5G CONNI

Private 5G Networks for Connected Industries

Deliverable D7.3

Second Intermediate Report

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List of Acronyms

5G CONNI	5G for Connected Industries
AMF	Access and Mobility Management Function
API	Application Programming Interface
AR	Augmented Reality
AUSF	Authentication Server Function
CDU	Central/Distributed Unit
CFR	Crest Factor Reduction
CNC	Computerized Numerical Control
CNM	Core Network Manager
CP	Control Plane
CPE	Customer Premises Equipment
CSI	Channel State Information
CU	Central Unit
DL	Downlink
DPD	Digital Pre-Distortion
DPDK	Data Plane Development Kit
DU	Distributed Unit
E	Enterprise
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
EPC	Evolved Packet Core
FPM	Fully Private Model
gNB	Gigabit Node B, 5G Base Station
GUI	Graphical User Interface
HARQ	Hybrid Automatic Repeat Request
IOT	Internet of Things
KPI	Key Performance Indicator
LAN	Local Area Network
LOS	Line of Sight
LTE	Long Term Evolution
MAC	Medium Access Control
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
MIMO	Multiple input, multiple output
MNO	Mobile Network Operator
MVNO	Mobile Virtual Network Operator
NFV	Network Function Virtualization
NFVI	Network Function Virtualization Infrastructure
NLOS	Non-Line of Sight
OAM	Operation, Administration and Maintenance
ONAP	Open Network Automation Platform
ORAN	Open RAN
OSM	Open Source MANO

PDCP	Packet Data Convergence Protocol
QoS	Quality of Service
RAN	Radio Access Network
RLC	Radio Link Control
RRC	Radio Resource Control
RU	Radio Unit
SA	Stand Alone
SINR	Signal to Interference and Noise Ratio
SP	Service Provider
SS-RSRP	Synchronization Signal Reference Signal Receive Power
SWOT	Strengths, weaknesses, opportunities, threats
TDD	Time Division Dupley
UC	Use Case
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	User Plane Function
URLLC	Ultra-reliable, low-latency communication
VIM	Virtualized Infrastructure Manager
VNF	Virtual Network Function
VNFD	Virtual Network Function Descriptor
VPN	Virtual Private Network
VR	Virtual Reality
VUCA	Virtual Uniform Circular Array
WAN	Wide Area Network

1 Explanation of the work carried out by the beneficiaries and overview of the progress

In its second year, the 5G CONNI project was able to build successfully on the results that had been achieved so far and further move towards its goal of demonstrating practical end-to-end industrial 5G applications in emerging new deployment models. A now well established communication between all partners and the two regions represented in the consortium has enabled consistent progress across all technical work packages. As documented in the present report, the project is well within reach of achieving its ambition going into its third year.

The second project year also marks the second year of the global COVID-19 pandemic, which continues to challenge businesses and people to adapt to a new reality of work and collaboration. After the initial phase of adjustments to these shifts in operating environment, the 5G CONNI consortium has maintained its grasp of the situation, carrying out all scheduled work according to the work plan. Delays in on-premise work resulting from lockdown measures during the first reporting period have been caught up entirely.

While the first reporting period was focused on concept work and creating common grounds between the diverse set of stakeholders in industrial private 5G networks as represented by the consortium, the second year saw a move to tangible implementation work. Measurements and new algorithms contributed to network planning methodology, while key elements for the demonstration system were developed and brought to laboratory integration. This is the foundation on which the project will build in bringing all pieces together during its third and final year.

1.1 Objectives

The work plan for the 5G CONNI project lays out six distinct objectives, which the project aspires to achieve. This section presents the progress on each objective as achieved by the work carried out in the second project year.

1.1.1 Objective 1

Realize at least two selected industrial 5G use cases at interconnected real-world trial sites in Europe and Taiwan

1.1.1.1 Work carried out towards the objective

This objective is the overarching demonstration objective of 5G CONNI. Within the second reporting period, work towards it has been carried on in the following work packages:

- WP2: Based on the operator models and candidate architectures discussed in deliverables D1.2 and D2.1, an overall architecture for the 5G CONNI trial system has been chosen and documented in deliverable D2.2.
- WP5: Bringing together the work of the other work packages, the first phase of WP5 focused on the in-lab pre-integration of components for the end-to-end trial system. Further detailing the system architecture of WP2, a functional architecture has been defined and described in D5.1 along with the integration plan, testing procedures and system components for the 5G CONNI network. In parallel, work towards the implementation of the use case “Robot Platform with Edge Intelligence and Control” was conducted.

1.1.1.2 Status of the objective

With the use cases defined, implementation work for the industrial applications to be demonstrated at the two demonstrator sites is well underway, as well as for one use case highlighting the international connectivity of the 5G CONNI system. In parallel, definition of the final system architecture has been concluded, moving quickly to the realization phase by continuously integrating the key enabling blocks developed by the consortium into the overall system.

1.1.2 Objective 2

Conduct measurements and develop tools for application specific coverage prediction and network planning with focus on indoor industrial environments

1.1.2.1 Work carried out towards the objective

This objective is at the core of 5G CONNI's value proposition. Within the second reporting period, work towards it has been carried on in the following work packages:

- WP3: A large scale radio channel measurement campaign in different scenarios in a real world industrial environment were conducted at carrier frequencies 3.7 GHz, 28 GHz and 300 GHz. Analysis of temporal channel characteristics were concluded while analysis of spatial characteristics is still ongoing. In parallel, new verification methodology for directional channel measurement systems was developed. For the Taiwanese trial site, detailed use case specific radio planning and simulative performance analysis was conducted. In parallel, an algorithm for optimal service placement in network edge nodes was developed. Finally, a monitoring interface for the 5G core network was developed.

1.1.2.2 Status of the objective

In the current reporting period, the bulk of work planned towards this objective was finished with great success, both on the European and the Taiwanese side of the consortium. On the EU side, the focus laid on extensive radio propagation measurements to facilitate deployment of industrial 5G and beyond, while on the Taiwanese side, work was focused on detailed network performance planning and simulation. New algorithms for network optimization and tools for operational monitoring complete the contributions towards the objective.

1.1.3 Objective 3

Investigate key enabling technologies for industrial applications with focus on mobile edge computing and URLLC communication

1.1.3.1 Work carried out towards the objective

As required by the demonstration use cases, 5G CONNI aims to close technological gaps and create new building blocks for industrial 5G applications. Within the second reporting period, work towards this objective has been carried on in the following work packages:

- WP4: Development is continuing on the key components of the 5G system comprising end devices, radio access infrastructure, core software and edge computing platform.

Considerable progress has been made on implementing the industrial application use cases selected for demonstration.

1.1.3.2 Status of the objective

Further developing the results already achieved during the first year of the project, the technologies and components developed mainly as part of Work Package 4 now continue to feed the integration work started in Work Package 5 towards the overall system demonstrator.

1.1.4 Objective 4

Provide input to regulatory bodies to facilitate realization of the developed operator models

1.1.4.1 Work carried out towards the objective

This objective aims at creating the necessary conditions that enable enterprises to deploy private 5G networks given the identified operator models. Within the second reporting period, work towards this objective has been carried on in the following work packages:

- WP1 & WP2: A detailed analysis of requirements and concerns for private 5G network operator models considering the different stakeholders perspectives has been conducted.
- WP6: Contact with the German national telecommunications regulation agency has been established to discuss project findings with the discussion still open.

1.1.4.2 Status of the objective

The comprehensive results of WP1 and WP2, which both concluded during the current reporting period, now provide a solid basis for discussing the current and future regulatory landscape with respect to industrial 5G deployments. Establishing contact with the German national regulation agency is the first step to disseminating key project results towards relevant authorities.

1.1.5 Objective 5

Develop methodologies for and conduct end-to-end 5G system verification with focus on interoperability and use case specific KPIs (e.g. latency, reliability)

1.1.5.1 Work carried out towards the objective

This objectives rationale is to ensure the relevance of developed technologies to the targeted application. Work towards it during the second reporting period includes:

- WP3: Detailed performance analysis and planning of network deployments to create a reference against which to test. In parallel, development of precision time measurement systems useful towards network latency evalution.
- WP5: Definition of a comprehensive test and integration plan for the overall demonstration system.

1.1.5.2 Status of the objective

With Work Package 5 Task 1 having started in the second project year, this objective has moved into the focus of work. At this point, interoperability is the key driver for ongoing activities. In the third year, this will shift towards performance evaluation and verification, building on the results that have been achieve so far.

1.1.6 Objective 6

Foster the collaboration of European and Taiwanese key players from both communications and production industries allowing them to leverage synergies and thus realize an increased impact on internationally harmonized regulation and standardization, creating better commercialization opportunities

1.1.6.1 Work carried out towards the objective

International cooperation and the exchange across different industries and markets was and remains a key driver of the 5G CONNI partners for creating this project. Essentially, the efforts in all work packages have contributed to this broad objective with a more prominent role played by

- WP6: Visibility for the project has been created by organizing and attending events in the academic and industrial sphere that allow for targeted dissemination of project results. Several scientific publications highlighted individual technical results, as well as the overall vision and progress of the project. Contributions by multiple partners to various standardization organizations (ETSI MEC, IEEE, ITU) have been made.
- WP7: An effort has been started to identify potentials for sharing of results and technologies across the two regions within the project.

1.1.6.2 Status of the objective

The objective has been fully met during the second project year. All partners have been engaging in active and open discussion, leading to a better mutual understanding of the application and wireless networking domains. With work moving quickly towards practical realizations of industrial 5G, interoperability and integration of the contributions by all partners has been a most important aspect during this year.

1.2 Explanation of the work carried out per Work Package

1.2.1 Work Package 1

The main objectives of Work Package 1 are (1) the identification of innovative 5G use cases and the analysis of their requirements, (2) the development of an evaluation methodology to verify and validate the use case implementation, and (3) the identification of requirements, aspects and concerns regarding suitable operator models for non-public 5G networks.

1.2.1.1 Status of the work package

WP1 was subdivided into two tasks, Task 1.1 and Task 1.2. While Task 1.1 has been concluded in the first year of the project, the activities in Task 1.2 have been successfully finished in the second year. The main technical results that have been achieved by WP1 during the second year are:

- A systematic exploration and characterization of different dimensions of operator models,
- An analysis of the interrelations between different operator model dimensions,
- The derivation of concerns and requirements regarding operator models based on staged questionnaires that have been circulated among the involved project partners,
- The evaluation of the requirements with respect to their criticality,
- The design of an evaluation sheet to score different operator models from different stakeholder perspectives, and
- The submission and publication of the deliverable D1.2.

With the finalization of the results listed above, Task 1.2 has been concluded, and with this also the entire Work Package 1.

The specific technical activities conducted in Task 1.2 are described below.

1.2.1.2 Work carried out & main results

1.2.1.2.1 Task 1.1: Use Case and Requirements Analysis

Task 1.1 has been concluded with the first year of the project.

1.2.1.2.2 Task 1.2: Requirements and Concerns Regarding Suitable Operator Models

This task started in M6 and ended in M15. WP1 (Use Cases & Requirements) has identified, in D1.1, innovative use cases for 5G networks in Smart Factories by elaborating on previously published scenarios and normative requirements and adding use cases based on recent 5G technology developments. However, many factory owners have concerns regarding the usage of a public land mobile network for enabling 5G-based industrial production. Therefore, non-public networks are needed and such non-public networks may be operated with different pros and cons. What a pro or con is often depends on the concrete context. Therefore, the goal of task 1.2 is to identify, collect and analyze general aspects that have to be considered.

CEA organized several Task 1.2 phone calls in order to study private 5G factory network requirements and evaluation methodology. BOSCH cooperated closely with CEA to set up different questionnaires to explore this topic together with all other involved partners. The questionnaires considered different operator model dimensions and the results are provided in D1.2. This document identifies and analyzes relevant requirements and concerns regarding suitable operator models for non-public 5G factory networks, which then may lay the basis for the design and evaluation of suitable operator models in WP 2. To explore the concerns of the different stakeholders, it is important to understand the different dimensions of operator models and how they are interrelated. 5G elements (e.g. 5G network functions, RAN components, etc.) and non-5G elements (e.g. enterprise IT), private 5G network lifecycle tasks and involved stakeholders (e.g. enterprise, MNO, service provider) are the most important dimensions. A deep analysis revealed that 10 different stakeholders can own or govern 23 elements in total. This is even more complex taking into account seven different locations, at which the elements (in particular, 5G components) can be installed, and the plethora of different lifecycle tasks (49 in total). In addition, each task involves a specific set of elements that are touched by the responsible stakeholder. From this deep analysis, a 67 concerns and related requirements have been collected from the perspectives of different stakeholders. In general, the concerns regarding operator models are attributed to different perspectives: confidentiality, integrity and availability of information, access to and control of elements (specifically 5G components), the private 5G network lifecycle and responsibilities and expertise required by the stakeholders for each task, regulatory aspects, and applicability and practicability. Each requirement is assessed in terms of importance and they are grouped to form 13 general aspects, whose criticality is determined based on the number of requirements per aspect and their importance ratings. The top five aspects (in terms of criticality) are: (1) Wrong or missing access to 5G elements by the enterprise, MNO or SP, (2) interoperability of security systems and alignment of security concepts of different stakeholders, (3) the lack of expertise to carry out lifecycle tasks, (4) confidentiality, integrity and availability of data, and (5) a lack of autonomy of a stakeholder. Finally, a stakeholder-specific (enterprise, MNO, service provider) operator model evaluation template is designed, which considers the importance of each requirement and also how such a requirement can be fulfilled, i.e., either a requirement can be fulfilled inherently by the operator model, through technical features or by contractual agreements. The template will help to evaluate concrete operator models (distribution of roles and responsibilities of the private 5G network lifecycle among stakeholders) regarding all 13 aspects and from the perspectives of the three most important stakeholder perspectives, i.e. the ones by the enterprise, the MNO and the service provider

Last but not least, part of these results have been included in a EURASIP journal paper with all other partners.

1.2.2 Work Package 2

Work Package 2 deals with the overall architectural design of the Private 5G Network covering radio access (RAN), core network and mobile edge computing (MEC). While the foundations of 5G system architecture have reached maturity in 3GPP standardization, non-private deployments add an additional layer of complexity by breaking the traditional stakeholder structure and introducing new requirements specific to enterprise users. Thus, this work package focuses on these aspects in defining the final 5G CONNI system architecture.

1.2.2.1 Status of the work package

Work package 2 was split in two tasks, with T2.1 covering architectural aspects of private 5G networks and T2.2 focusing on deployment and operator models. Both tasks started at the beginning and were concluded at the end of the current reporting period. Results achieved in the second project year include:

- A detailed SWOT analysis of the four different architectural models identified in T2.1 and documented in D2.1
- Definition of the overall 5G CONNI demo system architecture covering both the European and Taiwanese trial site as well as their interconnectivity
- Definition and discussion of use cases for international interconnectivity between industrial facilities equipped with private 5G networks
- A detailed analysis of suitable operator models based on the methodology developed in T1.2, covering the perspectives of different stakeholders involved in private 5G networks

These results are documented in D2.2.

1.2.2.2 Work carried out & main results

1.2.2.2.1 Task 2.1: Architectural Design for Private 5G Networks

This task focused on defining several architectural models for 5G network deployment. The different network architectures for network functions placement and management which were investigated and reported in D2.1 have been evaluated (cf. D2.2) via a SWOT analysis and in terms of the operator models which were designed by T1.2 – see D1.2 and, in parallel, the activities of Task 2.2. Task 2.1 also worked on the description of possible inter-site use cases, which led to the definition of some concrete aspects of the inter-connected setup of the EU-TW architecture. Additional work has been done on the interoperability between the different demo sites, both within the EU partners as well as with the TW partners. The results will be documented in deliverable D2.2, due in M24 of the project, and contributed (together with the work of WP5) to the final definition of the 5G CONNI Demo System Architecture based upon the analysis and checking of all the functional, nonfunctional requirements, and the additional goals as put forward in D1.1.

1.2.2.2.2 Task 2.2: Deployment and Operational Strategies for Private 5G Networks

Task 2.2 was concerned with the analysis of deployment strategies (RAN), in particular with respect to costs, as well as with the analysis and the detailed evaluation of suitable operator models.

With the high degree of disaggregation of network functions found in the 5G system and the increasing potential for virtualization ever closer to the physical layer, a larger design space for possible deployment models and architectures is opened up. While this has already been discussed in the context of the four different architecture options defined in D2.1, it applied exclusively to the core part of the network. Since in two of the models, the RAN is also under governance of a party other than a traditional MNO, a more detailed discussion of the implications on infrastructure scalability and requirements is included in D2.2.

In Task 1.2 of Work Package 1, a detailed operator model evaluation methodology and an evaluation template have been devised. Using this template, which is depicted in Figure 1, all four models have been evaluated in Task 2.2. The procedure was the following: The template has been circulated among different project partners and each of the partners evaluated all four models from the perspective of a certain stakeholder, namely the enterprise, the MNO, a service provider. Here, each requirement has been evaluated against the model characteristics and the degree of fulfillment of the requirement, the latter being categorized as (1) Inherently fulfilled by operator model, (2) If not inherently fulfilled, fulfilled by technical feature, (3) If neither fulfilled inherently nor by technical feature, fulfilled by contract between stakeholders, and (4) Cannot be fulfilled at all. Each partner provided a brief explanation of the chosen option to obtain more detailed insights.

ID	Concern	Requirement	Evaluation: How is the requirement fulfilled? Select one option, please. Architecture/operator model: Fully Private Model Stakeholder perspective: Enterprise				Comment (Please provide a very short explanation of your choice)
			Inherently fulfilled by operator model.	If not inherently fulfilled, fulfilled by technical feature?	If neither fulfilled inherently nor by technical feature, fulfilled by contract between stakeholders ?	Cannot be fulfilled at all.	
A1	Wrong or missing access to elements by a stakeholder						
B-2.1	Management of MEC platform (or part of it) by the Enterprise while the platform is off-premise might raise concerns regarding accessibility, and management by the SP or MNO might raise concerns regarding integrity and proper management.	For any operator model, the MEC platform shall be well accessible by the Enterprise for management purposes, even it is located off-premise and owned by another stakeholder.	☐	☐	☐	☐	
B-2.2	Elements are the wrong accessed by unrelated personnel and then cause system problems.	Stakeholders need to establish reasonable authority control to avoid wrong access by unrelated personnel.	☐	☐	☐	☐	
B-3.2	Stakeholder can't do emergency maintenance on premise 24/7 because premise is closed or access to it is limited	For a third-party operator model, 24/7 emergency maintenance service shall be possible, e.g. through a 24/7 field service concept	☐	☐	☐	☐	
B-3.3	Remote access to stakeholder's equipment is interrupted because of failure in the transport environment	Remote access to stakeholder's equipment shall be ensured and the impact of failure shall be minimized, e.g. through implementing an out-of-band management concept.	☐	☐	☐	☐	
B-3.4	The operation of the personnel can not find the source of the problem.	Enterprises must make clear location access requirements and it shall be included in a global architecture	☐	☐	☐	☐	

Figure 1: Short Extract of the Operator Model Evaluation Template.

Table 1: Summary of total scores (normalized, see D1.2) for the different operator models and from different stakeholder views.

	FPM	Hyb	MVNO	MNO
E	0.83	0.67	0.70	0.69
MNO	0.79	0.70	0.77	0.76
SP	0.48	0.65	0.62	0.43

The qualitative and quantitative (including the ones in Table 1) results, as well as, the conclusions have been documented in the deliverable D2.2.

1.2.3 Work Package 3

The activities carried out within WP3, task 3.1, include the development of a very effective channel sounding system used to carry out an intensive channel measurement campaign within Bosch premises. The collected data have been analyzed and used to produce novel channel models that will provide the basis for the ensuing system design. A specific feature of the adopted system is to measure not only delay parameters but also angular information. In addition, a very detailed capacity dimensioning has been carried out within the industrial premises in Taiwan to accurately predict the indoor wireless network performance prior to installation. In Task 3.2, preliminary considerations for network monitoring performance are provided, which includes the RAN, core network and edge cloud monitoring. Finally, optimal service placement algorithms have been developed and compared with alternative options. The results are incorporated in the deliverable D3.1, which has been prepared on time and submitted with a one-month delay only because of internal approval from one of the partners.

1.2.3.1 Status of the work package

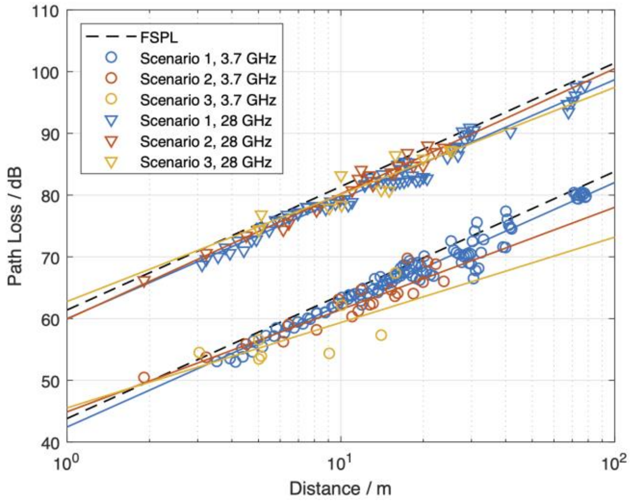
The activities of Work Package 3 started in month 4 of the project and will conclude at the end of month 34. While some activities only require theoretical efforts and algorithm developments, and thus have not been strongly affected by COVID-19 crisis, other activities, such as channel measurements at BOSCH facilities that where initially planned to take place during the first project year had to be delayed. However, these delays were compensated during the second project year and all activities proceeded as planned. Main results achieved during this reporting period include:

- Implementation of the planned comprehensive radio channel measurement campaign in an industrial setting and generation of first analysis results
- Application oft he developed connectivity map estimation algorithm to real world data supplied by BOSCH and ITRI
- Detailed radio planning and simulation results fort he TW demo site
- Development of a novel algorithm for edge service placement
- Implementation of core network monitoring functionality

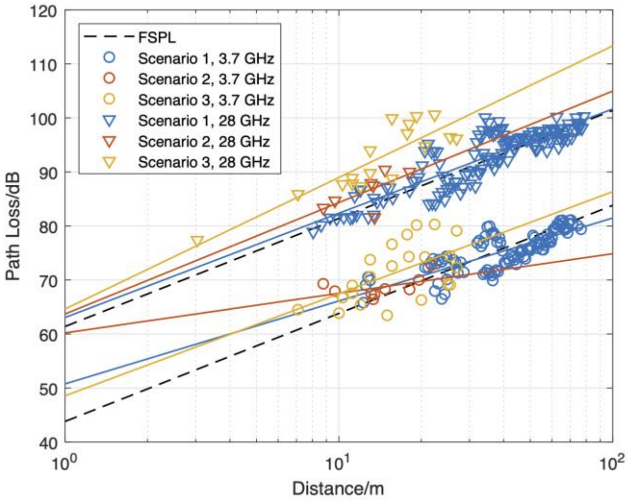
1.2.3.2 Work carried out & main results

1.2.3.2.1 Task 3.1: Application-centric Planning of Private 5G Networks

The activities in Task T3.1 include the development of a channel sounder, carried out by HHI, which includes a virtual uniform circular array antenna (VUCA) used to add valuable angular information about the received signal. The channel sounding sequence was generated directly at the RF frequencies, at 3.7 and 28 GHz, with a bandwidth of up to 2 GHz. In several locations, the system was also upgraded to carry out measurements also at 300 GHz. The results have been analyzed to produce new channel models for the challenging scenario of an industrial premise. Some results obtained in the 3.7 and 28 GHz bands are reported in Figure 2, for the Line-of-Sight (LOS) and Non-Line-of-Sight (NLOS) conditions, considering three different scenarios, as detailed in D3.1.



a) LOS condition



b) NLOS condition

Figure 2: Path loss in a) LOS condition and b) NLOS condition.

Besides path loss, the delay spread and the K factor were also estimated form the measurement data. The results are summarized in Table 2.

Scenario	Perimeter (Scenario 1)				Storage Area (Scenario 2)				Shop Floor (Scenario 3)			
Frequency	3.7 GHz		28 GHz		3.7 GHz		28 GHz		3.7 GHz		28 GHz	
LOS/NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS
Path Loss (FI)												
$PL_0(d_0)$ (dB)	42.44	50.77	59.99	63.06	44.90	60.21	59.92	63.71	45.53	48.56	62.77	64.63
n	1.98	1.53	1.94	1.93	1.66	0.73	2.03	2.06	1.38	1.89	1.73	2.44
σ (dB)	1.39	2.27	1.21	2.60	1.69	1.61	1.04	2.53	3.45	4.41	1.82	3.20
Path Loss (FR)												
$PL_0(d_0)$ (dB)	43.81	43.81	61.38	61.38	43.81	43.81	61.38	61.38	43.81	43.81	61.38	61.38
n	1.88	1.96	1.82	2.04	1.75	2.14	1.90	2.27	1.57	2.27	1.86	2.71
σ (dB)	1.43	2.41	1.28	2.62	1.70	2.46	1.10	2.54	3.49	4.46	1.85	3.26
K-factor												
Mean (dB)	4.28	-	7.22	-	4.53	-	5.78	-	4.87	-	-3.83	-
σ (dB)	3.92	-	7.68	-	4.06	-	4.98	-	2.76	-	-2.99	-
Delay Spread												
Mean (ns)	26.27	56.04	19.88	30.82	24.12	34.54	20.93	24.89	19.62	38.11	21.53	25.65
Median (ns)	20.71	52.61	16.37	30.19	21.77	34.68	20.75	26.34	16.78	38.82	21.03	25.97
σ (ns)	17.28	21.37	10.99	13.47	9.09	7.02	8.07	3.72	6.31	8.15	7.57	8.41
95% Conf. (ns)	68.99	93.10	39.08	57.49	38.69	48.63	33.89	28.24	29.51	49.19	35.00	38.92

Table 2: Estimated Large Scale Parameters

The channel sounder was then extended to be able to work in the 300 GHz band, using the functional block diagram illustrated in Figure 3.

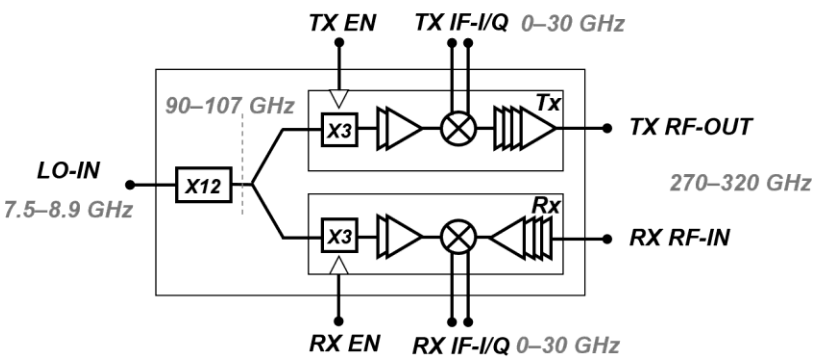


Figure 3: Functional block diagram of the 300 GHz transceiver waveguide module.

The research activity on the estimation of the connectivity map have also progressed with respect to the first year. SAP, ITRI and BOSCH agreed in a joint collaboration where ITRI provides some real data from their industrial premise, SAP processes the data using the algorithms developed during the project and BOSCH provides a contribution to map some measured parameters such as received signal strength into data rate in a realistic scenario.

Another major item within this task is the planning of private 5G radio networks designed for the industrial use cases identified in Work Package 1. The objective is to predict the indoor wireless network performance accurately prior to installation, which could help the network designer to assess the number and location of base stations that we should deploy to ensure the target requirements of vertical applications will be met. To this end, ITRI, in collaboration with Alpha Networks, has proposed the cell planning methodology, which covers two phases, namely 1) Coverage and Key Performance Metric Analysis and 2) System Performance Evaluation of Real-life Network Deployment. Based on the building structure modeling and gNB antenna patterns provided by Alpha Networks, phase 1 is to evaluate the coverage through two main network parameters, SS-RSRP and CSI-SINR. While phase 1 ensures the basic connectivity of a mobile with certain signal strength or quality requirements, phase 2 is going further to incorporate the traffic map of vertical use cases in order to evaluate the performance of real-life network deployment. In particular, Figure 4 and Figure 5 illustrate the traffic map that specifies the traffic characteristics and traffic service area. Three use cases described in D1.1 are planned to be implemented and installed in the same factory and served by the same 5G system, namely UC1: Process diagnostics by CNC and sensing data collection, UC2: Using Augmented/Virtual Reality for Process Diagnosis and UC3: Cloud-Based Controller for fixture system with vibration mitigation. The QoS requirements for each use case are provided, which includes downlink throughput, uplink throughput, number of users and mobility. The CPEs for UC1 and UC3 are considered to be fixed in the green and blue region respectively, while the AR users for UC2 are expected to move slowly in the green region. In addition, some important scheduling parameters of the base station that will influence the user experience are taken into account, including TDD UL-DL configuration, MIMO transmission modes, etc. The goal is that the throughput requirements of each user should be met while the cell load (time-frequency resources of the base station) is less than 90% to account for fluctuations of traffic.

Use Cases	Mobility	Num. of users	UL TPut requirement	DL TPut requirement
Process Diagnostics by CNC and Sensing Data Collection	Fixed (green region)	2 CPEs ▮▮	CNC & sensing data:16Mbps/UE	NA
Augmented/Virtual Reality for Process Diagnosis	Pedestrian (green region)	2 AR glasses ▲▲	Live video: 2Mbps/UE	Remote rendering data: 50Mbps/UE
Cloud-based Controller for fixture system with vibration mitigation	Fixed (blue region)	1 CPE ▮	<1 Mbps/UE	<1 Mbps/UE

Figure 4: Traffic characteristics of three use cases

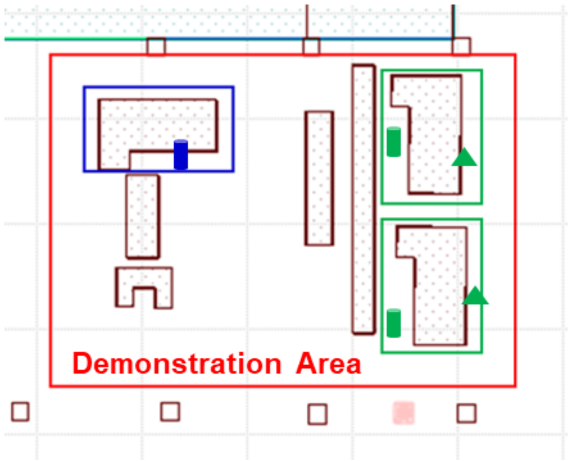


Figure 5: Traffic Map of Three Use Cases

The simulation result is provided in Table 3 and it shows that the network design is expected to meet the target requirements of the use cases in the specified area.

Traffic Results	**User DL Avg. TPut (Mbps)**	**User UL Avg. TPut (Mbps)**	**DL Cell Load**	**UL Cell Load**
2 data collection CPEs	1.1	19.508 (>16)	8.5%	20.2%
2 AR users	56.387 (>50)	3.74 (>2)		
1 cloud controller CPE	1.096 (>1)	1.904 (>1)		

Table 3: System Performance Simulation Results

The predicted average downlink and uplink throughput per UE for UC1 are 1.1 and 19.508 Mbps respectively, 56.387 and 3.74 Mbps for UC2, and finally 1.096 and 1.904 Mbps for UC3. Moreover, the downlink and uplink cell load are 8.5% and 20.2% respectively, which is far below the 90% threshold. This is in line with our expectations since the demonstration area is small and has virtually uniform channel conditions with SINR above 30dB.

1.2.3.2.2 Task 3.2: Private 5G Network Monitoring, Operation and Management

One of the challenges in network planning is the placement of network services in the Edge Servers (ES) and the routing of delay-sensitive applications, exploiting distributed storage and computing resources at the edge servers, which are typically limited in terms of storage and computational capability with respect to the central cloud, but at the same time enable delay-critical applications, with controllable delay. SAP has developed an algorithm to find the optimal service placement in the edge cloud allowing all user devices to obtain the requested services in the shortest possible time, including routing the requests to the optimal edge node. The method minimizes the total delay experienced by each user device, including the communication and computation delays needed to upload the measured data and to process them at the selected edge cloud. The association of every user to an access point ad an edge server is inherently a combinatorial problem. To overcome computational issues, SAP has developed a method to solve the problem combining an integer linear program with a randomized strategy that make the problem scalable. Three types of virtual machines have been considered: micro, small and extra-large, each type having its own requirements in terms of processing and storage. The proposed method compares favorably with a state of the art method based on the matching algorithm. The details of the performance are reported in deliverable D3.1. As an example of application, in Figure 6 we report the ratio between the total latency experienced using the proposed algorithms and the total latency achievable with the benchmark obtained using the matching theory method, as a function of the storage capacity of each storing device.

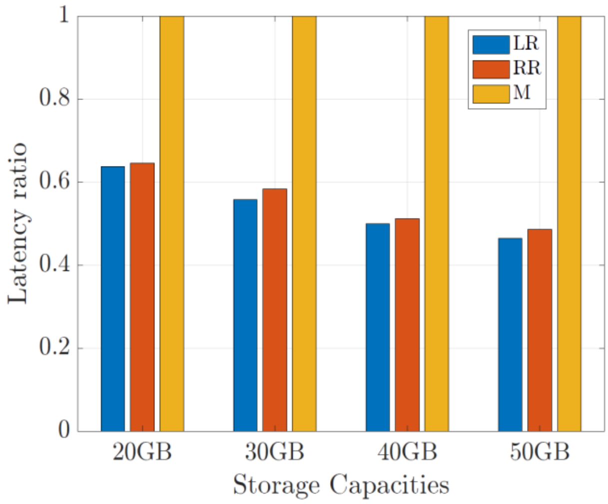


Figure 6: Total service delay normalized to the delay of the matching algorithm.

The result is clear: the proposed method clearly outperforms the matching algorithm. Furthermore, it is evident how the more storage capacity is available at each server, the less requests are routed to the core cloud, and then the system experiences less delay in delivering the results from the applications. The matching algorithm experiences a bigger delay due to a frequent request routing to the central cloud, especially when the bound on the storage capacity is very tight. Our algorithm performs much better because the service placement allows the system to amortize the cost of storing a lot of data, reusing the same virtual machine for more users. An example is shown in Figure 6.

Finally, preliminary considerations about the design of strategies to monitor the network performance have been carried out, as detailed in Deliverable 3.1, including RAN monitoring, edge cloud monitoring and core network monitoring.

The 5G Core Network Manager (CNM) was introduced to provide a single clean, consistent management interface regardless of network element type. The graphical interface was introduced to reduce training requirements, and allow operator personnel to quickly drill down to the source of any issue to keep your network running at optimal efficiency.

5G CNM consolidates OA&M operations for all network elements and provides:

- Fault Management of all network elements to provide best-in-class GUI capabilities by integrating with OAM
- Simple graphical datafill editor for Configuration Management
- Consolidated Performance Management of all network elements to provide simplified GUI with advanced features
- Robust Security Management to set user/group level controls to provide access to network elements

A variety of changes are being implemented within 5G networks to meet efficiency, performance and unique demands of the various use cases, and the Operation Support Systems (OSS) require some fundamental changes as well. For the OAM Dashboard shown below, it uses the RESTful API and MQTT protocol to make the Fault Configuration Accounting Performance and Security (FCAPS) data available and integrated to CNM.

1.2.4 Work Package 4

This work package covers the development of radio network, core network, mobile edge computing and industrial applications to ensure these technologies to implement industrial use cases on private 5G networks successfully for industrial requirements. The industrial requirements focus on 5G eMBB and URLLC scenario, which already is defined in D1.1 use cases and requirements.

1.2.4.1 Status of the work package

This work package started in March 2020.

In task 4.1, Alpha Networks continues working on RAN system development, including 5G CPE and gNodeB, and has provided 5G SA RAN prototype. CEA has investigated how to enable deterministic URLLC. For that purpose, CEA has worked on the design of the network orchestrator and on the combination of URLLC mechanisms using NS3 simulator. Moreover, CEA has investigated novel HARQ scheme for early decision-making. CEA is currently working on scheduling strategies for URLLC (determinist vs. opportunist approaches).

As part of T4.2, Athonet has been working on the ETSI NFV-like instantiation and orchestration of legacy 4G first and then 5G mobile core network components via OSM. The framework has been successfully tested in-lab as well as during the recurrent ETSI NFV Plugtests. Using the Athonet VNFDs, it is possible to integrate the mobile core network with MANO implementations derived from OSM and from ONAP, provided by different vendors. III have enhanced the 5GC prototype for its performance and efficiency by the specific architecture and interfaces

In T4.3, the solution for MEC deployments for the full-on-site and the hybrid architectures has been designed by Athonet and testing is ongoing in preparation of the final demonstrations. Chunghwa Telecom has provided the 5G SA prototype bump-in-the-wire MEC platform and still developed multi-PDU session and multi-QoS flow functions. Chunghwa Telecom has provided ECoreCloud (ECC) NFV platform and MANO to manage Mobile Edge Enabler (MEE) VNF.

In Task 4.4, ITRI has worked on three vertical use cases, namely (1) Process Diagnostics by CNC and Sensing Data Collection (2) Using Augmented/Virtual Reality for Process Diagnosis (3) Cloud-based CNC . Among these implemented use cases, (1) & (2) were implemented on a five-axis machine tool and (3) was implemented on a flexible fixture system, which is a specialized machine to test the cloud-based controller. For use case (1), 6 accelerometers were installed on the five-axis machine tool. Machining data and CNC data were collected and sent to the tool condition monitoring software deployed in MEC. For use case (2), 3D model of the machine have been created. Two application were developed for machine operator and remote expert, these two applications share the same 3D machine model and synchronized by the machine data from the WebAPI server developed by IMTC. The prototype of cloud CNC has been developed and tested on the flexible fixturing system by sending vibration suppression motion commands from cloud controller to the ground controller to evaluate overall performance. Moreover, SAP developed and tested algorithms for the dynamic allocation of radio and computational resources in a monitoring system where peripheral devices collect data and send them to an edge server that runs machine learning algorithms to take decisions about the observed data. The allocation is carried out in order to find an optimal balance between energy consumption, service delay, and accuracy of the decisions taken by the edge server. Different constraints are incorporated in the method, including service delay, which incorporates queueing delay in the communication and computation queues, and energy consumption. CEA has collaborated with SAP on dynamic resource allocation for computation offloading and on semantic and goal oriented communications. Furthermore, SAP has started developing methods for dynamic service placement, generalizing the methods developed in WP3 to the dynamic case.

1.2.4.2 Work carried out & main results

1.2.4.2.1 Task 4.1: Radio Network Technical Enablers

The main activities of Task 4.1 is developing 5G RAN components, specifically the CPE and gNodeB complying with 3GPP.

An industrial application CPE (Customer Premises Equipment) has been developed, the main feature of 5G NR CPE are listed as below:

- 5G NR Sub-6(WAN)
- 2x GE Ethernet ports(LAN)
- WiFi Dual band(WLAN)

The second RAN component is the gNodeB. Alpha Networks has been developing a disaggregated gNodeB solution that is consisted of a RU and a CDU.

- RU: The radio unit implements lower physical layer with split option 7.2 defined in ORAN standard. It needs to support CFR (crest factor reduce) and DPD (digital pre-distortion) function to comply with 3GPP standard. In RF front-end system, the PA (power amplifier) RF component boosts RF power at the transmitter side, and the LNA (low noise amplifier) provides a better sensitivity level at the receiver side. The key considerations of RU design are size, weight, and power consumption, and target RU spec as below.
  - Matrix: x4TRx
  - TX Power: +24dBm (250mW)
  - Frequency band: n78 (3700MHz-3800MHz) / n79 (4800MHz-4900MHz)
  - Dimension: 218mm x 218mm x 65mm
  - PoE power supply
  - Synchronization: 1588v2
  - Comply with 3GPP standard TS 38.104
- CDU: 5GNR CDU is consist of DU and CU. DU runs the RLC, MAC, and parts of the physical layer, and its operation is controlled by the CU, the centralized unit that runs the RRC and PDCP layers. The main features of CDU are listed as below:
  - 10G SFP x8, 25G SFP x4
  - DL 256QAM / 4 layers
  - UL 64QAM / 2 layers
  - Maximum support x4 RUs
  - X4 UE/TTI
  - Connected UE: 256+

Alpha Networks has built the prototype of 5G NR gNodeB and CPE equipment, the end-to-end lab integration test is being conducted. The gNodeB and CPE will be deployed at ITRI IMTC at the end of month 26 to realize the selected use cases. As the integration test result by month 16, the End-to-End throughput is up to more than 240 Mbps.

CEA has investigated how to enable deterministic URLLC. For that purpose, CEA has worked on the design of the network orchestrator and on the combination of URLLC mechanisms using NS3 simulator. Our contribution consists first of all in classifying enabling solutions according to the multi-level diversity. The introduction of additional diversity (i.e., hardware and signal processing) to the pre-existing diversity (i.e., time, space, frequency) brings interoperability and allows the combination of several technologies. This classification will act as a lookup table for the combination of diversity having an impact on the performance of the end-to-end (E2E) network in terms of reliability, latency/jitter and efficiency. Our second contribution is a new methodology to design an E2E orchestrator taking into account the heterogeneity and coexistence of services, the dynamic evolution of needs (e.g., traffic, number of users, QoS) and the changing environment. Using the lookup table, the AI-based orchestrator will dynamically modify network parameters and elastically combine diversity to adapt to possible impairments. Before continuing the evaluation of the AI-based orchestrator, we have modified a NS-3 network simulator to multiplex low latency mechanisms (e.g., frame design) and reliability enhancing mechanisms (e.g., multiple antenna, redundancy and adaptive modulation and coding exploiting code/time/space diversity). This simulator is used to evaluate the impact of the combination of mechanisms exploiting a diversity subset on the E2E URLLC performance at RAN level cooperating with EPC/LTE core network. Moreover, CEA has investigated novel HARQ scheme for early decision-making. This work resulted in the submission of a conference paper applied to HARQ mechanisms and a patent. In this paper, we study the tradeoff between resource efficiency and latency under the constraint of target reliability of beyond 5G networks. Based on the latency distribution statistic, the early decision maker exploits the confidence level of each action, instead of the send-wait-react mode. The efficiency-latency tradeoff is achieved by the timing of the decision. The earlier the decision is made, the greater the latency gain, at the cost of resource efficiency. This decision maker is applied to the HARQ procedure and is based on a strategy that allows a number of parallel retransmissions than a single one. We show that by appropriately capturing a number of retransmissions before acknowledging the feedback, the end-to-end latency and jitter gains are achieved at the cost of reduced resource efficiency.

Figure 7 shows the outage probability over E2E latency. The results detail the E2E latency achieved to reach an outage of from 0.99 up to 0.99999 with different level of redundancy R. They also demonstrate how the latency gap is optimized to reach a more critical outage from the more relaxed outage by increasing R. In general, an optimal R will facilitate the system to reach a target outage sooner than in other cases. However, in the case of a bad channel and frequent traffic rate, the aggregation queuing effect dominates the latency gain.

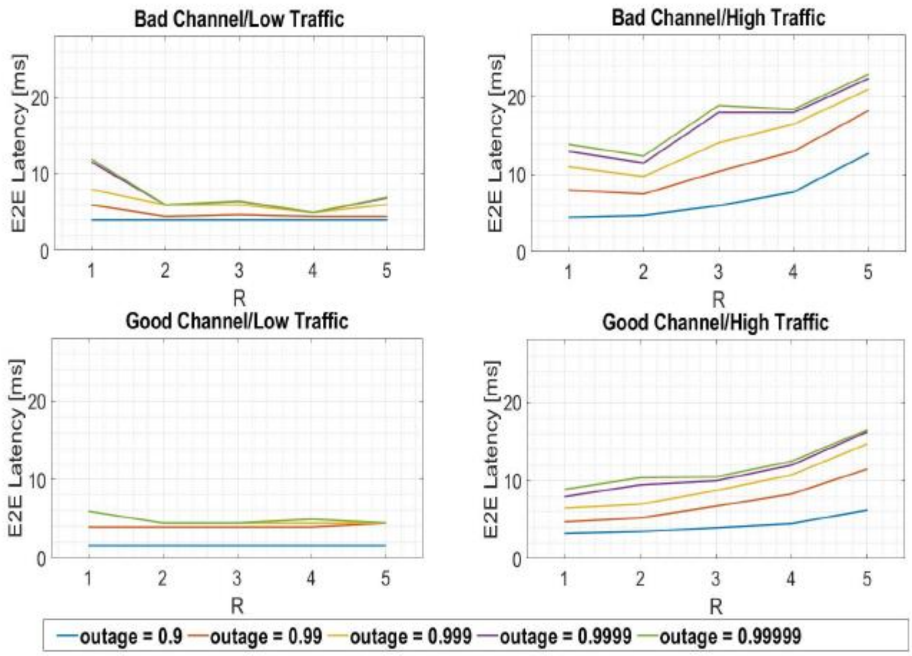


Figure 7: Outage probability on E2E Latency as a function of R, channel conditions and traffic source rates

CEA is currently working on scheduling strategies for URLLC (determinist vs. opportunist approaches).

1.2.4.2.2 Task 4.2: Core Network Technical Enablers

T4.2 focuses on the development of the core network components to realize private local 5G networks that meet the envisioned industrial application requirements. Two complementary activities have been carried out. On the one hand, directions, a lightweight orchestration framework capable of performing the lifecycle management of a private mobile core prototype has been designed and developed. The adopted testbed architecture for interface and VNF instantiation and configuration tests is made of two open-source pieces of software. OpenStack acts as the VIM and NFVI, providing the host infrastructure. OSM manages and orchestrates the NFV ecosystem, by contacting the Element Manager (EM) of a 5G network function through the Ve-Vnfm interface. Special focus has been reserved to the analysis and implementation of an ETSI-compliant NFV SOL002 interface to enable orchestrators such as Open Source MANO (OSM) to interact with the core VNFs. The performance evaluation results obtained so far testify that the average core network instantiation time is 136.08 seconds and the average initial configuration time is 566.92 seconds, obtaining an average total deployment time of just 703.01 seconds.

III 5G Core for enterprise and private network scenarios. We especially focus on data plane efficiency and system reliability. Thus, we develop both software and hardware solutions for data plane to enhance packet processing and load monitoring. By this way, the throughput can achieve to 10Gbps and to keep the data plane latency less than 1ms. For various environment enterprises use cases, III 5GC also support interworking with MEC and local breakout applications. Beside all the benefits of Basic function, we also support more than 100,000 UEs, and data plane acceleration technology with DPDK or SmartNIC solution, furhermore throughput > 10Gbps and Latency < 1ms.

1.2.4.2.3 Task 4.3: Mobile Edge Cloud Enablers

In Task 4.3 of work package 4, MEC technologies has been developed two types in 5G CONNI project. One is the hybrid 5GC solution in European testbed; the other is the bump-in-the-wire type in Taiwanese testbed that is described in D4.1.

Among the options for the mobile network architecture discussed in Section 3 of D2.1, a special focus has been reserved to the splitting of CP and UP functions in the hybrid 5GC solution. Because of its high flexibility, this was chosen as the reference architecture for the European testbed of 5G-CONNI, and it entails 1) a remote control center, typically placed in a central cloud or datacenter, which acts as CP manager and provides the configuration, provisioning and monitoring functions; 2) an edge node, located on-premise, which includes the UPF platform and forwards user traffic to/from the RAN and local applications, thus keeping the traffic local whenever necessary, without exiting the factory premises. Such an architecture meets the requirements of 5G systems, which are conceived to allow a more flexible deployment of the data plane, aiming to natively support edge computing. As a consequence, a MEC platform can easily be mapped into the 5G system architecture. In this framework, chosen as the reference scenario for 5G-CONNI's European testbed, the MEC host's data plane is mapped to the 5G's UPF element.

The bump-in-the-wire MEC SA prototype has been developed that can interoperate between 5G standalone base stations and core networks and base on 3GPP SA standalone specifications. The MEC 5G SA prototype is performed the control plane test such as registration, deregistration, service request and AN release procedures and data plane test such as GTP extension header encapsulation and decapsulation. The architecture of MEC 5G SA prototype is shown in Figure 8. The MEC SA prototype has been integrated with III's 5G core network and Alpha's 5G base station. The ITRI IMTC's application, named Process Diagnostics using Augmented Reality (AR) has also been integrated with 5G MEC SA prototype. The prototype of all network components integration from the Taiwan site has been deployed at ITRI IMTC field for IEEE Globecom 2020 demo.

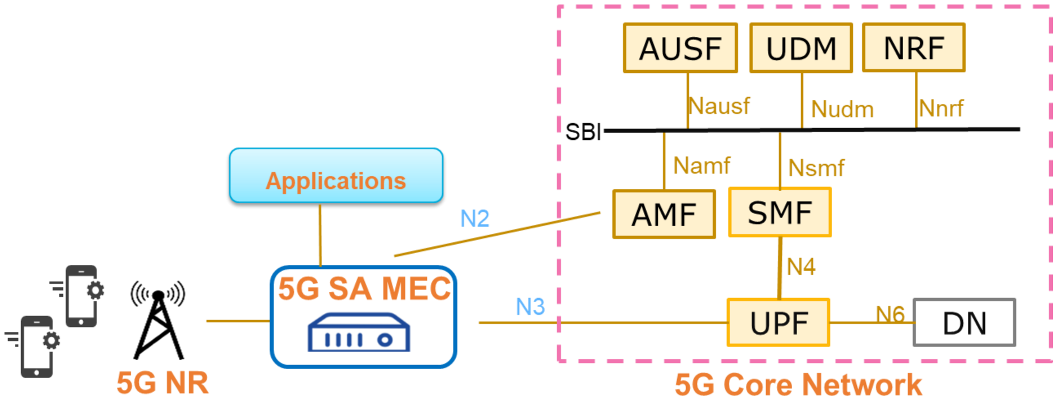


Figure 8: Architecture of the MEC 5G SA prototype

1.2.4.2.4 Task 4.4: Industrial Application Enablers

CEA has also collaborated with SAP on dynamic resource allocation for computation offloading. In this work, we study the problem of energy efficient computation offloading enabled by edge computing. In the considered scenario, multiple users simultaneously compete for limited radio and edge computing resources to get offloaded tasks processed under a delay constraint. The radio resource allocation takes into account inter- and intra-cell interference, and the duty cycles of the radio and computing equipment have to be jointly optimized to minimize the overall energy consumption. To address this issue, we formulate the underlying problem as a dynamic long-term optimization. Then, based on Lyapunov stochastic optimization tools, we decouple the formulated problem into a CPU scheduling problem and a radio resource allocation problem. Whereas the first one can be efficiently solved using a fast iterative algorithm, the second one is solved using distributed multi-agent reinforcement learning due to its non-convexity and NP-hardness. The resulting framework achieves up to 96.5% performance of the optimal strategy based on exhaustive search, while drastically reducing complexity. The proposed solution also allows to increase the network's energy efficiency compared to a benchmark heuristic approach.

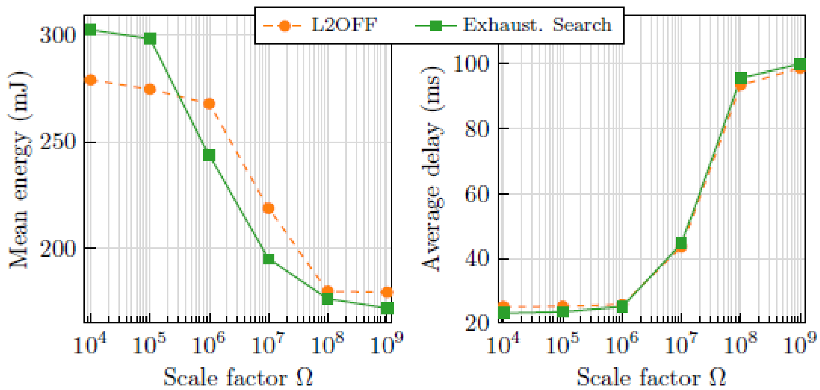


Figure 9: Energy-delay trade-off w.r.t. the small factor for K = 6 UEs and for a fixed delay constraint of 100 ms

A major item within this task is the initial implementation of use cases selected in Task 1.1 at ITRI shopfloor, including necessary computation offloading strategies to enable complex processing of data collected from shopfloor to guarantee continuous monitoring and anomaly detection during industrial processes. The progress of implementation and installation of the enablers are as follow:

- As shown in Figure 10, three-axis accelerometer has been attached on the Litz TM-2500 5-axis turn mill machine and connected with an industrial PC to collect CNC data as well as sensing data for process data analysis. The collected CNC data and sensing data are also shown inFigure 10. A webapi server is implemented to provide access of the CNC data and sensing date for process diagnosis and AR/VR applications
- Software module for data collecting is ready and will be connected with MEC by the end of November.
- Implementation architecture for the Using Augmented/Virtual Reality for Process Diagnosis use case is shown in Figure 11. A 3D model of the machine tool has been constructed for applications for machine operator and remote expert. Both applications can access machine CNC data and sensing data via webapi so that 3D models are synchronized.

The cloud-based CNC software and the test machine has been constructed and tested under distributed network architecture (shown in Figure 12) where the motion command generation, motion command execution modules are separated. The test machine is shown in Figure 13, which is a flexible fixture system used in aerospace part machining. In the test scenario, a steel plat workpiece is installed on the fixture system and exited by a shaker to simulate the vibration during machining process. The cloud controller sends a series of motion command to particular moving axis to reduce the vibration.

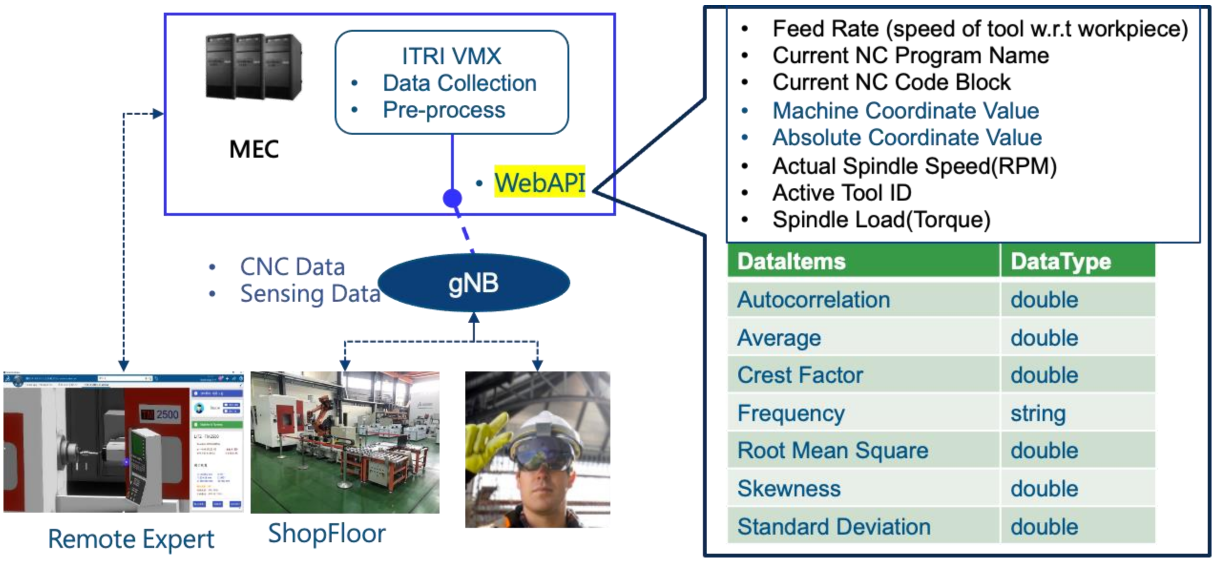


Figure 10: Implementation for the Process Diagnostics by CNC and Sensing Data Collection use case

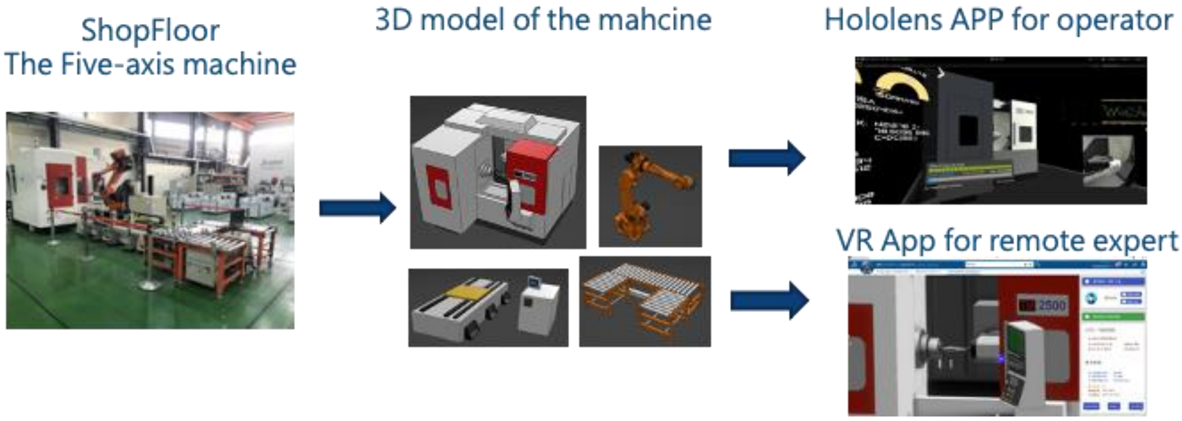


Figure 11: Implementation for the Using Augmented/Virtual Reality for Process Diagnosis use case

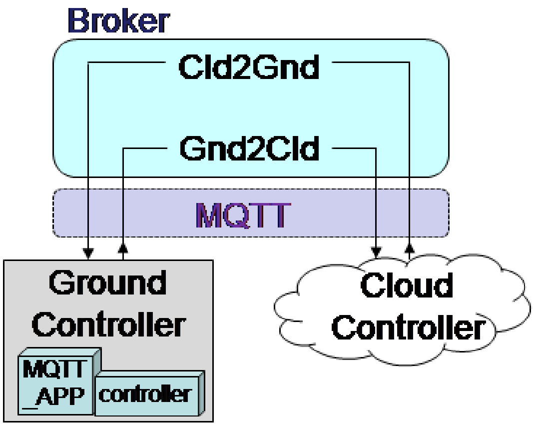


Figure 12: Architecture of the cloud CNC

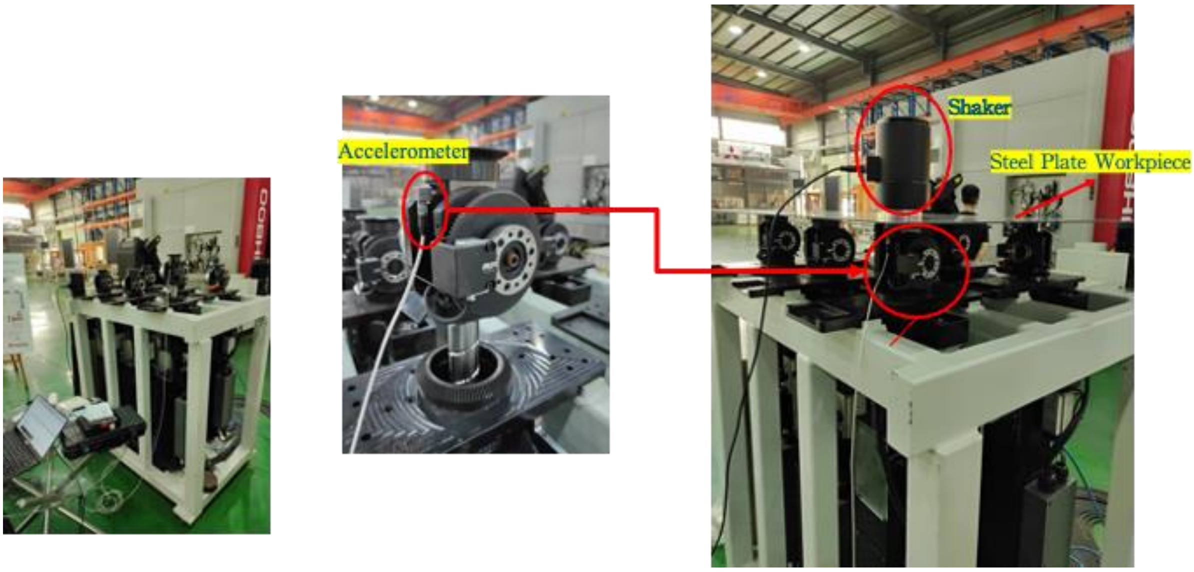


Figure 13: Test machine for the cloud CNC

1.2.5 Work Package 5

The objectives of WP5 are to integrate the E2E system designed in WP2, comprised of 5G CPE, gNB, MEC, core and factory floor applications to ensure that the functionality and performance meet the requirements of specific use cases defined by WP1.

1.2.5.1 Status of the work package

Activities are split into three tasks: T5.1 deals with integration and verification of a preliminary prototype in the lab, including multi-site inter-connection; T5.2 deals with the deployment of the lab prototype in the factory premises with functional verification; T5.3 conducts KPI assessment of the system.

1.2.5.2 Work carried out & main results

1.2.5.2.1 Task 5.1: Realization of the selected use cases

All activities carried out so far in the context of Task 5.1 were documented by D5.1, which also contains the list of hardware and software components provided by the various partners in order to build the test sites. In the framework of this task, we provided an overview of the general 5G system architecture adopted by 5G CONNI. A functional architecture was defined, based on the motivating use cases (cf. D1.1) and the corresponding models identified in D2.1. All the details about such an architecture are reported in D5.1.

The network architecture deployed on the European side is depicted in Figure 14 and is conceived to interconnect three main sites: an enterprise's headquarters, a factory, and a separate central cloud. Over these three sites, two complementary core network deployments (one fully on-site at the factory and one hybrid, cf. D5.1) provide the whole setup with the required networking features and functionalities. In particular, the on-site deployment at the factory enables edge computing by directly steering the traffic generated by the wireless devices towards the edge servers (and *vice versa*), where a dedicated BOSCH-owned over-the-top application function runs.

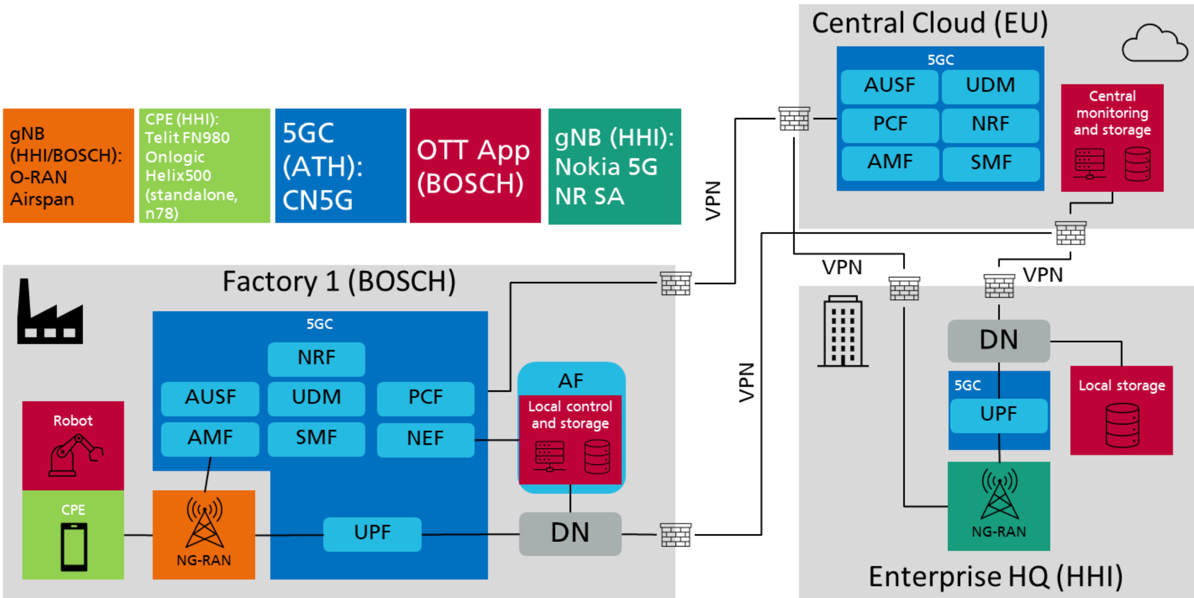


Figure 14: Network architecture for the European demo site

In addition, both the factory and the headquarters will be supplied with next-generation RAN equipment both disaggregated, O-RAN-compliant and not, made available by HHI to support 5G wireless access over the frequencies between 3.7 and 3.8 GHz reserved for private networks in Germany. More details on such setup, including the full inventory and features of the employed hardware, are available in D5.1, Section 2.

The 5G network logical architecture of the Taiwanese trial site is illustrated in Figure 15, where the enterprise data center and manufacturing site are interconnected with the following features:

- Disaggregated RAN system running at 4.8 to 4.9GHz is ORAN compliant and option 7.2 split is implemented.
- 5G Core deployed at the enterprise data center and equipped with a central monitoring system which enables five O&M features, namely: (1) Fault Management, (2) Configuration Management, (3) Accounting Management, (4) Performance Management, and (5) Security Management.
- Local breakout of user-plane traffic is enabled by the MEC platform and transparently integrated between the base station and 5G Core without signaling connections.
- Three use case are served by the same 5G network.

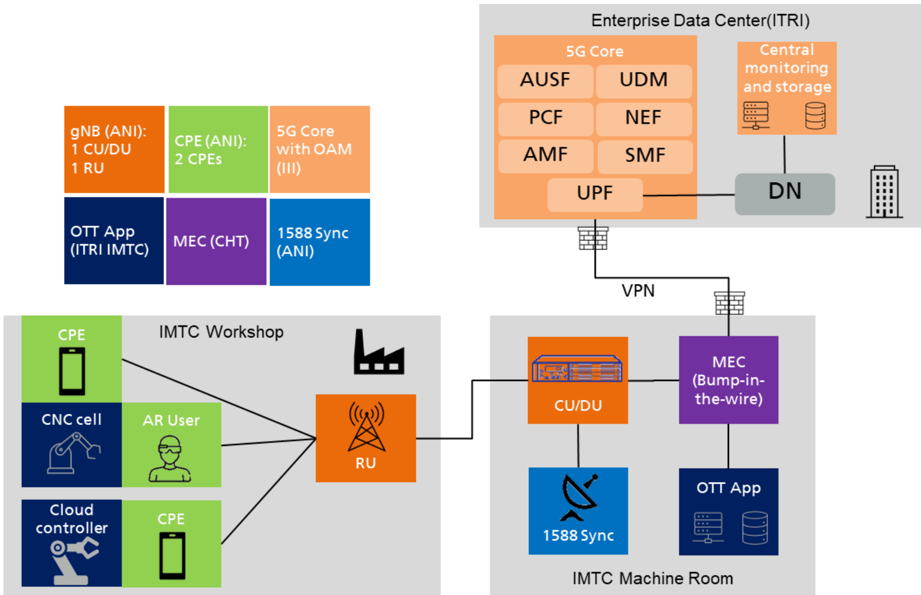


Figure 15: Network architecture for the Taiwanese demo site

Finally, the 5G CONNI's E2E testbed architecture merges into a single framework the EU and the TW setups, with the goal of building a prototype of intercontinental company network deployment that benefits from the technological innovations developed by the project. An initial description of such setup is provided in D5.1 and will be integrated in D5.2 and D5.3.

In Task 5.1, progress has also been made in terms of conceptual work and first implementation steps towards the realization of parts of the use case “Robot Platform with Edge Intelligence and Control”. Here, a distributed control architecture has been devised, which enables control from the edge cloud while closing the control loop over the wireless air interface. A concrete concept for this architecture has been implemented and first performance and stability tests have been conducted. As, at the time of writing this report, no integration with the actual 5G System has taken place yet, 5G latency has been emulated for these tests. The first test results show that the robot operates in a stable manner, as long as the latency and/or jitter does not exceed certain values. The hardware and software setup of the use case has been documented in D5.1.

The preliminary integration tests and tools were defined, allowing to draft an effective testbed deployment plan (cf. D5.1). The system integration plan for the EU and TW setups will be carried out until the end of year 2021.

On the TW side, the comprehensive in-lab test program has been proposed to ensure that all the subsystems will work together properly for the selected use cases in a pre-live industrial environment. As illustrated in Figure 16, this program will go through four phases to make sure that the system is ready for deployment. Initially, phase 0 is the conformance test performed by the vendor and covered in Work Package 4. While the goal of phase 1 is to verify the equipment from different vendors works together as defined in the standard, phase 2 is to ensure that the product offers an acceptable level of quality in terms of performance and stability after the product has passed multi-vendor IOT. The main KPI captured in phase 2 will be TCP/UDP throughput or latency. Finally, phase 3 is to determine to what extent the desired performance is achieved for the vertical use cases defined in D1.1. The application traffic could be real or emulated. If the traffic is emulated, the main KPI captured here is based on passive analysis to quantify how network imperfections affect the user experience.

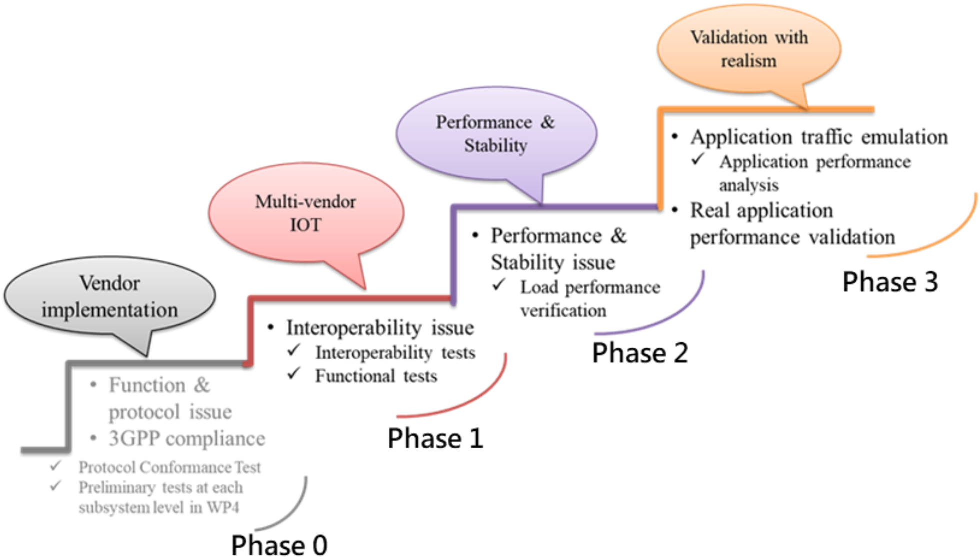


Figure 16: In-lab test process

In addition, 4 in-lab test configurations and 37 test cases have been identified and considered for each phase of the test program. Each test case has been assigned to specific test configurations, which is illustrated in Figure 16 and Figure 18.

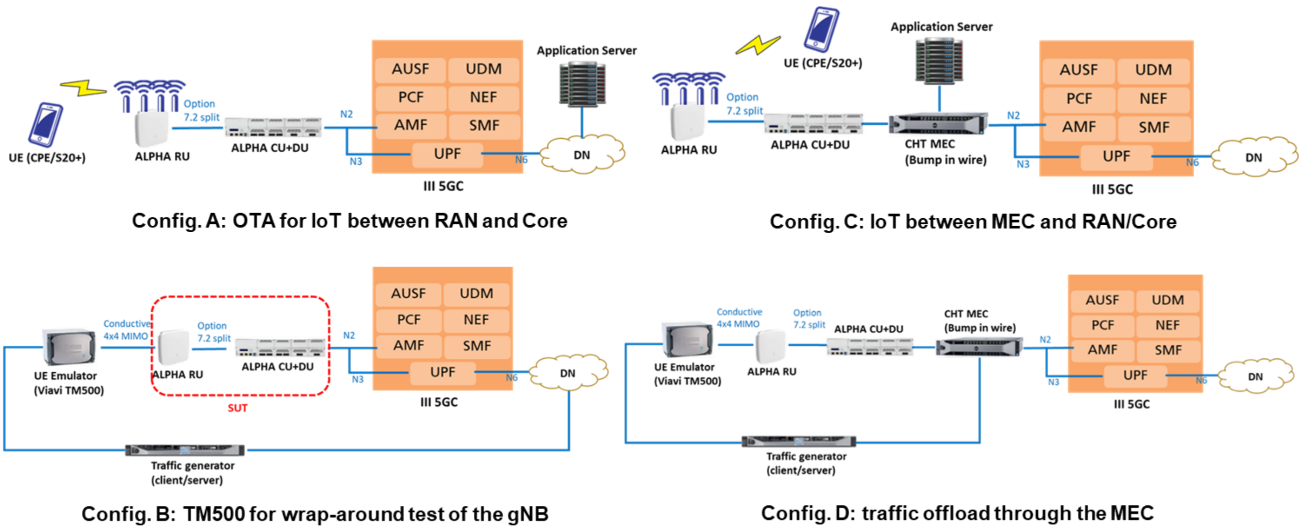


Figure 17: Four Test Configurations

The Multi-vendor IOT test group includes 12 test cases and applies to the configuration A or C. It aims at the procedures when the mobile switches on and registers with the 5G core network, which covers 1) registration and PDU session establishment, 2) Different RRC states transfer, 3) QoS management, and 4) traffic offload and forwarding. The Performance and

Stability test group includes 21 test cases and applies to the configuration A or B. The UDP/TCP performance measurements and round-trip time latency at different channel conditions are evaluated here. Finally, validation with Realism test group includes 4 test cases and applies to the configuration D. This group is dealing with application-layer performance measurements rather than UDP or TCP layer to ensure that the combined requirements of three use cases can be fulfilled by the same 5G network.

Test ID	Test Item	Test Objective	Test Configuration
1.1	NG Setup	Successful NG interface setup between gNB and 5GC	A/C
1.2	UE Initial Registration with IMSI identity	UE initial registration with IMSI identity	A/C
1.3	UE Initial Registration with GUTI identity	UE initial registration with GUTI identity	A/C
1.4	PDUSession Establishment	Successful establishment of the PDU session	A/C
1.5	UE Deregistration		
1.6	Access Network Release		
1.7	UE-Triggered Service request		
1.8	NW-Triggered Service Request		
1.9	Management of QoS flow by Allocation and Retention Priority (ARP)		
1.10	Management of QoS flow by 5G QoS identifier(5QI)		
1.11	N3 GTP-U processing (GTP decap/encap)		
1.12	N3 GTP-U processing (data forward)		

Phase 1

Test ID	Test Item	Test Objective	Test Configuration
2.1	Average UDP DL Throughput at Cell Center	One UE successfully initiates Iperf UDP DL transfer at cell center with RSRP=-60dBm and record the average TPut	A
2.2	Average UDP UL Throughput at Cell Center	One UE successfully initiates Iperf UDP UL transfer at cell center with RSRP=-60dBm and record the average TPut	A
2.3	Average TCP DL Throughput at Cell Center	One UE successfully initiates Iperf TCP DL transfer at cell center with RSRP=-60dBm and record the average TPut	A
2.4	Average TCP UL Throughput at Cell Center	One UE successfully initiates Iperf TCP UL transfer at cell center with RSRP=-60dBm and record the average TPut	A
2.5	Average UDP DL Throughput at Cell Middle		
2.6	Average UDP UL Throughput at Cell Middle		
2.7	Average TCP DL Throughput at Cell Middle		
2.8	Average TCP UL Throughput at Cell Middle		
2.9	Average UDP DL Throughput at Cell Edge		
2.10	Average UDP UL Throughput at Cell Edge		
2.11	Average TCP DL Throughput at Cell Edge		
2.12	Average TCP UL Throughput at Cell Edge		

Phase 2

Test ID	Test Item	Test Objective	Test Configuration
3.1	Performance Evaluation using Traffic Profile of the AR Use Case	To assess the system performance using the traffic profile of the AR use case	D
3.2	Performance Evaluation using Traffic Profile of the Data Collection Use Case	To assess the system performance using the traffic profile of the data collection use case	D
3.3	Performance Evaluation using Traffic Profile of the Cloud-Based Controller Use Case	To assess the system performance using the traffic profile of the cloud-based controller use case	D
3.4	Performance Evaluation using Traffic Profile of the Combined Use Case	To assess the system performance using the traffic profile of all vertical applications at IMTC	D

Phase 3

Figure 18: Test Cases for Different Phases

1.2.5.2.2 Task 5.2: Test and Evaluation in Real-World Production Environments

Task 5.2 started in month M19 of the project and its goal is to deploy the lab prototype into the real-work factory.

On the European side, discussions have taken place in order to specify certain aspects of the integrated architecture (between the EU and Taiwan), which themselves are in accordance with the IT policies of the enterprise (BOSCH) and which can also be implemented in a practicable manner. These aspects, amongst others, include network service specifications and VPN configurations.

On the Taiwanese side, part of the test cases designed in Task 5.1 were selected for in-lab system integration. The regression tests in phase 1 on 5QI have been concluded, where several interoperability issues have been identified and fixed. In addition, performance tests in phase 2 were performed using over-the-air configuration, where UDP and TCP performance measurements have been evaluated and optimized. Currently, we're entering phase 3 to evaluate the performance using the traffic profile of the use case. In the meantime, the on-premise integration plan will be identified and the lab prototype is planned to be deployed into the IMTC plant in the end of 2021, with all control-plane functions running properly.

1.2.5.2.3 Task 5.3: E2E Performance Measurement and KPI Analysis

Task 5.3 has not started yet.

1.2.6 Work Package 6

The focus of work package 6 is (1) the dissemination of project results within the research and industrial communities and (2) the following of and contribution to relevant standardization and regulation activities.

1.2.6.1 Status of the work package

The work package is divided into two tasks: Task 6.1 covers the dissemination activities, including conference and journal publications, workshops, and the project website. For Task 6.2, the consortium is monitoring the ongoing standardization and regulation activities within the appropriate groups and is also actively contributing where possible.

Dissemination to academic audiences through regular conferences and to the general public through trade shows is still heavily impacted by the COVID19 situation, but alternative means like online conferences and sessions, virtual booths at trade shows and open access journals are becoming more and more common and are leveraged by the project consortium.

1.2.6.2 Work carried out & main results

1.2.6.2.1 Task 6.1: Dissemination

The main objective of Task 6.1 is the dissemination of project results to both academic audiences and the general public. For this, a project website was set up at https://5g-conni.eu where news, deliverables and public dissemination information is published.

Project results were submitted towards various relevant technical and non-technical bodies and fora, in order to ensure that the research and innovation results are communicated to the wider 5G community. In January 2021, Athonet hosted the UPTIME conference at Villa Marconi, Bologna, Italy. Here, a dedicated session was hosted for EU funded projects and 5G CONNI was presented and discussed. ITRI has worked with Small Cell Forum and the consortium members to organize the dissemination activity at Small Cell World Summit 2021 to promote project results. In particular, an online virtual booth has been setup to display project achievements, which is shown in Figure 19. Moreover, ITRI has organized a speaking slot in the session “Industry 4.0 and Private Networks, Edge Computing”, which was presented by Athonet from the perspective of 5G CONNI project. 5G CONNI partner Fraunhofer HHI co-organized the Workshop on Terahertz Channels and Systems in collaboration with 5G mmW Channel Model Alliance, IEEE VT-S Propagation Committee, and IEEE SA P2982. In line with one of the project's focus areas, the workshop focused on latest results in the field of radio propagation research at millimeter-wave and Terahertz frequencies. Finally, the project’s flyers were distributed at the 5G World event in London, UK, in September of 2021.

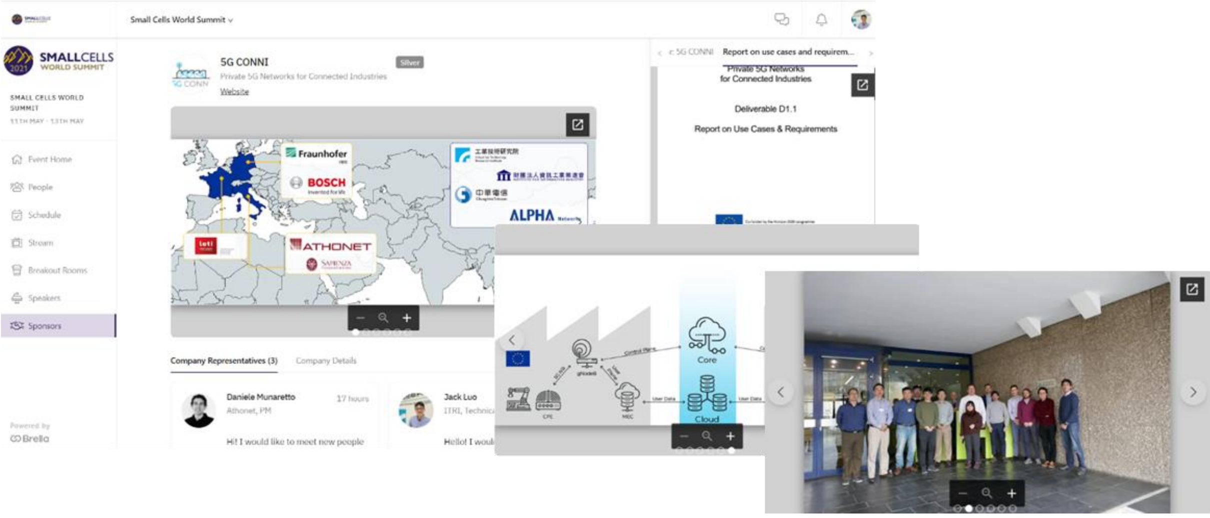


Figure 19: Online virtual booth at SCWS 2021

In the second year of the project, six journal publications and seven conference paper contributions in connection with the project were accepted at conferences and transactions and are listed in Table 4.

Table 4: List of Publications Related to the Project

Type	Authors & Title
Journal	M. Merluzzi, P. Di Lorenzo, S. Barbarossa, "Wireless Edge Machine Learning: Resource Allocation and Trade-offs", IEEE Access, March 2021
Journal	E.C. Strinati, S. Barbarossa, "6G networks: Beyond Shannon towards semantic and goal-oriented communications", Computer Networks, May 2021
Journal	S. Barbarossa, S. Sardellitti, "Topological Signal Processing: Making Sense of Data Building on Multiway Relations", IEEE Signal Processing Magazine, Nov. 2020, pp. 174-183
Journal	C. Battiloro, P. Di Lorenzo, P. Banelli, S. Barbarossa, "Dynamic Resource Optimization for Decentralized Estimation in Energy Harvesting IoT Networks", IEEE Internet of Things Journal, Dec. 2020
Journal	M. Maman, E. Calvanese Strinati, L. Dinh, T. Haustein, W. Keusgen, S. Wittig, M. Schmieder, S. Barbarossa, M. Merluzzi, F. Costanzo, S. Sardellitti, H. Klessig, S. Vitthalrao Kendre, D. Munaretto, M. Centenaro, N. di Pietro, S.-P. Liang, K.-Y. Chih, J. S.-J. Luo, L.-C. Kao, J.-C. Huang, J.-S. Huang and T.-Y. Wang, Beyond Private 5G Networks: Applications, Architectures, Operator Models and Technological Enablers, accepted with minor revision to EURASIP JWCN journal
Conference	P. Di Lorenzo, C. Battiloro, M. Merluzzi, S. Barbarossa, "Dynamic Resource Optimization for Adaptive Federated Learning at the Wireless Network Edge", ICASSP 2021, June 2021
Conference	S. Sardellitti, S. Barbarossa, P. Di Lorenzo, "Online Learning of Time-Varying Signals and Graphs", ICASSP 2021, June 2021
Conference	Emilio Calvanese-Strinati et al., "Beyond 5G Private Networks: the 5G CONNI Perspective ", 2020 IEEE Globecom Wkshps, Dec. 2021
Conference	M. Sana, M. Merluzzi, N. d. Pietro and E. Calvanese Strinati, "Energy Efficient Edge Computing: When Lyapunov Meets Distributed Reinforcement Learning," 2021 IEEE International Conference on Communications Workshops (ICC Workshops), 2021, pp. 1-6

Conference	S. Wittig, A. Schultze, M. Peter, W. Keusgen, “Over-the-Air Verification of Angle-of-Arrival Estimation in Millimeter-Wave Channel Sounders”, 2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall), Sep. 2021.
Conference	M. Schmieder, H. Klessig, A. Schultze, S. Wittig, M. Peter, W. Keusgen, “Channel Measurements and Large Scale Parameter Estimation in an Industrial Environment”, 2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall), Sep. 2021.

Furthermore, novel technological approaches were communicated through (invited) speeches at conferences and workshops:

- S. Barbarossa, "Pervasive Artificial Intelligence for 6G Networks", JIC Workshop on Intelligent IoT for 6G Networks, Jan. 2021
- N. di Pietro, "On 5G Mobile Networks", University of Milan Bicocca, Italy, May 2021
- M. Centenaro and D. Munaretto, "On 5G Mobile Networks", University of Naples Federico II, Italy, Jun. 2021.
- S. Barbarossa, "New tools for next generation networks: From topological signal processing to goal-oriented communications", Como PhD Summer School, July 2021
- S. Barbarossa, "Wireless Edge Machine Learning", Futurewei University Days Workshop, August 2021
- S. Barbarossa, "Goal-oriented communications: How to be more efficient by transmitting less", 17th International Symposium on Wireless Communication Systems, Berlin, Sep. 6, 2021
- E. Calvanese Strinati, "Toward 6G with Semantic and Goal-Oriented Communications", Como PhD Summer School, July 2021.
- E. Calvanese Strinati, „ Beyond 5G Networks with Semantic Communications, Digiscom Seminars, Paris, 1 of June 2021.
- E. Calvanese Strinati, „6G Fundamentals – Panel Discussion 6G Symposium – Shaping Industry & Society Beyond 5G, Mai 2021, Virtual Conference.
- E. Calvanese Strinati, „Revolution is in the Air – Part 1: The Air Interface“, Plenary Panel at 6G Symposium, Fall 2021, 21 of September 2021.

Figure 20: Invitation for 6G Symposium

1.2.6.2.2 Task 6.2: Standardization & Regulation

The main objective of this task is the monitoring of and contribution to relevant standardization and regulation bodies. In the second year, the project consortium focused on contributions to ETSI MEC ISG, IEEE and ITU. In the ETSI MEC ISG, Athonet contributed to the work item DGS/MEC-0033 IoT API.

HHI is actively contributing to the IEEE Millimeter-Wave Channel Sounder Verification group that is developing the IEEE P2982 standard for channel sounder performance verification. The results of work package 3 are leveraged in contributions to this working group.

Furthermore, results of work package 3 were also used in a contribution to the ITU Study Group 3 that is refining ITU recommendation P.1238: Propagation data and prediction methos for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 450 GHz. Path loss data extracted from the measurements that were conducted during the 5G CONNI project was submitted to ITU and will be included in the Study Group 3 databanks containing radiowave propagation measurement data.

Finally, contact with the German national telecommunications regulation agency has been established to discuss how results and insights from the 5G CONNI project can be used in future regulation of private 5G networks.

1.2.7 Work Package 7

The aim of this work package is the management and administration of the project as well as reporting and interfacing towards the EU and the Taiwanese Funding Agency. The work package is led by the project management team whose members are HHI, which acts as the coordinator for the European part of the project and ITRI, which acts as the technical project manager and coordinator for the Taiwanese part.

Work package 7 is referred to as work package 0 in the Technical Annex 1-3 of the original project proposal and was re-numbered due to technical constraints of the EU SyGMA portal.

1.2.7.1 Status of the work package

As the support work package for the project, WP7 activities are going on continuously in parallel to technical work and ensure a regular exchange between partners as well as compliance with technical, legal and financial requirements. The legal and financial responsibilities of the EU project coordinator (HHI) are supported by Fraunhofer headquarters in Munich, whereas all other administrative work is carried out at HHI.

During the second year of the project, the primary coordinator Dr. Wilhelm Keusgen left his position at Fraunhofer HHI and consequently had to step down as project coordinator. The position was taken over by Mr. Sven Wittig, who previously already held operational responsibility for the project. Dr. Keusgen remains involved in the project as a scientific advisor.

1.2.7.2 Work carried out & main results

Two tasks within WP7 cover administrative and technical aspects of project management, respectively.

1.2.7.2.1 Task 7.1: Administrative project management

Tools

Fraunhofer HHI continues to provide and host the following digital tools to enable a successful implementation of the project which is spread out not just over different countries but also continents:

- ownCloud as a secure shared drive, to host all project documents

- Microsoft Teams as a video conferencing and messaging tool
- Dedicated mailing lists for the consortium and work packages
- Project website as part of the dissemination strategy
- Development of specific templates for documents, slides, and posters and supplying them to partners for dissemination during event

Monthly general consortium calls are held as a fixed point for communication between partners and tracking of the project's progress. There is also a dedicated project management call between HHI and ITRI taking place in preparation of the monthly consortium call. Further regular conference calls are technically motivated and are organized by the work package leaders with frequency depending on workload but at least on a monthly basis. These conference calls are monitored by the project coordinators.

Financial Management

The project coordinator on EU side receives pre-financing from the EU, which is distributed among the EU partners according to the legal framework. The project accounting is maintained and monitoring by Fraunhofer and is reported to the EC. The financial controlling of the project is done in close cooperation with the EC such that potential queries could be clarified on short notice.

The financial project management for the Taiwanese part of the project is performed according to Taiwan's national rules and reporting takes places in close cooperation with the national funding agency.

Contractual and legal issues

Contractual and legal affairs are coordinated and handled by the legal department at Fraunhofer HQ, Munich, Germany. In the current reporting period, no specific legal issues arose within the consortium that required special attention.

Interfacing with funding agencies

The project coordinators are in perpetual communication with the EC and the Taiwanese funding agency as well as with the 6G Office (formerly 5G Office) in Taiwan. In particular, periodic updates on risks caused by the COVID-19 pandemic where addressed. A topic of particular interest during the second reporting period was strategies for cross-regional exploitation of project results. The respective coordinators at HHI and ITRI engaged in active discussion, both with each other and their respective funding agencies, to achieve a mutually beneficial orientation of activities both within and beyond the 5G CONNI project.

1.2.7.2.2 Task 7.2. Technical project management

Project Meetings

In the second year of the project, two virtual meetings took place, which were organized by the project coordinators. Due to restrictive measures as part of national COVID-19 containment strategies, in-person meetings were impossible throughout the reporting period.

- Virtual General Assembly (November 26th – 27th 2020)
- Virtual General Assembly (June 10th – 11th 2021)

Every meeting had a two day agenda focused on discussing the state of the project as well as matters of overarching importance. To accommodate time difference between Europe and Taiwan, the meeting format was put in densely packed schedule with strict emphasis on technical progress.

At the time of writing for this report, resumption of international travel and in-person meetings is unforeseeable. A continued virtual operation on an international level is likely for at least the first half of the last project year.

External Advisory Board

The project has an external advisory board with two members (Nokia and Rohde & Schwarz). Although the project coordinators are in occasional discussion with the advisory board members, a closer interaction e.g. in form of a workshop was not possible due to restriction caused by the pandemic. Representatives of the advising companies were invited to attend the Virtual General Assembly meeting and given access to project deliverables prior to publication.

Interfacing with standardization bodies

Currently the project is observing 5G and related standardization activities and is contributing to the work of different standardization bodies with the help of project partners who participate in or ar a member of the respective organizations, i.e. ETSI-MEC, IEEE and ITU.

A detailed survey on standardization activities has been conducted among consortium members. Active participation in standardization including contributions has been reported by HHI (IEEE, ITU) and ATH (ETSI). Willingness to contribute without concrete plans was expressed by BOSCH, III. Participation in standardization relies heavily on individual partners' commitment and general activity beyond the project. Currently, partners previously participating in 3GPP standardization have reduced their resource commitment in this body due to reasons outside this project's influence.

Contact with the German national telecommunications regulator has been established to discuss the project's findings.

This work is coordinated and overseen by the project management team.

COVID-19 Risk Assessment and Risk Mitigation

The continuing COVID-19 pandemic remains an impact factor on project activities. However, after an initial period of adjustment, the individual partners as well as the project consortium have converged on a mode of operation capable of complying with the overall project work plan and objectives. As requested by the first periodic review, a detailed periodic risk reporting and monitoring procedure has been put in place to enable the project coordinators for a quick identification of potential impacts on the project.

Depending on the respective local dynamic of the pandemic in individual partners' contries, bilateral contacts within countries or regions are temporarily possible. However, international travel on a scale that allows convening all project partners remains impossible.

Beyond that, the risks created by the COVID-19 pandemic may be categorized as follows:

1. Resource availability
   Especially in the early phase of the pandemic, most companies adjusted their operations in reaction. This led to temporary changes in resource availability (especially w.r.t. personnel) as compared to the work plan. However, in the meantime all partners involved in the project have successfully adjusted and are able to contribute as planned. Possible future developments are monitored by regular risk assessments.
2. Site access
   As part of COVID-19 containment procedures, most companies continue to restrict access to mission critical facilities. After a shift of measurement activities planned as part of WP3 by 6 months, this work could be completed to the full extent in March 2021. In

the current reporting period, WP5 activities were mostly focused on in-lab integration and thus were not adversely affected. On the Taiwanese side, demo site access is less problematic, since it may be handled internally at ITRI. On the European side, the current development of the pandemic and progression of vaccination efforts provide a high likelihood of at least partial access in line with the work plan requirements. As part of the newly implemented risk monitoring procedures, this is re-assessed on a monthly basis.

3. Limited physical dissemination opportunities
   The cancellation or shift to virtual form of many major business and academic events poses a challenge for the dissemination of project results. The consortium is making ongoing efforts in identifying and using suitable dissemination channels, especially in organizing and participating in events with a more focused audience.

1.3 Impact

The impact plan and strategies from the description of action (DoA) section 2.1 remain largely unchanged. No major updates are required. The five expected impacts and their current status are summarized below.

Expected impact 1: Proving feasibility of private 5G networks while defining new operator models and developing planning tools and edge cloud technologies for efficient deployments

5G CONNI is addressing the technical challenges of future 5G mobile networks in the context of Factories of the Future (FoF): network capacity increase in ultra-dense network topologies, end-to-end latency reduction and access management for massive number of devices. FoF applications have even higher requirements in terms of data rate, latency, efficiency and mobility than generic 5G applications. In order to cope with the increasing diversity of wireless systems in manufacturing, 5G CONNI is developing radio network, Mobile Edge Computing (MEC) cloud, core network and applications for the industrial sector. The main goal is to ensure that industrial use cases can be successfully implemented on private 5G networks for requirements covering high data rates (eMBB) and ultra-reliability and low latency communication (URLLC).

The project consortium has investigated and evaluated a selection of technologies that are foreseen to unlock several key 5G challenges. As a result of this, a number of use cases and requirements were defined and reported on in deliverable D1.1. Additionally, suitable architecture and operator models were identified and described in deliverable D2.1. However, many factory owners have concerns regarding the usage of a public land mobile network for enabling 5G-based industrial production. The project consortium has thus identified and analyzed relevant requirements and concerns regarding suitable operator models for non-public 5G factory networks, as described in D1.2, which then may lay the basis for the design and evaluation of suitable operator models in WP 2. Last but not least, the results of the evaluation and the operator models were included in several paper contributions.

Expected impact 2: Contribution to understand and transfer how to plan, deploy, operate and maintain a private 5G network in a factory

In order to provide a solid understanding on how to plan, deploy, operate and maintain a private 5G network in a factory environment, the 5G CONNI project has realized channel measurements of specific scenarios and model environments that are found in industrial applications. Based on these measurements, the project is developing suitable integration concepts and is validating the potential and feasibility of proposed technologies. At least one of the selected use case will be show-cased by end-to-end testbeds both in Taiwan and Europe. Finally, new business opportunities from the Industry 4.0 provider's perspective have been identified. 5G CONNI will support industrial players in their Industry 4.0 efforts with comprehensive services and will contribute to a smooth migration path towards 5G-based production facilities.

The 5G CONNI project partners have carried out an extensive measurement campaign in industrial environments. Originally, these measurements were planned for M15 of the project. Due to access restrictions to the measurement environments because of the COVID-19 pandemic, the measurements have been postponed to M18. The collected data have been analyzed and used to produce novel channel models, providing the basis for the ensuing system design. Furthermore, extensive work was carried out towards radio planning and mapping. Simulations using ray-tracing techniques in 3D-modeled trial sites provided insights into cell planning based on the requirements of specific use cases. Novel algorithms to build connectivity maps based on (sparse) measurements were developed.

Expected impact 3: Successfully demonstrate industrial applications in real-world 5G trial systems, potentially with global interconnectivity

A substantial part of the project is the development of end-to-end testbeds by both Taiwanese and European partners. 5G CONNI will demonstrate 5G radio, network and cloud technologies featuring high peak data rates and network density, ultra-low latency, and high reliability as enablers for future Smart Factories. This will be done by integrating private local 5G networks into a multi-site end-to-end industrial communication testbed. By closely collaborating with each other, Taiwanese and European partners will realize an international multi-site 5G Smart Factory demonstrator.

The work towards this expected impact is progressing as planned. Both the Taiwanese and European partners are on track with planning their respective demonstrators and the interconnectivity of the testbeds. D5.1 contains the list of hardware and software components provided by the various partners in order to build the test sites. All the details about EU and TW architectures, based on the motivating use cases (cf. D1.1) and the corresponding models identified in D2.1, are also reported in D5.1. Finally, the 5G CONNI's E2E testbed architecture has been merged into a single framework the EU and the TW setups, with the goal of building a prototype of intercontinental company network deployment that benefits from the technological innovations developed by the project. An initial description of such setup is provided in D5.1 and will be integrated in D5.2 and D5.3.

Expected impact 4: Contribution to trigger and facilitate the fast adoption of 5G CONNI key concepts by industrial players

One main focus of the project is the cooperation towards industrial consensus between Europe and Taiwan on 5G key aspects such as standards, spectrum, architecture and interoperability. Novel technologies on the device, infrastructure and core network levels and their joint optimization will be provided. Another central aspect of 5G CONNI is the interoperability to ensure a barrier-less adoption of the technology by the society and to facilitate the establishment of new economic models. The wide range of demonstrations will be showcased at a key event to reveal the technological achievements in the field of 5G, this validating the potential and the feasibility of the proposed technologies. At least two selected industrial 5G use cases will be realized at interconnected real-world trial sites in Europe and Taiwan.

In the results achieved so far, attention has been paid to the requirements of practical industrial deployments, addressing not only technological but also organizational aspects. By applying this guiding principle, the immediate usefulness of the results for industrial players is increased. Other than that, the work plan towards this expected impact remains unchanged, with all partners actively planning the testbeds and demonstrators. The consortium is closely monitoring the COVID-19 situation and is taking necessary precautions to showcase the achievements in a virtual environment in the case that an in-person demonstration remains impossible. Several partners have experience in showcasing project results in multimedia-based form (e.g., through videos). For example, ITRI has worked with Small Cell Forum and the consortium members to promote project achievements with an online virtual booth at Small Cell World Summit 2021.

Expected impact 5: Contribution to standards and regulation aiming at private industrial 5G, exploiting the EU-Taiwan cooperation for working towards harmonized regulation for spectrum and numbering

Several 5G CONNI consortium partners are strongly involved in pre-standardization and standardization in all 5G relevant fields. The project can therefore rely on the required experience for identifying key elements to be standardized in new generations of technologies and to drive corresponding new proposals. Furthermore, spectrum policies will be discussed with national regulators in both the EU and in Taiwan.

Even though standardization and regulation is heavily impacted by the COVID-19 situation, the 5G CONNI partners are actively following and contributing to standardization and are adopting to the virtualized nature of the meetings.

1.3.1 Impact on academia and research

The project is active in well-known academic conferences such as VTC, GLOBECOM, ICC, ICASSP. In such conferences, the 5G CONNI project has been publishing key results in addition to holding keynotes and invited talks with a range of interested topics for researchers, and hosting workshops and tutorials related to private 5G and beyond in industrial environments. In addition, several journal papers have been published, including one specifically describing the project and selected results in EURASIP JWCN. The still ongoing COVID-19 pandemic remains a challenge for dissemination of scientific results and fruitful exchanges, however, the partners are adapting by making use of now established virtual or hybrid event formats, both by participating and organizing. While these are mostly an inferior replacement of in-person events, they do offer the opportunity to address an even larger audience and remove barriers for participation. Several successful and well-attended events organized and attended by 5G CONNI participants have demonstrated this advantage of virtual dissemination formats.

1.4 Deliverables and milestones

The following tables list the deliverables and milestones that fell into the reporting period captured by this report.

Table 5: List of deliverables

No.	Deliverable Name	Work Packages	Due Date	Delivery Date
D1.2	Report on Relevant Requirements and Concerns Regarding Suitable Operator Models	WP1	31.12.2020	18.12.2020
D4.1	Initial specification and implementation of the building blocks	WP4	31.03.2021	31.03.2021
D6.2	Intermediate Report on Dissemination and Standardization	WP6	31.03.2021	31.03.2021
D5.1	E2E In Lab System Integration Report	WP5	30.06.2021	28.06.2021
D3.1	Report on Measurements & Network Planning Methodology	WP3	31.07.2021	31.08.2021
D2.2	Final Report on Private 5G Network Architecture and Operator Models	WP2	30.09.2021	30.09.2021
D7.3	Second Intermediate Report	WP7	30.09.2021	30.09.2021

Table 6: List of milestones

No.	Milestone Name	Due Date	Delivery Date	Means of verification
M2	5G CONNI trial system architecture definition, including use cases, requirements and operator models	31.12.2020	18.12.2020	D1.1, D1.2, D2.1 delivered
M3	Specification and first implementations of key building blocks finished	30.09.2021	30.09.2021	D2.2, D3.1, D4.1 delivered

2 Update of the plan for exploitation and dissemination of result

No major updates to the project's general dissemination and exploitation plan as laid out in the grant agreement and the dissemination plan (D6.1) are required. Despite the challenges posed by the COVID-19 pandemic, external dissemination activities have continued successfully. An overview of dissemination activities during the first half of the project ist given in the Intermediate Report on Dissemination and Standardization (D6.2). With respect to their individual exploitation plans, the project participants report the following:

HHI

HHI adheres to the original exploitation plan and reports no updates. As a research institution, HHI continues to disseminate technical results primarily in the scientific community by means of scientific publications. Moreover, HHI is specifically active in the area of radio channel measurements and contributes by organizing targeted events and co-chairing standardization activities, which have created channels particularly well suited for dissemination of project results. Meanwhile, the project helps HHI broaden ist overall knowledge of wireless communications in industrial manufacturing and ensure relevance of current and future research conducted in that area.

In the second project year, HHI had an ongoing discussion with ITRI on cross-regional exploitation of project results, exploring options of disseminating them locally, for example via ist membership in 5G Berlin innovation cluster.

BOSCH

BOSCH has been following the initially planned exploitation plan and there are no updates to the plan itself. In addition to the exploitation of the results of the first project year, in the second year, BOSCH could considerable make use of the understandings of the different operator models and their evaluations, the channel measurements at one of BOSCH's plants and the further development of concepts and algorithms around the planned use case demonstrator. Furthermore, BOSCH's continues to explore new business opportunities with regards to Industry 4.0 in general and 5G-enabled factories in particular.

ATH

For ATH, there is no update on the exploitation plan as the work proceeds as planned.

Specifically, ATH is accelerating the market growth, and, to a broader extent, increasing the awareness and business opportunities of private cellular networks for the industry vertical.

Furthermore, ATH has been active in the diffusion of project activities via scientific publications, standardization contributions, and attendance/hosting of public events.

CEA

CEA has followed the exploitation plan proposed in 5G CONNI proposal and there are no update to the original plan. 5G CONNI project will contribute to increase CEA know-how on connectivity in factory of the future, to better understand current industry needs, and to identify new challenges for its future research activities. At short term, the outcomes of CEA's investigations on multiple access schemes and mobile edge computing, having the specific targets of improving QoS (reliability, latency, availability...) in future 5G URLLC networks, will be protected through patents whenever applicable, disseminated through publications in high-rank international conferences, journals, and workshops and promoted in several events. On a longer term, the results of 5G CONNI will contribute to enhance the offers of CEA to industrial partners in search of wireless URLLC solutions in the context of factory of the future applications.

SAP

SAP is currently disseminating 5G CONNI research related results through the publication of journal papers in high quality and impact journals, as well as conference papers in (mostly IEEE) conferences and workshops. During the second year of the project this dissemination plan led to the publication of 4 IEEE journal papers and 2 IEEE conference papers. The results obtained within 5G CONNI will also open the possibility to introduce the topic in the education courses of students at the university, and to assign master and PhD theses.

ITRI

There are no updates on the exploitation plan from ITRI. Based on the outcomes and deliverables produced in second year, ITRI has achieved a good understanding of vertical 5G-enabled use cases, private networks, and the end-to-end system integration. In addition, despite the impact of COVID-19, ITRI has organized a virtual dissemination activity at Small Cell World Summit 2021, where a virtual booth was setup and a speech has been made at industry 4.0 session.

ANI

There is no major update to the plan of exploitation. In the second project year, Alpha Networks has delivered prototype of RAN components, and the integration work of RAN, CHT MEC, and III core network are still ongoing. We will continue working with CHT, III, and ITRI for E2E system integration.

CHT

For CHT, there is no update on the exploitation plan, and the work item proceeds as planned. This year, we launched MEC 5G SA prototype and integration with III's 5G core network, ANI's 5G base station and ITRI IMTC's Process Diagnostics using Augmented Reality application, which was exhibited on IEEE Globecom2020 and 2021 Small Cells World Summit virtual booth. We will keep developing the MEC 5G SA for the functional and non-functional requirements of industrial applications in the 5G CONNI project.

III

III is the main maintainer and key contributor of the 5G SA core network for use cases in Taiwan demo site. For the additional exploitation plan from III, include deploying the III Core on kubernetes platform for system integration. Future more III provide the OAM system that can shows the Tabs of OAM Dashboard for general 5G Core execution information that includes the information like CPU Usage, Memory Usage and the healthy management of each PODs.

3 Update of the data management plan

Not applicable.

4 Follow-up of recommendations and comments from previous review(s)

The project received the review report for the first project year three months in to the second year, i.e., January 2021. The recommendations contained in this report were carefully considered by the 5G CONNI consortium and are replied to as follows:

Listing of project related publications

A list of publications has been added to the project website

Advisory panel

During the second project year, members of the advisory panel have been participating in General Assembly meetings and given access to deliverables prior to submission. A suitable member from the Taiwanese side has not yet been identified.

Channel measurement contingency plan

A multi-stage contingency plan has been defined and implemented. Channel measurements have been carried out in March 2021 to the full extent planned, adding a third frequency band at 300 GHz as compared to the original work plan to maximize utilization of industrial facility access and potential impact on research beyond 5G.

Interconnected demo definition

A discussion of use cases for the interconnected test bed has been included in D2.2. Discussion on implementation details for the remote expert / monitoring use case is ongoing.

Changes to deliverable D1.1

The 5G CONNI partners appreciate the reviewers' constructive feedback regarding the deliverable D1.1. Accordingly, additional insights with respect to the selection of the use cases have been added to sections 2.6.1 and 2.6.2, and an elaborate description for the peculiarities of UC-2 and UC-3 is provided in a new section 3.3.

Changes to deliverable D2.1

Editorial changes have been implemented a more detailed comparison, including a SWOT analysis and selection of architecture is included in D2.2

Changes to deliverable D6.1

A detailed survey on planned dissemination activities has been conducted among consortium members. Active participation in standardization including contributions has been reported by HHI (IEEE, ITU) and ATH (ETSI). Willingness to contribute without concrete plans was expressed by BOSCH, III. Participation in standardization relies heavily on individual partners' commitment and general activity beyond the project. Currently, partners previously participating in 3GPP standardization have reduced their resource commitment in this body due to reasons outside this project's influence.

Contact with the German national telecommunications regulator has been established to discuss the project's findings.

Changes to deliverable D7.1

A detailed periodic risk assessment procedure was defined and established

Changes to deliverable D7.2

Updates of the risk assessment and contingency plans have been provided. The observed discrepancies pertaining to the number of publications have been resolved.

5 Deviations from Annex 1 and Annex 2

5.1 Tasks

As shown in Sec. 1.4, D3.1 was submitted with delay. Due to the nature of the information contained therein, a prolonged approval procedure was required at one participating beneficiary with key personnel reacting with delay due to summer vacations.

5.2 Use of resources

5.2.1 Unforeseen subcontracting

Not applicable.

5.2.2 Unforeseen use of in kind contribution from third party against payment or free of charges

Not applicable.

Annex I: Summary of the work carried out by each beneficiary

Work Package 1

Partner	Description of work
HHI	N/A
BOSCH	BOSCH has been leader of Work Package 1 and Task 1.1 on the European side. In the second project year, BOSCH's focus was on the concerns and requirements regarding suitable operator models for private 5G networks. Here, BOSCH cooperated closely with CEA to set up different questionnaires to explore this topic together with all other involved partners. The questionnaires considered different operator model dimensions, as described in Section 3.1 of D1.2. The structured analysis of concerns and requirements helped BOSCH considerably to deeply understand the benefits and pitfalls of different operator models that are highly relevant to the BOSCH plants. Concerns and requirements were intensively analyzed Bosch-internally against various internal regulations and practical challenges. Finally, BOSCH has driven forward - with general approval by the consortium - the methodology to rate the different operator models in light of the various requirements. BOSCH has also been the editor of D1.2.
ATH	After having contributed to D1.1, especially in Section 2.2, where relevant use cases for functional requirements were proposed, Athonet participated to a few preliminary discussions related to operators model evaluations as part of the preparation of D1.2, though not being actively involved to T1.2.
CEA	CEA was Task1.2 leader on Requirements and concerns regarding suitable operator models. CEA organized several T1.2 phone calls, studied private 5G factory network requirements and evaluation methodology and contributed to D1.2 deliverable. CEA cooperated closely with BOSCH to set up different questionnaires to explore this topic together with all other involved partners. CEA helped to define characteristics of operator models, stakeholders involved in operator models, private 5G network lifecycle, interdependence between operator an deployment models and about concerns and requirements regarding operator models. Part of these results have been included in a EURASIP journal paper with all other partners.
SAP	N/A
ITRI	In the second year of the project, ITRI has contributed to task 1.2 on the requirements and concerns regarding suitable operator models. In particular, ITRI worked closely with BOSCH, CEA and CHT to provide inputs to different questionnaires on the characteristics of an operator model for private 5G networks. Finally, ITRI has worked on quantitative analysis on different operator models, which can be used to verify and validate that a certain operator model can be satisfactorily adopted.
ANI	N/A
CHT	Chunghwa Telecom contributed to D1.2 in section 3 characteristics of an operator model for private 5G network, Annex 1 lifecycle description, and required competencies and Annex 2 elements touched during private 5G network lifecycle. Review all sections of D1.2, and provide comments in section 2 preliminary considerations, section 3 characteristics of an operator model for private 5G networks, section 4 interdependence between operator and deployment models and section 5 concerns and requirements regarding operator models. Chunghwa Telecom has participated in the bi-weekly work package conferences and discussed concerns about definition, lifecycle and requirements regarding operator models. Chunghwa Telecom also contributed to D1.2 in section 4 interdependence between operator and deployment models by questionnaires.

III	III participated in the WP1 weekly calls, and analysis of innovative use cases and their associated requirements for 5G in an industrial setting. we also evaluates whether to relate functional requirements in table (section 2.4) to the ones provided in section 2.2; reduces description of use case (groups) in section 2.4 to 3 lines

Work Package 2

Partner	Description of work
HHI	As work package lead of WP2, HHI has continued to moderate the discussion on the 5G CONNI demonstration system architecture via regular conference calls and mailing list exchanges. As part of the operator model evaluation efforts in WP2, HHI conducted a SWOT analysis on the different architecture options laid out in D2.1 with the partners providing input from different stakeholder's perspectives. As editor of D2.2, HHI structured the inputs from WP2 participants and aimed for a consolidation of WP2 and WP1 work.
BOSCH	In Work Package 2, BOSCH has been contributing to the discussions to refine the overall 5G CONNI system architecture and its various components (i.e. the combination of the different architectural options and operator models). The definition of the intercontinental setup between the EU and Taiwan substantially helped BOSCH to obtain a deep understanding of the architectural and practical challenges and solutions for private 5G networks that span across multiple sites. This is especially important as BOSCH has also a large number of worldwide distributed manufacturing sites. The most important aspect for BOSCH in Work Package 2 has been the evaluation of the operator models, e.g. the SWOT analysis, based on the preparatory work in Work Package 1, which itself resulted in D1.2. Here, BOSCH refined the methodology and coordinated the execution of the operator model evaluation, so that the models have been evaluated from different perspectives (as represented by the involved 5G CONNI partners) against the defined requirements in D1.2. BOSCH also contributed substantially to the consolidation and description of the final results of the operator model evaluation in D2.2. BOSCH is also the leader of Task T2.2 on the European side.
ATH	Athonet regularly attended calls for contributing to WP2, especially as task leader in T2.1. Athonet contributed to the user stories, to the network architecture design (network function mapping), and to deliverables D2.1 and D2.2. In particular, Athonet provided inputs to Section 2.2.2, 2.2.3, and 2.2.4 of D2.1, respectively related to SIMs, RAN, and core assets. Further, Athonet participated in the definition of two 5G network architecture options that are deeply described in Section 3.1 and 3.2 of D2.1, with related ownership and governance details. This helped organize and harmonize the graphical elements for the final representative building blocks. Finally, Athonet provided edits/remarks through the document. After that, Athonet worked on the SWOT analysis of the architecture options and on the evaluation of the operator models that are presented in D2.2. As discussed in this deliverable, this helped making the final decisions on the architectural setups adopted in WP5 for the European and end-to-end testbeds.
CEA	N/A
SAP	N/A
ITRI	ITRI has been involved in Task 2.2, which covers the full 5G CONNI enterprise Private 5G Network and system architecture, including solutions for multi-site interconnectivity. As a starting point, a SWOT analysis on four architecture options described in D2.1 has been performed. In addition, ITRI has contributed to section 4.3.2 MVNO model in operator model evaluation chapter where model-specific

	results have been provided from the perspective of different stakeholders. In section 6, ITRI has provided inputs to the main architectural features of Taiwanese setup. Finally, ITRI has worked with BOSCH to propose five interconnected use cases and identify the benefits, scenarios and implications on architecture for each use case. One of the use cases (UC5: Remote expert support for process diagnosis) has been adopted as the demonstrator.
ANI	N/A
CHT	Chunghwa Telecom contributed to D2.2 in the area of SWOT analysis of deployment model and operator model evaluation. In the operator model evaluation, CHT contributed to MNO's perspective and proposed some statements of the evaluation results. Chunghwa Telecom has participated in the regular work package 2 conferences to discuss the EU-TW interconnected use case and demo architecture.
III	III participates in the WP2 regular calls, and analysis the overall system and network architecture addressing the specific requirements of private 5G networks; also discuss the architecture for the European and Taiwanese trial site, as well as solutions for their interconnectivity. We participated in section 4.3, and also focus on the section 6.2

Work Package 3

Partner	Description of work
HHI	Activities in WP3 were focused on conducting the planned radio propagation channel measurement campaign in an industrial environment. Due to the COVID-19 pandemic the campaign which had originally been planned for H2/2020 had to be moved to Q1/2021. In preparation, HHI integrated its channel sounding systems into a transportable setup, which was then used at an active production plant of BOSCH. Channel measurements were conducted in the different scenarios that had been previously defined in WP3 at the three frequencies 3.7 GHz, 28 GHz and 300 GHz. At each frequency, spatially resolved measurement techniques were used. HHI contributed an initial evaluation and analysis of the measurement results to D3.1 and will continue to work on more detailed analyses for D3.2. To validate and characterize performance of directional channel sounders, HHI developed new verification methodology based on multi-path compact antenna test ranges. Furthermore, HHI designed and built prototype hardware to realize the distributed clock synchronization system concept that had been developed during the first year of the project.
BOSCH	The global COVID-19 pandemic has been limiting and delaying the work in Work Package 3, in particular the one related to the channel measurements in the BOSCH plant. Nevertheless, measurements could take place in March 2021. Here, BOSCH planned, coordinated and supported the measurement campaign in close cooperation with HHI and the plant responsibles.
ATH	N/A
CEA	N/A
SAP	As leader of WP3, SAP has coordinated the activities that brought to produce the deliverable D3.1. SAP has also been the leader of Tsk 3.1, within which it extended the analysis of the method proposed for building a connectivity map from sparse measurements, employing tools from the newly developed field of topological signal processing. SAP has also made a plan with ITRI to apply the method to real data provided by ITRI. As leader of Tsk 3.2, coordinated the activities and developed a method for the optimal placement of edge cloud resources,

	mainly virtual machines and contents, in order to minimize the service delay., including communication and computation delays.
ITRI	In Work Package 3, ITRI has worked on the cell planning of private 5G network at IMTC to predict the radio coverage and quality. In particular, ITRI has proposed two-phase cell planning methodology, namely phase1: Coverage and Key Performance Metric Analysis and phase2: System Performance Evaluation of Real-life Network Deployment. In phase 1, two main network parameters, namely SS-RSRP and CSI-SINR have been used to evaluate the coverage. For phase 2, ITRI has incorporated the traffic map of vertical use cases described in D1.1 in order to evaluate the performance of real-life network deployment. Finally, the system performance simulation results have been provided, which shows the number and location of base stations that we should deploy to ensure the target requirements of vertical applications will be met.
ANI	Alpha Networks is the leader of WP3 in Taiwan side. In the 2nd project year, Alpha Networks continues work with ITRI for Task 3.1 cell planning and simulation. Alpha Networks has contributed to D3.1 in section 7, network monitoring and RAN monitoring.
CHT	Chunghwa Telecom contributed to D3.1 in section 7.3 edge cloud monitoring and presented partners with the ECoreCloud monitoring system on the general assembly. Chunghwa Telecom has participated in WP3 regular monthly conference calls for discussing network planning and given technical presentations regarding MEC monitoring systems. Chunghwa Telecom also contributed to D3.1 in the area of further results regarding private 5G network monitoring.
III	III has been attending the regular project meetings and discussing the planning, operation and maintenance of the private network which is designed for the industrial use cases with CONNI partners. III provide the OAM system that can shows the Tabs of OAM Dashboard for general 5G Core execution infor-mation that includes the information like CPU Usage, Memory Usage and the healthy management of each PODs.

Work Package 4

Partner	Description of work
HHI	N/A
BOSCH	N/A
ATH	Athonet attended the calls of WP4, especially as task leader in T4.2 and T4.3. As part of T4.2, Athonet has been working on the ETSI NFV-like instantiation and orchestration of legacy 4G first and then 5G mobile core network components via OSM. The framework has been successfully tested in-lab as well as during the recurrent ETSI NFV Plugtests. Using the Athonet VNFDs, it is possible to integrate the mobile core network with MANO implementations derived from OSM and from ONAP, provided by different vendors. In T4.3, the solution for MEC deployments for the full-on-site and the hybrid architectures has been designed and testing is ongoing in preparation of the final demonstrations.
CEA	As WP4 Leader, CEA organized regular WP4 phone call and moderated the discussion about 5G CONNI technical enablers for industrial application. CEA, as editor, contributed and finalized D4.1 deliverable on initial specification and implementation of building blocks. CEA has investigated how to enable deterministic URLLC. For that purpose, CEA has worked on the design of the network orchestrator and on the combination of URLLC mechanisms using NS3 simulator. Moreover, CEA has investigated novel HARQ scheme for early decision-making. This work resulted in the submission of a conference paper applied to HARQ

	mechanisms and a patent. CEA has also collaborated with SAP on dynamic resource allocation for computation offloading and on semantic and goal oriented communications. CEA is currently working on scheduling strategies for URLLC (determinist vs. opportunist approaches). CEA has initiated the discussion about the Table of contents of the next deliverable (D4.2)
SAP	In WP4 SAP developed and tested algorithms for the dynamic allocation of radio and computational resources in a monitoring system where peripheral devices collect data and send them to an edge server that runs machine learning algorithms to take decisions about the observed data. The allocation is carried out in order to find an optimal balance between energy consumption, service delay, and accuracy of the decisions take by the edge server. Different constraints are incorporated in the method, including service delay, which incorporates queueing delay in the communication and computation queues, and energy consumption. Furthermore, SAP has started developing methods for dynamic service placement, generalizing the methods developed in WP3 to the dynamic case.
ITRI	In this Work Package, ITRI has been involved in Task 4.4 and worked on three vertical use cases, namely (1) Process Diagnostics by CNC and Sensing Data Collection (2) Using Augmented/Virtual Reality for Process Diagnosis (3)Cloud-based CNC . Among these implemented use cases, (1)&(2) were implemented on a five-axis machine tool and (3) was implemented on a flexible fixture system, which is a specialized machine to test the cloud-based controller. For use cases(1), 6 accelerometers were installed on the five-axis machine tool. Machining data and CNC data were collected and sent to the tool condition monitoring software deployed in MEC. For use case (2), 3D model of the machine have been created. Two application were developed for machine operator and remote expert, these two applications share the same 3D machine model and synchronized by the machine data from the WebAPI server developed by IMTC. The prototype of cloud CNC has been developed and tested on the flexible fixturing system by sending vibration suppression motion commands from cloud controller to the ground controller to evaluate overall performance.
ANI	Alpha Networks the task leader of Task 4.1 in Taiwan side. In the 2nd project year, Alpha Networks continues working on RAN system development, including 5G CPE and gNodeB, and has provided 5G SA RAN prototype. Alpha Networks has contributed to D4.1 section 4, Radio Network Technical Enablers.
CHT	Chunghwa Telecom is the leader of Work Package 4 and Task 4.3 on the Taiwan side, and has been actively contributing to and coordinating technical enablers for industrial applications. CHT has participated in WP4 regular four week's conference call and collected the development progress of 5G network components and industrial applications progress of each partner. Chunghwa Telecom has provided the 5G SA prototype bump-in-the-wire MEC platform and still developed multi-PDUsession and multi-QoSflow functions. Chunghwa Telecom has provided ECoreCloud (ECC) NFV platform and MANO to manage Mobile Edge Enabler (MEE) VNF. Chunghwa Telecom contributed to D4.1 in section 2.2 MEC part of design considerations and section 6.2 MEC 5G SA prototype.
III	III participates in the WP4 regular calls, we have enhanced the 5GC prototype for its performance and efficiency by the specific architecture and interfaces

Work Package 5

Partner	Description of work
HHI	HHI's work in WP5 has been focused on the in-lab integration of the 5G system to be used in the European part of the demo setup. Specifically, a virtualized Open RAN system was integrated into a self-contained, transportable rack, which

	may later be moved to the demonstration site. In parallel, infrastructure at HHI's site was prepared for later integration of the interconnected multi-site demonstrator. Preliminary integration tests with the core network provided by Athonet werde performed. The results of these activities were contributed to D5.1.
BOSCH	In Work Package 5, BOSCH has been actively contributing to the discussions around details of the overall 5G CONNI architecture and its implementation (in-lab integration). Furthermore, detailed in-factory integration discussions led to first ideas and plans to (1) integrate BOSCH's use case with the 5G System and (2) integrate the 5G system with the Enterprise IT, especially in light of the inter-continental 5G CONNI setup. Besides this, BOSCH's main activities were focused on the implementation of a test robot (Franka Emika) with intelligence, i.e. path planning control function as a closed control loop, outsourced to an edge cloud (currently a PC workstation). Most effort so far, was related to the implementation of the closed loop control function, which is robust enough to deal with 5G System latency and jitter, while preserving accuracy of the executed trajectory. Since no 5G System was ready yet for integration with the application, 5G latency was emulated between the robot and the edge cloud application.
ATH	Athonet led the activities of WP5 together with the WP co-leader ITRI, keeping a special focus on the European setup and the end-to-end system integration. Athonet organized regular monthly calls with all partners involved in WP5, as well as dedicated calls with relevant partners on specific aspects of the integration activities. Athonet coordinated the preparation of D5.1 together with the WP and T5.1 co-leader ITRI. The deliverable starts with an overview of the general 5G system architecture adopted by 5G CONNI. A functional architecture is defined, based on the motivating use cases (cf. D1.1) and the corresponding models identified in D2.1. This is followed by a presentation of the hardware and software components provided by the partners in order to build the test sites. Next, the initial testbed deployment plan is described, including a presentation of the preliminary integration tests and tools. As an individual participant to the WP5, Athonet run performance and acceptance tests of the software which will be provided to the final demonstration of the project.
CEA	CEA contributed to D5.1 deliverable and made the review of the final version. CEA participated to WP5 phone calls and to discussion related to WP4 building block transfer as WP4 Leader.
SAP	In this WP, SAP has followed the activities carried out in Task 5.1 with the goal of identifying the algorithms that are more suitable for being integrated in the testbed.
ITRI	As the leader of Work Package 5, ITRI has been actively involved in Task 5.1: Realization of the selected use cases, which covers the in-lab system integration as well as the envisioned end-to-end setup. In this task, ITRI's focus is on the Taiwanese system integration in the lab environment. The in-lab test program with four phases and four test configurations has been proposed to ensure that all the subsystems will work together properly for the selected use cases in a pre-live industrial environment. A total of 37 test cases have been designed for the test program. Moreover, ITRI has not only reported several interoperability and performance issues but also identified the root causes to some extent and compiled the issue list for equipment vendors including III and Alpha. In addition, two implementation options and software/hardware requirements have been provided for the interconnected use case to be demonstrated (UC5).

ANI	In the 2nd project year, Alpha Networks has been working on integration of the network components, and E2E interoperability and performance tests. Alpha Networks has contributed to D5.1 section 3, Hardware and Software Setup.
CHT	Chunghwa Telecom contributed to D5.1 in section 3 MEC part of hardware and software setup and section 4 cooperation with ITRI for MEC integration plan test. CHT deployed MEC 5G SA version prototype and integrated with AR use case at ITRI IMTC site for Globecom 2020 demo. Chunghwa Telecom has participated in WP5 regular monthly conference calls for discussion of the EU-TW architecture and progress of deployment and test.
III	III participated in the WP5 weekly calls, and join the Field testing wiith other component. Also doing the trouble shooting and version upgrade for the 5G core

Work Package 6

Partner	Description of work
HHI	HHI has contributed to WP6 by (co-)authoring three publications: “Over-the-Air Verification of Angle-of-Arrival Estimation in Millimeter-Wave Channel Sounders” and “Channel Measurements and Large Scale Parameter Estimation in an Industrial Environment” that were submitted to IEEE VTC Fall, and and “Beyond Private 5G Networks: Applications, Architectures, Operator Models and Technological Enablers”, which is submitted to the EURASIP Journal on Wireless Communications and Networking. Furthermore, HHI co-organized a workshop on Terahertz Channels and Systems in collaboration with 5G mmW Channel Model Alliance, IEEE VT-S Propagation Committee, and IEEE SA P2982, and contributed channel propagation data to the ITU DBSG3.
BOSCH	BOSCH has been actively contributing to and co-authoring two publications: “Channel Measurements and Large Scale Parameter Estimation in an Industrial Environment”, which is submitted to IEEE VTC Fall, and “Beyond Private 5G Networks: Applications, Architectures, Operator Models and Technological Enablers”, which is submitted to the EURASIP Journal on Wireless Communications and Networking. BOSCH is further closely following 3GPP activities with respect to non-public networks, security and the outcomes of related study and work items.
ATH	Athonet contributed to Tasks 6.1-6.2, as well to the Deliverable D6.1 and D6.2. In particular, Athonet co-authored the following papers with other project partners: 1. “Beyond Private 5G Networks: Applications, Architectures, Operator Models and Technological Enablers”, submitted to EURASIP JWCN, Apr. 2021. 2. “Energy Efficient Edge Computing: When Lyapunov Meets Distributed Reinforcement Learning,” presented at IEEE ICC Workshops, June 2021. 3. “Discontinuous Mobile Edge Computing,” submitted to IEEE TGCN, June 2021. Moreover, Athonet hosted the UPTIME conference, held on Jan. 27, 2021, at Villa Marconi, Bologna, Italy, where a dedicated session was hosted for EU funded projects and 5G-CONNI was presented and discussed. Also, Athonet gave a presentation entitled “5G CONNI: an overview” at the Small Cells World Summit (SCWS) 2021 – Session on “Industry 4.0 and Private Networks, Edge Computing” in collaboration with 5G CONNI partners. Athonet contributed to the work item DGS/MEC-0033 IoT API, under ETSI MEC ISG. Finally, Athonet presented the project activities to academic seminars held at the University of Milan Bicocca and University of Naples Federico II.

CEA	CEA led and actively contributed to the 5G CONNI joint conference paper published to GLOBECOM and is the editor of the 5G CONNI joint journal paper submitted to EURASIP and accepted under minor revision. CEA contributed to a joint paper with SAP on energy efficient edge computing and on semantic and goal oriented communications. CEA has submitted a paper for improving HARQ for URLLC to an IEEE CCNC2022 conference. CEA has submitted a patent on early decision maker for URLLC. Moreover, CEA has organized or participated to events promoting 5G CONNI project (e.g., summer school in como lake, Workshops WDN-5G&6G in WCNC 2020, cloud and energy efficiency in ICC, Tutorial in IEEE CCNC 2020)
SAP	SAP has contributed extensively to the dissemination activities by promoting 5G CONNI through 3 invited talks at international workshops and promoting the project in a PhD summer school. SAP published also 4 journal papers in top class journals and 3 conference papers in renowned international conferences.
ITRI	As the work package contributor, ITRI has worked with Small Cell Forum to organized the dissemination activity at Small Cell World Summit 2021 to promote project results. In particular, an online virtual booth has been setup to display project achievements. Moreover, ITRI has organized a speaking slot in the session “Industry 4.0 and Private Networks, Edge Computing”, which was presented by Athonet from the perspective of 5G CONNI project.
ANI	In the 2nd project year, Alpha Networks has contributed to 5GCONNI EURASIP JWCN, Beyond Private 5G Networks, section 6.2 Monitoring. Alpha Networks has contributed to D6.2 section 3.2, Partner Update.
CHT	Chunghwa Telecom contributed to the EURASIP JWCN journal paper for section 6.4 key enabling technologies. Chunghwa Telecom has participated in the biweekly Taiwan site conferences and discussed demonstrations for Small Cell World Summit 2021. Chunghwa Telecom also contributed to D6.2 in the area of section 3.2 partner update.
III	III is the main maintainer and key contributor of the 5G SA core network for use cases in Taiwan demo site. For the additional exploitation plan from III, include deploying the III Core on kubenetes platform for system integration. Furthermore, for monitoring the 5G system execution and resource usage status for applications, III also develops and enhances the OAM system to raise the performance and manage the resource.

Work Package 7

Partner	Description of work
HHI	In its role as the Project Coordinator, HHI’s work in WP7 encompassed all administrative project management duties and an interface role between the consortium, EC and the Taiwanese 5G Office. HHI continues to host monthly management calls with the assistant Project Coordinator at ITRI as well as consortium calls. Two two-day consortium meetings were organized, both of which had to be held virtually due to the COVID-19 pandemic. HHI also closely collaborated with the project’s Technical Manager at ITRI on technical project management, contributing to monitoring of progress in individual work packages and quality assurance by overseeing creation of deliverables and subsequent reviews. Due to the still ongoing COVID-19 pandemic, HHI has implemented a continuous risk monitoring process to keep track of possible impacts on the project.
BOSCH	BOSCH has been participating in the regular project meetings, the review meeting and the virtual general assembly, and has contributed to almost all project deliverables and reports (except for Work Package 4).

ATH	Athonet contributes to the planned project reports in collaboration with 5G CONNI partners.
CEA	CEA has been participating in the regular project meetings, the review meeting and the virtual general assembly, and has contributed to the project deliverables and reports.
SAP	Sapienza contributes to the planned project report, has participated in the monthly consortium meetings and the bi-annual virtual General Assembly meetings.
ITRI	As the assistant project coordinator, ITRI has been involved in every work package and covered all technical and research related coordination as well as interfacing with the 5G Office. ITRI has been organizing bi-weekly project management calls to monitor and coordinate all technical work packages on Taiwanese side. In the meantime, ITRI worked with project coordinator HHI to share responsibilities for administrative project management between the European and Taiwanese side of the consortium.
ANI	Alpha Networks has been participating monthly project meeting, WPs' meeting, and virtual general assembly. Alpha Networks has also participated bi-weekly project review meeting in Taiwan side.
CHT	Chunghwa Telecom has participated in monthly general meetings to know the organization issues, the progress of each work package and risk assessment. Chunghwa Telecom attended Virtual General Assembly meetings to discuss the work carried out by each partner.
III	III has been attending the regular project meetings and discussing the planning and working on D7.3