Video Proxy based on NGINX; 2) Message Bus based on RabbitMQ	UAV; GPU at edge; tablet (with client App); 5G mobile router	6	UWS testbed, Paisley, UK; Greek ExFa, Greece	1) Reduced video streaming latency, with NGINX optimised; 2) Improved AI detection accuracy and reduced inference time	Y	Y
UC6	1: AR-assisted Maintenance	3	2	SHARE Server (Business Logic & Application Data)	1) Media Server based on WebRTC; 2) STUN/TURN Server based on coturn	SHARE Server (External Cloud Service e.g., MS Azure); AR smart glasses RealWear HMT-1	3	MS Azure, Frankfurt, Germany + Oculavis headquarter, Aachen, Germany	Improved video quality for the AR, with a new WebRTC encoding parameter playground developed	Y	Y
UC7	1: Crossroad Safety	5	4	1) Location Compiler; 2) Web Map; 3) Collision Detection	Message Bus based on Web Sockets	Mobile phone (with client App), UWB hardware, 5G mobile router	7	iLink testbed; Whirlpool ExFa, Italy	Improved location accuracy, Improved collision avoidance by reduced latency and inference, improved operational performance	Y	Y
UC8	1: UAV-assisted 5G Network Performance Monitoring	5	5	1) Network Monitoring; 2) Measurement Reference; 3) Agent Probes Management; 4) Analytics and Presentation; 5) Video Monitoring	1) Video/media proxy with WEBRTC/HLS/RTMP/RTSP 2) Standard linux suite of networking tools (e.g. ping, traceroute, iperf etc.)	UAV, 5G Smart phone and 5G gateway running qMON measurement agents	10	Whirlpool ExFa, Italy	Reduced deployment time, with containerisation method optimised	Y	Y

Deviations: There are no deviations with respect to the planned work for Use Cases 1, 2, 3, 4, 5, 6 and 8.

Use Case 7 deviation: slight adjustment of the scope of the use case, although it still remained the same use case technically.

Task 4.3 – Assistance to 3rd party nApp owners for deployment over the 5G platform

Leader:	UBITECH
Participants:	UOP, PPC, WHR, UWS, UNIS
Duration:	M13 – M30
Description of activities:	This task has been successfully completed. Firstly, third-party support processes were well defined, including a Guidance Technical Manual, instructing end users on how to onboard their nApps onto the 5G-INDUCE platform; detailed and user-friendly, with step-by-step visual aids, examples, and troubleshooting tips; Onboarding environment, configuring the application environment, ensuring compatibility with the 5G-INDUCE infrastructure, and meeting the required standards for deployment; Validation check pipelines, providing easiness of using the platform by offering automated validation checks performed via the project's GitLab repository; Exposing Area, exposing ways the 5G-INDUCE platform offers for the onboarded applications to external developers through an intuitive GUI and respective APIs. Secondly, third-party activities were promoted, as highlighted here including technical collaboration actions taken with ICT-41 projects, especially VITAL-5G nApp of IoT Management Platform (sensing and monitoring), 5GMETA nApp of Driver Awareness and Safety (obstacles and signals detection); commercial nApps onboarded and tested over 5G-INDUCE platform, including Link Robotics nApp of Localisaion and Navigation, and Level7 nApp of DDoS Mitigation Platform for 5G, having showcased the 5G-INDUCE platform's ability to support diverse use cases and industry needs.
Deviations:	This task was extended in line with the extension of the whole project.

2.5 WP5 – Integration over Experimentation Infrastructures

WP5 is responsible for managing the integration of the platform over the ExFas and the preparation of the ExFas in view of the planned use case testing scenarios. For this reason, WP5 includes the overall integration process and provides the updated implementation and experimentation workplan, as well as the infrastructure deployment activities.

The key objectives of WP5 are:

- To integrate the 5G nApp deployment and network orchestration platform over the experimentation facilities, and enable the nApp integration process according to the targeted facilities;
- To provide a clear integration work plan implementing a continuous integration cycle;
- To implement the targeted Experimentation facilities in Valencia, Cassinetta and Athens including the physical interconnection with the Industrial facilities and the supporting access and core network 5G infrastructure.

The following paragraphs provide in further detail the activities and main achievements per task within the reporting period.

Task 5.1 – Overall experimentation and integration work plan

Leader: ERC

Participants: UBITECH, CNIT, COSMOTE, PPC, UOP, 5COM, FORD, WHR, INFOCOM

Duration: M10 – M24

Description of activities: The project integration workplan followed the development actions in three main technology areas related with:

a) the 5G-INDUCE platform, which is responsible for the onboarding, deployment and runtime management of nApps
b) the nApp use cases, which are defined and structured as deployable requests of linked application and network function micro-services and
c) the experimentation infrastructures that integrate the platform and use case nApps.

The integration workplan was designed to align with the objectives of validating the DevOps testbed, deployment of the platform over the ExFa sites, and executing UC demonstration actions, adhering to the project's three phases (design, development, validation) and tuned to the planned release cycles for platform components and nApp modules. The workplan is divided into seven detailed phases, covering the entire process from design through deployment, validation, and demonstration. These phases integrated outcomes from both the platform and use cases, leading up to final deployment on the ExFas. Each of the seven phases included specific actions related to the three core development areas, establishing a unified and synchronized framework for development and testing activities. The integration workplan outlined detailed experimentation activities that are closely linked to the overall integration process. These activities were divided into two main categories: system-level validation, which involves pre-testing and ensuring the readiness of the platform and ExFa infrastructure, and service-level validation, which focused on assessing nApp use cases within fully operational experimental setups. Each category ensured that the respective components meet the necessary standards for functionality and performance.

After M18, the primary focus shifted to defining the experimentation workplan, building on integration efforts with the DevOps testbed and initial performance testing results. The results of this work were intended to guide the ExFa testing activities and establish a unified validation framework applicable to various use cases, including potential third-party cases and extensions.

Deviations: There are no deviations.

Task 5.2 – Experimentation Facilities in support of targeted use cases

Leader: WHR

Participants: FORD, PPC, ERC, OTE, WIND3, CNIT, UOP

Duration: M13 – M24

Description of activities: **ExFa-ES (FORD ERC)**:

Spanish experimentation facility installation activities after M18 continued, in order to install outdoor antennas and validate the correct operation of the 5G RAN network and UPF usage. Specifically, at the 5Tonic lab, a fully operational 5G Core (5GC), including components like AMF, SMF, and UDM, is used for 5G-INDUCE use case experimentation. These components are hosted on several Dell PowerEdge

R640/R740 servers housed within a rack at the 5Tonic Data Center. Initially, all experimentation was conducted at the 5Tonic lab, where the entire standalone 5G network operated. This setup provided network coverage through RAN equipment in certain rooms, and all 5GC control plane components, including the User Plane Function (UPF), ran locally at 5Tonic. This environment allowed for early experimentation and debugging of use case applications, while the final distributed setup was being prepared. Later, the RAN equipment and UPF were relocated to Ford's premises, extending 5G coverage to Ford's location, allowing experiments to be conducted there. In this configuration, the 5GC control plane components, except for the UPF, continue to operate at 5Tonic. Different Data Network Names have been configured on the 5GC to specify which UPF to use, with the corresponding Access Point Name (APN) defined on the User Equipment (UE). When the UE connects to the 5G network and initiates traffic, the 5GC instructs the RAN equipment on which UPF to utilize. The UPF at Ford runs on a Dell PowerEdge R640 server in a rack at Ford's factory. The 5G system establishes a GTP tunnel between the RAN node and the UPF at Ford to manage user plane traffic. Spanish ExFa's indoor and outdoor coverage have been validated though specific tests and through the deployments and testing of the nApps that were deployed there.

ExFa-GR (PPC OTE):

After M18, installations on the Greek ExFas have continued, focusing on two main sites: the Core site, where the packet core is installed, and the RAN site, which hosts the network's access components. These sites are approximately 15 km apart and connected by a packet optical transport network (POTP), which includes various transport network elements, such as servers and switches. OTE switches, linked to the OTE IP Core through a 10 Gbps line, connect the infrastructure at the OTE Labs (Core site) with the RAN site at PPC.

The installation at OTE-PPC has been finalized and now supports a 5G SA Release 16 testbed using the ATHONET Packet Core. This packet core is divided into two main components: the Control Plane Function (CPF) and the User Plane Function (UPF), both implemented as containers. The CPF encompasses four critical network functions: Access and Mobility Management Function (AMF), Session Management Function (SMF), Authentication Server Function (AUSF), and User Data Management (UDM) Function.

The finalized installation of the RAN is comprised of the following equipment:

Table 3 RAN equipment

Type	Manufacturer	Model	Information	Quantity
Radio Unit	Ericsson	ERS4408	4x4 MIMO, Carrier Aggregation and 256 QAM	1
Radio Unit	Ericsson	Radio Dots	4x4 MIMO, Carrier Aggregation and 256 QAM	4
Network Equipment	Ericsson	6630	Baseband Unit, 15 CPRI/9 eCPRI, LTE+NR with up to 12 CCs LTE and 12 CCs NR in dual mixed mode	1
Transport		IDU	FO Bridge	1

Finally, transport network testing has been conducted, measuring a delay of 200 nanoseconds.

ExFa-IT (WHR, WIND3, CNIT):

After M18, installation and testing continued on the core network, RAN, and programmable infrastructure. All use cases are connected with the WindTre (W3) core network to an orchestrator installed at CNIT premises.

The MEC servers at the W3 data center in Settimo Milanese were validated and configured as follows: The first server, acting as an SGW/PGW, emulates a local core network and is equipped with 4x10Gbps Ethernet interfaces, 2x10GE-LR optical links to the W3 core network, and 2x10GE-LR optical links to the W3 radio network, along with 2x10GE copper interfaces for connecting to a dedicated vApps server. The second server, connected to the first, hosts applications to ensure low latency at the edge. Both servers run on Ubuntu Server 18.04, with MEC applications virtualized via Docker. They feature secure connectivity to external servers and a virtual firewall to protect the SGW/PGW from unauthorized access.

For the packet core setup, the Non-Standalone core network, adhering to Option 3.x, was a virtualized infrastructure implemented using Virtual Machines to be used for testing at the Cassinetta site. In this configuration, the SGW and PGW functions were deployed at the MEC edge site, while control plane functions such as the Mobility Management Entity (MME) and HSS were hosted at the W3 core network. The central MME manages local SGW selection based on 3GPP DNS procedures and the Tracking Area Code (TAC) of the radio where the user equipment (UE) was connected. This architecture allows traffic offloading based on the Access Point Name (APN), enabling W3 to maintain complete control over the MME while keeping the data plane separate, thus avoiding any impact on existing networks or business operations. The network currently operates on Release 15 standards. The implementation of this solution involved three steps: configuring SGW selection based on IMSI number series and geographic area on the MME, setting up a new private APN (5GINDUCE) on the DNS to route traffic to the MEC PGW, and updating the APN on the HLR and HSS. The trial leverages existing W3 infrastructure, including E-UTRAN – NR Dual Connectivity, and makes use of their extensive 5G rollout with Base Band Units (BBUs) and Radio Remote Units (RRUs) supporting Dynamic Spectrum Sharing (DSS) and TDD. WindTre ensured 5G coverage at the Cassinetta site with antenna VA138, configured to connect 5G coverage to the MEC server. A VPN was setup between CNIT and the MEC, in order to guarantee connectivity to the platform; however, this solution highlighted an issue about VPN configuration, which made impossible to proceed with this architectural setup and forced to a workaround to support ExFa-IT deployment

The alternative solution for Use Cases Connectivity was guaranteed with W3 commercial core network directly to CNIT without MEC platform. A public IP address is configured on SIM cards as required in trial and APN configuration is **myinternet.wind.**

This solution was used to validate in 2023-24 all the use cases in plan for ExFa-IT (UC4, UC6, UC7, UC8).

The test and validation required several re-loops on each use case to ensure a proper data gathering for KPI consolidation and user validation.

The activities required also the installation of hardware devices in the shop floor to support UC7 and UC8 demos, as well as some assessment and measurement sessions to optimize 5G devices' positioning and to gather data related to installed 5G equipment health and safety compliance.

	An alternative solution for ExFa-IT connectivity was designed and deployed by CNIT through a mobile testbed installed in the factory shop floor in 2024 and used to test 2 of the ExFa-IT use cases (UC7 and UC8). The idea of MT (CNIT Mobile Testbed) is to have a unique block of devices, that can be easily moved to remote areas (Cassinetta in our case), merging data (gNb, antenna) and compute/controller components (servers). The MT is configured to reach the CNIT testbed in Genoa via its own dedicated connection. So, the software elements in MT (nApps, 5G deployment, NFVCL, etc.) can easily communicate with the Genoa testbed elements (OSS, NAO, etc.). The MT core is composed of 3 mini Supermicro servers, running a single instance of OpenStack with 3 compute nodes. On top of the OpenStack layer, an instance of Kubernetes is installed with 1 controller and 2 workers. An Intel NUC acts as the gateway for the infrastructure. This goal is reached using “metalcl” and “OpenVPN” client for external access. Physical connections between elements are guaranteed by the use of a Mikrotik switch for local components. On the other side a 4G Teltonika router is used for Internet connection (MT to CNIT testbed). A 5G Liteon all-in-one antenna/gNb is used for UEs’ connectivity. The deployment of this solution required a physical installation of the testbed into the testing area in Cassinetta refrigeration factory shop floor and, also in this case, some activities related to 5G equipment health and safety compliance assessment.
Deviations:	No deviations for any of the ExFas.

Task 5.3 – Continuous integration of the 5G platform over Experimentation Infrastructures

Leader:	UBITECH
Participants:	OTE, WIND3, ERC, CNIT, UWS, UNIS
Duration:	M10 – M42
Description of activities:	The 5G-INDUCE CI pipeline was designed to ensure that software-based components are developed, validated, and seamlessly integrated into the platform, following a well-defined agile lifecycle. Each new feature intended for incorporation into the 5G-INDUCE platform triggers a dual-path development cycle that ensures comprehensive testing and review processes. Initially, the partner responsible for the new feature submits merge requests to a dedicated CI platform hosted on their standalone GitLab branch. This submission initiates the CI pipeline, which employs CI runners to perform a series of automated pre-merge jobs, including building the code, performing lint checks, and executing unit tests in isolated containers. Additionally, integration tests are conducted on a dedicated Kubernetes-based infrastructure to confirm that the new feature integrates correctly with existing components. Successfully completing these pre-merge jobs is essential to move forward to the review stage. After automated testing, the merge request undergoes development reviews to verify code quality and compliance with project standards. If any issues are detected during the pre-merge jobs or code review, the development team must refine the code until all quality requirements are met. Once the merge request passes review and is approved, the post-merge pipeline is triggered. This final phase re-executes the builders and integration tests to ensure the stability of the main or development branch and that the newly integrated feature does not introduce any disruptions. This approach ensures that each feature is tested and integrated, maintaining the overall integrity

and performance of the 5G-INDUCE platform throughout its development lifecycle and to all the experimentation facilities.

According to the integration plan that was carefully executed the first integration was with the DevOps testbed in CNIT. The DevOps testbed integration, which utilizes the "Free5GC" software to implement its 5G core, was accomplished between M12 and M21, providing a flexible and open-source framework for core network functionalities that can be easily adapted and scaled. The Free5GC software is dynamically configured and deployed at runtime using a Helm chart, integrated within the Kubernetes cloud cluster on the premises of CNIT. This phase established a stable environment for deploying and testing platform components and was vital in building a reliable foundation. The system consistently hit initial performance benchmarks, ensuring all core functionalities operated as expected. After the successful DevOps integration, the focus moved to integrating the platform with Spanish and Greek ExFas. The Spanish experimentation facilities, particularly the 5Tonic infrastructure at the ERC, FORD, and UPV sites, utilize the ETSI NFV-SOL 006 API to define Network Service (NS) descriptors and manage network services. To enable network slicing, specific Network Service Descriptors (NSDs) were onboarded to allow dynamic resource allocation and management across slices. The 5Tonic 5G core supports various parameters for each slice, including coverage area, latency, and throughput. Extensions to the OSS (particularly in the NFVCL, which is developed as a thin layer between the OSS and the external programmable resources) were made to manage network slices and their parameters via the NFV-SOL 006 API. Extensive testing confirmed the ability to add new slices, verify their parameters, and execute termination commands. The integration with the Spanish ExFa, specifically with the 5Tonic 5G core, was finished by November 2023 (M35).

The Greek ExFa uses a proprietary version of the Athonet 5G Core, which required additional extensions to the OSS (NFVCL) for effective integration. These developments included enabling communication between the NFVCL and the Athonet 5G Core, where the core subsystem sends a list of existing slices to the NFVCL during system boot. The NFVCL updates its internal database with this information, ensuring that slice configurations are up to date. When the OSS submits a slice-intent request, the NFVCL checks the database to see if a compatible pre-allocated slice is available. If such a slice is found, the NFVCL instructs Athonet to perform an attachment operation, allowing specific IMSI lists to access the slice resources. This integration enables the NFVCL to manage slice resources efficiently, meeting the operational needs of the Greek ExFa's 5G infrastructure. The Greek ExFa integration with the Athonet 5G core was successfully completed by June 2023 (M30).

For the Italian ExFas, a dual-path integration strategy was implemented to address varying technical constraints and capabilities. Option 1 treated the Wind3 network as a “black box,” offering basic 5G connectivity without advanced programmability, which simplified the initial integration and was completed on schedule by February 2023 (M26). To provide greater flexibility and control, Option 2 used a compact version of the hardware used in the DevOps setup, featuring a small cluster running Free5GC as the 5G core, deployed via Helm charts on Kubernetes. This setup faced significant challenges, such as compatibility issues with existing commercial devices and frequency overlap problems, requiring extensive troubleshooting and iterative adjustments. To thoroughly test the capabilities and performance of the 5G network, the Mobile Testbed employed a range of User Equipment (UE) devices. These included two smartphones—a Google Pixel 8 Pro and a Realme 7 RMX2111 —representing typical consumer devices, a D-Link DWR-2101 router for assessing

	network connectivity in fixed installations, and two Avalue Technology minicomputers used as gateway devices for specialized applications. Within ExFa-IT activities the data integration to support UC4 deployment was completed, ensuring the data pipeline activation through the 5G network.
Deviations:	For the three experimentation facilities and particular the DevOps, the Spanish and the Greek site the integration over them was on time and according to the integration plan. For the Italian site the integration was different. The first attempt, using the WIND3 network as a "black box," was on time but, owing to the limited programmability and control over network configurations, another attempt has been followed. The second approach involved CNIT setting up a self-contained data center and access network at BEKO (formerly Whirlpool). This option provided a more flexible and adaptable infrastructure, overcoming the limitations of the first approach, by offering continuous operation and enhanced network and data management capabilities, thereby addressing initial setup delays and constraints; however, it encountered significant issues including network instability and frequent incompatibilities with commercial devices. These problems required extensive troubleshooting and iterative adjustments, leading to delays. As a result, the integration of this solution was delayed until May 2024.

2.6 WP6 – nApp Validation, Verification and Showcasing

WP6 is responsible for validating nApp functionalities, evaluating performance KPIs and showcasing the capabilities, interoperability and lifecycle management simplicity of the nApps.

The key objectives of WP6 are:

- To verify and validate the nApp functionalities over the integrated infrastructure using the DevOps test bed prior to any deployment in the ExFa, thus providing feedback for optimization and changes.
- To evaluate the performance of the nApp solutions under the related use case scenarios and in accordance with the targeted KPIs.
- To showcase specific capabilities for advance service delivery over a 5G experimentation infrastructure attached to real industrial environments, while also demonstrating the interoperability characteristics of the overall platform and the simplicity in the deployment and modification of targeted nApps,

The following paragraphs provide in further detail the activities and main achievements per task within the reporting period.

Task 6.1 – Net-App adaptability to 5G platform over DevOps testbed

Leader:	CNIT
Participants:	INFOCOM, UBITECH, UNIS
Duration:	M13 – M33
Description of activities:	The refinements needed on the 5G-INDUCE platform have been carried out supported on the usage of the testbed as a validation tool. Dummy nApps were tested to check the behaviour of the extensions made to the NFVCL in the SB-OSS to enable the interaction with NFV Orchestrators via NFV SOL 006 descriptors. Also, the actual project nApps have been tested in the 5G-INDUCE platform DevOps testbed, using the appropriate NFV blueprints that the platform requires. This eased the way to a successful onboarding on the ExFas.
Deviations:	No deviations.

Task 6.2 – Verification-Validation and performance estimation

Leader: ERC

Participants: {ALL}

Duration: M19 – M42

Description of activities: The activities in this task can be split in two: the verification of the 5G-INDUCE platform readiness and the verification of the ExFa infrastructure readiness.

On the first track, the work was focused on validating the interaction of the testbed with the NAO, the proper handling of nApp deployments and the high-level orchestration of network and compute resources. To this end, the following was checked: i) proper exchange of messages between NAO and OSS; ii) requested resources and NFs are provided given a slice intent; iii) tenant spaces are created; iv) successful deployment of NFs and nApps, and finally correct operation of nApps are effected. Some of the interesting performance to measure in this track were the total time since the moment of request to the NAO until the service is up and running, the service modification time due to policy and connectivity requirements changes, and the use of optimized computational resources.

On the second track, the work was focused on validating the proper deployment of the network infrastructure, the connectivity among all parts and the good performance of the 5G network. To verify the connectivity among all parts, some basic testing was done to check that some parts of the infrastructure were reached from different sites. Additionally, checking in the RAN nodes that the interfaces towards the Core are up is a good indicator that the connectivity between the RAN site and the Core site is working. Furthermore, confirming that the UEs get registered in the 5G network is an essential step to validate the 5G network readiness. Once the UEs were registered, iperfs and pings were performed to obtain the maximum data rate capacity and ideal round-trip time latency achievable with the 5G RAN resources deployed, which is useful to guarantee that the nApps requirements are going to be met.

The results of this work have been documented in D6.1.

Deviations: Extension of six months from original project timeplan.

Task 6.3 – Demonstration of nApp usage scenarios over the Experimentation Facilities

Leader: OTE

Participants: {ALL}

Duration: M31 – M42

Description of activities: Partners gathered at the ExFa locations and executed the use cases. This provided the experience of running the use cases in actual industrial environments and draw conclusions. The performance of the use cases was measured, gathering metrics such as the data rate demanded by the nApps, the latency incurred in the end-to-end transport and processing, the CPU loads, and the end user experienced quality. These results are documented in D6.2.

Videos were recorded to be able to showcase the demos. These videos are available for public showcasing, as was done in the project webinar held on July 23, 2024.

Deviations: Extension of six months from original project timeplan.

2.7 WP7 – Dissemination, Communication and Exploitable Market Potentials

WP7 is responsible for carrying out the project's Dissemination, Exploitation, and Impact Creation activities. This implies that all project findings must be communicated with all interested parties, be part of a specific business strategy, and thus, be used as a component of a product generated by the participating partners or the community.

The key objectives of WP7 are:

- To raise awareness of the 5G-INDUCE nApp platform in Industry, MNO and nApp development community, and to the broader scientific community, through targeted communication activities, dissemination in related events and interaction with the 5G-PPP and other industrial 4.0 forums.
- To embody the results of the project in 5G deployment actions led by MNOs, as well as standardization bodies.
- To engage the active participation of industrial focus groups and innovative SMEs in the deployment of new nApp services and the exploitation of the developed solutions.
- The validation of the nApp solutions in terms of market-oriented potentials through business planning of the developed concepts and tools and identification of targeted end-users and potential customers.

The following paragraphs provide in further detail the activities and main achievements per task within the reporting period.

Task 7.1 – Dissemination, Clustering and 5G PPP interaction

Leader: UOP

Participants: {ALL}

Duration: M01 – M42

Description of activities: In terms of Dissemination Activities, there have been 49 representations of 5G-INDUCE in form of press releases, webinars, workshops and exhibitions in major events hosted across Europe, while 14 publications in conference/workshop proceedings and 12 articles in prestigious journals also took place. The project also had a booth at the IEEE International Conference on Communications in Rome, Italy, in June 2023, and organized a Special Session on “5G and Beyond Orchestration Platforms and Use Cases — Enhancing Network Applications' Capabilities” at the IEEE Co-sponsored 7th International Balkan Conference on Communications and Networking (BalkanCom 2024), Ljubljana, Slovenia, in June 2024. Moreover, the consortium members contributed to 2 Whitepapers of 5G-PPP organization.

The table below provides a list of the 5G-INDUCE publications during M22-M42:

Table 4 5G INDUCE publications

#	Authors	Publication
Conference proceedings / Workshop		
1	R. Bolla, R. Bruschi, F. Davoli, C. Lombardo, J. F. Pajo, B. Siccardi	"Machine-Learning-Based 5G Network Function Scaling via Black- and White-Box KPIs" Proc. 21st Mediterranean Communication and Computer Networking Conference (MedComNet), Ponza, Italy, June 2023, p. 143-150, IEEE, Piscataway, NJ, USA, 2023

2	Panagiotis Zikos, Stathis Vlachos, Despina Tomkou, George Tsironis	"The 5G-INDUCE European Project: Smart-safety proliferation as an Industry 4.0 Enabler" 4th Symposium on Circular Economy and Sustainability, Technical University of Crete, Heraklion, Crete, Greece, 2023
3	Julio Diez-Tomillo, Jose M. Alcaraz-Calero, Qi Wang	"Empirical Comparison of Face Verification Algorithms from UAVs" Proc. 2023 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), IEEE, New York, NY, USA, 2023
4	Mohammad Al Selek; David Tena-Gago; Jose M. Alcaraz-Calero; Qi Wang	"Transfer Learning-Enabled IoT System for Continuous Prediction of Vehicle CO2 Concentration" Proc. 2023 IEEE International Smart Cities Conference (ISC2), IEEE, New York, NY, USA, 2023
5	Raffaele Bolla, Roberto Bruschi, Alessandro Carrega, Franco Davoli, Chiara Lombardo, Beatrice Siccardi	"A Stochastic Knapsack Model for Energy Efficient Management of Multi-Server Queues" 7th International Balkan Conference on Communications and Networking (BalkanCom 2024), Ljubljana, Slovenia, June 2024; IEEE, Piscataway, NJ, 2024
6	M. Khadmaoui-Bichouna, J. M. Alcaraz Calero, and Q. Wang	"5G RAN service classification using Long Short-Term Memory Neural Network" Proc. 2024 International Wireless Communications and Mobile Computing (IWCMC), IEEE, New York, NY, USA, 2024
7	Julio Diez-Tomillo, Javier Saez-Perez, Ignacio Martinez-Alpiste, Christina Lessi, Thanos Xirofotos, Kiatos Athanasios, Dimitrios Klonidis, Qi Wang and Jose Alcaraz-Calero	Next-Gen Industry 4.0 with 5G: Enabling Secure and High-Performance Services for Critical Infrastructure" Proc. 7th International Balkan Conference on Communications and Networking (BalkanCom 2024), Ljubljana, Slovenia, June 2024; IEEE, Piscataway, NJ, 2024
Articles in Journals		
1	Lekidis, A.	"Federated learning for 5G-enabled infrastructure inspection with UAVs" Energy Informatics, 5:66, Springer, Berlin, Germany, 2022
2	Mohamed Khadmaoui Bichouna, Gelayol Golcarenarenji, Ignacio Martinez-Alpiste, Jose M. Alcaraz Calero	"Edge Computational Offloading for Corrosion Inspection in Industry 4.0" IEEE, New York, NY, USA, 2022
3	Etienne-Victor Depasquale, Franco Davoli, Humaira Rajput	"Dynamics of Research into Modeling the Power Consumption of Virtual Entities Used in the Telco Cloud" MDPI Sensors, vol. 23, no.1, art. 255, Jan. 2023, p. 1-69, MDPI, Basel, Switzerland, 2023

4	Julio Diez-Tomillo, Jose M. Alcaraz-Calero, Qi Wang	"Face Verification Algorithms for UAV Applications: An Empirical Comparative Analysis" Journal of Communications Software and Systems, Vol. 20, No. 1, p. 1-12, Croatian Communications and Information Society in cooperation with the University of Split, FESB, Croatia, 2024
5	Julio Diez-Tomillo, Ignacio Martinez-Alpiste, Gelayol Golcarenarenji, Qi Wang, Jose M. Alcaraz-Calero	"Efficient CNN-based low-resolution facial detection from UAVs" Neural Computing and Applications, Vol. 36, p. 5847-5860, Springer, New York, NY, USA, 2024
Whitepapers		
1	M. Lorenzo et al.	"Innovation Trends in I4.0 enabled by 5G and Beyond Networks," Oct. 2023, doi: 10.5281/ZENODO.8367578.
2	Bessem Sayadi et al.	"Network Applications: Opening up 5G and Beyond networks, V2.0," Jul. 2023, doi: 10.5281/ZENODO.8134429.

Deviations: None in particular

Task 7.2 – Standardization Activities

Leader: ERC

Participants: CNIT, WIND3, OTE, UOP, WHR, PPC, FORD

Duration: M01 – M42

Description of activities: The 5G-INDUCE project focused on 3GPP Release 18 standardization efforts in the second half of its execution, building on earlier work with Releases 15-17. Key areas of interest aligned with 5G-INDUCE objectives included experimentation with Industry 4.0 trials over various 5G Private Network technologies and architectures. Ericsson, as a key partner, made significant contributions to 3GPP standards, including 30+ Ericsson-authored and 70+ co-authored contributions to SA2 in 2023. Two specific Ericsson contributions to 3GPP SA2 for Release 18 were highlighted. The first addressed QoS filtering criteria corrections, while the second focused on the translation of Internal-External Information for Assisting Application Layer AI/ML Operations. These contributions address gaps in network observability and guaranteed QoS in 5G networks, which are essential for enhancing Private Network capabilities. The standardization efforts aim to enable better end-to-end performance monitoring, observability, programmability, and optimization in 5G networks. This work contributes to creating standardized interoperable solutions for network exposure and analytics, facilitating collaboration between application providers, network operators, and private network users. By addressing these key aspects, the project is helping to pave the way for more advanced and efficient 5G network implementations, particularly in the context of Industry 4.0 and private network scenarios.

Deviations: None in particular.

Task 7.3 – Communication activities, data management and liaisons with 3rd parties

Leader:	UOP
Participants:	CNIT, UBITECH, UWS, 8BELLS, OTE, WIND3
Duration:	M01 – M42
Description of activities:	In terms of communication activities, a significant effort has been made to lead and coordinate a cooperative activity among the interested European projects, with the goal of collaboratively attracting third parties and SMEs to experiment on the projects' platforms. This initiative applies to projects from the ICT-41 call, projects from the Industry 4.0 verticals, and other projects in which the partners participate. The approaching strategy was primarily through direct contact with the project's dissemination, exploitation, and impact creation leaders, but also through the 5G-PPP Working Groups, Task Board, and Steering Board. Regarding the ICT-41 projects, 5G-INDUCE led the unofficial coordination action, bringing all the projects together in a monthly conference call to discuss and decide in common actions and activities. A product of this cooperation was the whitepaper "Network Applications: Opening up 5G and Beyond networks, V2.0". The social media contribute to the development of these communication channels. Throughout the project's duration, 5G-INDUCE's official LinkedIn profile and YouTube channel have served as repositories for relevant materials and information. The project's final workshop, which provides a comprehensive summary of the outcomes and technologies developed, is accessible through the official YouTube channel. For the IEEE International Conference on Communications held in Rome in 2023, promotional materials including flyers and two posters were designed to represent the project.
Deviations:	The industrial Advisory Board was selected, but no specific meeting was held.

Task 7.4 – IPR & Innovation Management

Leader:	8BELLS
Participants:	{ALL}
Duration:	M01 – M42
Description of activities:	The Task began by gathering all the innovations of the 5G-INDUCE project, encompassing both background (BG) and foreground (FG) assets. The consortium selected and reached a consensus on the Key Exploitable Results (KERs) from the pool of innovations. The 5G-Induce innovations were subjected to business analysis methods, such as SWOT analysis and LEAN canvas, in order to ascertain prospective benefits and anticipate any corresponding drawbacks or vulnerabilities. This analysis offered valuable perspectives to the individuals responsible for innovation, allowing them to improve and fortify their resources. "The complete 5G-INDUCE Orchestration Platform" was recognized by CNECT-INNOVATION-RADAR as Tech-Ready (https://innovation-radar.ec.europa.eu/innovation/48818), along with "A software component for drone-assisted network performance and coverage monitoring in industrial environments" (https://innovation-radar.ec.europa.eu/innovation/48815), by partner ININ. The business study, together with the market analysis conducted on numerous trends, assisted in creating a strategic plan for the commercialization of the project. At the beginning of the project, each partner created their own exploitation plans, which were

revised according to the business and market assessments, in order to optimize the potential for commercialization.

A collaborative effort amongst the project partners resulted in the development of a shared exploitation plan. Various commercialization tactics were given and reviewed for each member and the consortium as a whole in order to enhance their commercialization endeavors. Ultimately, the consortium members and partners reached a consensus regarding the ownership of the Key Exploitable Results and their specific responsibilities in the creation and utilization of these advancements.

The continuation of the IPR process was presented, as Ericsson identified a new Key Exploitable Result (KER) towards the end of the project.

Deviations: None in particular

Task 7.5 – Exploitable Market Potentials

Leader: UOP

Participants: WHR, FORD, PPC, OTE, WIND3, UBITECH, ININ, 5COMM, YBVR, ASTI, ILINK, INFOCOM, 8BELLS, SUITE5, K3Y, OCULAVIS

Duration: M01 – M42

Description of activities: The exploitation activities for the 5G-INDUCE project have progressed significantly since the initial business modeling efforts. The project has moved from identifying potential business models to developing and refining specific strategies for commercialization of key exploitable results (KERs).

A comprehensive market analysis of the 5G ecosystem has been conducted, examining market trends, key players, and their interactions. This analysis has informed the development of business models, with a focus on the operator-centric Business-to-Business-to-Any (B2B2X) model.

The Network Application Orchestrator (NAO) platform has emerged as the primary exploitable outcome, serving as the common foundation for all NetworkApps developed within the project. Standardization efforts have been concentrated on the NAO platform and its components.

The development of business plans for KERs has utilized various strategic frameworks, such as SWOT analysis and LEAN Canvas. These methodologies have been instrumental in creating succinct business models. As the project has evolved, these analytical approaches have undergone continuous refinement and adaptation.

Individual and joint exploitation plans have been developed for consortium partners, outlining how they intend to utilize and commercialize project results. These plans cover various commercialization paths including product development, licensing, service provision, and further research.

Key business models have been identified for major project outcomes like the NAO, Operations Support System (OSS), and various use case-specific NetworkApps. Revenue streams have also been defined, including licensing fees, support services, consultancy, and development of targeted solutions.

The results of this work have been documented in D7.7.

Deviations: None in particular

3 Impact creation

3.1 Exploitable results

The main exploitable results as identified and updated by the consortium, with the corresponding ER number and a short description, are presented in Table 1. The IPR table has been continuously updated through the whole duration of the project.

Table 5 Identified Exploitable Results

ER Number	Exploitable Result (ER)	Short Description	Main Partner(s)
ER1	5G-INDUCE Platform	The complete 5G-INDUCE platform	Project Consortium
ER2	NAO	Undertake the deployment, real-time management, and graceful un-deployment of Industry 4.0 nApps, while inherently providing elasticity and compliance with certain high-level nApp policies.	Project Consortium
ER3	OSS	Provides the interface that translates Application requests into Network connectivity and resource allocation requirements.	Project Consortium
ER4	UC1 nApps	Autonomous indoor fleet management	ASTI, Fivecomm
ER5	UC2 nApps	Smart operation based on human gesture recognition	ybVR, ASTI, Fivecomm
ER6	UC3 nApps	VR Immersion and AGV Control	Asti, ybVR, Fivecomm
ER7	UC4 nApps	ML-Supported Edge Analytics for Predictive Maintenance	Suite5
ER8	UC5 nApps	Inspection and surveillance services for critical infrastructures	UWS
ER9	UC6 nApps	Remote Service Platform for Inspection, Maintenance and Repair	Oculavis
ER10	UC7 nApps	Crossroad control for safety	iLink
ER11	UC8 nApps	Drone assisted network performance and coverage monitoring for industrial infrastructures	ININ

3.2 Exploitation plans per partner

Large Enterprises

Ericsson: The knowledge build and solution outcomes from the project are expected to help Ericsson España to improve its positioning in this new market of value-added services, in order to serve our customers at global levels. The exploitation approach adopted has considered the following aspects, for which an update by the end of the project is provided: i) the Knowledge build in the specific subjects addressed by the project through collaboration with the academic and SME partners. This has been largely achieved already, with special intensity in the collaboration with UBU, 5COMM and YBVR for crafting and validating the Use Cases of 5G-INDUCE in the Spanish Cluster, hosted at Ford factory. Ii) the Joint exploration and assessment, primarily with the Communication and Digital Service Providers, of new challenges and potential breakthrough solutions addressing control, orchestration and management needs in the scoped vertical industries scenarios. This has been achieved through the organization of specific workshops with involvement of key actors in the value chain of 5G-based I4.0 services, and also reflected in the broader research work performed within 5G-PPP for the I4.0-5G whitepaper published in October 2023. Iii) The pursuit of new partnerships with high-tech SMEs participating in the consortium, for mutually supporting our business offerings in the mid-term, and for jointly tackling further technology challenges identified along the project (through further R&D collaborations). This has been articulated through forging, or participating in, new research consortia proposals at Spanish and European level, pending evaluation at the time of writing this report.

UniSystems: 5G-INDUCE presents a significant opportunity for UniSystems, as a leading system integrator and multinational technical solutions provider, to expand its services offerings in the industrial sector and beyond. The project's results provide valuable insights and expertise that can be applied to reinforce UniSystems' current services portfolio in various related vertical sectors, such as transportation logistics and fleet management, both within the national and international market. Moreover, 5G-INDUCE offers an opportunity for UniSystems to investigate new advanced topics, like drone fleet control and VR control of Automated Guided Vehicles (AGVs), which align with future plans of the company. UniSystems recognizes the importance and value of the 5G-INDUCE platform and intends to further enhance its interface towards a more user-friendly, intelligent and efficient version that could potentially include improved handling of high-level requests and translation into deployment and policy requests, ensuring a seamless experience for clients.

OTE: Through 5G-INDUCE OTE, as a telecommunication provider, had the opportunity to identify the network requirements and design and implement a network that could support services offered to Industry 4.0. At the same time, OTE tested the network's operation in real case scenarios in an industrial environment. In the project, OTE cooperated with partners integrating a fully operational testbed which was used in three use cases: Predictive maintenance for Power Generator, UAV inspection and surveillance, AR assistance for maintenance procedures. OTE had the chance to communicate the outcomes of this work in several business forums and related events, at national and European level. Additionally, OTE diffused these results within the 'wider' OTE Group of Companies where the company is Leader, as well as to the DT Group of Companies where OTE is an active member.

WIND Based on the progress WIND3 has achieved in the deployment of MEC platform in order to guarantee low latency and performance of the 5G network, WIND3 has considered the potential exploitation approach and activities performed during the project. Potential commercialization and other exploitation activities have been identified; WIND3 has deployed this solution in other similar funded projects; furthermore, it has implemented a similar platform for existing Business Customers. The after-project exploitation plan must include the analysis of platforms considering 5G core StandAlone when it will be available. WIND3 has improved its internal know-how related to 5G and MEC in the innovative field. The exploitation activities will mainly concern following vertical markets: smartgrid, Industry4.0, automotive, smart city, etc.

Industries

Whirlpool: Beko Europe (formerly Whirlpool EMEA) will support the exploitation plan of 5G-INDUCE extending the 4 UCs, developed for Cassinetta refrigeration Factory, to the other EMEA factories, in compliance with BEKO Europe purchasing policy and Digital transformation roadmap. The company will evaluate the solution of 5G local industrial infrastructure at factory level with orchestrator capability embedded into the new IT organization. Whirlpool/BEKO Europe will also support 5G-INDUCE dissemination participating as industrial testimonial, invited as speaker in public events and in internal workshops held with EMEA factories network.

FORD: Ford Almussafes has contributed to the 5G-INDUCE project by providing the necessary facilities to successfully carry out use cases UC1, UC2, and UC3. The company will internally evaluate the 5G solution within the current IT infrastructure and recommend other company plants to undertake similar innovative projects using 5G solutions for various new technologies. The combination of 5G and cutting-edge technologies promises to enhance safety, efficiency, and productivity in Ford's manufacturing processes, making it a significant step toward the future of smart factories.

PPC: Through its participation in the 5G-INDUCE project, PPC has further advanced its know–how on 5G communication systems and acquired new knowledge and insights on how they could improve the business activities of PPC. Moving forward, PPC will showcase the findings of the project and the results of the use cases to internal stakeholders (e.g., maintenance administrators, directors of power plants, etc.) and will initiate discussions with them on how the developed NetworkApps can be incorporated in relevant operations. Based on the feedback received by the internal stakeholders, and the current needs of the company, PPC plans to initiate discussions with the technology providers of UC4 to investigate the adoption of the relevant NetworkApps for predictive maintenance and fault prediction. Furthermore, PPC will examine via its Robotics Lab the commercial exploitation of the solution produced in UC 5 for using drones to detect corrosion in near shore power plants and infrastructure, as well as offshore wind farms. Finally, PPC through its relevant Inspection units will explore the wider exploitation and deployment of the tools developed in UC 6 to facilitate remote inspection and maintenance of critical infrastructure.

SMEs

UBITECH: As a leading SME in the creation of innovative software solutions, UBITECH has managed to significantly enhance its service management and orchestration framework with the innovative developments incorporated in NAO (Network Application Orchestrator) framework. Furthermore, standardized interfaces have been established and successfully tested with OSS, while also innovative addons have been provided for the service update, monitoring and policy engine mechanisms that enable the runtime management of applications. Significant insight has been brought also with respect to the application and services for industrial environments.

ININ: Based on the progress ININ has achieved in development and productization of its qMON test and monitoring automation solution and through the exploitation approach and activities performed during the project lifetime (cooperation with other partners in the field, market research, dissemination and demonstration activities, validation activities in Industry 4.0 use cases), potential commercialisation and other exploitation activities have been identified and realized. Advanced features of qMON have been recognized as suitable to be utilized in two SNS-JU projects already in progress (6Green, Exigence), as well as the solution has been included into a couple of other R&D project proposals. Further, existing commercial customers are already benefiting from new features and with another large-enterprise industrial customer the solution is in the delivery phase.

FiveComm: 5Comm aims to offer their product and service as both a licensed solution and a consultancy service to mobile robotics companies. This strategic approach will support future research projects focused on 5G and 6G technologies. Their NetworkApp will be disseminated among mobile robotics companies to gather valuable feedback and ensure its seamless adaptation to clients' systems. By offering a consultancy service, they can tailor the solution to meet specific customer needs and provide ongoing support. Alternatively, licensing the NetworkApp allows to reach a broader market, enabling companies to integrate 5Comm's innovative technology into their operations independently.

YBVR: YBVR's participation in the 5G-INDUCE project, with the development of Use Case 3 (VR immersion and AGV control), was used to explore the possibility of commercializing this solution with 5G support for industrial environments. This experience has helped the YBVR innovation team to propose a new service within the company to monitor industrial processes in dangerous or inaccessible environments. The key points of this service will be the 5G network capacity for uploading immersive videos, the flexible edge computing resources to process the video and compile and overlay the real-time data of the environment on the video, and the player APP developed for immersive (VR headset) and non-immersive (smartphone or tablet) devices to monitor the data and images.

ASTI/ABB: The outcomes are going to expand the range of functionalities of the AMRs platform and will allow to improve the technical quality of all the ABB products. This is going to contribute to a significant increase in the sales figure of the company and the opening of new target markets and geographic sectors. The execution of the project has been fundamental to achieve the fulfilment of the 2025 objectives, in which it is estimated to reach an annual sales figure of 50M €. ABB has identified a list of clients that could need AMRs in their installation with a significant added value for their production system and the consequent competitive advantage

ILINK: In the strategic rollout of ILINK's indoor positioning application, developed under the 5G-INDUCE HORIZON Project, the company's aim is to leverage the high TRL of the application to enter and expand within the market as a fully-fledged product. The application, which utilizes ultra-wideband sensors for precise indoor tracking, has been rigorously tested in extensive industrial environments, enabling real-time monitoring of workers and forklifts. A standout feature of the application is the innovative collision avoidance algorithm that proactively sends alerts to prevent accidents, enhancing operational safety. In the transition from project completion to commercialization, ILINK's exploitation strategy will focus on enhancing product visibility through targeted marketing campaigns and direct engagements at industry-specific conferences and exhibitions.

INFOCOM: INFO is already exploiting the competencies it gained through the participation in the 5G-INDUCE project, and, especially, in the design, development and integration of the 5G-INDUCE Platform carried out in the scope of WP3, WP5 and WP6. In fact, INFO is applying such competencies in two new innovation projects, started in 2024 and funded by the Liguria Region (Italy) from the European Regional Development Fund' (ERDF) 2021-2027 budget. These two projects pertain the development and large-scale tests in real environments (TRL 6/7) of, in one case, a massive IoT (Internet of Thing) system for the monitoring of critical road infrastructures for the prevention of disasters, and, in the second case, a reliable, low latency machine to machine system for the command and control of marine USVs (Unmanned Surface Vehicles) provided with sensors for monitoring the quality of water and air in ports and near-shore areas.

8BELLS: Eight Bells has been actively participating in the 5G-INDUCEProject, where they are building an Intrusion Detection System (IDS) that may provide incident warnings. They have also successfully tested predictive algorithms within UC4. Based on the knowledge gained from this initiative, Eight Bells has already taken action to maximize the benefits by combining the IDS with a mitigation mechanism, thus advancing research in this field. In addition, their skill in Artificial Intelligence and Machine Learning has greatly improved, achieving a higher level of knowledge through the utilization of the considerable experience acquired from the implementation of the 5G-INDUCEproject. Their goal is to persist in the study and produce a thorough product, making use of the knowledge and insights gained during the project.

SUITE5: Suite5 through its participation in the 5G-INDUCE project and the development of the UC#4 NetworkApp further advances its technological and innovation know-how related to 5G in manufacturing systems and succeeded to introduce new AI/ML services to its current services portfolio of data-driven intelligence. Following the end of the project, Suite5 aims to exploit the developed NetworkApp in various domains, that require the provision of real-time predictive maintenance decision, while the overall application that has been delivered is capable of leveraging 5G capabilities to solve other problems as well, as it provides the ability to design various AI pipelines that can be customised to the needs of different domains/end users. Exploitation activities will target primarily Manufacturing Enterprises and Big Industries that are in need of more flexible, dynamic and scalable analytics based on large streams of data in the specific ICT domains that handle business critical systems. These stakeholders will be reached through personalised contacts with existing or potential clients and through the participation in fairs or through online communication channels.

K3Y: K3Y will exploit the results and solutions of 5G-INDUCE by utilising its capacity in creating, maintaining and optimising the usage of big data, visualised IDPS and Fog / IoT-enabled simulation environment. K3Y will further advance the use of visual-based anomaly detection to deliver more reliable NetworkApps and services. Additionally, K3Y will expand the IoT tools within the simulation environment by incorporating more Fog devices, nodes, and protocols, including trusted UAVs, to support large-scale applications. K3Y will mainly investigate the exploitation of the NetworkApp Orchestrator (NAO), the exploitation of UC4 NetworkApps for predictive maintenance and fault prediction and the exploitation of UC6 NetworkApps to facilitate remote inspection and maintenance of critical infrastructure. Specifically, K3Y will explore the internal utilisation of these results for further development and the potential to offer consultancy services. Exploitation activities will focus on targeting private sector companies in Bulgaria, showcasing the benefits and capabilities of 5G-INDUCE solutions. K3Y will reach the target audience through personalized contacts with existing and potential clients, participation in industry fairs, and online communication channels.

OCULAVIS: The goal is to further develop 5G-INDUCE mobile applications to optimize their use in 5G environments, aiming for a final product that provides quality on demand. Furthermore, the system setup will be evaluated and enhanced to be optimized for public and private 5G network scenarios, specifically targeting large manufacturing industries and SMEs, with a focus on the Automotive, Energy, Life Sciences, Machine Tool Makers, and Plant Manufacturers sectors requirements. Their monetization strategy includes introducing premium subscription licenses for newly developed features such as adaptive bandwidth on demand and on-premise hybrid media server deployment. The software will remain closed-source, and we will retain all IP rights to the processes and software codes. Ongoing research and development will continue through follow-up projects to evolve features (e.g., with efforts to reduce the carbon footprint and minimize server usage and costs).

Academia R&D

CNIT: As a research institution, the main goal of CNIT is to exploit the results achieved during the project activity in future research projects and in the advancement of its research infrastructure, in terms of Laboratory equipment and software. In this respect, two items that will – and, to some extent, already did – significantly contribute to this advancement are the OSS (Operation Support System) and the DevOps testbed.

UWS: UWS through its Research & Enterprise Services department has investigated the potential commercialisation opportunities partially based on the use case (UC5) led by the UWS team. The involved partner PPC has been approached for this initiative, and a UWS spin-out has been created recently and is expected to be officially launched in March 2024. Moreover, UWS has conducted relevant standardisation activities in ITU-T and contributed to the creation of a new ITU standard: ITU-T Recommendation Y.Sup71

(2022), "Use cases for autonomous networks"[2]. In addition, UWS plans to utilise the R&D outcomes especially the demos from the trials to enhance the teaching materials in related modules for UWS students at the honours degree and postgraduate/research levels, thereby improving teaching quality and increasing students' satisfaction.

UOP: University of Patras is developing know-how for methodologies pertaining to 5G networking, testing and application-oriented management. In 5G-INDUCE, Up as WP7 leader and with its supportive role has strengthened its expertise of its Networks & Optical Communication (NOC) research group regarding technologies and solutions for 5G infrastructures and access points, while also reinforced the collaborations with the industry sector and standardization bodies. Following the end of the Project, University of Patras aims to exploit the Network Application development for the promotion of knowledge for educational purposes and the expansion of research activities as a common exploitable target for all academic partners.

[2] See https://www.itu.int/ITU-T/recommendations/rec.aspx?id=15041&lang=en and https://www.itu.int/rec/T-REC-Y.Sup71-202207-P/en

4 Follow up on recommendations from the first periodic review period

1. The project has to come up with a plan to achieve its objectives regarding impact beyond the end of the project on 3rd. parties and stakeholders outside the consortium. This can involve starting (and maintaining) an open source community for nApps deployment based on NAO and OSS, related documentation, webinars, white papers, standardisation activities and/or contribution of reusable components to market places.

The project has followed closely and actively the related activities among ICT-41 projects on creating a common nApp repository (under 5GASP) and on enhancing collaboration (see D4.3). Beyond this the project has tried to create impact in the specific area of manufacturing industry through 5GPPP actions and the sound contribution in the extracted white paper. Furthermore, the project paid significant attention in the creation of the appropriate dissemination material including both demonstration videos as well as material that explains in detail the platform onboarding features and process.

2. The KPI for the use cases have to measure also ease of nApp development and deployment (e.g. % of reused code, time for deployment etc.).

One of the key metrics reported is the deployment time of nApps. This has been evaluated for all use cases and also for different types of platform provisioning models. Moreover, it was split and analysed in deployment steps, in order to see the key contributions of each step in the overall deployment time. The nApp development is a quality metric and cannot be measured directly. However, the project adopts methodologies like the definition of nApps as linked micro-services, as well as DevOps processes (as described in D5.3) that significantly ease the development effort and most importantly minimize the debugging time due to potential errors.

3. Clearly describe how 5G communication requirements will be handled in nApp handling. Especially explain if 5G IoT special requirements will be handled, such as 3GPP Rel 16 TSN (time sensitive network) for instance or other 3GPP IoT & Industry 4.0 features.

The topic of TSN has not been addressed. It is noted that one of the key features of the 5G-INDUCE platform is the separation between application orchestration level and the compute and network resource orchestration levels. This essentially separates the end-user (application driven) requirements, from the actual handling of resources and connections. In turn, the handling of the 5G infrastructure requirements (according to the end user demands) is handled through the programmable and adaptable interface developed for the SBI of the 5G-INDUCE OSS. This eases the integration of the 5G-INDUCE platform with underlay infrastructure systems, which may include, among many others, TSN approaches. However, the main focus for the platform was to interact with different types of both commercial and more advanced and research oriented programmable network solutions providing the handling of 5G infrastructure.

4. Describe APIs in details, and explain if TMF, CAPIF, SOL006 or others sources, or proprietary.

Extensions were made to the NFVCL in the SB-OSS to enable the interaction with any NFV Orchestrator via NFV SOL 006 descriptors. Furthermore, the TMF service order model has been adopted in the latest versions of the NAO. However, this is not integrated in 5G-INDUCE as it requires significant modification in the interfacing with OSS, which would affect the validation phase of the workplan.

5. Documentation on nApps onboarding is recommended: A tutorial and a handbook how to use the orchestration platform by the App developers is needed. The use case partners will also need it.

The recommended documentation was created. Furthermore, a space with all the required processes was created in GitLab and hosted all use cases.

6. The demos should also show automated scaling to cope with dynamic demands.

This has been addressed through the related slice update and policy handling mechanism of the platform and released with the final version of it.

7. The project suggest currently a top down orchestration. However, App deployment may fail. Hints should be provided to the developer in an iterative feedback loop to allow for App adaption to achieve finally a deployment. Moreover resource costs of requirements must not be neglected.

A monitoring and end-user alerting mechanism for successful or unsuccessful nApp deployment had been included already in the early platform release. Moreover, an extension has been implemented in the final platform release to allow certain parameters to be declared as hard or soft constraints. The overall process allows hard only constraints to be guaranteed and soft constraints to be implemented in a best effort way. If hard constraints cannot be satisfied, then manual modifications are required by the end users to change the nApp parameters and resubmit the deployment request.

8. Consider Resiliency and redundancy, in particular for a wireless approach (i.e. uRLLC) for industry acceptance.

Indeed, resiliency is a very important feature, in particular for specific applications, and therefore it has been already encountered as one of the performance metrics in 5G-INDUCE. The metric is included in D2.2 subsection 4.3.2. The overall concept is to introduce pre-calculated redundant paths for certain critical nApp components and to include these redundant paths in the original deployment. Therefore, in case of a failure, a much faster reconfiguration is possible immediately when a triggering event appears (e.g., failure of a node). This is opposed to the normal reconfigurability through the NAO and achieved significantly fast resiliency responses, since it can be triggered directly by the network orchestrator or as a response to a monitored parameter at the application life-cycle management level.

9. Consider security and data protections from the beginning to ensure acceptance by industry. This should also include aspects of different campus network solutions with (partial) on side infrastructure.

According to the project objectives, the security aspects are addressed from the point of view of the nApp deployments. The topic includes the main activities of the planned nApp extensions applicable over multiple use case nApp deployments. Such nApp security components (e.g., packet filtering-firewalling, deep packet inspection linked to malicious attack detection engines) have been considered in the last phase of the nApp development cycle; The functional nApp component extensions have been developed by M24 and integrated by M27. It is noted that platform-related security aspects, beyond those offered already by OpenStack and Kubernetes at the IaaS/PaaS level (such as cluster access privileges certification, multi-tenant isolation, role-based access control, etc.) are out of the scope of the project (e.g., risk assessment processes).

10. Consider sustainability requirements and energy efficiency, slice energy efficiency, including carbon footprint of the SW being developed, nApp code.

The consortium identified that this is an important topic, in line also with the latest directions of the EU. However, significant effort would have been required, in order to properly address energy efficiency as a validation metric, especially in distributed deployment scenarios; it might have been even harder to provide convincing testing scenarios at large scale. Since the main focus was on the platform deployment and exploitation towards Industrial nApp services, the specific recommendation remained in our radar mostly as an optional field of study. As such, it has been the subject of some of the project related publications:

- R. Bolla, R. Bruschi, A. Carrega, F. Davoli, C. Lombardo, B. Siccardi, "A Stochastic Knapsack Model for Energy Efficient Management of Multi-Server Queues," in Proc. 7th International Balkan Conference on Communications and Networking (BalkanCom 2024), Ljubljana, Slovenia, June 2024, pp. 224-229, IEEE, Piscataway, NJ, 2024;

- E.-V. Depasquale, F. Davoli, H. Rajput, "Dynamics of research into modeling the power consumption of virtual entities used in the telco cloud," Sensors, vol. 23, art. 255, pp. 1-69, Jan. 2023; R. Bolla, R. Bruschi, F. Davoli, L. Ivaldi, C. Lombardo, B. Siccardi, "An AI Framework for Fostering 6G towards Energy Efficiency," in Proc. 61st FITCE International Congress "Future Telecommunications: Infrastructure and Sustainability" - Special Session 2 Intelligence at the Network Edge, Rome, Italy, Sept. 2022, p. 1-6, IEEE, Piscataway, NJ, 2022;
- R. Bolla, R. Bruschi, A. Carrega, F. Davoli, C. Lombardo, "Trading off power consumption and delay in the execution of network functions by dynamic activation of processing units," Proc. 2022 1st International Workshop on Network Energy Efficiency in the Softwarization Era, Milan, Italy, June 2022, pp. 1-6, IEEE; Piscataway, NJ, 2022. The topic has become the main theme of the new Horizon Europe project 6Green (Green Technologies Green Technologies for 5/6G Service-Based Architectures, https://www.6green.eu/), also coordinated by CNIT.

11. The semantic gap between application providers and 5G infrastructure providers/operator needs further attention.

The distinction between roles is a key structural characteristic of the 5G-INDUCE platform. In the adopted concept, the separation between the NAO part and the OSS enables the application-related matters to be handled, independently of the network resource management and allocation actions, yet permitting reciprocal interaction, in order to allow application-driven features to determine the networking features. In principle this separation is aligned with the key roles expected in future application-driven 5G deployments. Application Developers/Providers offer and/or manage modular and “chainable-by-design” nApps, i.e., consisting of a number of chainable application components, abstracted from physical and networking resources. They deal with the NAO functionalities including nApp onboarding, lifecycle management and definition of application related policies. Infrastructure Providers, operating a programmable (5G) network infrastructure, are offered the role to provide network resources for 5G services/applications. Particularly, either they perform the programmable dynamic provisioning of network resources by handling the application graphs of the 5G applications, or they directly expose programmable network interfaces to third parties (possibly service providers) for the support of the 5G-INDUCE framework. In the value chain enabled by the 5G-INDUCE platform deployment, the application developers announce to service providers or to Infrastructure providers (depending on the business model), in a formal way, the resource (networking, storage, compute) requirements that should be satisfied when the application graph is instantiated.

12. The tasks description in the report should point out to scientific papers and SDO contributions they produced.

Scientific publications and potential SDO contributions are not subject to specific tasks, but to overall activities in WPs and across WPs. Therefore, they have been addressed collectively under WP7.

13. Increase dissemination towards relevant stakeholders, in particular vertical industries especially since the key stakeholder have no immediate plan to leverage the 5G work, it is important to reach out outside to other Industry players for 5G Induce to have a real impact. Make more use of webinars given the current pandemic situation. Improve number of scientific publications related to the architecture and innovations.

Dissemination material was extensively produced, also in the form of videos, and publicized over social media. Direct contacts were also fostered with other ICT-41 projects and with participation in SME WG of 5G PPP. A final project Workshop in webinar form was held to promote the platform.

14. Come up with a clearer exploitation and standardisation plan including identified bodies, timeline and responsible partners. Improve SDO relations in SDOs directly related to the topic: ETSI NFV, ETSI ZSM, 3GPP (describing identified bodies, timeline and responsible partners). Consider contributions to standards & opensource, i.e NFVCL contribution to ETSI OSM, or 5G-Induce yaml description to ETSI NFV or to OSM, etc.

The exploitation plan has been updated, and a market evaluation study has been performed. The plan includes the main stakeholders, their relationship to the main exploitable items and sectors, and the market influence and scientific impact that each one can generate. The project has made three presentations to the ITU-T Focus Group on Autonomous Networks (FA-GN), as described in T7.2. A number of relevant standardization bodies, open-source communities, knowledge and practice communities such as 6G-IA, and industry forums where 5G-INDUCE can make contributions have been identified. In the second reporting period. Particularly, Ericsson, as a key partner, made significant contributions to 3GPP standards, including two specific contributions to 3GPP SA2 for Release 18.

15. Improve scientific publications related to the architecture and innovations. we understand that it is planned after M24, so we expect this in the upcoming next phase.

The project produced a total of 14 contributions in Conference/Workshop proceedings and 12 journal papers; additionally, it participated in 2 Whitepapers from 5G PPP Working Groups. In particular, relation with architecture and innovation can be found in the Whitepaper "Innovation Trends in I4.0 enabled by 5G and Beyond Networks" 5G-PPP, 5G-PPP White papers, 2023, as well as in a number of papers listed in the corresponding section of the project website.

16. Reinforce the advisory board with industry 4.0 expert that has deployed 5G in his factory and can help with technical insights and business value.

No actions have been taken towards this direction. However significant feedback received internally from participating industries on the usage of 5G applications, and also from partner Ericsson through the related joint publication activities in 5GPPP.

17. The next phase will be a critical milestone for WP3 and development as well as WP5 and experimentation. It will involve lots of interactions across different teams and different countries, Greece/Italy/Spain. Communication will be key as well as proper documentation of the software (APIs, handbook), processes and actions. Project management will be important to make sure no critical *issues delay the project.*

Identifying the criticality of this phase, the project management and technical management team have monitored closely the developments across the three main development areas (see introduction part of technical report D1.3). All these activities have been coordinated in parallel, providing direct feedback among them. For example, the platform development activities defined the interfacing with the ExFas and the requirements for the platform integration. In turn, the infrastructure providers defined together with the use case nApp developers the infrastructure deployment requirements to fully support the targeted nApp tests and demonstrations. The nApps in turn defined specific NAO functionalities that must be supported. Moreover, deviations to the workplan were identified and commented in the Section 1.3 of deliverable D1.2, together with the expected mitigation period and the reasoning behind it. In the final phase of the project, the main effort has been directed to the final testing and demonstration actions. A key risk that was related with the delay in 5G-INDUCE platform development (already communicated in the previous reporting period) was monitored and as a result a request for amendment was issued well in advance with a clear workplan for the requested 6-month extension.

5 Deviations from Annex 1 and Annex 2 (if applicable)

5.1 Tasks

No major or critical deviations from the project workplan, as updated in the two Consortium requested Amendments, which have been accepted on 26 October 2022 and on 28 November 2023, respectively, by the European Commission, have occurred. The activities in all the WPs have provided results in line with expected milestones and objectives, albeit with some delay in few activities. A key risk that was related with the delay in 5G-INDUCE platform development (already communicated in the previous reporting period) was monitored and as a result the request for the second amendment was issued well in advance with a clear workplan for the requested 6-month extension.

The details on small deviations per task, where applicable, have been provided in the relevant sub-sections in section 2 above.

5.2 Use of resources

The Table 6 hereinafter reports the actual effort expenditure in terms of PMs per WP declared by the partners for the second reporting period, i.e. from 1 July 2022 (M19) to 30 June 2024 (M42).

In addition, since this reporting period is the final reporting period for the 5G-INDUCE project, we provide also in Table 7 the cumulative Person Months (PMs) per WP that have been spent by the partners since the beginning of the project.

Furthermore, tables showing the effort and the usage percentages declared for each WP in RP2 and in the entire project follow (see Tables 8-11).

It is worth noting that the actual effort expenditure reported in all the tables has been originated by considering together the PMs declared under both the cost category "a) Direct personnel costs declared as actual costs" and "c) Direct personnel costs declared as unit costs ► c1) SME owner/Natural person costs", in order to give a comprehensive outlook on the activities carried out in the project's WPs.

The partners of the 5G-INDUCE consortium with budget in the cost category "c) Direct personnel costs declared as unit costs ► c1) SME owner/Natural person costs" are: ININ, ILINK, 8BELLS, SUITE5 and K3Y.

In all tables, we highlighted in red/blue, as major deviations, those partners whose percentage of total effort expenditure in the entire project's lifespan exceed the threshold of 20% compared to the planned effort. This implies that partners showing a percentage > 120.00% of the total effort spent in RP1 + RP2 are considered overspending (red), while partners with a percentage < 80.00% are marked as underspending (blue).

Regarding the effort expenditure in the second reporting period, which encompasses the 57% of the project lifespan, it can be noted that the percentage of the total effort declared by the consortium is in line with the residual PMs of the planned use of resources: in fact, it amounts to about 70% of the budgeted PMs, which, considering the 41% of effort spent in the first reporting period, leads to an overall percentage of 111% compared to the planned effort.

This percentage of effort spent in the second reporting period approximately corresponds to the 65% of the personnel costs foreseen for the project, which, when added to the personnel costs spent in first reporting period and the other direct and indirect costs, brings the total costs for the project to just over 97% of the total budget.

Table 6 Effort expenditure in the second reporting period

Beneficiary	WP1	WP2	WP3	WP4	WP5	WP6	WP7	Declared in RP2	*Planned*	*RP2/Pl %*
1 - CNIT	8.09	0.00	6.88	0.00	7.40	13.51	5.25	**41.13**	*66.00*	*62.32%*
2 - OTE	0.65	0.00	0.00	0.00	10.85	15.60	3.70	**30.80**	*52.00*	*59.23%*
3 - WIND3	0.49	0.00	0.00	0.00	4.72	5.96	2.87	**14.05**	*25.00*	*56.21%*
4 - ERC	0.22	0.00	0.00	0.00	2.65	17.58	1.66	**22.11**	*39.00*	*56.69%*
5 - UNIS	0.44	0.00	2.03	4.19	0.73	3.39	1.92	**12.70**	*44.00*	*28.86%*
5.1 - UNIS-EL	0.00	0.00	3.01	1.99	13.30	3.24	0.00	**21.54**	*26.00*	*82.85%*
6 - WHR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	*9.63*	*0.00%*
7 - FORD	0.00	0.00	0.00	0.00	0.85	10.43	0.00	**11.28**	*39.00*	*28.92%*
8 - PPC	0.50	0.00	0.00	2.98	10.30	15.94	2.51	**32.23**	*52.00*	*61.98%*
9 - UOP	4.93	0.00	10.92	0.00	8.74	10.97	14.90	**50.46**	*43.00*	*117.35%*
10 - UWS	2.39	0.00	0.00	11.15	1.77	10.60	5.99	**31.90**	*40.00*	*79.75%*
11 - UBITECH	6.21	0.00	10.29	6.14	20.32	9.56	3.53	**56.05**	*69.00*	*81.23%*
12 - ININ	0.53	0.00	4.35	8.99	6.61	6.34	1.28	**28.09**	*48.00*	*58.51%*
13 - 5COMM	0.59	0.00	0.00	17.00	5.50	37.95	2.89	**63.93**	*90.00*	*71.03%*
14 - YBVR	1.60	0.00	0.00	8.80	1.94	7.10	1.47	**20.91**	*36.00*	*58.08%*
15 - ASTI	1.47	0.00	0.00	19.89	1.65	10.62	2.21	**35.84**	*21.00*	*170.67%*
15.1 - UBU	0.23	0.00	0.00	7.70	0.00	3.95	0.98	**12.86**	*17.00*	*75.65%*
16 - ILINK	0.53	1.86	0.00	3.86	9.27	12.96	2.35	**30.83**	*60.00*	*51.38%*
17 - INFOCOM	0.56	0.28	26.30	6.30	11.25	9.20	1.50	**55.39**	*70.00*	*79.13%*
18 - 8BELLS	1.04	0.00	4.01	15.51	15.17	17.09	9.60	**62.42**	*58.00*	*107.62%*
19 - SUITE5	0.55	0.00	0.00	7.63	8.63	8.22	1.12	**26.15**	*47.00*	*55.64%*
20 - K3Y	0.47	0.00	12.53	13.17	7.09	11.89	2.88	**48.03**	*65.00*	*73.89%*
21 - OCULAVIS	0.79	0.00	0.00	14.69	9.18	7.54	2.39	**34.59**	*57.00*	*60.68%*
22 - WHMAN	0.80	0.00	0.00	0.20	16.10	12.10	1.80	**31.00**	*32.60*	*95.09%*
All	**33.08**	**2.14**	**80.32**	**150.19**	**174.02**	**261.74**	**72.80**	**774.29**	***1106.23***	***69.99%***
Planned	*39.03*	*110.10*	*105.00*	*267.00*	*250.00*	*236.10*	*99.00*	***1106.23***		
All/Pl %	*84.75%*	*1.94%*	*76.50%*	*56.25%*	*69.61%*	*110.86%*	*73.53%*	***69.99%***		

Table 7 Effort expenditure in the entire project

Beneficiary	WP1	WP2	WP3	WP4	WP5	WP6	WP7	Total in RP1+RP2	*Planned*	*Tot/Pl %*
1 - CNIT	14.06	6.00	18.82	0.00	11.09	15.28	8.32	**73.57**	*66.00*	*111.47%*
2 - OTE	1.16	15.00	0.00	0.00	17.25	16.70	4.60	**54.71**	*52.00*	*105.21%*
3 - WIND3	0.99	7.83	0.00	0.00	5.99	5.96	3.87	**24.65**	*25.00*	*98.61%*
4 - ERC	0.83	6.40	0.00	0.00	12.76	18.70	3.58	**42.27**	*39.00*	*108.38%*
5 - UNIS	1.00	8.00	8.00	16.99	2.73	4.00	5.10	**45.82**	*44.00*	*104.14%*
5.1 - UNIS-EL	0.00	0.00	4.00	2.30	16.28	4.00	0.00	**26.58**	*26.00*	*102.23%*
6 - WHR	0.20	4.10	0.00	3.70	1.40	0.00	0.20	**9.60**	*9.63*	*99.69%*
7 - FORD	0.34	0.21	0.00	0.94	2.41	13.06	0.07	**17.03**	*39.00*	*43.67%*

8 - PPC	1.00	5.99	0.00	6.00	19.10	17.10	5.00	**54.19**	*52.00*	*104.21%*
9 - UOP	4.93	3.68	12.76	0.00	8.74	10.97	17.18	**58.26**	*43.00*	*135.49%*
10 - UWS	2.68	3.73	0.00	27.68	2.71	10.60	9.14	**56.54**	*40.00*	*141.34%*
11 - UBITECH	7.06	7.90	15.59	7.28	21.58	9.56	4.09	**73.06**	*69.00*	*105.88%*
12 - ININ	0.99	3.00	6.00	15.80	6.91	7.54	2.57	**42.79**	*48.00*	*89.15%*
13 - 5COMM	1.39	7.40	0.00	38.13	17.25	38.01	5.97	**108.15**	*90.00*	*120.16%*
14 - YBVR	2.23	3.13	0.00	26.46	3.61	7.10	2.41	**44.94**	*36.00*	*124.83%*
15 - ASTI	1.91	5.05	0.00	30.82	6.75	10.62	3.29	**58.44**	*21.00*	*278.29%*
15.1 - UBU	0.57	0.00	0.00	13.29	0.00	5.03	1.15	**20.04**	*17.00*	*117.88%*
16 - ILINK	1.00	6.00	0.00	25.00	9.95	12.96	5.00	**59.91**	*60.00*	*99.85%*
17 - INFOCOM	0.86	3.48	35.19	8.05	14.71	10.09	2.23	**74.61**	*70.00*	*106.59%*
18 - 8BELLS	1.90	5.68	6.17	20.11	16.94	17.09	15.59	**83.48**	*58.00*	*143.93%*
19 - SUITE5	1.09	1.98	0.00	17.04	12.45	8.22	1.54	**42.31**	*47.00*	*90.03%*
20 - K3Y	0.99	2.00	17.99	16.00	12.01	12.00	4.01	**65.00**	*65.00*	*100.00%*
21 - OCULAVIS	1.63	4.51	0.00	26.84	12.03	8.79	4.99	**58.79**	*57.00*	*103.14%*
22 - WHMAN	0.88	0.00	0.00	0.20	17.90	13.60	1.80	**34.38**	*32.60*	*105.46%*
All	**49.68**	**111.06**	**124.52**	**302.62**	**252.55**	**276.98**	**111.70**	**1229.11**	***1106.23***	***111.11%***
Planned	*39.03*	*110.10*	*105.00*	*267.00*	*250.00*	*236.10*	*99.00*	***1106.23***		
All/Pl %	*127.30%*	*100.87%*	*118.59%*	*113.34%*	*101.02%*	*117.31%*	*112.82%*	***111.11%***		

Table 8 Effort expenditure details: WP1, WP2

Beneficiary	WP1					WP2				
	Planned	Declared in RP2	RP2 / Pl %	Total	To / Pl %	Planned	Declared in RP2	RP2 / Pl %	Total	To / Pl %
1 - CNIT	12.00	**8.09**	67.42%	**14.06**	117.17%	6.00	0.00	0.00	6.00	1.00
2 - OTE	1.00	**0.65**	65.00%	**1.16**	116.00%	15.00	0.00	0.00	15.00	1.00
3 - WIND3	1.00	**0.49**	48.95%	**0.99**	98.95%	8.00	0.00	0.00	7.83	0.98
4 - ERC	1.00	**0.22**	22.00%	**0.83**	83.00%	6.00	0.00	0.00	6.40	1.07
5 - UNIS	1.00	**0.44**	44.00%	**1.00**	100.00%	8.00	0.00	0.00	8.00	1.00
5.1 - UNIS-EL	0.00	**0.00**	N/A	**0.00**	N/A	0.00	0.00	N/A	0.00	N/A
6 - WHR	0.23	**0.00**	0.00%	**0.20**	86.96%	4.10	0.00	0.00	4.10	1.00
7 - FORD	1.00	**0.00**	0.00%	**0.34**	34.00%	4.00	0.00	0.00	0.21	0.05
8 - PPC	1.00	**0.50**	50.00%	**1.00**	100.00%	6.00	0.00	0.00	5.99	1.00
9 - UOP	3.00	**4.93**	164.33%	**4.93**	164.33%	4.00	0.00	0.00	3.68	0.92
10 - UWS	1.00	**2.39**	239.00%	**2.68**	267.73%	4.00	0.00	0.00	3.73	0.93
11 - UBITECH	6.00	**6.21**	103.50%	**7.06**	117.67%	8.00	0.00	0.00	7.90	0.99
12 - ININ	1.00	**0.53**	53.00%	**0.99**	99.00%	3.00	0.00	0.00	3.00	1.00
13 - 5COMM	1.00	**0.59**	59.00%	**1.39**	139.00%	7.00	0.00	0.00	7.40	1.06
14 - YBVR	1.00	**1.60**	160.00%	**2.23**	223.00%	3.00	0.00	0.00	3.13	1.04
15 - ASTI	0.50	**1.47**	294.00%	**1.91**	382.00%	3.00	0.00	0.00	5.05	1.68
15.1 - UBU	0.50	**0.23**	46.00%	**0.57**	114.00%	0.00	0.00	N/A	0.00	N/A

16 - ILINK	1.00	**0.53**	53.00%	**1.00**	100.00%	6.00	1.86	0.31	6.00	1.00
17 - INFOCOM	1.00	**0.56**	56.00%	**0.86**	86.00%	4.00	0.28	0.07	3.48	0.87
18 - 8BELLS	1.00	**1.04**	104.00%	**1.90**	190.00%	3.00	0.00	0.00	5.68	1.89
19 - SUITE5	1.00	**0.55**	55.00%	**1.09**	108.71%	2.00	0.00	0.00	1.98	0.99
20 - K3Y	1.00	**0.47**	47.00%	**0.99**	99.00%	2.00	0.00	0.00	2.00	1.00
21 - OCULAVIS	1.00	**0.79**	79.00%	**1.63**	163.00%	4.00	0.00	0.00	4.51	1.13
22 - WHMAN	0.80	**0.80**	100.00%	**0.88**	110.00%	0.00	0.00	N/A	0.00	N/A
Total	**39.03**	**33.08**	**84.75%**	**33.08**	**84.75%**	**110.10**	**2.14**	**0.02**	**111.06**	**1.01**

Table 9 Effort expenditure details: WP3, WP4

Beneficiary	WP3					WP4				
	Planned	Declared in RP2	RP2 / PI %	Total	To / PI %	Planned	Declared in RP2	RP2 / PI %	Total	To / PI %
1 - CNIT	18.00	**6.88**	0.38	**18.82**	104.56%	0.00	**0.00**	N/A	**0.00**	N/A
2 - OTE	0.00	**0.00**	N/A	**0.00**	N/A	0.00	**0.00**	N/A	**0.00**	N/A
3 - WIND3	0.00	**0.00**	N/A	**0.00**	N/A	0.00	**0.00**	N/A	**0.00**	N/A
4 - ERC	0.00	**0.00**	N/A	**0.00**	N/A	0.00	**0.00**	N/A	**0.00**	N/A
5 - UNIS	8.00	**2.03**	0.25	**8.00**	100.00%	16.00	**4.19**	26.19%	**16.99**	106.19%
5.1 - UNIS-EL	4.00	**3.01**	0.75	**4.00**	100.00%	2.00	**1.99**	99.50%	**2.30**	115.00%
6 - WHR	0.00	**0.00**	N/A	**0.00**	N/A	3.70	**0.00**	0.00%	**3.70**	100.00%
7 - FORD	0.00	**0.00**	N/A	**0.00**	N/A	4.00	**0.00**	0.00%	**0.94**	23.50%
8 - PPC	0.00	**0.00**	N/A	**0.00**	N/A	6.00	**2.98**	49.67%	**6.00**	100.00%
9 - UOP	10.00	**10.92**	1.09	**12.76**	127.60%	0.00	**0.00**	N/A	**0.00**	N/A
10 - UWS	0.00	**0.00**	N/A	**0.00**	N/A	20.00	**11.15**	55.75%	**27.68**	138.38%
11 - UBITECH	15.00	**10.29**	0.69	**15.59**	103.93%	8.00	**6.14**	76.75%	**7.28**	91.00%
12 - ININ	6.00	**4.35**	0.73	**6.00**	100.00%	18.00	**8.99**	49.94%	**15.80**	87.78%
13 - 5COMM	0.00	**0.00**	N/A	**0.00**	N/A	36.00	**17.00**	47.22%	**38.13**	105.90%
14 - YBVR	0.00	**0.00**	N/A	**0.00**	N/A	21.00	**8.80**	41.90%	**26.46**	126.00%
15 - ASTI	0.00	**0.00**	N/A	**0.00**	N/A	9.50	**19.89**	209.37%	**30.82**	324.42%
15.1 - UBU	0.00	**0.00**	N/A	**0.00**	N/A	11.50	**7.70**	66.96%	**13.29**	115.57%
16 - ILINK	0.00	**0.00**	N/A	**0.00**	N/A	25.00	**3.86**	15.44%	**25.00**	100.00%
17 - INFOCOM	22.00	**26.30**	1.20	**35.19**	159.95%	13.00	**6.30**	48.46%	**8.05**	61.92%
18 - 8BELLS	4.00	**4.01**	1.00	**6.17**	154.25%	14.00	**15.51**	110.79%	**20.11**	143.64%
19 - SUITE5	0.00	**0.00**	N/A	**0.00**	N/A	19.00	**7.63**	40.16%	**17.04**	89.71%
20 - K3Y	18.00	**12.53**	0.70	**17.99**	99.94%	16.00	**13.17**	82.31%	**16.00**	100.00%
21 - OCULAVIS	0.00	**0.00**	N/A	**0.00**	N/A	24.00	**14.69**	61.21%	**26.84**	111.83%
22 - WHMAN	0.00	**0.00**	N/A	**0.00**	N/A	0.30	**0.20**	66.67%	**0.20**	66.67%
Total	**105.00**	**80.32**	**76.50%**	**124.52**	**118.59%**	**267.00**	**150.19**	**56.25%**	**302.62**	**113.34%**

Table 10 Effort expenditure details: WP5, WP6

Beneficiary	WP5					WP6				
	Planned	Declared in RP2	RP2 / Pl %	Total	To / Pl %	Planned	Declared in RP2	RP2 / Pl %	Total	To / Pl %
1 - CNIT	8.00	**7.40**	92.50%	**11.09**	138.63%	15.00	**13.51**	90.07%	**15.28**	101.87%
2 - OTE	15.00	**10.85**	72.33%	**17.25**	115.00%	15.00	**15.60**	104.00%	**16.70**	111.33%
3 - WIND3	6.00	**4.72**	78.72%	**5.99**	99.89%	6.00	**5.96**	99.40%	**5.96**	99.40%
4 - ERC	12.00	**2.65**	22.08%	**12.76**	106.33%	16.00	**17.58**	109.88%	**18.70**	116.88%
5 - UNIS	2.00	**0.73**	36.50%	**2.73**	136.50%	4.00	**3.39**	84.75%	**4.00**	100.00%
5.1 - UNIS-EL	16.00	**13.30**	83.13%	**16.28**	101.75%	4.00	**3.24**	81.00%	**4.00**	100.00%
6 - WHR	1.40	**0.00**	0.00%	**1.40**	100.00%	0.00	**0.00**	N/A	**0.00**	N/A
7 - FORD	16.00	**0.85**	5.31%	**2.41**	15.06%	10.00	**10.43**	104.30%	**13.06**	130.60%
8 - PPC	18.00	**10.30**	57.22%	**19.10**	106.11%	16.00	**15.94**	99.63%	**17.10**	106.88%
9 - UOP	8.00	**8.74**	109.25%	**8.74**	109.25%	6.00	**10.97**	182.83%	**10.97**	182.83%
10 - UWS	3.00	**1.77**	59.00%	**2.71**	90.39%	8.00	**10.60**	132.50%	**10.60**	132.50%
11 - UBITECH	20.00	**20.32**	101.60%	**21.58**	107.90%	8.00	**9.56**	119.50%	**9.56**	119.50%
12 - ININ	8.00	**6.61**	82.56%	**6.91**	86.31%	9.00	**6.34**	70.39%	**7.54**	83.72%
13 - 5COMM	20.00	**5.50**	27.50%	**17.25**	86.25%	20.00	**37.95**	189.75%	**38.01**	190.05%
14 - YBVR	3.00	**1.94**	64.67%	**3.61**	120.33%	6.00	**7.10**	118.33%	**7.10**	118.33%
15 - ASTI	3.00	**1.65**	55.00%	**6.75**	225.00%	4.00	**10.62**	265.50%	**10.62**	265.50%
15.1 - UBU	0.00	**0.00**	N/A	**0.00**	N/A	4.00	**3.95**	98.75%	**5.03**	125.75%
16 - ILINK	10.00	**9.27**	92.70%	**9.95**	99.50%	13.00	**12.96**	99.69%	**12.96**	99.69%
17 - INFOCOM	13.00	**11.25**	86.54%	**14.71**	113.15%	14.00	**9.20**	65.71%	**10.09**	72.07%
18 - 8BELLS	14.00	**15.17**	108.36%	**16.94**	121.00%	12.00	**17.09**	142.42%	**17.09**	142.42%
19 - SUITE5	12.00	**8.63**	71.92%	**12.45**	103.73%	11.00	**8.22**	74.73%	**8.22**	74.73%
20 - K3Y	12.00	**7.09**	59.08%	**12.01**	100.08%	12.00	**11.89**	99.08%	**12.00**	100.00%
21 - OCULAVIS	12.00	**9.18**	76.50%	**12.03**	100.25%	12.00	**7.54**	62.83%	**8.79**	73.25%
22 - WHMAN	17.60	**16.10**	91.48%	**17.90**	101.70%	11.10	**12.10**	109.01%	**13.60**	122.52%
Total	**250.00**	**174.02**	**69.61%**	**252.55**	**101.02%**	**236.10**	**261.74**	**110.86%**	**276.98**	**117.31%**

Table 11 Effort expenditure details: WP7, all WPs

Beneficiary	WP7					All WPs				
	Planned	Declared in RP2	RP2 / Pl %	Total	To / Pl %	Planned	Declared in RP2	RP2 / Pl %	Total	To / Pl %
1 - CNIT	7.00	**5.25**	75.00%	**8.32**	118.86%	66.00	**41.13**	62.32%	**73.57**	111.47%
2 - OTE	6.00	**3.70**	61.67%	**4.60**	76.67%	52.00	**30.80**	59.23%	**54.71**	105.21%
3 - WIND3	4.00	**2.87**	71.86%	**3.87**	96.86%	25.00	**14.05**	56.21%	**24.65**	98.61%
4 - ERC	4.00	**1.66**	41.50%	**3.58**	89.50%	39.00	**22.11**	56.69%	**42.27**	108.38%
5 - UNIS	5.00	**1.92**	38.40%	**5.10**	102.00%	44.00	**12.70**	28.86%	**45.82**	104.14%
5.1 - UNIS-EL	0.00	**0.00**	N/A	**0.00**	N/A	26.00	**21.54**	82.85%	**26.58**	102.23%
6 - WHR	0.20	**0.00**	0.00%	**0.20**	100.00%	9.63	**0.00**	0.00%	**9.60**	99.69%

7 - FORD	4.00	**0.00**	0.00%	**0.07**	1.75%	39.00	**11.28**	28.92%	**17.03**	43.67%
8 - PPC	5.00	**2.51**	50.20%	**5.00**	100.00%	52.00	**32.23**	61.98%	**54.19**	104.21%
9 - UOP	12.00	**14.90**	124.17%	**17.18**	143.17%	43.00	**50.46**	117.35%	**58.26**	135.49%
10 - UWS	4.00	**5.99**	149.75%	**9.14**	228.45%	40.00	**31.90**	79.75%	**56.54**	141.34%
11 - UBITECH	4.00	**3.53**	88.25%	**4.09**	102.25%	69.00	**56.05**	81.23%	**73.06**	105.88%
12 - ININ	3.00	**1.28**	42.50%	**2.57**	85.50%	48.00	**28.09**	58.51%	**42.79**	89.15%
13 - 5COMM	6.00	**2.89**	48.17%	**5.97**	99.50%	90.00	**63.93**	71.03%	**108.15**	120.16%
14 - YBVR	2.00	**1.47**	73.50%	**2.41**	120.50%	36.00	**20.91**	58.08%	**44.94**	124.83%
15 - ASTI	1.00	**2.21**	221.00%	**3.29**	329.00%	21.00	**35.84**	170.67%	**58.44**	278.29%
15.1 - UBU	1.00	**0.98**	98.00%	**1.15**	115.00%	17.00	**12.86**	75.65%	**20.04**	117.88%
16 - ILINK	5.00	**2.35**	47.00%	**5.00**	100.00%	60.00	**30.83**	51.38%	**59.91**	99.85%
17 - INFOCOM	3.00	**1.50**	50.00%	**2.23**	74.33%	70.00	**55.39**	79.13%	**74.61**	106.59%
18 - 8BELLS	10.00	**9.60**	96.00%	**15.59**	155.90%	58.00	**62.42**	107.62%	**83.48**	143.93%
19 - SUITE5	2.00	**1.12**	56.00%	**1.54**	76.95%	47.00	**26.15**	55.64%	**42.31**	90.03%
20 - K3Y	4.00	**2.88**	72.00%	**4.01**	100.25%	65.00	**48.03**	73.89%	**65.00**	100.00%
21 - OCULAVIS	4.00	**2.39**	59.75%	**4.99**	124.75%	57.00	**34.59**	60.68%	**58.79**	103.14%
22 - WHMAN	2.80	**1.80**	64.29%	**1.80**	64.29%	32.60	**31.00**	95.09%	**34.38**	105.46%
Total	**99.00**	**72.80**	**73.53%**	**111.70**	**112.82%**	**1,106.23**	**774.29**	**69.99%**	**1,229.11**	**111.11%**

Explanations of major deviations in terms of effort

Total effort compared to planned effort in entire project: > 120% → overspending / < 80.00% → underspending

For each partner for which a major deviation in terms of effort has been identified, the justifications provided are reported below.

7 – FORD (FORD ESPANA SL)

Underspending: 43.67%

The initial project objectives have been achieved without requiring a high level of staff dedication, especially from expert and experienced personnel. Furthermore, the development and validation of the UC1, UC2 and UC3 required less effort than initially anticipated due to the development and cooperation of other consortium partners.

9 – UOP (PANEPISTIMIO PATRON)

Overspending: 135.49%

The deviation in the actual person-months at UOP is due to the involvement of junior researchers in certain tasks of the project. Due to the nature of the project (IA), it was originally planned to be executed by senior and experienced researchers, however we identified that the project would be appropriate and in line with the research goals of PhD students and young, less experienced researchers. As a result, there was an increase in overall PMs but no budget overspending was incurred.

10 – UWS (UNIVERSITY OF THE WEST OF SCOTLAND)

Overspending: 141.34%

The reason for UWS overspending in PMs was due to the fact that UWS needed more efforts for the following:

(1) took more efforts to fulfil the leadership in WP4 by proactive and extensive R&D activities (including over the 6-month extension) to allow leading by examples for partners to follow;
(2) took more efforts than planned to complete the testing over the DevOps platform and the Experimental Facilities due to various optimisation and adaptation work;
(3) took additional efforts to help the project to achieve more tangible standardisation results (beyond the planned tasks for UWS) with the contribution to an ITU standard: ITU-T Recommendation Y.Sup71 (2022), "Use cases for autonomous networks"[3].

It is noted that UWS did not exceed the overall budget by employing researchers at lower salary grade whilst having managed delivering all the commitments planned and additional work unplanned.

13 – 5COMM (5G COMMUNICATIONS FOR FUTURE INDUSTRY VERTICALS SL)

Overspending: 120.16%

5COMM has overspent little more than +20% of expected efforts in PMs used. However, this is not reflected in the total personnel costs, which are better aligned with the expectations.

This difference is due to the fact that the PM cost in Fivecomm was finally slightly lower than the one planned. The mix between senior and mostly junior researchers in the team was different to what it was initially planned. This means that more than 120% of PM efforts were spent, but using the same budget and delivering as expected. It is important to highlight that our technical objectives have been fulfilled accordingly, and all tasks have been successfully implemented.

14 – YBVR (YERBA BUENA VR EUROPE SL)

Overspending: 124.83%

YBVR underestimated the effort of the coordination with the project management in WP1 (this was our first European project; furthermore, the project extension affected on this part), and also we found more work than expected in the technical WPs, in particular in the validation with the ExFa (5TONIC and Ford factory), mainly due to external problems in the facilities.

15 – ASTI (ASEA BROWN BOVERI SA, was: ASTI MOBILE ROBOTICS SA)

Overspending: 278.29%

The reason why ASTI/ABB has deviated from the initial estimate is that junior technicians have been assigned to the project, who therefore need considerably more time to perform the same task.

18 – 8BELLS (EIGHT BELLS LTD)

Overspending: 143.93%

WP4: Changes in Linux distributions removed certain security features, forcing a rebuild of the Surikata-based solution to ensure full functionality with tools like Elasticsearch, Filebeat, and Kibana.

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[3] See https://www.itu.int/ITU-T/recommendations/rec.aspx?id=15041&lang=en and https://www.itu.int/rec/T-REC-Y.Sup71-202207-P/en.

WP5: Algorithms for predictive maintenance were developed, but delays arose due to the lack of specific datasets. This led to additional effort in searching for a suitable alternative dataset to train the models.

WP7: The constantly shifting business landscape, particularly due to the privatization in the energy sector, required more extensive research, meetings, and studies to adapt to new challenges. Additionally, the SWOTs and Lean Canvases have been analysed more extensively, adding extra effort.

Unforeseen subcontracting (if applicable)

Not applicable.

Unforeseen use of in kind contribution from third party against payment or free of charges (if applicable)

Not applicable.

6 Conclusions

As noted in the introduction of this document, the primary goals of the 5G-INDUCE project were:

- the development of an end-to-end service orchestration platform over enabling 5G experimentation infrastructures (with specific target in the Industry 4.0 vertical sector), able to provide the essential mechanisms for the onboarding of advanced 5G Network Applications (nApps) and the efficient management of the infrastructure resources, independently of the underlay network orchestration layer;
- the experimental demonstration and showcasing of the effective application of the developed tools in 8 Industry 4.0 Use Cases, over 3 different Experimentation Facilities (ExFas).

In line with the principle of separation of concerns between the cloud-native vertical applications' domain and the networking domain, the aim was to provide the enabling interfacing layer between the vertical sector end-users and the infrastructure owner to select, deploy and also extend their 5G applications with the appropriate networking features that comply with the application requirements, in terms of physical network constraints (such as bandwidth and latency), as well as functional constraints (such as locality, resiliency, security). Moreover, the 5G-INDUCE platform enables nApp developers to have a common interface for the porting of nApps, either as complete services (in the form of linked application components) or individual extension components to existing services. To demonstrate the applicability and potentiality of the platform, as well as to provide quantitative evaluations of KPIs, the project has chosen eight Use Cases from the industrial sector, whose constituent nApps have been implemented as chains of micro-services, deployed by means of the NAO, and enabled to create the needed network slices and allocate corresponding network resources by the OSS. After a first deployment over the DevOps testbed, the eight UCs have been experimentally evaluated and demonstrated over the three available ExFas that were created during the course of the project.

All experimental activities have been successfully conducted and allowed the collection of significant KPIs. In general, the three development areas of the project have been successfully implemented.