5G CONNI

Private 5G Networks for Connected Industries

Deliverable D7.4

Final Project Report

Co-funded by the Horizon 2020 programme
of the European Union in collaboration with Taiwan

Date of Delivery: 30.12.2022
Project Start Date: 01.10.2019 **Duration:** 39 Months

Document Information

Project Number:	861459
Project Name:	Private 5G Networks for Connected Industries

Document Number:	D7.4
Document Title:	Final Project Report
Editor:	Sven Wittig (HHI)
Authors:	Sven Wittig (HHI) Mathis Schmieder (HHI) Henrik Klessig (BOSCH) David Ginthoer (BOSCH) Nicola di Pietro (ATH) Daniele Ronzani (ATH) Daniele Munaretto (ATH) Mickael Maman (CEA) Lam Dinh (CEA) Emilio Calvanese Strinati (CEA) Sergio Barbarossa (SAP) Jack Luo (ITRI) Shuo-Peng Liang (ITRI) Winson Huang (ANI) Jen-Hau Chan (CHT) Kiun-Cheng Huang (CHT) Yueh-Feng Li (CHT) Frank Chih-Wei Su (III)
Dissemination Level:	Public
Contractual Date of Delivery:	31.12.2022
Work Package	WP7
File Name:	861459-5G CONNI-D7.4-Final Project Report-v1.0.docx

Revision History

Version	Date	Comment
0.1	21.12.2022	Initial contributions
0.2	22.12.2022	Sec. 1.3: Integrated Impact section Annex I: Changes to HHI subsections
0.3	23.12.2022	Integrated contributions by SAP to Sec. 1.2.3, Sec. 2, Sec. 4 and Annex I
0.4	23.12.2022	Added Sec. 1.1 Cleaned up sensitive information
0.5	28.12.2022	Editorial changes
1.0	30.12.2022	Version for submission

Table of Contents

List of Figures

List of Acronyms

5G	5th Generation of mobile cellular networks
5G CONNI	5G for Connected Industries
5GC	5G Core network
AR	Augmented Reality
CDU	Central/Distributed Unit
CNM	Core network monitoring
CP	Control Plane
CPE	Customer premise equipment
DoA	Direction of arrival
E2E	End-to-End
eMBB	Enhanced mobile broadband
ETSI	European Telecommunications Standards Institute
EU	European Union
FM	Fault management
FSPL	Free-space path loss
gNB	gNodeB (5G base station)
IoT	Internet of Things
ISG	Industry Specification Group
KPI	Key Performance Indicator
LOS	Line-of-sight
MEC	Multi-access Edge Computing
NFV	Network Function Virtualization
NLOS	Non-line-of-sight
NPN	Non-Public Network
NS	Network Service
NSS	Network Slice Subnet
OAM	Operation Administration and Maintenance
OSM	Open Source MANO
RAN	Radio Access Network
RF	Radio Frequency
RMS	Root mean square
RU	Radio unit
TW	Taiwanese
UE	User Equipment
UP	User Plane
URLLC	Ultra-reliable low-latency communication
VNF	Virtual Network Function
VR	Virtual reality
VUCA	Virtual Uniform Circular Array
WP	Work Package (most frequently followed by a number)

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

After the third and final year of the project, the 5G CONNI consortium has successfully concluded technical work with the demonstration of three selected use cases for 5G in industrial applications. During this last reporting period, the ongoing efforts of all partners converged in an international end-to-end 5G network demonstrator spanning three geographical locations and realizing multiple new deployment models for non-public networks. A further intensified communication and collaboration within the consortium led to an exchange of data and technology that is reflected in the achieved results and the demonstration system itself. As documented in the present report, the objectives set out for the project have been achieved.

1.1 Objectives

Six distinct objectives have been laid out for the 5G CONNI project have been laid out in the work plan. This section presents the progress on each objective as achieved by the work in the first 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 final reporting period, work towards it has been carried on in the following work packages:

- WP4: Implementation work on the two demonstration use cases “Process Diagnosis Using Augmented/Virtual Reality with CNC and Sensing Data Collection” and “Cloud-based Controller for Fixture System” was finalized, the former also being the basis for the global inter-site demonstration use case. Detailed documentation is provided in deliverables D4.2 and D4.3.
- WP5: Based on the in-lab pre-integration work of the previous reporting period, the end-to-end 5G network for the 5G CONNI system was moved to and installed at the respective manufacturing facilities in Europe and Taiwan. Preliminary performance analyses and use case integration progress was reported in D5.2. The finalized overall system architecture, including integration between the different international sites is presented in D5.3 along with a performance analysis and discussion of the implemented industrial use cases.

1.1.1.2 Status of the objective

With the successful demonstration of one use case at the European site of the 5G CONNI demonstration system, two use cases at the Taiwanese site and one globally interconnected use case shared between both sites, the objective has been fully achieved.

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 final reporting period, work towards it has been carried on in the following work packages:

- WP3: The last reporting period included a further, more comprehensive analysis of the radio propagation measurement data that had previously been collected. In addition to angular parameters, the indoor-to-outdoor measurements and measurements at 300 GHz have been processed with results reported in D3.2. Furthermore, the signal map algorithm of D3.1 was tested on data from the IMTC demonstration site.

1.1.2.2 Status of the objective

After the bulk of work towards this objective had been carried out in the second reporting period, the past year focused primarily on the remaining scenarios and parameters of the measurement campaign. In addition, comparison between measurement and simulation and algorithm validation was performed, helping to ensure the relevance of the achieved results with respect to this 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 final reporting period, work towards this objective has been carried on in the following work packages:

- WP4: Development on the components of the 5G system to be deployed as part of the 5G CONNI demonstrators was concluded, with some results already going beyond what has been integrated in the end-to-end system. Novel approaches for URLLC communication are also presented in deliverables D4.2 and D4.3.

1.1.3.2 Status of the objective

Further developing the results already achieved during the first two years of the project, the technologies and components developed mainly as part of Work Package 4 were used in the integration work of Work Package 5 to set up the overall system demonstrator in the factory environments. A significant part of the investigated technologies was shown in the end-to-end use case demonstrations.

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 final reporting period, work towards this objective has been carried on in the following work packages:

- WP6: The results of WP1, WP2 and WP3 have been presented and discussed in detail with the German national telecommunications agency.

1.1.4.2 Status of the objective

Through the results achieved within the project, a fruitful exchange between HHI and BNetzA has been established. Campus deployments and non-public networks remain a topic of high relevance to industry and other players, with the regulatory situation just starting to accommodate their specific requirements. This informal and pragmatic channel thus offered both BNetzA and, via HHI, the 5G CONNI consortium a valuable platform to exchange experiences from practice.

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: Development and integration of monitoring solutions for radio-level KPIs such as throughput and latency in the RAN equipment used at the Taiwanese demonstration site.
- WP5: Continuation of the test and integration plan towards the final end-to-end demonstrator system. For the use cases, detailed measurements covering throughput and latency under different load conditions and analysis of their influence on the application performance were conducted.

1.1.5.2 Status of the objective

With the industrial applications completely implemented and integrated into the demonstration system, comprehensive performance evaluations in a real-world environment became possible. The demonstrations themselves and the measurements obtained from them help to create a better understanding of the capabilities and challenges of current 5G wireless technology in the new application areas that were targeted in its inception.

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

- WP5: The last year of the project saw a particularly strong interaction between partners and integration between their different contributions while working on the overall integration of the 5G CONNI demonstration system. In particular, by testing interoperability and integrating network components developed by both European and Taiwanese partners into one site of the European part of the 5G CONNI network, as well as developing a unified provisioning system for the entire network, partners had the opportunity to gain valuable insights and improve their technology. Finally, the highly relevant remote expert use-case was realized between the interconnected European and Taiwanese sites of the network, based on a common technology platform.
- 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 publications in scientific conferences and journals highlighted individual technical results. Internal dissemination of the project results within the project partner's organizations ensured an impact on their future operations.

1.1.6.2 Status of the objective

The objective has been fully met during the third project year with a further intensified interaction between all partners. All partners have been engaging in active and open discussion, leading to a better mutual understanding of the application and wireless networking domains. Interoperability and integration of the contributions by all partners remained an important aspect during this year, thus creating the opportunity to improve and advance the partner's technologies. Additionally, technology and data was shared between partners and regions, leading to a joint demonstration and several joint publications.

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 within the second year. With this, there were no activities to be reported for this reporting period.

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 within the first year of the project.

1.2.1.2.2 Task 1.2: Requirements and Concerns Regarding Suitable Operator Models

Task 1.2 has been concluded within the second year of the project.

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 pack-age 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 second reporting period. There were no further activities in the current reporting period.

1.2.2.2 Work carried out & main results

1.2.2.2.1 Task 2.1: Architectural Design for Private 5G Networks

The activities of this task were formally concluded at the end of the second year of the project, and there are no updates compared to what reported in D7.3 [1]. As a reminder, this task focused on defining several architectural models for 5G network deployments, including a SWOT analysis of the different proposed network architectures and operator models. Further, the task worked on the description of inter-site use cases, with insights transferred to WP5 for the actual demo implementation.

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. Like Task 2.1, it was concluded at the end of the second reporting with all outcomes documented in D2.2 [2] and D7.3 [1], respectively.

The main outcome of this task, which is also a significant result from the perspective of the entire project, is the detailed evaluation of private 5G operator models which my serve as a basis for decision for prospective users.

1.2.3 Work Package 3

The goal of WP3 was to develop methodologies and tools for efficiently realizing new operator models for private 5G networks. One of the key tools was the derivation of channel models suitable for industrial applications, based on extensive measurements taken in an industrial scenario. Network planning and resource allocation based on appropriate channel models have been investigated. Furthermore, methods for monitoring of operational networks with respect to resource utilization, performance and regulatory compliance have been developed.

1.2.3.1 Status of the work package

WP3 is subdivided in two tasks: T3.1 - Application-centric planning of Private 5G Networks and T3.2 - Private 5G Network Monitoring, Operation and Management. The activities of WP3 ended in July 2022 and are reported in D3.1 and D3.2. In spite of the difficulties associated to the outbreak of Covid-19, which produced non trivial difficulties in carrying out the measurement campaign within Bosch's premises, the deliverables have been produced in the due time. D3.1 was prepared in time and delivered with a delay only because of Bosch closure for one summer month. An amendment of D3.1 has been prepared to answer the questions raised by the reviewers.

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 first important task of T3.1 was the derivation of channel models suitable for private 5G networks operating in an industrial environment. To this purpose, HHI developed a channel sounder and used it to carry out a thorough channel measurement campaign conducted at a BOSCH manufacturing facility. Using distributed untethered reference clocks at the transmitter and receiver, the setup allows to conduct measurements in a highly flexible manner without the need for a wired connection between transmitter and receiver. At the receiver, a virtual uniform circular array antenna (VUCA) is used to enable the estimation of angle-of-incidence information by applying the CLEAN technique with real-valued beamspace MUSIC as a DoA estimator. Over the last years, this setup has been used in a number of measurement campaigns with great success, mainly at 28 and 67 GHz. For the 5G CONNI project, a novel variant of the VUCA for sub 6 GHz measurements, specifically at 3.7 GHz, has been developed. Angle-resolved measurements in azimuth direction at 300 GHz were also enabled by mounting the receiver on a precision rotation stage. Examples of path losses in Line-Of-Sight (LOS) and Non-LOS conditioned are reported in the figures below.

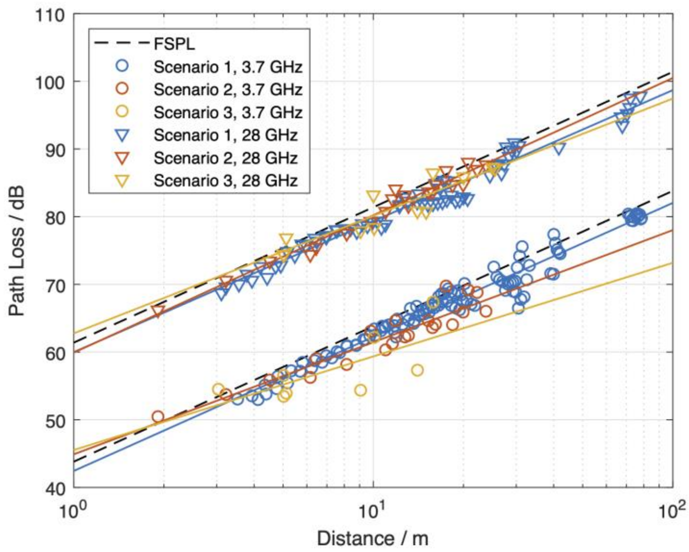


Figure 1-1: Path loss in LOS condition.

The results of the evaluation in NLOS are shown in Figure 1-2 with the same symbols and colors as in LOS. Here, it can be seen that the path losses in scenario 1 are very close to FSPL, both at 3.7 and 28 GHz. This can be explained by the fact that, while the direct LOS path was blocked, the area between Tx and Rx was much less cluttered than in scenarios 2 and 3, where the path loss is considerably higher than FSPL

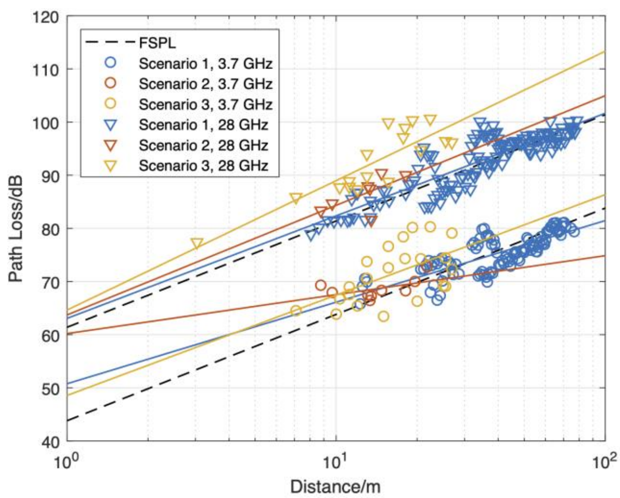


Figure 1-2: Path loss in NLOS condition.

The estimated large scale parameters (Path Loss, K-factor and RMS Delay Spread) are summarized in Table 1-1. Together with the angular results in this deliverable, a complete channel model of the characterized environment is given.

Table 1-1: Estimated Large Scale Parameters

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	-	4.16	-	-4.99	-
σ (dB)	3.92	-	7.68	-	4.06	-	4.98	-	3.19	-	5.87	-
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

The channel sounder setup used to conduct the measurements allows also the extraction of spatial information at the receiver in the form of a temporally and spatially resolved list of discrete propagation paths and their powers. Using this information, angular power profiles (APP) and root mean square (RMS) of the Azimuth angle spread of arrival (ASA) have been estimated.

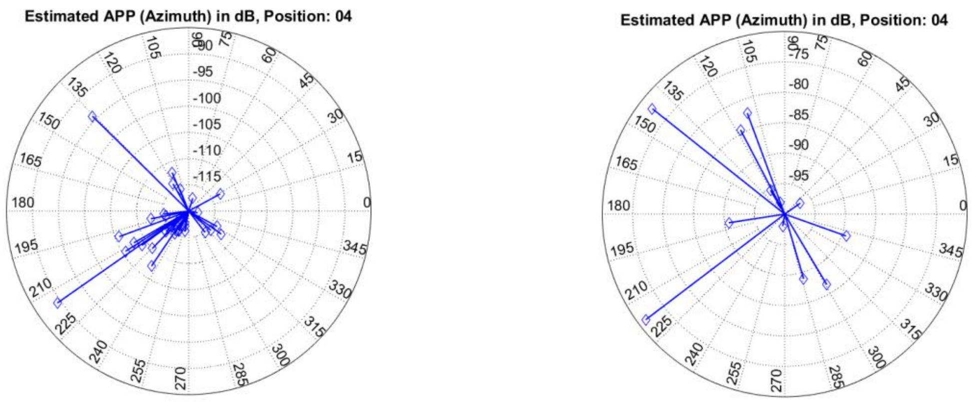


Figure 1-3: Angular power profiles at measurement point 4 in scenario 2, 3.7 and 28 GHz, LOS

Some examples are reported in Figure 1-3 and in Figure 1-4: Figure 1-3 shows the angular power profiles in line of sight (LOS) condition for two measurements taken from measurement point 4, in scenario 2, at 3.7 (left) and 28 GHz (right); Figure 1-4 shows the angular power profiles in NonLOS (NLOS) condition for two measurements taken from measurement point 11, in scenario 3, still at 3.7 (left) and 28 GHz (right).

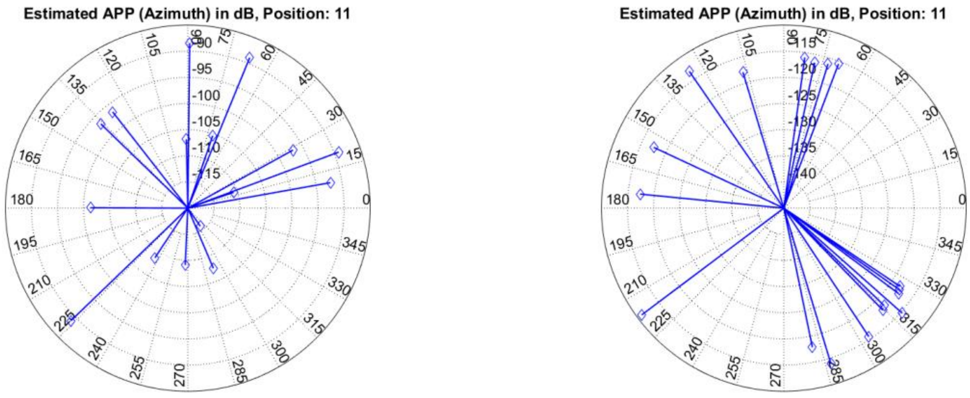


Figure 1-4: Angular power profiles at measurement point 11 in scenario 3, 3.7 (left) and 28 GHz (right), NLOS

While a strong component impinging at around 220° can be seen for both frequencies, the other angles of arrival do not share a strong similarity.

The other important issue, related to security concerns, is to check that the spillover of the RF energy radiated outside of the targeted industrial environment is very limited. This is especially important in areas with a large number of neighboring potential network operators, where it is vital to keep inter-site interference to a minimum. Figure 1-5 shows two examples of spillover, reporting the power delay profiles of the indoor to outdoor measurements at 3.7 and 28 GHz.

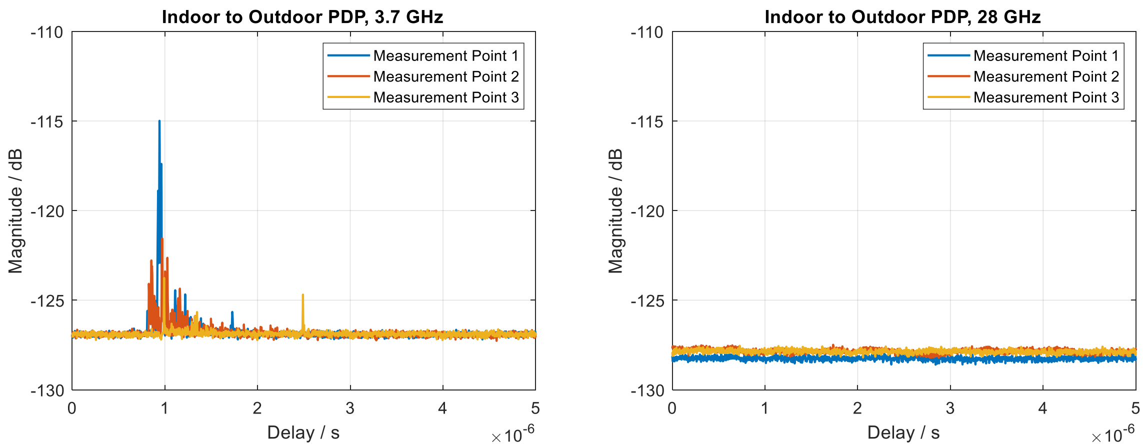


Figure 1-5: Indoor-to-Outdoor power delay profiles at 3.7 and 28 GHz

Figure 1-5 shows that, while at 3.7 GHz, some reception is possible, with a maximum SNR of 12 dB at measurement point 1, 5 dB at measurement point 2 and 3 dB at measurement point 3, at 28 GHz, no reception of the sounding signal was possible at all measurement positions.

The other activity in T3.1 was the reconstruction of the connectivity map, reporting some link parameters, such as throughput, associated to a set of multiple transmitter/receiver positions. SAP, developed a new algorithms, simpler to implement than the algorithms developed in the previous year, because based on a line graph rather than simplicial complexes. Then, exploiting the collaboration with ITRI that provided data from the 3D model of the Taiwanese industrial site at IMTC, SAP tested the new algorithms. An example is reported in Figure 1-6 and Figure

1-7, reporting, respectively, the true and recovered throughput (within the red rectangle) obtained by observing only N_s=10 throughput samples. The 10 pairs of Tx-Rx sampled throughputs are identified with different colours: the squares around each sampled receiving nodes in Figure 1-7 have the same colour of the associated transmitter. The color on each circle within the red rectangle represent the throughput from the transmitting (the red square on the bottom) and the point located on the circle.

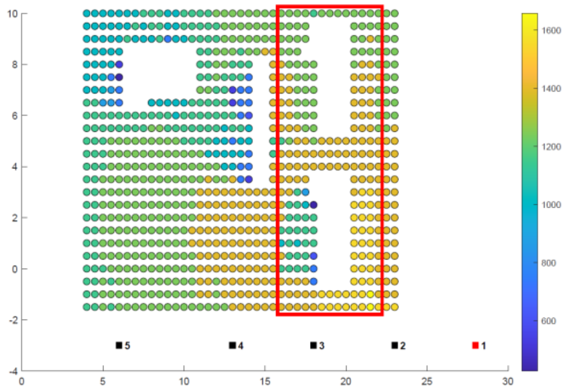


Figure 1-6: True throughput map associated to Tx_1

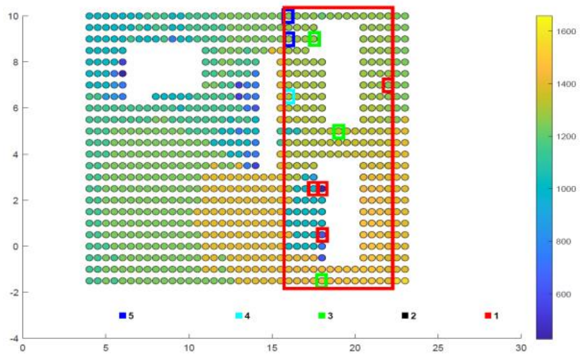


Figure 1-7: Recovered throughput map associated to Tx_1 with $B=N_s=10$

Comparing the two plots, we can see that the estimation error is very low.

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

The overall goal of T3.2 is to set-up an application-centric network design with the goal to devise a resource allocation strategy that enables the production process to proceed smoothly, with proper remote control of the whole process.

SAP has developed novel algorithms for finding the optimal placement of radio and computational resources in the edge cloud and for the association between mobile devices, radio access points and edge servers, including also the optimal routing across the edge cloud. The goal is to find an allocation of resources that makes possible to offload computations from the peripheral devices to the edge servers, while guaranteeing the desired service delay, which includes both transmission time and computation time. The requests can be handled either locally, on some of the edge servers or to a distant cloud, if needed. The proposed algorithm has been compared with two alternatives: conventional methods that associate each mobile devise to the nearest radio access point and to the co-located edge server, outperform the methods already developed and reported in D3.1, thanks to the inclusion of the optimal association of mobile devices to radio access points and edge servers. Thanks to the collaboration with HHI, SAP has also tested the algorithms in an industrial scenario, exploiting the channel models derived by HHI.

The proposed optimized solution, named JSPRR-RA, has been compared with two alternative methods: a) a solution, named MA (Matching Algorithm), which combines the conventional association between mobile devices and radio access points /RAP) based on the SNR at the RAP, and a matching theory algorithm used to distribute the tasks among the available RAP's and edge servers; b) the methods, named Joint Service Placement and Request Routing (JSPRR), explored in the previous deliverable D3.1. A comparison, in terms of mean service delay per device, is shown in Figure 1-8, where we compare the average service delay, as a function of the computational capabilities available at the edge servers, for the three methods. The figure shows that the new method, JSPRR-RA, offers a significant gain in terms of average service delay with respect to both MA and JSPRR methods.

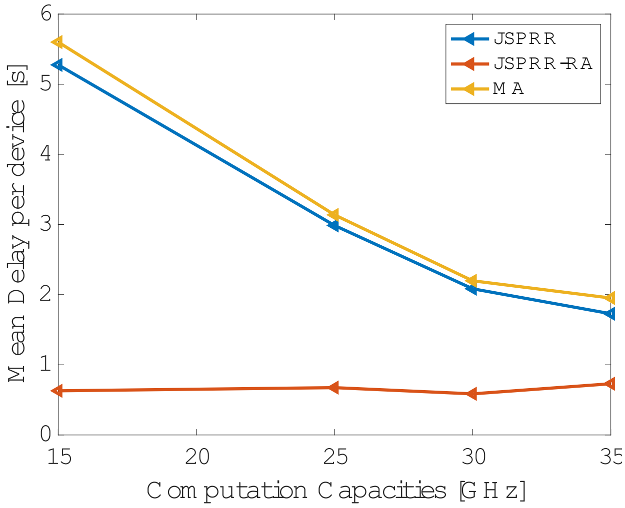


Figure 1-8: Average device delay, for different computation capacities

The other major task of T3.2 is developing tools for monitoring network components, including RAN monitoring, Core network monitoring, and Edge cloud monitoring.

RAN network monitoring

Regarding to the private 5G network OA&M, based on the 5G RAN system developed in Task 4.1, ANI designed and developed the RAN monitoring system with the protocol of NETCONF. NETCONF is the industrial standard for communication between server and client. In the 5G RAN, server was implemented in the CDU and client was in the workstation which can access the RAN.

A YANG model was also provided as the management interface in the CDU. Dozens of KPIs including the Configuration Management (CM), Performance Management and Fault Management (FM) were defined this YANG model. Based on this, user in the workstation is able to access the 5G RAN to monitor and control and would have an idea of how the 5G RAN performed. Figure 1-9 shows the 5G RAN OA&M architecture described above.

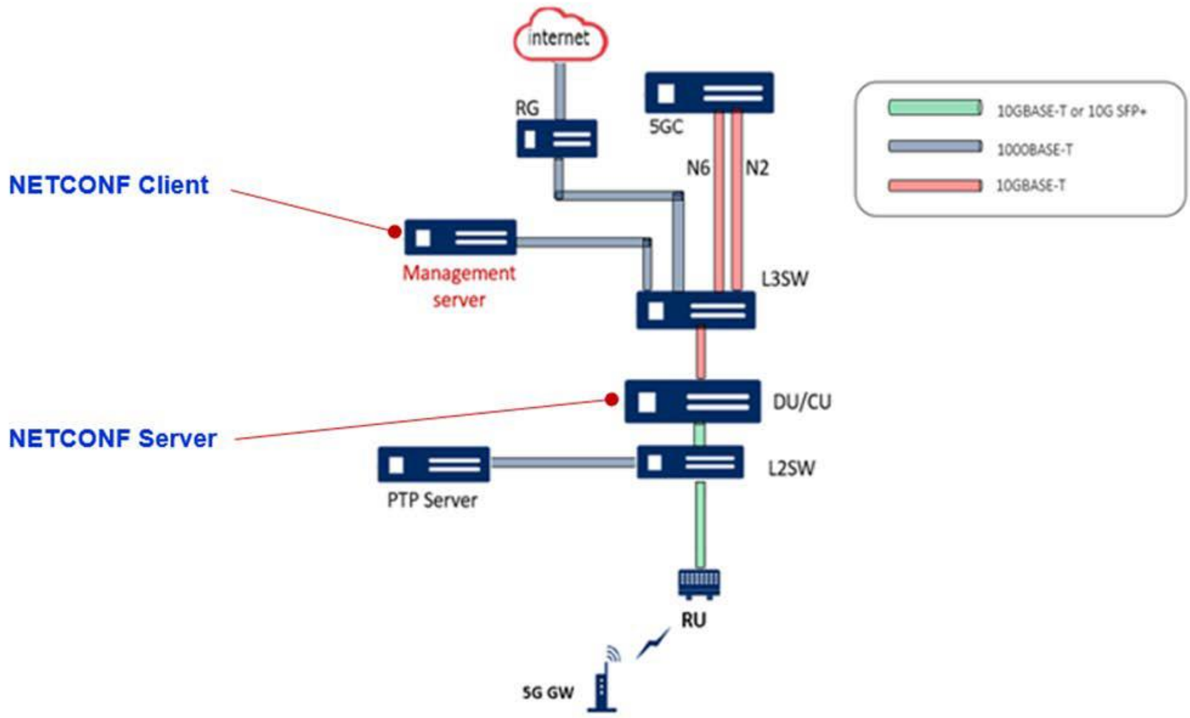


Figure 1-9: 5G RAN OA&M Architecture

The 5G RAN OA&M also can support the use cases, e.g. Data collection, AR Diagnostic and Flexible Work holding, in the WG5, KPIs regarding to throughput, latency and reliability would also defined in the YANG models. The users could monitor how the 5G RAN system performed.

Core network monitoring

The new tools to monitor the Core network monitoring have been developed by III. A graphical interface was introduced to reduce training requirements and allow operator personnel to quickly drill down to the source of any issue to keep the 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 data fill 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

The 5GC CNM GUI consolidates the following OA&M operations for the core network:

- General Information: shows general 5G Core execution information that includes information like CPU usage, memory usage and healthy management, which had been reported in D3.1.
- Performance Monitoring: manages overall performance of the network system to avoid potential performance bottlenecks, which had been reported in D3.1.
- Fault Management, Configuration Management, Accounting Management and Security Management functions are new functionalities that have been developed in 2022.

With fault management, the potential problems are identified to keep the network system operational and minimize the downtime. The FM alert system sets three kinds of warning event with different color to distinguish their severity. For example, if the UE authentication failure will be alerted as the most serious event, it will marked as red. An example of operation of the Fault Management tool is shown in Figure 1-10.

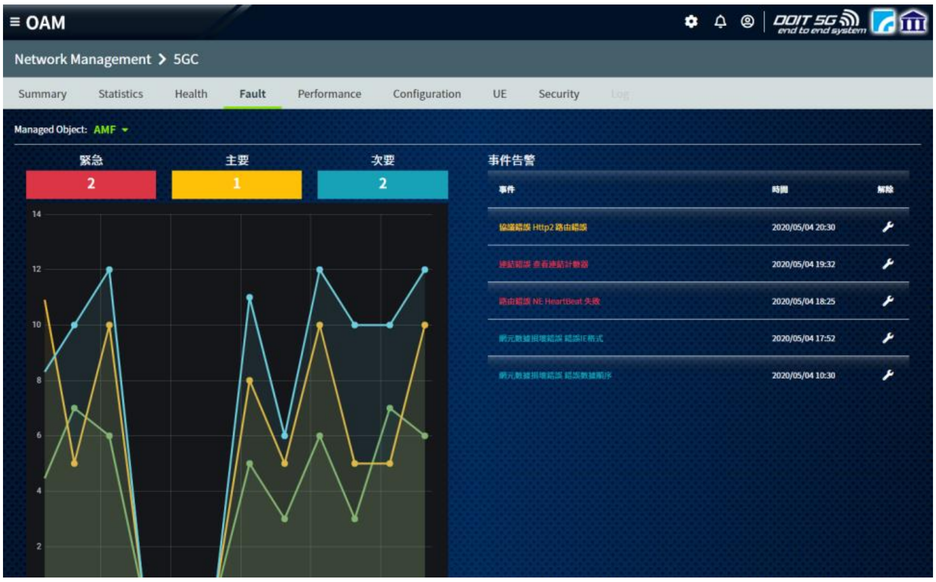


Figure 1-10: The FM of 5G Core OAM

Edge cloud monitoring

The new tools to monitor the edge cloud have been developed by CHT. The deployment of private 5G networks in smart factories without interruption of industrial applications is a necessary requirement. Production line interruptions can result in substantial monetary losses. Therefore, the monitoring of the continuous operation of the industrial application can be realized through the edge cloud. In the Taiwanese deployment of the 5G CONNI project, we implemented a 5G smart factory with a monitoring mechanism, as shown in Figure 1-11. Our edge cloud platform built the cloud controller application with PCI pass-through, remote control interface, and compatible drivers, according to the structure based on the ETSI MANO architecture. The Mobile Edge Enabler VNF on edge cloud platform provides the traffic steering for cloud controller and ground controller. The edge cloud platform provides a complete monitoring solution to ensure the continuous operation of application services at smart factories. Moreover, the cloud controller must guarantee a buffer size greater than 100 and a latency time less than 30 ms to ensure efficient and stable machining processes. Therefore, CHT developed monitoring interfaces to maintain the continuous operation of the cloud-based controller of a fixture system application. When the monitoring parameters exceed the proposed requirements, the edge cloud platform sends an alarm notification to the administrator, as shown in Figure 1-11.

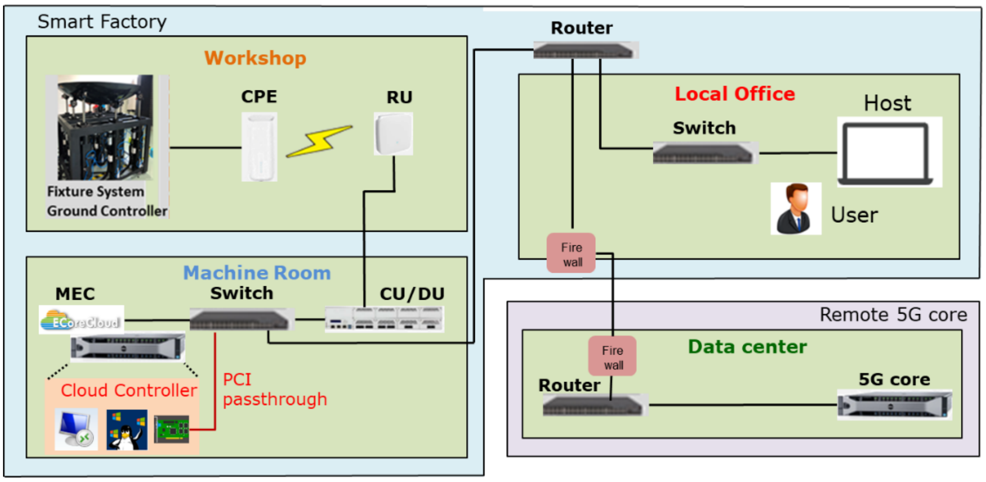


Figure 1-11: Edge cloud platform of 5G CONNI Taiwanese testbed

1.2.4 Work Package 4

WP4 (Technical Enablers for Industrial Applications) covers Mobile Edge Computing (MEC) cloud development, industrial application technical development, radio network technical development, and core network technical development for industrial field. The main goal of this work package is to ensure industrial use cases can be implemented on private 5G networks successfully for industrial requirements, including high data rates (eMBB) and low latency (URLLC).

1.2.4.1 Status of the work package

This work package ended in October 2022.

In task 4.1, the 5G CONNI project built a RAN system composed of CDU, RU, and CPE as RAN implementation. gNodeB and CPE have been deployed in ITRI IMTC for industrial application and have been optimized to meet the requirements (e.g., bandwidth and low latency) of the selected use case.

In task 4.2, 5G CONNI project proposed two complementary 5G Core networks: 5G core prototype and lightweight orchestration framework. The components of the 5G core prototype are defined as self-contained, independent and reusable network functions (NFs) together with a well-defined Service Based Interface (SBI) using HTTPv2 that can be used to invoke services. The 5GC provides interfaces and integrates with Application Network (AN), Mobile Edge Computing (MEC), and gNB. The 5G Core also provides interfaces to support Network OAM (Operations Administration and Maintenance) functions. 5G CONNI project also worked on the ETSI NFV-like instantiation and orchestration of 5G mobile core network components via OSM Release Eleven. With the designed VNFDs, it is possible to deploy a mobile core network with off-the-shelf, standard-compliant MANO implementations such as OSM and ONAP. 5G CONNI project focused on the implementation of the semantic of the Ve-Vnfm reference point, to make OSM able to directly configure the core network in an ETSI standard approach. 5G CONNI project has updated the orchestration framework with OSM metric collection.

In task 4.3, two implementations of MEC are proposed by 5G CONNI for the European and Taiwanese testbeds: the hybrid 5GC solution and the bump-in-the-wire solution. Hybrid 5GC solution consists in the splitting of CP and UP functions through OSM, giving more flexibility for the mobile network deployment. The 5GC CP network functions (e.g., AMF, UDM, SMF, etc.) is deployed in the central NFVI server, while the 5GC UPF, the only component acting as UP function, is deployed in the edge NFVI server. This approach allows the support of edge computing, with the consequent possibility of installing a MEC platform. MEC 5G SA based on a bump-in-the-wire architecture develops handover, multi-PDU sessions and multi-QoS flows functionalities. The bump-in-the-wire solution proposes a MEC platform with virtualization capability and VNF management. The virtualization capability is responsible for virtualizing edge computing functions, industrial applications and any needed applications to the MEC platform to realize flexible deployment. The VNF management supports the essential management demands of ETSI NFV specifications and adjusts the performance of VNFs to achieve the required transmission delay, execution performance and resource management.

In Task 4.4, 5G CONNI project worked on three vertical use cases, namely (1) process diagnostics using Augmented/Virtual Reality (2) cloud based controller for CNC and (3) the multi-site use case. For the process diagnostics, remote rendering technique has been adopted and the 3D model of the demo site and target machine have been built and loaded in the GPU workstation and rendered by Dassault System software. The viewport of 3D scene can be updated with the IMU information from user device so that a smooth user experience of navigating through the 3D scene can be achieved. 5G CONNI project also investigates advanced functionalities for future private 5G networks. First, 5G CONNI proposes a dynamic resource allocations for URLLC. This novel dynamic decision maker framework enables a reliable, resource and delay-optimized scheduling suitable for dynamic URLLC scenarios (e.g., intermittent traffic source rate, time-varying channel). Second, 5G CONNI proposes a dynamic strategy for resource allocation in the edge cloud, aimed at finding the optimal trade-off between energy consumption and service delay, taking into account both computational and radio resources. More specifically, we considers the service placement, incorporating also the storage resources necessary to run virtual machines in the edge cloud. Finally, 5G CONNI proposes a goal-oriented communication scheme, a very novel communication strategy that has the potentials to outperform the conventional Shannon-based approach in all cases where communication occurs to fulfill a common goal between source and destination. We generalizes the approach exploiting the information bottleneck principle as a driving principle, by incorporating convolutional neural networks, used as encode/decode pairs, trained offline and used adaptively online during the communication process.

1.2.4.2 Work carried out & main results

1.2.4.2.1 Task 4.1: Radio Network Technical Enablers

In task 4.1, CEA investigated how to enable deterministic URLLC. For that purpose, CEA proposed a novel scheduling methodology (combining reactive and proactive resource allocation strategies) specifically devised for URLLC services. CEA offers an evaluation of the proposed methodology in the case of the well-known Hybrid Automatic Repeat reQuest (HARQ) protocol in which the proactive strategy allows a number of parallel retransmissions instead of the "send-wait-react" mode. To this end, CEA proposed some deviations from the HARQ procedure and benchmark the performance in terms of latency, reliability outage and resource efficiency as a function of the level of proactivity. Afterwards, CEA highlighted the critical importance of proactive adaptation in dynamic scenarios (i.e. with changing traffic rates and channel conditions). Thus, CEA formulated the two dynamic resource scheduling problems by considering the traffic arrival in the network layer, the queue behaviors in the data link layer and the risk of applying vulnerable decision which causes packet loss. The first proposed solution (**proactive**) applies decisions dynamically based on channel, traffic dynamics and long-term packet loss. Based on Lyapunov stochastic optimization tool, CEA proposed a mathematical framework to understand the performance-delay trade-off by minimizing the objective function of the total resource allocation and the total queue length that was parameterized by a V value. The second proposed solution (**dynamic**) proposes a reliable, resource and delay-optimized scheduling suitable for dynamic scenarios (e.g., random bursty traffic, time-varying channel) based on Lyapunov optimization. It takes into account the traffic arrival at the network layer, the queue behaviors at the data link layer and the risk that the applied decision might trigger packet loss. It exploits a better trade-off between latency, reliability and resource efficiency, is aware of long-term or short-term reliability requirements and dynamically adapts to the traffic behavior and channel impairments. The trade-off between the resource efficiency, latency and reliability is achieved by the timing and intensity of decisions and can be parameterized with V and α.

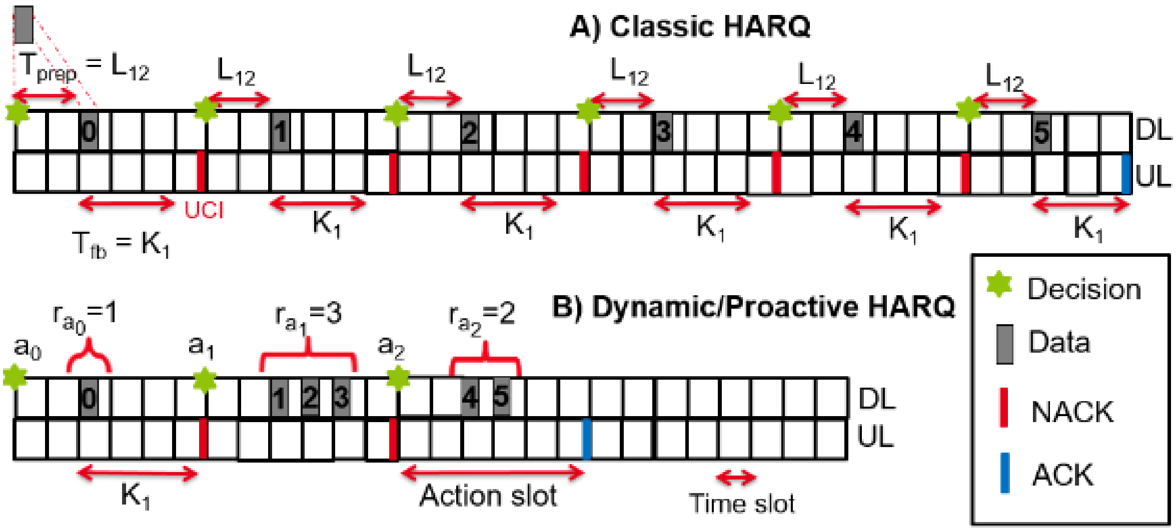


Figure 1-12: Different DL HARQ procedures: (A) classical, (B) Dynamic and proactive RTXs

Figure 1-13 compares the Complementary Distribution Function (CDF) of latency for different HARQ schemes: (i) Classic HARQ procedure, (ii) Fixed number of parallel RTXs, (iii) our proactive HARQ adaptation with a fixed maximum number of RTXs ($R_{max} = 10$) and (iv) our proposed optimization (Dynamic HARQ) in which $R_{max} = \sum_{a_0}^{a_{max}} r_{n,a_j}$. We select two pairs of (V, α) parameters: (25, 2) for good reliability and considerably low latency and (60, 0) for very good resource efficiency and latency.

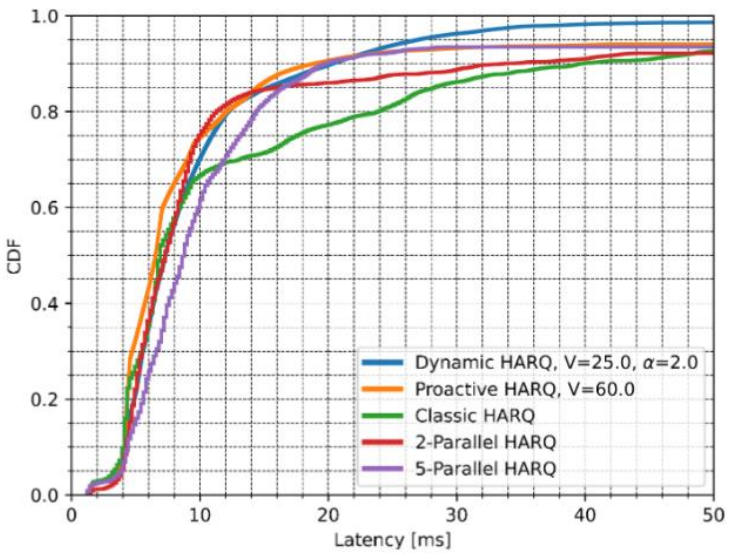


Figure 1-13: CDF of latency for reactive RTX, fixed 2-parallel RTX, fixed 5-parallel RTXs, our proactive adaptation algorithm with V=60 and our Dynamic HARQ with V=25 and $\alpha = 2$

As expected, the latency of Classic HARQ is the highest and spreads out over time. 2-parallel and 5-parallel HARQ improve latency at the cost of decreasing resource efficiency to 0.8 and

0.6, respectively due to the lack of adaptation when needed. Dynamic HARQ offers two tradeoffs. When V=60 and α =0, we improve resource efficiency and latency but not reliability. When V=25 and α =2, we improve reliability at the cost of a slight degradation in latency in the best case.

Based on the 3GPP Rel.15 and O-RAN alliance standard, the 5G Radio Access Network (RAN) specification was defined by ANI, see D4.1 [3]. In Task 4.1, ANI was focusing on the design and implementation of the 5G RAN system including the CPE, indoor n78 and n79 RU and CDU (CU +DU) for private network. RU is connecting with CDU with the option 7.2 specification O-RAN alliance defined. A CPE was also developed in order to complete the end to end connection from the CPE to the 5GC. Several 5GCs such as Ericson, ATHONET, Druid and free5GC were interoperability-tested with the CDU and connect well.

Figure 1-14 is the 5G RAN system ANI developed. This 5G RAN system including the n79 RU was also deployed in ITRI IMTC field site in Taiwan for selected use cases for WG5 tasks. There is an n78 RU which was also integrated and interoperability-tested with ATHONET 5GC.

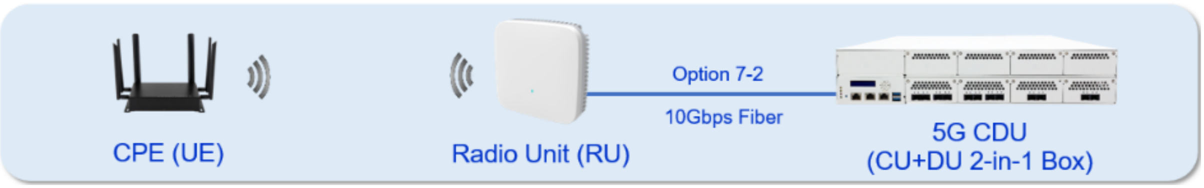


Figure 1-14: 5G RAN system

In the D4.2 [4], Initial RU test reports related to RF performance shows in Table 1-2. It is 3GPP standards compliance.

Item	Spec	Chain 1	Chain 2	Chain 3	Chain 4	Result
EVM	<4.5%	3.7%	3.62%	3.93%	3.82%	Pass
Freq. error	<485 Hz	-41.87 Hz	-46.46 Hz	-46.41 Hz	-40.79 Hz	Pass
ACLR	<43.2 dBc	-48.27 dBc	-47.98dBc	-46.91dBc	-47.12dBc	Pass
Sensitivity	<-86.4 dBm	-92 dBm	-92 dBm	-92 dBm	-92 dBm	Pass

Table 1-2

Other test results such as cell coverage, E2E throughput, and the end to end latency for 5G system were also performed.

Finally, in the last project period, more tests was performed and system was optimized especially for WG5 use cases e.g. Data Collection, AR Diagnostic and Flexible Work holding, details please see D4.3 [5].

1.2.4.2.2 Task 4.2: Core Network Technical Enablers

Task 4.2 focused on the design and development of a 5G Core network (5GC) prototype (III) and development of new features and functionalities for a Network Function Virtualization (NFV) orchestration framework.

In the last project period, ATH finalized its work on the ETSI-NFV-like orchestrator, with the completion of last improvements compared to the second year and the demonstration of all its updated/completed functionalities. The Open Source MANO (OSM) deployed in the demonstrational setup was updated to one of the last versions (Release Eleven) and a collection feature specific to Virtual Network Function (VNF) metrics was integrated, in order to retrieve and visualize 5GC metrics in a central monitoring system. Prometheus has been adopted as a metric collection software. Furthermore, a complete and automatic onboarding, instantiation, and configuration framework of the ATH 5GC was provided (see Figure 1-15).

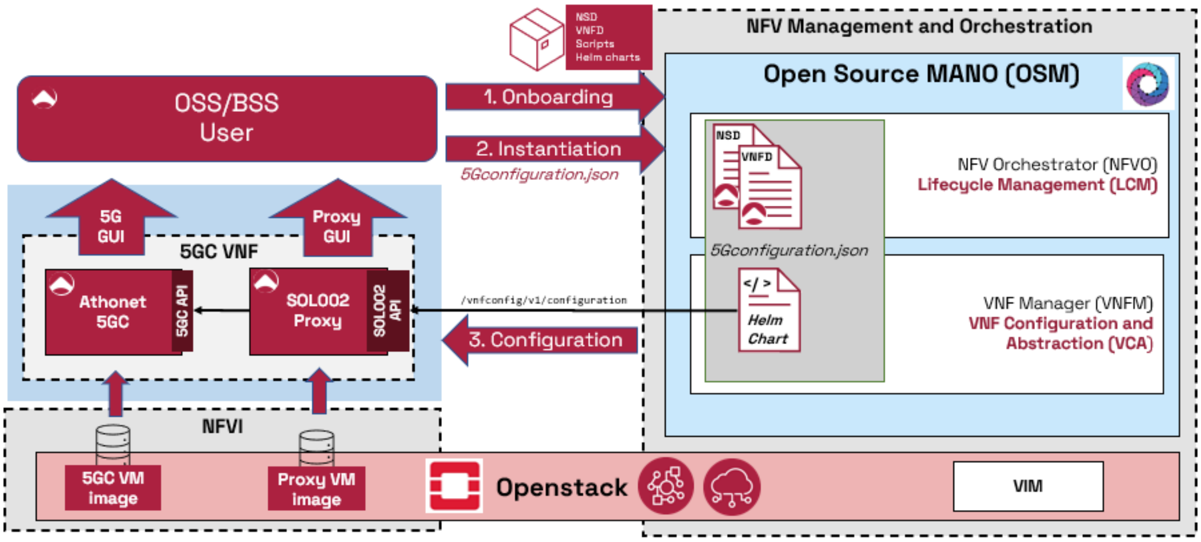


Figure 1-15: Finalized functional orchestration framework architecture.

Important achieved goals are the fully automatic instantiation and configuration of the 5GC with OSM and the implementation of the ETSI-compliant SOL002 interface to enable the standard interaction with OSM and the 5GC VNF configuration process. Another advancement for the 5GC configuration is the adoption of Helm charts instead of Proxy charms (Juju), thus making the configuration framework directly working on K8s cluster to make pods for VNF configuration. This approach resulted in a faster 5GC configuration process, obtaining a total of 107 seconds for full configuration, compared to the Juju framework counterpart, which achieved a total of 383 seconds with all the applied optimizations (see D4.2 [4]). A detailed illustration of the instantiation and configuration duration is shown in Figure 1-16. All these activities and more detailed final results were documented in D4.3 [5].

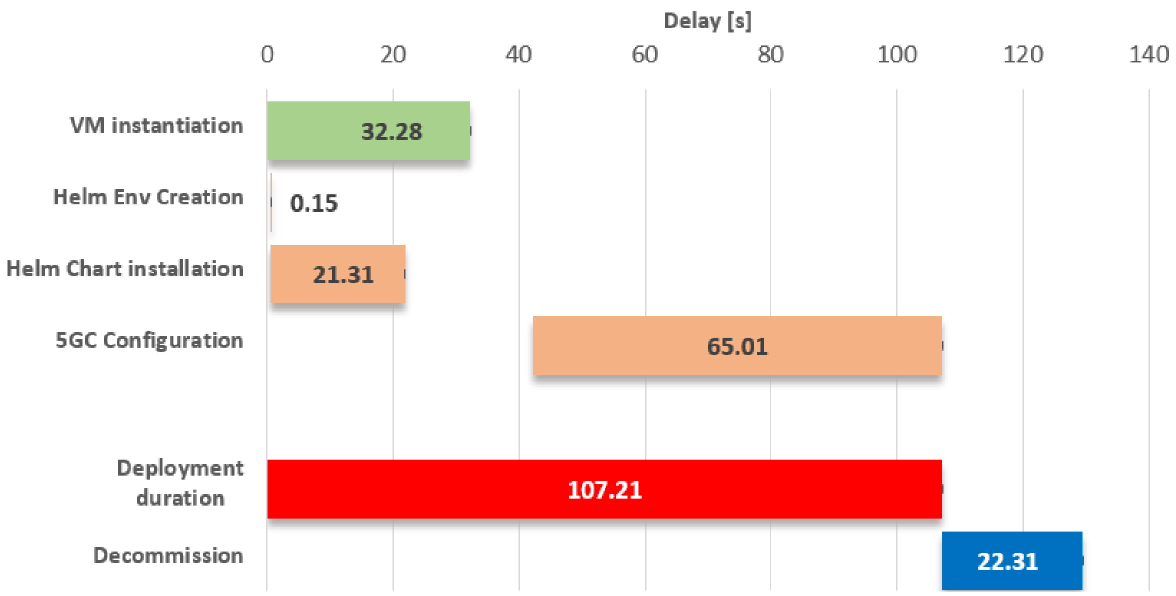


Figure 1-16: 5GC deployment duration adopting Helm Charts framework.

Finally, as a complementary work, ATH developed a provisioning procedure of a Network Slice Subnet (NSS) modeled as a Network Service (NS), composed of several VNFs. The work resulted in a proof of concept developed within the ATH orchestrator testbed, demonstrating the implementation of an on-demand provisioning procedure of an NSS composed of VNFs from potentially different vendors. The work was also presented during a live demo at the *IEEE International Conference on Network Softwarization, 27 June–1 July 2022, Milan, Italy.*

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, furthermore throughput > 10Gbps and Latency < 1ms.

The 5G Core Network (5GC) has been specified in 3GPP with the aim to increase the operational efficiency and support various new advanced services for industries and consumers. The III 5G Core provides efficient data plane and system reliability.

The main functional specifications are:

- 5G Core Component: AUSF / UDM / PCF / NEF
- Support Function List: Xn & N2 Handover / Multiple PDU Session / Multiple QoS Flow per Session
- OAM: Configure Management / Fault Management
- Support more than 100,000 UEs
- Data Plane acceleration technology : DPDK or SmartNIC solution
- Throughput > 10Gbps and Latency < 1ms
- Local Breakout support
- High Availability support
- Cloud-Native architecture

In the Taiwanese demonstration site, the 5G core network is designed for service-based architecture (SBA) and follows 3GPP Release 15+ as a standalone (SA) solution. The III-5GC containerizes all core network functions with C/U split architecture, enabling the enterprise to distribute these functions wherever and whenever needed. All the modules can be deployed on virtual machines on top of a large number of virtualization environments, and managed as a Kubernetes platform.

1.2.4.2.3 Task 4.3: Mobile Edge Cloud Enablers

For the European testbed of 5G CONNI, a hybrid 5G solution was considered, consisting in the splitting of Control-Plane (CP) and User-Plane (UP) functions. Based on this assumption, ATH tested this deployment model in its in-lab testbed, by creating a second Network Function Virtualization Infrastructure (NFVI) node, and integrating it to the original framework adopted for the activity performed in Task 4.2, which served as the central NFVI node. Furthermore, the deployment of a typical 5G Non-Public Network (NPN) was emulated in this extended framework, adopting dedicated NS/VNF descriptors and 5GC configurations. To conduct the tests, the improved version of the NFV orchestration system (see Section 1.2.4.2.2) was used. The obtained result is a proof-of-concept demonstration of the hybrid architectural model deployment defined in WP2, fully configured and functioning.

As part of T4.3 and standardization activities, ATH also worked on the technical definition and feasibility of the MEC IoT Service being standardized in the ETSI ISG MEC033 – IoT API specification. In order to demonstrate the IoT working system, several IoT API calls were implemented and tested in-lab at ATH's premises, over the same NFV testbed infrastructure. The whole experimental system architecture is represented in Figure 1-17.

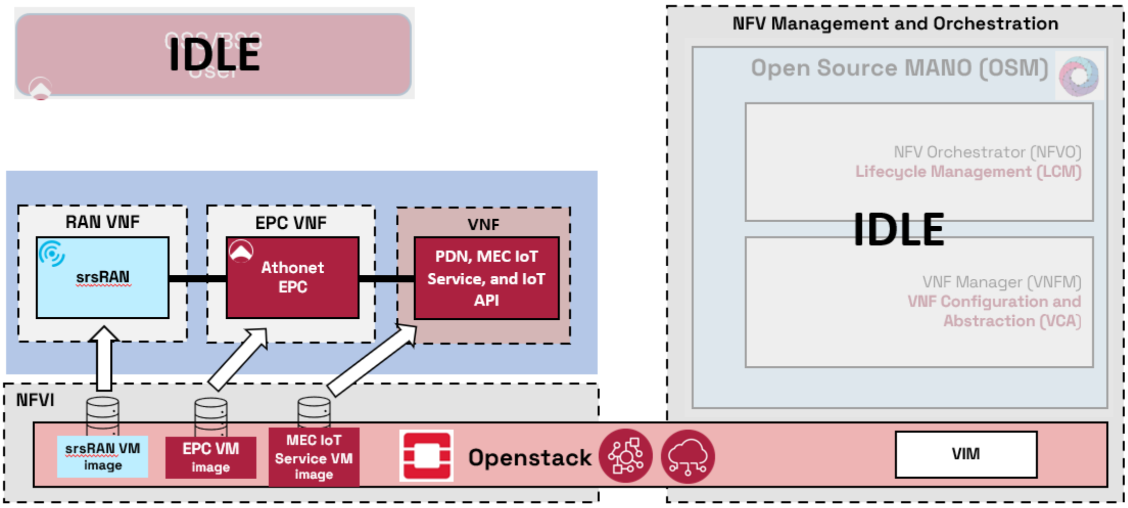


Figure 1-17: IoT service and API system architecture deployed in ATH premises.

In the Taiwanese testbed, the bump-in-the-wire MEC SA provides multi-PDU sessions, multi-QoS flow and handover based on 3GPP SA standalone specifications described in D4.2. The MEC also has the advanced features of virtualization and VNF management. The industrial applications virtualized on the MEC platform could be monitored for continuous operation at smart factories. For VNF management, MEC platform extends industrial application scale conveniently and deploys new industrial applications faster. In the Taiwanese deployment of the 5G CONNI project, we virtualized the use case of Cloud-based Controller for Fixture System as shown in Figure 1-18. Taiwanese partners also integration test with new version of AR use case, and demonstrated it as AR remote expert in EU-Taiwan Joint 6G SNS Workshop in November 2022. Through the AR glasses, the AR remote expert can easily remote to ITRI IMTC industrial facility and assist the machine operator.

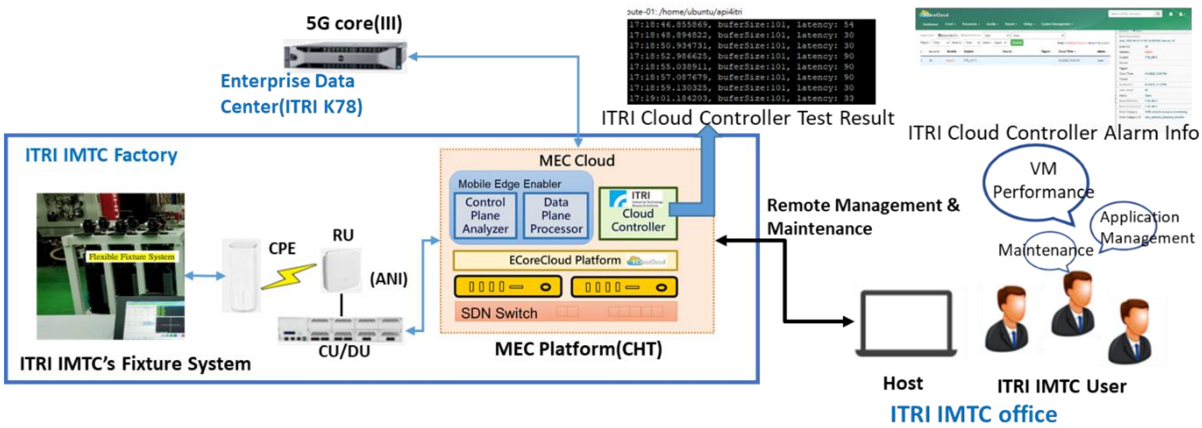


Figure 1-18: Cloud-based Controller for Fixture System integration with MEC Platform

1.2.4.2.4 Task 4.4: Industrial Application Enablers

ITRI has finished the final implementation of two vertical use cases, namely: "combined UC-1/UC-2: Process Diagnosis Using Augmented/Virtual Reality with CNC and Sensing Data Collection" and "additional UC: Cloud-based Controller for Fixture System".

For the combined UC1/UC2, implementation architecture is shown in Figure 1-19. Remote rendering technique has been adopted in the implementation of this use case. The 3D model of the demo site and target machine have been built and loaded in the GPU workstation and rendered by Dassault Systèmes software. With the help of the nVidia CloudXR package, the rendered scene can be streamed to user device such as head-mount display, tablet or cell phone. The viewport of 3D scene can be updated with the IMU information from user device so that a smooth user experience of navigating through the 3D scene can be achieved.

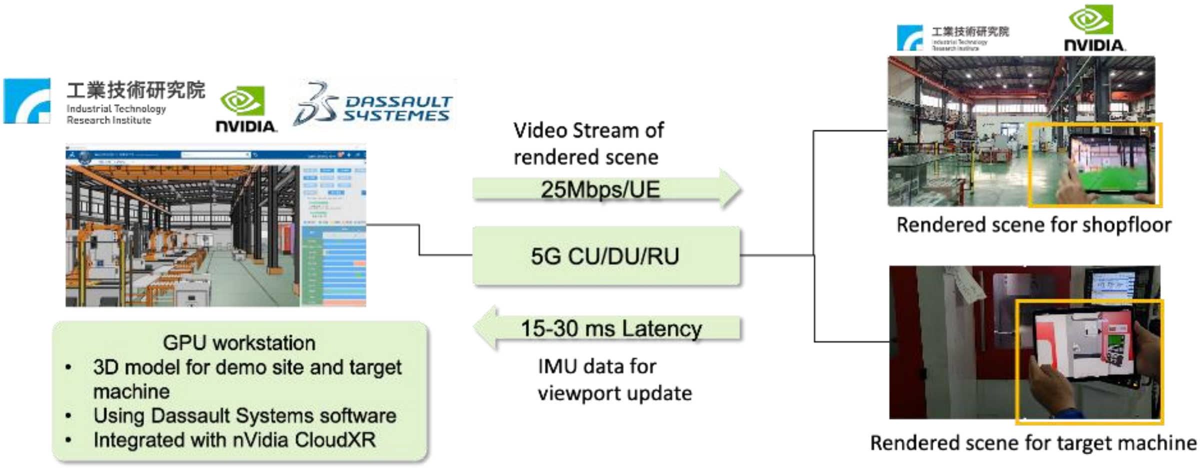


Figure 1-19: System architecture of remote rendering

Figure 1-20 shows the specification of the information shown in 3D scene of the target machine, where

1. Production management information: current work order for the workpiece and progress of machining process
2. Machine Operational Data: machine coordinate, spindle speed, federate, spindle loading
3. Sensing Data: 3-axis vibration data from spindle and workpiece, totally 6 channels of sensing data

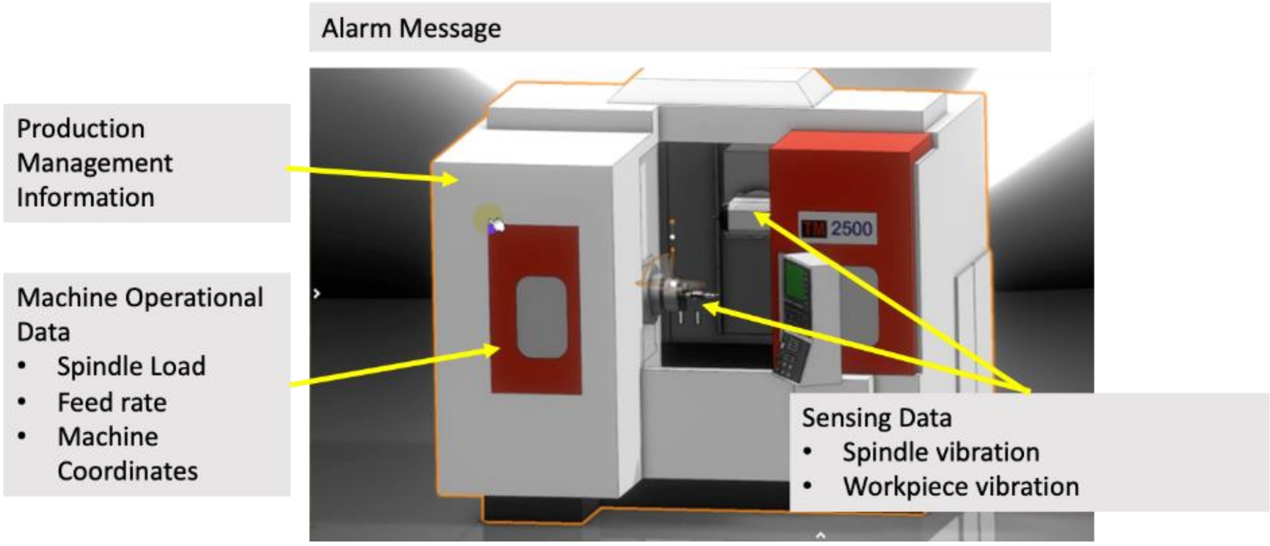


Figure 1-20: Specification of the 3D scene of the target machine

Machining error can be calculated from machine operational and sensing data during machining process and output in terms of point cloud. The point cloud of error distribution can then be shown in the 3D scene via remote rending as shown in Figure 1-21.

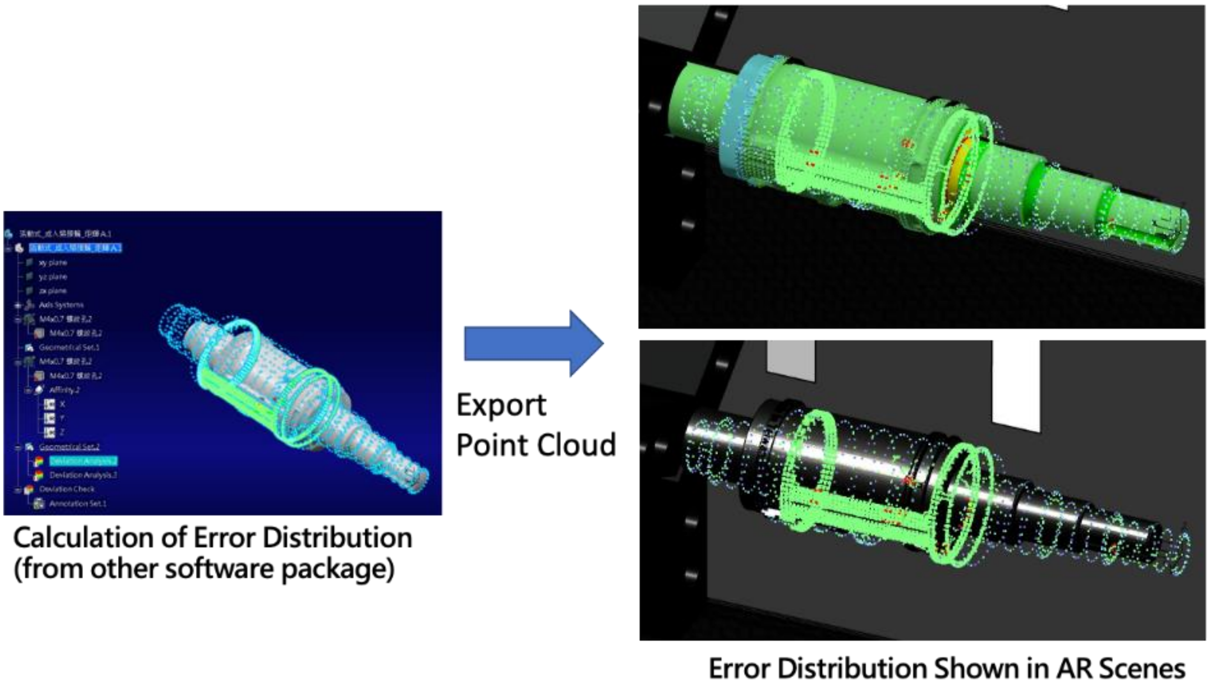


Figure 1-21: Specification of the 3D scene of the target machine

For the additional UC, the cloud-based CNC software and the test machine has been constructed and tested under distributed network architecture (shown in Figure 1-22) where the motion command generation, motion command execution modules are separated. Figure 1-22 illustrates the flexible fixture system used in aerospace part machining. In the test scenario, a steel plat work piece is installed on the fixture system and exited by a shaker to simulate the vibration during machining process. To observe the effect of the vibration suppression, a cup of water was placed on the steel plat. The detected vibration signal is also shown on the sensor data acquisition system. When the vibrator sends a fixed vibration frequency at 35 Hz, the sensor detected and send back to cloud controller. The controller sends a series of motion command packages(40 motion commands package) at 10 ms time span in response to the vibration an reduced the overall vibration amplitude at 35 Hz.

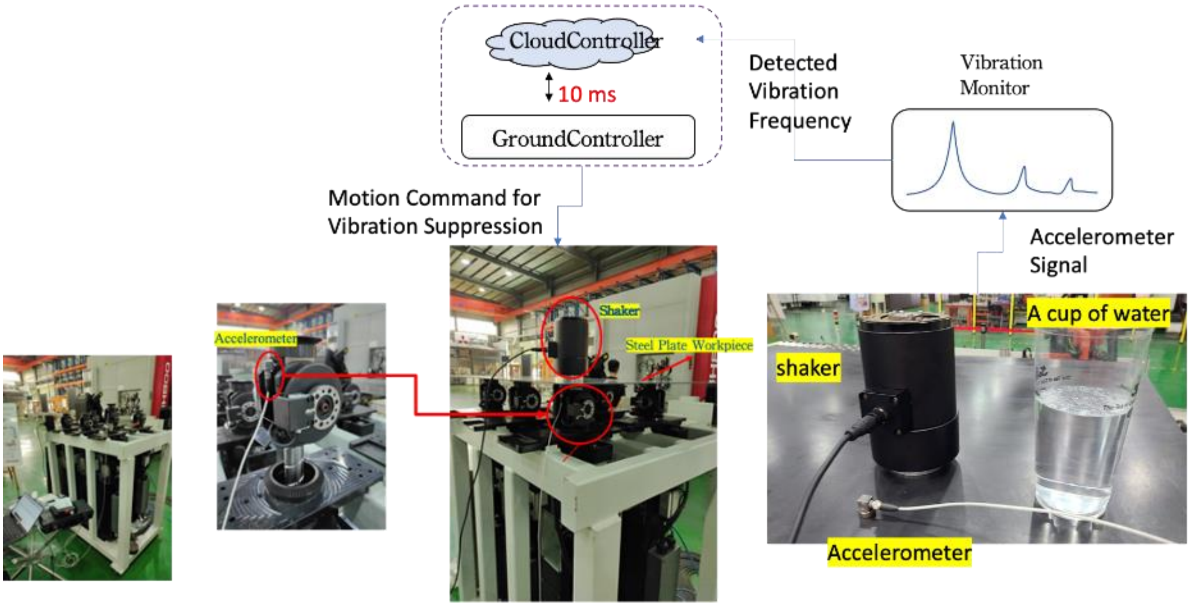


Figure 1-22: The test architecture of the cloud-based controller

CEA proposed a novel hybrid grant-based and grant-free radio access scheme for Ultra Reliable and Low Latency Communications (URLLC). CEA provided two multi-agent reinforcement learning algorithms to optimize a global network objective in terms of latency, reliability and network throughput: Multi-Agent Deep Q-Learning (MADQL) and Multi-Agent Deep Deterministic Policy Gradient (MADDPG). In MADQL, each user (agent) learns its optimal action-value function, which is based only on its local observation, and performs an optimal opportunistic action using the shared spectrum. MADDPG involves the attached gNB function as a global observer (critic), which criticizes the action of each associated agent (actor) in the network. By leveraging centralised training and decentralised execution, we should achieve a shared goal better than the first algorithm.

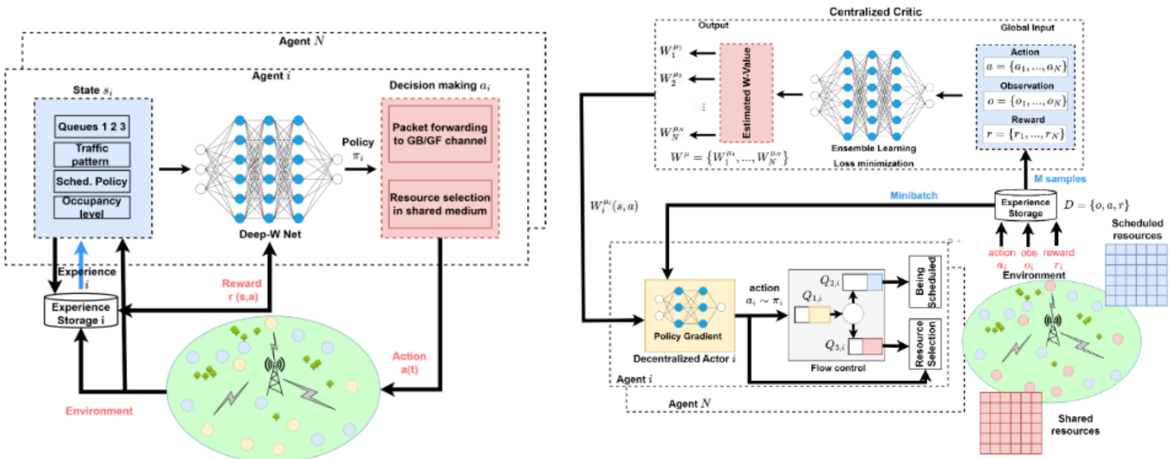
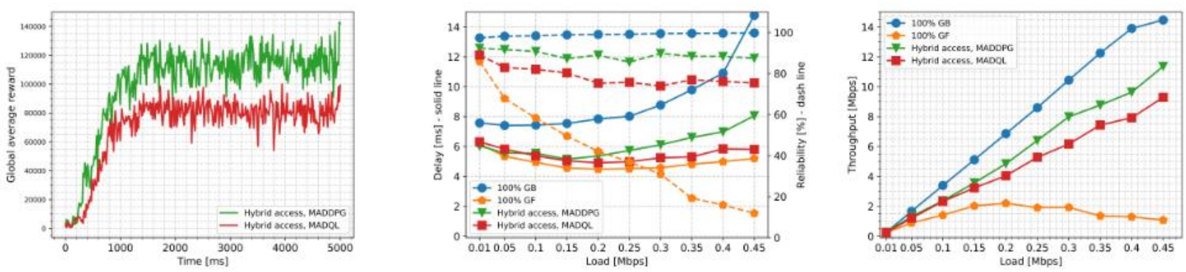


Figure 1-23: Multi Agent Deep W(Q)-Learning architecture (MADQL) and multi-Agent Deep Deterministic Policy Gradient Decision architecture (MADDPG)

By means of a system-level simulation, where a full protocol stack is considered, it has been demonstrated that the use of semi-distributed approach (MADDPG), with the support of centralized gNb (critic) having the full evaluation of each associated agent (actor), provides better opportunistic access with fast uplink delay and less collision between users. However, the application of the MADQL approach where only local observation is possible should not be discarded when the algorithm favours agents that exploit shared spectrum access to minimise their uplink latency at the cost of collisions and thus reduce transmission reliability and throughput. The performance gains of our proposal are confirmed when compared with the typical centralized, round-robin scheduling policy (100% GB) and the decentralized, slotted ALOHA protocol (100% GF).



(a) Average reward for a 0.1 Mbps traffic load (b) Delay and Reliability performance (c) Throughput performance

Figure 1-24

This contribution, not included in D4.3, has been submitted to IEEE ICC 2023.

1.2.5 Work Package 5

The main objective of WP5 was to integrate the E2E system designed in WP2, comprised of 5G User Equipment (UE), gNB, MEC, 5GC, and factory floor applications, so to ensure that each of these components functionalities and the overall performance meet the requirements of specific use cases defined by WP1.

1.2.5.1 Status of the work package

WP5 is formally concluded, and its goals were successfully achieved. During the last period of the project's lifetime, after the submission of the Second Intermediate Report D7.3 [1], the work of the WP consisted in concluding the activities of T5.1 "Realization of the selected use cases" and T5.2 "Test and Evaluation in Real-World Production Environments" and in carrying out the full T5.3 "E2E Performance Measurement and KPI Analysis." As reported in more detail below, this consisted in completing the interconnection of EU and TW setups into a fully merged 5G networking framework, in the finalization of the E2E trial deployment, and in the execution of the project's deployed use cases, with the corresponding collection of performance results and Key Performance Indicators (KPIs) at a network and application level. Descriptions and results were documented in D5.2 [6] and D5.3 [7].

1.2.5.2 Work carried out & main results

1.2.5.2.1 Task 5.1: Realization of the selected use cases

The last reporting period contained also the last six months of Task 5.1's work. During these months, the following activities were carried out by the consortium [6], [7]:

i) Full refinement of the list of hardware and software equipment utilized for the project's selected use cases.
ii) Consolidation of the architectural configuration and full deployment of the 5G elements over the different testbed sites, especially for what concerns the E2E cross-site use case.
iii) Deployment and configuration of the application-level, non-5G-related software and hardware components utilized in the selected use cases.
iv) Overall system integration, in synchrony with the integration and validation tests of T5.2.

In particular, we report in Figure 1-25 the project's final architectural setup.

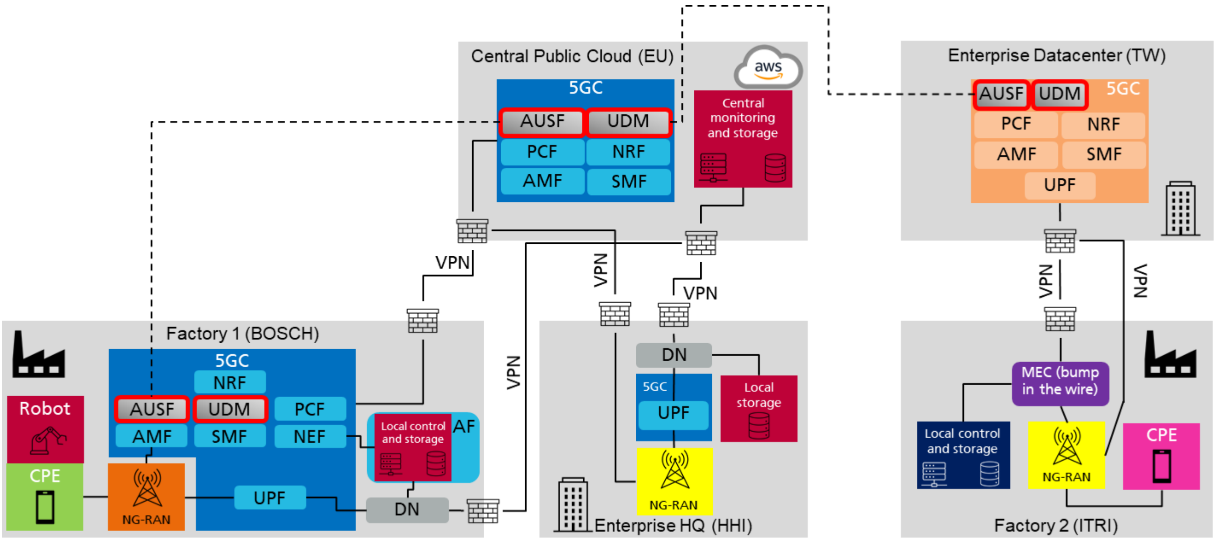


Figure 1-25: Final 5G CONNI architectural setup

The 5G network and use-case deployment activities on the EU side involved in this last period the following activities:

- Completion of the 5G private network and MEC deployment at BOSCH's site and interconnection between such site and HHI's (playing the role of the company's headquarters in the project's use case).
- Robot integration at BOSCH site and integration of its wireless control system.
- Deployment of the on-cloud 5GC network instance provided by ATH, and integration of the latter at HHI with the gNB provided by ANI.

Analogously, at the TW testbed site, the 5G network and use-case integration activities were concluded.

- The end-to-end 5G network has been deployed into IMTC plant and basic control-plane and user-plane functions are running live properly.
- To make sure the latency requirements of Cloud-based controller can be met, the test item 2.5 reported in D5.2 [6] was revisited and tested again. The round-trip-time value of ping packets be-tween UE and the application server has been improved significantly with min/avg/max/mdev = 10.5/20.5/28.7/5.1 ms

In addition, to foster EU-TW collaboration, an additional gNB supplied by Alpha will be integrated at HHI. To this end, a remote integration program of Alpha n78 gNB with Athonet 5GC has been proposed. The remote test infrastructure consisted in a PPTP-VPN based transport network, connecting the Alpha lab to central public cloud where Athonet 5GC was hosted. A total of 8 interoperability test items have been verified and the initial result shows good level of interoperability between Alpha gNB and Athonet 5GC. This test group covers essential procedures when the gNB establishes signalling connection to the 5GC, followed by UE registration and data transfer.

Moreover, as described in D5.2 [6] and D5.3 [7], the E2E 5G network deployment included the development of a synchronized UE provisioning and management system, developed by the project's partners to interconnect the EU and TW 5G networks. Such a centralized Operation Administration and Maintenance (OAM) system was designed and implemented for managing two physically separated 5G systems. The OAM system is located in Taiwan and accesses both III's 5GC deployed there and ATH's 5GC instances, located in Europe, via an OAM adaptor and ATH's function node access module (cf. Figure 1-26).

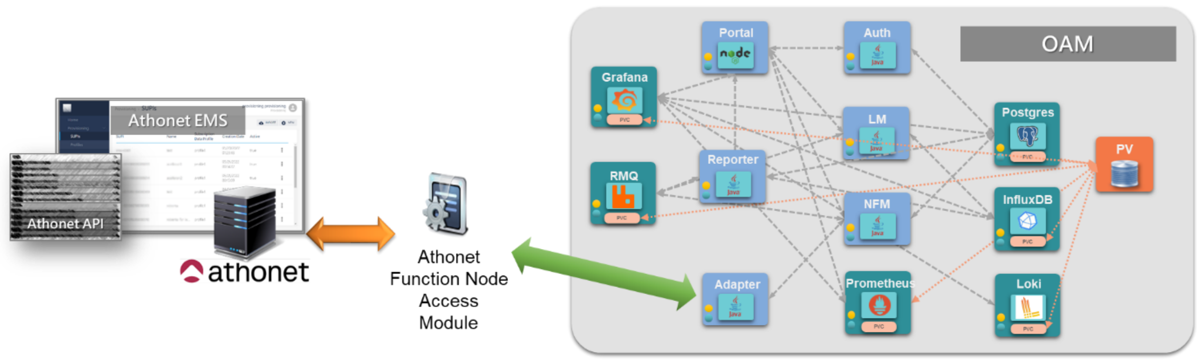


Figure 1-26: Remote access mechanism for the unified UE provisioning system

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

Task 5.2 focuses on the deployment of the initial in-lab prototypes in a real-world production plant. Most of the results on this task are reported in D5.3 [7]. For the European 5G testbed, both use cases, i.e., the robot edge control and the remote expert use case, have been successfully deployed in a BOSCH factory shop floor.

Several tests were conducted to evaluate functionality of the use cases in a real-world environment, as well as network measurements to evaluate the end-to-end performance of the 5G system. Several KPIs including packet loss, data rate, packet rate, latency, jitter, and packet inter-arrival times have been measured using network taps. Based on the networking performance, application behaviour was evaluated and functionality was verified under different network conditions.

Overall, very consistent network performance on the shop floor with around 280Mbps peak rate in downlink and no packet losses was measured. Both use cases could be executed, i.e., the robot control in the edge and remote expert including the 3D model streaming to a mobile device as intended using the 5G infrastructure.

The robot controller was also tested under heavy cross-traffic, which emulates real-world conditions where the 5G system is used by multiple applications with heterogeneous requirements in terms of bandwidth and latency. iPerf was used to test the system to generate background traffic, the effect on the robot application in terms of packet delay is exemplarily shown in Figure 1-27. With increasing cross-traffic, an increase in latency and jitter was observed.

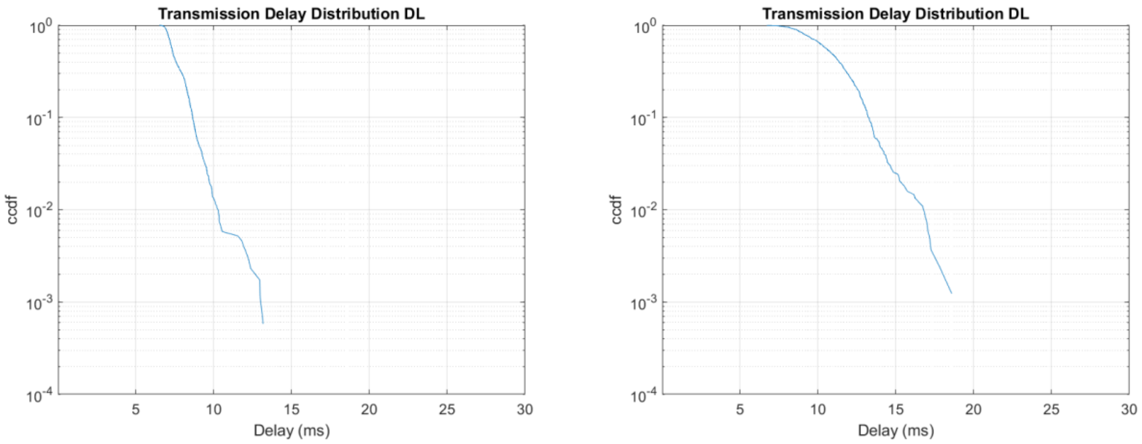


Figure 1-27: Latency of robot control packets in downlink with 0 Mbps (left) and 150 Mbps (right) cross-traffic.

To evaluate the effect of the network on the application, the robot trajectories were precisely traced. Figure 1-28 shows an example of the deviation in speed between the commanded and actually executed trajectory in the presence of cross-traffic.

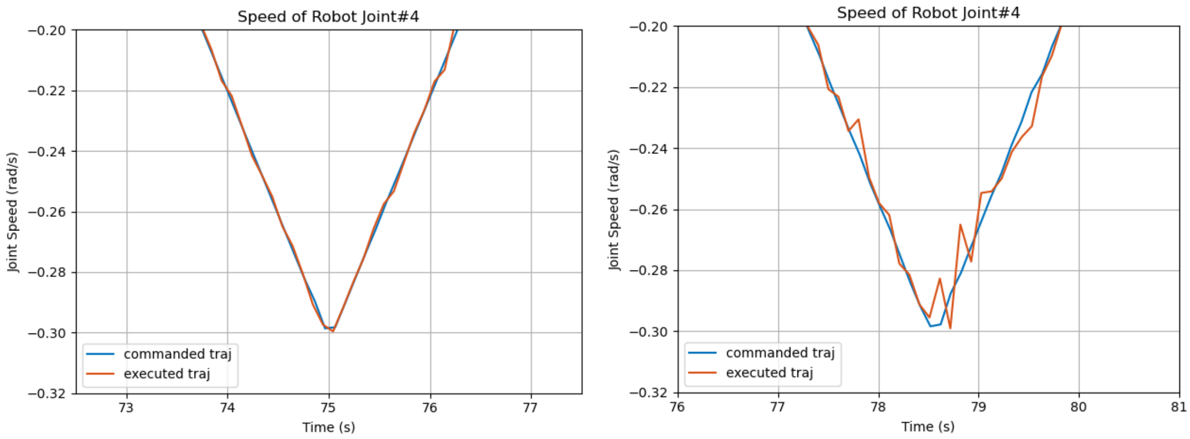


Figure 1-28: Deviation in robot trajectory speed for 0 Mbps (left) and 150 Mbps (right) cross-traffic.

With this approach, the impact of different network conditions on the application behaviour could be precisely measured and evaluated, as reported in detail in D5.3 [7].

The inter-site remote expert has been tested successfully with a live connection between the Taiwanese and European 5G testbed. A dedicated server running a digital twin of the physical milling machine located on the IMTC shop floor has been deployed in the BOSCH factory. The digital twins on the IMTC and BOSCH site are synchronized using a WebAPI provided by ITRI. Several tests including emulation and real-world measurements to evaluate the network requirements between the two sites have been conducted. Figure 1-29 shows the architecture used by ITRI to evaluate the real-world performance of the digital twin synchronization and remote rendering.

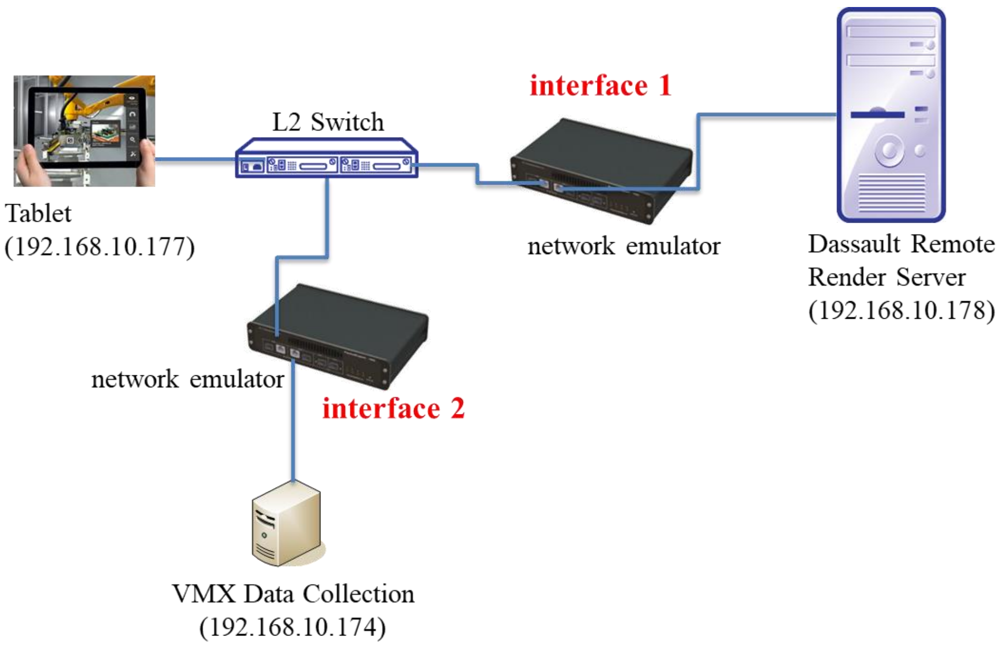


Figure 1-29: Architecture for testing real-world impairments

On interface 2, representing the connection between the BOSCH and IMTC site, an average of 270 ms round-trip time has been measured with a bandwidth of up to 0.2 Mbps.

On interface 1, different latency values between the tablet and remote rendering server have been evaluated to assess the Quality of Experience (QoE) of the video stream. Up to 15ms latency, no impairments have been observed, up to 30ms latency only minor impairments during fast motion became apparent. This test was repeated on the real production site in the BOSCH factory and a delay <15ms was measured for 99.9% of all packets.

Regarding the on-premise integration in TW, the physical system architecture of shop floor is illustrated in Figure 1-30, which includes the 5G system, transport network and OT/CT integration. The setup will interconnect two main sites via VPN.

1. The facility at ITRI that represents an enterprise's data center.
2. The pilot production site (ITRI's IMTC, Intelligent Machinery Technology Center) that represents the enterprise's manufacturing site. It involves a machine room to host most of the network elements and a metal workshop.

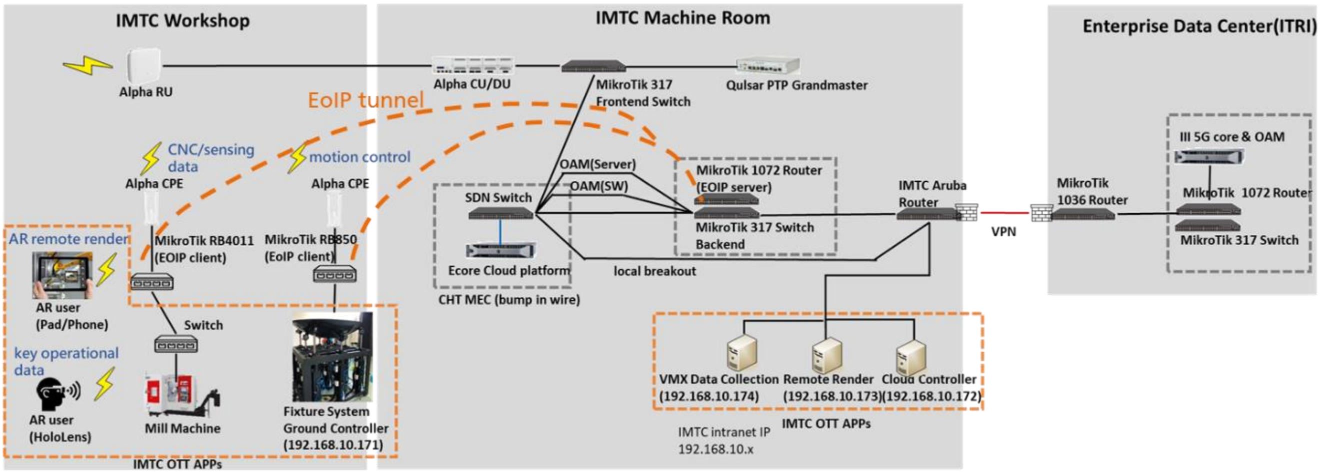


Figure 1-30: E2E network architecture of TW setup.

The aforementioned 5G system has been deployed into the factory. Figure 1-31 shows pictures taken from the IMTC premises, where we can see the III 5G core network at the enterprise data center on the right, Alpha CU and DU of gNB and CHT MEC at the machine room in the middle. In addition, the radio unit is installed at the workshop.

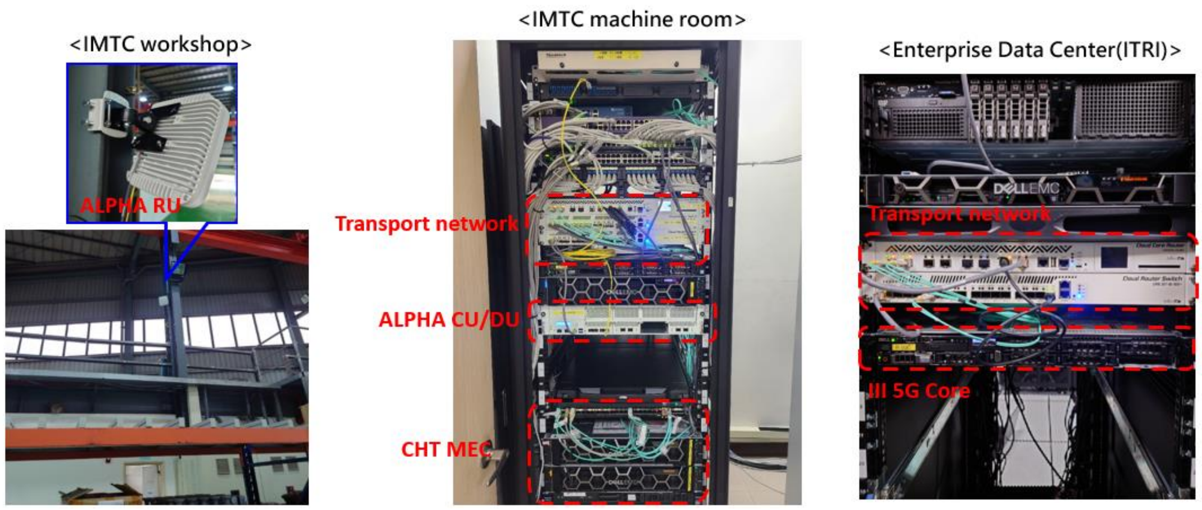


Figure 1-31: Taiwan in-factory integration.

Finally, two use cases have been implemented and integrated with the 5G system, namely:

1. Combined UC-1/UC-2: Process Diagnosis Using Augmented/Virtual Reality with CNC and Sensing Data Collection
2. Additional UC: Cloud-based Controller for Fixture System

Figure 1-32 and Figure 1-33 shows the integration of 5G system with these two use cases. For the combined UC1 and UC2, two OTT applications including data collection and analysis and remote render are hosted by the dedicated server, which is connected to the MEC platform for local breakout of user-data streams. A 5G CPE is used to provide wireless connectivity to the milling machine to transport CNC machine and sensing data towards the data collection and analysis. In addition, the re-mote rendering technique has been used to transport the video stream of rendered scene to the tablet via 5G. The viewport of 3D scene can be updated with the IMU information from the tablet so that a smooth user experience of navigating through the 3D scene can be achieved. The combined UC1/UC2 is extended to the inter-site UC.

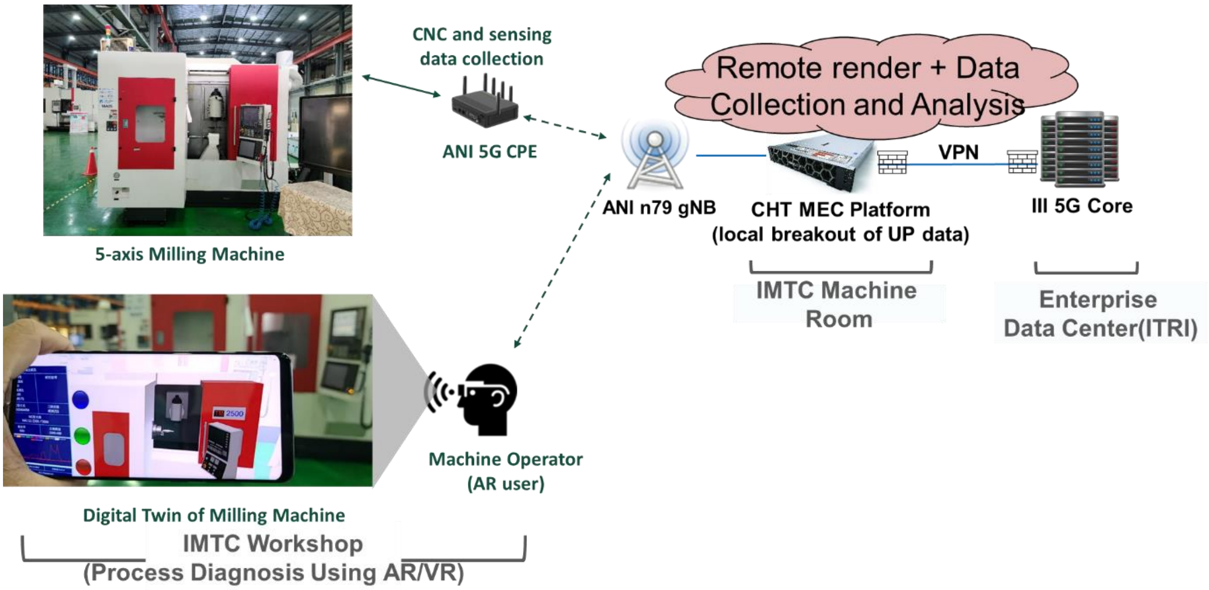


Figure 1-32: Integration of 5G system with combined UC1/UC2

For the additional UC, the cloud controller has been virtualized to the MEC platform so that the OTT application can be managed and monitored. The cloud controller has to send a series of motion commands to the ground controller to reduce the vibration during the milling process in a timely manner via 5G.

As the network may not always be able to guarantee the required QoS of the use case due to unpredictable impairments of the wireless channel, two key performance measurements have been monitored, namely: latency and buffer size, to inform the factory personnel about imminent networking issues that could jeopardize the machining process. Latency is used to measure the application processing time and 5G transmission time. Buffer size indicates the motion commands received at the ground controller. If these performance indicators exceed certain thresholds, the factory personnel will be notified to take countermeasures to prevent a further degradation. The details of the monitoring and alerting functions enabled by the MEC platform can be found in D4.3 [5]. The validation of this use case using 5G is shown in Figure 1-34, where a plastic cup is used for illustration. The objective is to suppress the vibration introduced by a shaker with frequency under 500 Hz. The test results shows that 80% of the vibration has been mitigated in terms of magnitude.

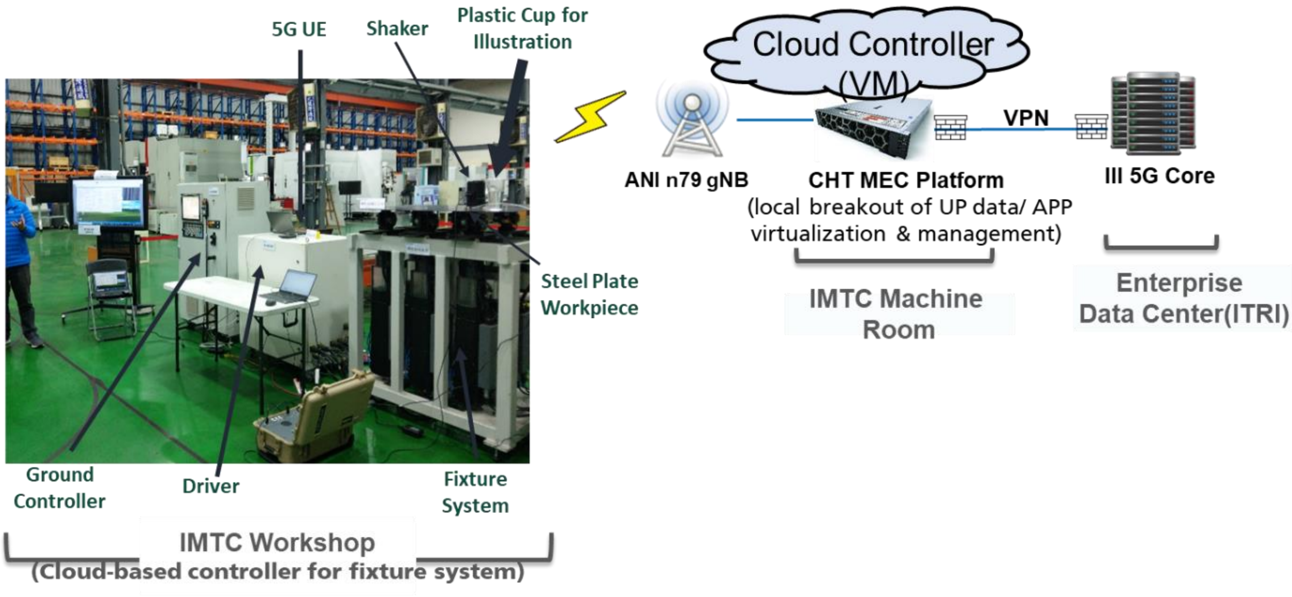


Figure 1-33: Vibration mitigation using cloud-based controller over 5G

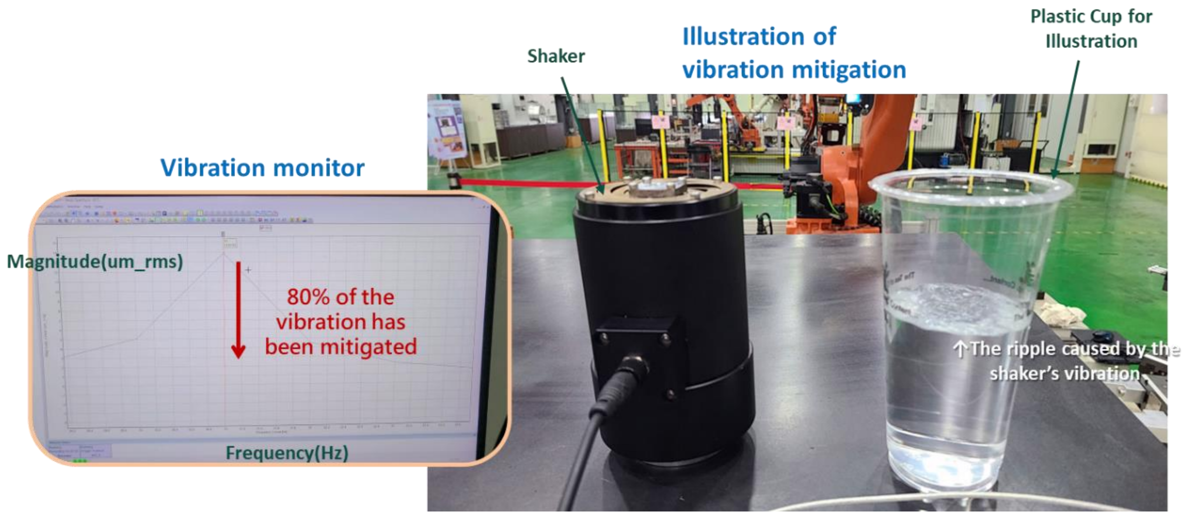


Figure 1-34: Illustration of vibration mitigation

1.2.5.2.3 Task 5.3: E2E Performance Measurement and KPI Analysis

On the Taiwanese side, the final performance measurement is shown in Table 1-3. Phase 1 test group includes 9 test cases and deals with the essential procedures when the mobile switches on and registers with the core network. In addition, data offload and forward have been verified via MEC platform. Finally, the transmission of L2 frames on top of the 5G system has been tested. Phase 2 group includes 5 test cases and covers UDP/TCP performance measurements and round-trip latency between UE and applications. The test results show that the basic control-plane function and user-plane data transfer of the 5G system are running live properly. In addition, the downlink and uplink TCP throughput and latency requirements of the use cases have been fulfilled.

Table 1-3: Test items

Test ID	Test Item	Test Objective	Test Results
1.1	NG Setup	Successful NG interface setup between gNB and 5GC	Pass
1.2	UE Initial Registration with IMSI identity	UE initial registration with IMSI identity	Pass
1.3	UE Initial Registration with GUTI identity	UE initial registration with GUTI identity	Pass
1.4	PDUSession Establishment	Successful establishment of the PDU session	Pass
1.5	UE Deregistration	Successful deregistration procedure triggered by the UE entering flight mode	Pass
1.6	Management of QoS flow by 5G QoS identifier(5QI)	Successful 5QI configuration of a QoS flow	Pass
1.7	N3 GTP-U processing (GTP decap/encap)	Successful encapsulation or decapsulation of the application packets to or from the UE	Pass
1.8	N3 GTP-U processing (data forward)	Successful data forwarding to the UPF if the traffic is not offloaded	Pass
1.9	L2 traffic via EoIP tunnel	Successful L2 data transfer on top of the 5G system	Pass
2.1	Average UDP DL Throughput at Cell Center	One UE successfully initiates Iperf UDP DL transfer at cell center with RSRP=-80dBm and record the average TPut	650Mbps
2.2	Average UDP UL Throughput at Cell Center	One UE successfully initiates Iperf UDP UL transfer at cell center with RSRP=-80dBm and record the average TPut	60Mbps
2.3	Average TCP DL Throughput at Cell Center	One UE successfully initiates Iperf TCP DL transfer at cell center with RSRP=-80dBm and record the average TPut	376Mbps
2.4	Average TCP UL Throughput at Cell Center	One UE successfully initiates Iperf TCP UL transfer at cell center with RSRP=-80dBm and record the average TPut	39.6Mbps
2.5	Average E2E Round Trip Time at Cell Center	One UE successfully initiates ping towards the application server at cell center and record the average round trip time	min/avg/max/mdev = 10.5/20.5/28.7/5.1ms; loss rate=0%

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 audiences through in-person events was heavily impacted by the COVID-19 crisis over the whole course of the 5G CONNI project. The consortium early on started leveraging alternative means like online conferences and sessions and virtual booths at trade shows to successfully inform both scientific and non-scientific audiences of the project results.

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 (https://5g-conni.eu) was set up at the beginning of the project and maintained with news, deliverables and public dissemination information.

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 2022, Athonet for the second time 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 Ministry of Economic Affairs (MOEA) in Taiwan to organize the dissemination activity at EU-Taiwan Joint 6G SNS Workshop to promote project results. In particular, a dedicated booth has been setup to display the inter-site use case, which is shown in Figure 1-35.

Figure 1-35: Demonstration of inter-site use case at EU-Taiwan Joint 6G SNS Workshop.

In the third year of the project, six journal publications and ten conference paper contributions in connection with the project were accepted or submitted at conferences and transactions and are listed in Table 1-4.

Table 1-4: List of publications related to the project

Type	Authors & Title
Journal	M. Merluzzi, N. d. Pietro, P. Di Lorenzo, E. C. Strinati (CEA) and S. Barbarossa (SAP), "**Discontinuous computation offloading for energy-efficient mobile edge computing**," in IEEE Transactions on Green Communications and Networking, vol. 6, no. 2, pp. 1242-1257, June 2022
Journal	C Battiloro, P Di Lorenzo, M Merluzzi, S Barbarossa (SAP), "**Lyapunov-based optimization of edge resources for energy-efficient adaptive federated learning**", IEEE Transactions on Green Communications and Networking, 2022
Journal	F Binucci, P Banelli, P Di Lorenzo, S Barbarossa (SAP), "**Adaptive Resource Optimization for Edge Inference with Goal-Oriented Communications**", accepetd for pubblication on the EURASIP Journal on Advances in Signal Processing, 2022.
Journal	S. Barbarossa et al. (SAP), **Semantic Communications Based on Adaptive Generative Models and Information Bottleneck**"", submitted to IEEE Communication Magazine, 2022
Journal	F. Costanzo, P. Di Lorenzo, S. Sardellitti. S. Barbarossa (SAP), "**Energy-Efficient Edge Computing with Dynamic Virtual Network Service Placement and Routing**", ready for submission to the IEEE Wireless Communication Letters.
Journal	F. Costanzo, P. Di Lorenzo, S. Sardellitti. S. Barbarossa (SAP), " **Virtual Service Placement and Routing with Resource Scheduling in Edge Cloud Networks**", to be submitted to IEEE Transactions
Conference	Ming-Yen Wu, Jiun-Cheng Huang, Yuan-Mao Hung, Cheng-Yi Chien (CHT), Jack Shi–Jie Luo, Shuo-Peng Liang (ITRI), **“The Edge Cloud Implementation and Application of Transnational Smart Factory of 5G Private Network”**, 2022 23rd Asia-Pacific Network Operations and Management Symposium (APNOMS 2022), Japan, 2022
Conference	A. Ishaq et al. (ATH), **“Service-based management architecture for on-demand creation, configuration, and control of a network slice subnet,"** 2022 IEEE 8th International Conference on Network Softwarization (NetSoft), 2022
Conference	F Binucci, P Banelli, P Di Lorenzo, S Barbarossa (SAP), "**Dynamic Resource Allocation for Multi-User Goal-oriented Communications at the Wireless Edge**", 30th European Signal Processing Conference (EUSIPCO), 697-701, 2022
Conference	F Pezone, S Barbarossa, P Di Lorenzo (SAP), "**Goal-Oriented Communication for Edge Learning Based On the Information Bottleneck**", ICASSP 2022
Conference	L. N. Dinh, M. Maman and E. Calvanese Strinati (CEA), “**Proactive Resource Scheduling for 5G and Beyond Ultra-Reliable Low Latency Communications**,” IEEE 95th Vehicular Technology Conference
Conference	L. N. Dinh, I. Labrij, M. Maman, and E. Calvanese Strinati (CEA), “**Toward URLLC with Proactive HARQ Adaptation,**” in 2022 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit)
Conference	A. Schultze, M. Schmieder, S. Wittig, H. Klessig (BOSCH), M. Peter and W. Keusgen (HHI), **"Angle-Resolved THz Channel Measurements at 300 GHz in an Industrial Environment,"** 2022 IEEE 95th Vehicular Technology Conference

Conference	S. Wittig, M. Peter and W. Keusgen (HHI), **"A Reference Model for Channel Sounder Performance Evaluation, Validation and Comparison,"** 2022 16th European Conference on Antennas and Propagation (EuCAP), 2022
Conference	L. N. Dinh, R. Bertolini, M. Maman (CEA), "**Dynamic Resource Scheduling Optimization for Ultra-Reliable Low Latency Communications: From Simulation to Experimentation**," in 2022 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Sep. 2022
Conference	L. N. Dinh, M. Maman and E. Calvanese Strinati (CEA), "**Hybrid Radio Resource Management for Ultra-Reliable Low Latency Communications based on Multi-Agent Reinforcement Learning**," submitted to IEEE ICC conference 2023, Rome, Jun. 2023

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

- Athonet, "5G Network Slicing: Athonet's Perspective and Testing Tools," organized by the Bicocca University of Milan (Italy), Dec. 20th, 2021
- Athonet, "5G Networks in Action – The Private Mobile Era," organized by the Federico II University of Naples (Italy) as part of the 5G Academy, May 11th, 2022
- Athonet, "5G Networks in Action – The Private Mobile Era," webinar organized by the Bicocca University of Milan (Italy), May 13th, 2022
- S. Barbarossa, "Semantic and goal-oriented communications via information bottleneck and topology", EuCNC Workshop on Semantic and Goal-Oriented Communications", June 2022.
- E. Calvanese Strinati, "Semantic and goal-oriented communications in 6G Networks", EuCNC Workshop on Semantic and Goal-Oriented Communications", June 2022.
- S. Barbarossa, "Network Intelligence", 61st FITCE International Congress, Sep. 2022.
- S. Barbarossa, "Semantic and goal-oriented communications", IFIP/IEEE PEMWN 2022: The 11th IFIP/IEEE international conference on performance evaluation and modeling in wired and wireless networks, Nov. 2022.
- S. Barbarossa, "Intelligent and autonomous systems and services", 5G-Italy, Nov. 2022
- E.Calvanese Strinati, "6G and the role of expressive languages', 6G Summit Abu Dhabi, Nov. 2022

During the final demonstration workshop held in Stuttgart, Germany, and Taoyuan, Taiwan, on December 12, 2022, a professional film crew accompanied the project consortium in order to produce high quality audiovisual material suitable for presenting the project results to a wider audience. At the time of writing of this report, the demonstration films are still in post-production. As soon as the final cut is available, the content will be disseminated via the project's website, as well as internal and external social media channels of the project partners. The targeted time frame for this is January 2023.

1.2.6.2.2 Task 6.2: Standardization & Regulation

The main objective of this task was the monitoring of and contribution to relevant standardization and regulation bodies. In the third year, the project consortium focused on contributions to ETSI MEC ISG and IEEE, and on discussions with the German national telecommunications regulation agency.

In the ETSI MEC ISG, Athonet continued contributing to the work item DGS/MEC-0033 IoT API with 10 submissions. They concern the means to integrate non-standard IoT platforms in a system that is instead compliant with the ETSI MEC framework. Moreover, ATH gave a presentation and demonstrated a proof-of-concept MEC IoT Service at the ETSI IoT Week, held in Sophia Antipolis (France) between Oct. 10th to 14th, 2022. The presentation focused on illustrating the IoT platforms of major cloud providers such as AWS and Microsoft Azure and their architecture, emphasizing the common procedures of deployment and configuration of message buses, IoT applications, and IoT devices.

HHI was and still is actively contributing – including filling the position of vice chair - to the IEEE Millimeter-Wave Channel Sounder Verification group that is developing the IEEE P2982 standard for channel sounder performance verification. This activity has also enabled a more targeted dissemination of the radio channel measurement activities in 5G CONNI, leading to the organization of multiple topical workshops and special sessions at international conferences.

Furthermore, path loss data extracted from the measurements that were conducted during the 5G CONNI project submitted in the second year of the project to ITU and are now included in the Study Group 3 databanks containing radiowave propagation measurement data.

Finally, one of the objectives of the 5G CONNI project was to provide input to regulatory bodies to facilitate realization of the developed operator models. Throughout the year 2022, HHI held regular phone conferences with the German telecommunications regulation agency BNetzA, where the project's results were shared in detail. BNetzA agreed on an ongoing cooperation with further meetings to be held in 2023.

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.

Even with the project concluding at the end of the year 2022, administrative management tasks will extend well into Q1/23, until all remaining contractual obligations of the consortium have been met.

1.2.7.2 Work carried out & main results

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.

Extension of the Project's Duration

While the impacts of the COVID-19 pandemic could be largely mitigated with respect to the activities of Work Packages 1 – 4, overall implementation and system integration activities of WP5 were still affected by delays, caused by a combination of resource availability issues, travel restrictions, restricted site/lab access and overall affected business processes. This also led to under-spending on part of some project participants as compared to the initial resource planning (as highlighted in the second review report). The 5G CONNI consortium thus decided in early 2022 to request a cost-neutral extension of the project by a total of 3 months, which was granted and ratified in an amendment to the grant agreement.

The detailed request for extension, including all changes to the work plan is given in Annex II.

1.2.7.2.2 Task 7.2. Technical project management

Project Meetings & Demonstration Workshop

In the third year of the project, two virtual and one hybrid all-hands meetings took place, which were organized by the project coordinators. Due to restrictive measures as part of national

COVID-19 containment strategies, international in-person meetings were impossible throughout the reporting period.

- Virtual General Assembly (December 9th – 10th 2021)
- Virtual General Assembly (June 30th 2022)
- Hybrid General Assembly & Final Demonstration Workshop (December 12th – 13th 2022)

Every meeting had a one to 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 planning for the last General Assembly meeting and the project's final demonstration workshop, resumption of international travel was unforeseeable. It was therefore held in a hybrid format, with the European side of the consortium convening at BOSCH's manufacturing facility and the Taiwanese partners at ITRI IMTC. The final hybrid General Assembly meeting was used to also hold the concluding demonstration workshop, during which the implemented use-cases where showcased. The hybrid format especially underlined the relevance of the remote expert assistance use-case. To make the workshop's demonstration accessible to a broader audience, a professional film crew documented it throughout the day.

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 are a member of the respective organizations, i.e. ETSI-MEC, IEEE and ITU.

The initial contact established with the German national telecommunications regulator has been intensified and evolved into a regular exchange on all topics related to mobile radio networks regulation, in the context of which the project results were presented and discussed.

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

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, as well as developed a comprehensive methodology for operator model evaluation. Leveraging the variety of different stakeholders in private 5G networks represented within the 5G CONNI consortium, this methodology was applied to the models defined earlier. The results, presented in D2.2, form a solid decision basis for businesses evaluating the use of private 5G in their operations.

Edge cloud and local break out solutions are key components for a successful integration of industrial use cases with 5G wireless communication. With bump-in-the-wire and hybrid cloud/local deployments developed and reported in D4.2, D4.3 and D5.3, two technological options could be demonstrated. The 5G CONNI demonstration system as described in D5.3 includes practical realizations of use cases that were discussed as driver for 5G requirements early on, such as real-time control of industrial machines from an edge cloud via the wireless link. It shows the capabilities and limitations of state-of-the-art 5G technology.

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. The measurement and simulation data obtained throughout the project was used for comparisons and validation of the developed algorithms across consortium partners. Furthermore, monitoring solutions for the RAN, core and edge cloud components of the system with access to KPIs relevant to the implemented uses cases were implemented.

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.

With a successful demonstration workshop held as part of the project's general assembly meeting in December 2022, the consortium made a significant move towards this expected impact. All initially identified use-cases were successfully realized and demonstrated, including a globally interconnected remote expert assistance demonstration spanning both the Taiwanese and European sites of the 5G CONNI demonstration system. 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 further refined within the in-factory integration report of D5.2 and system validation of 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.

As a distinguishing feature of the 5G CONNI project, 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. Dissemination of the demonstration results achieved at the industrial application partners on both sides of the consortium, both internally to other relevant departments and externally in the cooperation with further partners, is already taking place. The significance of the project's contribution lies in matching abstract 5G concepts to state-of-the-art technology, thus giving them an anchor in practical reality that helps in creating a mutual understand between the industrial and information and communications technology communities.

Documentation of the project's achievements in the form of easily accessible audiovisual material is expected to expose them to a broader audience beyond professionals in the respective fields.

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 involved in pre-standardization and standardization in fields relevant to 5G. 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. Specifically, a regular exchange with the German national regulator has been maintained over the course of the last reporting period with special focus on the experiences in practical private campus network deployments as well as frequency allocation and numbering issues. With respect to future regulation, the use of millimeter-wave and sub-THz frequencies for mobile radio networks was discussed.

While standardization activities within 3GPP hat to be scaled back, consortium members regularly contributed to other relevant groups within their area of expertise, including ETSI MEC and IEEE.

1.3.1 Impact on academia and research

The project has been active in well-known academic conferences such as VTC, ICC, ICASSP, PIMRC, EuCAP, EuCNC and EUSIPCO. In such conferences, the 5G CONNI project has been publishing key results in addition to giving keynotes and invited talks with a range of related topics for researchers. Furthermore, partners have been hosting conference workshops, tutorials and webinars related to private 5G and beyond in industrial environments in the context of several academic events. In addition to conference publications, a number of journal papers have been published, accepted or are currently under review, including journals such as IEEE Transactions on Green Communications and Networking, EURASIP Journal on Advances in Signal Processing, IEEE Communications Magazine and IEEE Wireless Communication Letters. The impact of the COVID-19 pandemic on the dissemination of scientific results lessened in the last reporting period, allowing consortium members to attend more in-person meetings and events while hybrid and purely virtual formats continued to be relevant. This allowed for more fruitful exchanges and reaching a larger audience. Due to lifted restrictions, dissemination activities within the project for the first time also included demonstrations shown at conferences and workshops.

1.4 Deliverables and milestones

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

Table 1-5: List of deliverables

No.	Deliverable Name	Work Packages	Due Date	Delivery Date
D4.2	Final specification and implementation of the building blocks	WP4	31.12.2021	17.12.2021
D5.2	E2E In-Factory System Integration Report	WP5	31.03.2022	31.03.2022
D3.2	Report on Network Performance Analysis, Maintenance and Monitoring	WP3	31.07.2022	04.08.2022
D4.3	Specification and implementation of advanced functionalities	WP4	30.09.2022	04.10.2022
D5.3	E2E Performance Measurements and Analysis	WP5	31.12.2022	22.12.2022
D6.3	Final Report on Dissemination and Standardization	WP6	31.12.2022	30.12.2022
D7.4	Final Project Report	WP7	31.12.2022	30.12.2022

Table 1-6: List of milestones

No.	Milestone Name	Due Date	Delivery Date	Means of verification
M4	Real world trial site deployment and use case integration finished	31.07.2022	04.08.2022	D3.2, D4.2, D5.2
M5	Successful performance validation in real world production environments, KPI analysis concluded	31.12.2022	22.12.2022	D4.3, D5.3
M6	Final Workshop held[1)]. Consolidation of dissemination, standardization and exploitation activities	31.12.2022	30.12.2022	Event took place[1)], D6.3

[1)] The final workshop was open to participants from the project partner's organizations. A professional film crew documented the event for dissemination to a broader audience.

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 [8] are required. An overview of dissemination activities during the second half of the project is given in the Final Report on Dissemination and Standardization [9]. With respect to their individual exploitation plans, the project participants report the following:

HHI

HHI continues to follow its initial plan for exploitation and dissemination of project results. No updates to the plan itself are reported. Within the 5G CONNI project, HHI has followed two primary lines of work: characterization of radio channels in the industrial environment and design and deployment of private 5G networks.

With respect to radio channel characterization, the work conducted in 5G CONNI led to major new developments and a modernization of HHI's channel sounding equipment and software toolchain. Internally, this has been used for introduction of new PhD and Master Students into the topic and serves as the basis for their future work. Externally, software and measurement methodology is shared with partners and customers as part of HHI's channel sounding solution. The extensive body of measurement data obtained from factory premises in the first half of the project continues to be analyzed and evaluated by PhD students. Selected results have been published, as well as contributed to ITU-R and IEEE standardization.

Furthermore, 5G CONNI enabled HHI to acquire expertise in the area of private 5G campus networks, both conceptually and operationally. Within the project, a major part of HHI's own multi-site 5G campus network and testbed infrastructure was planned and built. This continues to serve as the basis for a larger number of ongoing and new funded research projects, as well as cooperations with industry partners and small to medium sized enterprises, for example in the context of 5G Berlin innovation cluster. Through the expertise gained within the project, HHI was able to build a continuing exchange with the German national telecommunications regulator BNetzA, providing independent insights on matters related to private mobile radio networks and radio propagation. This exchange is already planned to extend well beyond the project's end date.

BOSCH

BOSCH has been following the initially planned exploitation plan and there were no updates to the plan itself. In addition to the exploitation of the results of the first two project years, in the third year, BOSCH could gain good insights and understandings from the development and implementation of the two use cases, Robot Platform with Edge Intelligence and Control and Remote Expert. They will be the basis for further exploring new business opportunities with regards to Industry 4.0 in general and 5G-enabled factories in particular. Beyond this, the concepts of network-of-networks and subnetworks in the context of Beyond 5G and 6G are being discussed. The work with private 5G networks in this project also laid a considerable part of the foundation to start future work in the direction of these two new concepts.

ATH

The individual exploitation plan remains substantially unvaried, because the project was concluded as planned, and Athonet considers achieved its objectives within 5G CONNI. In addition to what already declared in the grant agreement and in the previous periodic reports, Athonet would like to highlight that its obtained results within the activities of WP4 are particularly suitable for further exploitation. Athonet is counting to build upon those results for its research and innovation activities and utilize the developed in-lab testbed for further activities in other subsidized European or national projects.

CEA

CEA has followed the initial exploitation plans until now. On the one hand, the outcomes of CEA's investigations on how to manage a private 5G network (orchestration and mobile edge computing), having the specific targets of improving QoS (reliability, latency, availability...) in future 5G networks, have been protected through patents (e.g. 1 filled and 1 under progress patent), and they have been disseminated through publications in high-rank international conferences, journals, and workshops. With 5G CONNI project, CEA has gained expertise in 5G private networks and will go on investigations on 5G network orchestration using deep reinforcement learning and on semantic and goal-oriented communications CEA will continue to promote the researches initiated in the project in several tutorials and workshops. On the other hand, CEA aims at the integration of some of the most promising concepts of multiple access in future communication devices with the objective to address a wide range of services. The results of 5G CONNI will contribute to enhance the offers of CEA to industrial partners in search of wireless URLLC solutions for future applications.

SAP

SAP has followed the initial exploitation plan. The expertise gained from working in 5G CONNI has been spread to the students, at both Master level and PhD level. Three PhD students of SAP are now working on the semantic and goal-oriented communication subject that originated from 5G CONNI. At the beginning of next year, SAP will lead a big Italian project on next generation networks precisely building on the expertise gained from 5G CONNI. The dissemination of these activities will continue through publications on international journal and conferences. A big national event, named 5G-Italy, has been used to disseminate the main ideas originated from 5G CONNI to Italian companies, universities and research centers.

ITRI

There are no updates on the exploitation plan from ITRI. Based on the outcomes and deliverables produced in third year, ITRI has achieved a good understanding of vertical 5G-enabled use cases, private networks, and the end-to-end system integration. In addition, ITRI has organized a physical dissemination activity at EU-Taiwan Joint 6G SNS Workshop, where a booth was setup to showcase the inter-site use case.

ANI

During the 5G CONNI project, ANI contributed the 5G RAN system including the CPE, indoor 250mW RU and CDU (CU+DU) which can work with the 5GC provided by III and ATHONET. The end-to-end system provides the 5G service for selected use cases in WP5.

Based on this outcome, ANI continues to deploy this system to enable several up-coming field trials for PoS and PoB. The uses cases in the PoS and PoB are different from those in 5G CONNI project. So the current indoor RU will integrated with DAS and a new 5W outdoor RU will be developed to be deployed in the field of factory and outdoor harbor.

ANI will continue to explore the 5G & B5G opportunities and provide the robust & cost-effective mobile communication system for the enterprise market.

CHT

For CHT, there is no update on the exploitation plan. In the third year, Chunghwa Telecom developed the MEC platform for 5G SA and integrated it with III's 5G core network, ANI's 5G base station and ITRI IMTC's industrial applications at ITRI IMTC site. We also virtualized and monitored the cloud controller application on the MEC platform, which result publish an AP-NOMS conference paper.

III

III is the key contributor of the 5G SA core network for use cases in Taiwanese demo site. The additional exploitation plan includes deploying the III core network on kubernetes platform for system integration. III also provide the OAM system with Fault Management, Performance Monitoring, Configuration Management, Accounting Management and Security Management functions, which can shows the tabs of OAM dashboard for general 5G Core execution information, including CPU usage, memory usage and the healthy management. The centralized UE provisioning function is also provided and integrated into OAM system.

3 Update of the data management plan

Not applicable.

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

The consortium's immediate response letter to the second review report is included in this document as Annex III.

The recommendations given in the review report are addressed as follows:

Not all partners are contributing to the publications of the project apart from one journal paper submitted to EURASIP which has the names of all the partners. More collaborative publications are encouraged.

Two joint publications by two European and Taiwanese partners, respectively, are reported in D6.3. One further joint publication by partners SAP and HHI, incorporating measurement data for algorithm validation is currently planned.

It is recommended that the teams work more closely together for example in the verification of the simulation tool as the factory environment is rather complex and very challenging with metallic structures etc… Although the two considered frequency bands are different, they are not excessively apart and verification at 3.7 GHz should provide a reasonable level of confidence at 4.85 GHz.

A section comparing the model parameters extracted from measurement data obtained at BOSCH's factory with the simulations performed for ITRI IMTC has been included in a revised version of D3.1.

It is recommended to estimate the spatial stationary parameters from the measurements.

The recommended parameter estimates have been extracted from measurement data and are reported in D3.2.

It is recommended that where applicable the most recent models are used e.g. ITU-R P. 1407-8 and ITU-R 1238-11.

No particular channel models where applied in the reported period, but wherever channel parameters were extracted, methodologies described in state of the art models, including ITU-R publications, were followed.

The signal reconstruction algorithm described in Sec. 4 of Deliverable 3.1 showed promising results (Fig.15) for Normalized square errors vs. number of samples. This algorithm shall be applied to the measurement results from ITRI IMTC industrial facility to test the capability and benchmark with results from the conventional radio planning tool. Evaluation of this algorithm for multiple base stations shall be included in year 3 of the project.

The algorithm has been successfully applied to the data provided by ITRI IMTC, as required. The evaluation of the algorithm performance in the multiple base stations scenario has not been possible because the training phase, necessary to learn the line graph (or the simplicial complex) from the experimental data, would have required a significant additional effort from ITRI to produce a lot of additional data under a very large number of configurations of the multiple base stations operating at the same time and covering the same region. Without this additional amount of data, the only claim that can be made about the performance of the proposed method refers to the case in which there are no interferences between nearby base stations.

The algorithm developed for service placement and request routing in Deliverable 3.1, can it be practically implemented in the trial and to measure its effect? It is suggested to consider demonstration of this technique.

The algorithm developed for service placement provide a performance gain that is worth of the additional complexity in a scenario where there is a high number of mobile devices asking for services running either in the edge cloud or in a central cloud, accessible through the core network. The scenario considered in the trial did not have such a large number of devices to justify the additional complexity of the resource allocation method.

In the review meeting a proposal for remote assistance using digital twin from EU to Taiwan with two options was presented. It is recommended to pursue Option 1 in the final demo.

Following the recommendation of the reviewers and based on an own analysis of the advantages and disadvantages of the two options, the partners decided for Option 1, namely to utilize the Dassault Systems 3DExcite rendering software instead of implementing an own, custom-built server application.

The consortium is encouraged to actively contribute to the 3GPP standard body.

Active, continuous and effective participation in 3GPP standardization is a resource-intensive effort that cannot be maintained in the scope of individual funded projects alone. At the start of 5G CONNI, project partner HHI was maintaining relevant supporting activities to disseminate project results to 3GPP. It was this activity that was intended to provide the main access to 3GPP for the 5G CONNI consortium. These activities, however, were scaled back during the COVID-19 pandemic by management decision, effectively eliminating the capability to contribute to 3GPP working groups.

Standardization efforts have since focused on those bodies to which partners had most effective access, such as ETSI MEC.

It is recommended that the web pages of the project provide more content. In addition, more patent applications are strongly recommended.

The website has been updated to reflect the latest status of project activities, publications and deliverables. As soon as the final demonstration videos finish post-production, they will also be made available through the website.

A total of three patent applications have been submitted as immediate result of the project, one by partner CEA and two by another European partner.

There is significant underspend and this needs to be addressed in the remaining period of the project.

The review report claims that there is underspend reported by all project partners. We cannot see that this claim is supported by the reported resource utilization with exception of one beneficiary. As there appears to be a misunderstanding, we want to highlight that the resource utilization tables represent an annualized comparison (i.e., target PMs for the relevant reporting period calculated based on percentage of WPs falling into that period) and a comparison of the current overall utilization vs. plan for the project. Likewise we want to stress that the statements by two of the European partners included in the periodic report relate solely to personnel costs being reported in a different category than given in Annex 2 (in line with their established and certified accounting practices; the deviation is due to an error in the preparation of the grant agreement) and do not address a purported underspend in any way. A respective statement has only been given the partner mentioned earlier in the first periodic report.

Request for revision of D3.1

1. The deliverable has been proof-read and overall presentation has been improved.
2. The measurement results for the 300 GHz band are presented in D3.2.
3. A section on comparison between measurement and simulation data has been added.
4. A figure showing a measured power delay profile to illustrate the dynamic range of the channel sounder was added. Additionally, parameter estimation methodology was explained based on this figure. Drift information on the reference clock was added. Switching rate does not apply to the used virtual array methodology, but information on acquisition times was added. K-factor estimates have been re-processed and corrected.
5. The data presented in the table is realistic. Firstly, the purpose of the simulation was to verify the system's applicability to the implemented use cases in the specific environment and system setup; this purpose is entirely met with the methodology and data as presented. The presented load situation accurately represents the considered use case and thus also helps in determining the number of required access points when scaling up.

Request for revision of D5.1

See response letter in Annex IV.

Request for revision of D6.2

The deliverable was resubmitted without changes.

The project website has been updated to reflect the information given in the deliverable.

The patents could not be mentioned in D6.2 due to them not being filed, yet, at the time of writing and submission. They are included in D6.3.

Regarding the rejected papers, the following justifications are given:

1. "Dynamic Resource Optimization and Altitude Selection in Uav-Based Multi-Access Edge Computing" by F. Costanzo, P. D. Lorenzo and S. Barbarossa (SAP), published at ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Barcelona, Spain, 2020, DOI: 10.1109/ICASSP40776.2020.9053594.
    a. This activity is related to Joint optimization of enabling technologies (radio, core, MEC) in Task 4.4. This study is extended to several scenarios in this paper such as UAVs but is very relevant for AGVs in factories.
    b. This paper is also related to Task 3.1 with Optimal placement of radio access nodes and sensing nodes
2. "Topological Signal Processing Over Simplicial Complexes" by S. Barbarossa and S. Sardellitti, published in IEEE Transactions on Signal Processing, vol. 68, pp. 2992-3007, 2020, DOI: 10.1109/TSP.2020.2981920
3. "Topological Signal Processing: Making Sense of Data Building on Multiway Relations" by S. Barbarossa and S. Sardellitti (SAP), published in IEEE Signal Processing Magazine, vol. 37, no. 6, pp. 174-183, Nov. 2020, DOI: 10.1109/MSP.2020.3014067.
    a. The two aforementioned papers are related to WP3 and lay the foundations for building the radio environment map, as reported in D3.1, where the proposed

algorithms encode the multiway relations among the observed data through the associated simplicial complex, inferred from the data, and then use the simplicial complex to build the connectivity map.

4. "Dynamic Resource Optimization for Decentralized Estimation in Energy Harvesting IoT Networks" by C. Battiloro, P. Di Lorenzo, P. Banelli and S. Barbarossa (SAP), published in IEEE Internet of Things Journal, DOI: 10.1109/JIOT.2020.3046383.
    a. This paper addresses distributed estimation of sensor data which is related to industrial IoT and thus within the scope of the project. This work is a learning problem close to journal paper #6 reported in D6.2, related to collecting, estimating and transmitting data. (Task 4.4)
5. "6G networks: Beyond Shannon towards semantic and goal oriented-communications" by E. Calvanese Strinati and Sergio Barbarossa (CEA and SAP), accepted for publication in Computer Networks (Elsevier), vol. 190, May 2021
    a. This paper addresses a goal oriented approach that is very much related to factory environment and control-communication optimizations. The main idea put forward in goal-oriented communications is that, whenever data are exchanged to fulfil a goal, the encoding strategy should be tailored to fulfil the requirements of the goal (e.g. decision accuracy, for example), rather than ensuring the bit-by-bit recovery of the transmitted data. This idea came out from the research in 5G CONNI, where the scope of the sensors sending data to a control unit is to enable the controller to take decisions with a required accuracy, within a given delay. This research paper opens the discussion to beyond 5G/6G use cases and it is already a highly cited paper.

For each of the journal papers submitted before the official start of the project, at least the second round of revisions was done within 5G CONNI.

5 Deviations from Annex 1 and Annex 2

5.1 Tasks

In the amendment AMD-861459-9 to the 5G CONNI grant agreement, the project's duration was extended from 36 to 39 months. The end date of work packages 5 – 7 and their respective tasks was shifted to M39. For details, refer to Annex II.

There were no deviations from Annex 1 of the grant agreement in force.

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.

6 References

[1] 5G CONNI, *D7.3: Second Intermediate Project Report,* 2021.

[2] 5G CONNI, *D2.2: Final Report on Private 5G Network Architecture and Operator Models,* 2021.

[3] 5G CONNI, *D4.1: Initial specification and implementation of the building blocks,* 2021.

[4] 5G CONNI, *D4.2: Final specification and implementation of the building blocks,* 2021.

[5] 5G CONNI, *D4.3: Specification and implementation of advanced functionalities,* 2022.

[6] 5G CONNI, *D5.2: E2E In-Factory System Integration Report,* 2022.

[7] 5G CONNI, *D5.3: E2E Performance Measurements and Analysis,* 2022.

[8] 5G CONNI, *D6.1: Dissemination Plan & Project Website,* 2019.

[9] 5G CONNI, *D6.3: Final Report on Dissemination and Standardization,* 2022.

[10] 5G CONNI, *D2.1: Intermediate Report on Private 5G Network Architecture,* 2020.

[11] 5G CONNI, *D6.2: Intermediate Report on Dissemination and Standardization,* 2021.

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

Work Package 1

N/A

Work Package 2

N/A

Work Package 3

Partner	Description of work
HHI	WP3 activities at HHI focused mainly on further evaluation and analysis of the extensive set of radio channel measurement data gathered in the reporting period. For all three measured frequencies, 3.7 GHz, 28 GHz and 300 GHz angle of arrival characteristics were evaluated. Comparison of angular power profiles at all three frequencies showed high similarity in terms of angles of arrivals for certain measurement points, especially in line of sight condition. At 3.7 and 28 GHz, statistical parameters for the angular spread of arrival in azimuth (ASA) were extracted that, together with the large scale parameters presented in D3.1, give a complete channel model of the characterized environment. For the measurements at 300 GHz, path loss, delay spread and angular spread of arrival were extracted. Furthermore, the ratio between strongest path, second, third paths, and residual power was evaluated. Finally, the indoor to outdoor measurements where evaluated, both from an interference and security stand point. The results show that at 3.7 GHz some signal was received outside of the industrial hall with a maximum SNR of 12 dB (including the high processing gain of the channel sounder setup), which is not relevant in terms of interference, but with sophisticated signal processing might be enough to recover some of the signaling and/or data. At 28 GHz, even with the high processing gain of the channel sounder, no signal was received outside of the hall.
BOSCH	BOSCH has continued following the WP3 activities of the consortium throughout the third project year.
ATH	N/A
CEA	N/A
SAP	In the third year, SAP has worked on improving the algorithms for building the connectivity map, using the data provided by ITRI, and extending the application to build a throughput map from sparse measurements of Reference Signal Received Power (RSRP). Furthermore, SAP worked on the optimal service placement, including the assignment of mobile devices to radio access points and to edge servers, incorporating the channel models developed by HHI.
ITRI	In the third year of the project, ITRI has worked with SAP on the connectivity map. In particular, ITRI has provided SAP with two data sets to verify the algorithm developed by SAP. More specifically, two data sets were produced, namely received signal strength and throughput, using the cell planning tool RANPLAN. In addition, ITRI has worked with CHT on the edge cloud monitoring of the additional UC (Cloud-based Controller for Fixture System). As the network may not always be able to guarantee the required QoS of the use case due to unpredictable impairments of the wireless channel, two key performance measurements have been monitored, namely: latency and buffer size, to inform the factory personnel about imminent networking issues that could jeopardize the machining process.

ANI	In the third project year, ANI contributed the 5G RAN monitoring results including the KPI of throughput, latency and reliability. The 5G RAN system was developed in the WP4 task.
CHT	Chunghwa Telecom contributed to D3.2 in section 5.3 edge cloud monitoring for the industrial application of cloud controller from ITRT IMTC. Chunghwa Telecom has participated in WP3 regular monthly conference calls for discussing network planning and given technical presentations regarding MEC monitoring systems.
III	Network monitoring functions has been implemented by III. The 5G Core Network Manager (CNM) with graphical interface provides a single clean, consistent management interface regardless of network element type. The general information, performance management functions have been developed in 2021, and the fault management, configuration management, accounting management, security management is developed in 2022. The result is shown on D3.2.

Work Package 4

Partner	Description of work
HHI	N/A
BOSCH	N/A
ATH	Athonet contributed to WP4 participating in the regular conference calls, co-leading and contributing to 2 tasks (4.2 and 4.3), and co-writing 2 deliverables (D4.2 and D4.3). In Task 4.2, Athonet worked on the finalization and testing of the ETSI NFV-like orchestration for the light and automatic 5G core deployment, management, and monitoring. Furthermore, Athonet developed a provisioning procedure of a Network Slice Subnet (NSS), presenting a demo at the *IEEE International Conference on Network Softwarization,* 27 June–1 July 2022, Milan, Italy. In Task 4.3, a proof-of-concept prototype of a hybrid 5G core model for non-public networks was designed and deployed in Athonet premises, with a demonstration of a MEC IoT Service as a mobile edge computing example, running on top of it. Such results were reported in D4.2 and D4.3.
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 D4.2 deliverable on final specification and implementation of building blocks. CEA investigated how to enable deterministic URLLC. For that purpose, CEA has investigated novel HARQ scheme for early decision-making. CEA evaluated the tradeoff between reliability, latency and resource efficiency by comparing the performance of classical reactive HARQ and proactive HARQ in a system level simulator, as a function of traffic source rate and channel conditions. Then, CEA demonstrated the application of dynamic decision maker framework that enables a novel proactive HARQ design to cope with a time-varying channel and intermittent traffic source rate. Based on Lyapunov stochastic optimization tool, a mathematical framework was proposed to understand the performance-delay trade-off by minimizing the objective function of the total resource allocation and the total queue length that was parameterized by a V value. Then CEA has extended this work to dynamic resource scheduling in D4.3. CEA proposed a reliable, resource and delay-optimized scheduling suitable for dynamic scenarios (e.g., random bursty traffic, time-varying channel) based on Lyapunov optimization. It takes into account the traffic arrival at the network layer, the queue behaviors at the data link layer and the risk that the applied decision might trigger packet loss. The trade-off between the resource efficiency, latency and reliability is achieved by the timing and intensity of decisions and can be parameterized with V and α. CEA also collaborated with SAP on Lyapunov-

	based Optimization of Edge Resources for Energy-Efficient Adaptive Federated Learning. CEA, as editor, contributed and finalized D4.3 deliverable on advanced mechanisms. These works resulted into several conference papers (4 published) and two patents (one published and one under progress). CEA also proposed novel hybrid (grant-based and grant-free) radio access scheme for URLLC. This solution is based on multi-agent reinforcement learning algorithm to optimize a global network objective in terms of latency, reliability and network throughput. This contribution, not include in D4.3, has been submitted to IEEE ICC 2023.
SAP	SAP developed, in collaboration with CEA, new algorithms for dynamic resource allocation, exploiting Lyapunov stochastic optimization, deriving the optimal scheduling of radio (transmit power) and computational resources (CPU clocks) in order to achieve the optimal trade-off between energy consumption (including the energy spent for transmission and processing), service delay (including transmit and processing delay), and decision accuracy. Then extended the application to a distributed setting using federated learning. SAP also proposed a new framework for goal-oriented communication based on the information bottleneck principle and combined the principle with stochastic optimization, to adapt the encoding strategy to the online channel state and to the current values of energy consumption and delay.
ITRI	ITRI is the leader of Task 4.4 “Industrial Application Enablers”. This involved the actual implementations of the use cases including combined UC-1/UC-2 and additional UC. For combined UC1/UC2, remote rendering technique has been adopted in the implementation of this use case. The 3D model of the demo site and target machine have been built and loaded in the GPU workstation and rendered by Dassault System software. With the help of the nVidia CloudXR package, the rendered scene can be streamed to user device such as head-mount display, tablet or cell phone. Moreover, this use case has been extended to inter-site UC (Remote expert support for process diagnosis) where the on-site machine operator can work with a remote expert via digital twins. Finally, for the additional UC, the cloud controller has been virtualized to the MEC platform. A series of motion commands generated by the cloud controller are sent to the ground controller to reduce the vibration during the milling process.
ANI	In the third project year, ANI contributed the 5G RAN system including CPE, RU and CDU, which comply with 3GPP specification and O-RAN specification, to enable the 5G technology. And some test results for different use cases was provided. This 5G RAN system was deployed in the field of Taiwan side, to continue contributing the WP5 tasks.
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 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 bump-in-the-wire MEC platform for multi-PDUsession and multi-QoSflow functions and advanced features for virtualization and VNF management (D4.2 & D4.3).
III	III is the key contributor of the 5G SA core network, III 5GC also support sending data through MQTT protocol. Thus, OAM messages can be sent in an efficient way. The outcome is shown on D4.3.

Work Package 5

Partner	Description of work
HHI	In WP5, HHI's work was focused on the integration of the final demonstrator system, including the 5G networks at the European demonstration site and the hybrid deployment at HHI's Berlin site. The self-contained network previously set up at HHI's laboratory was moved to BOSCH's demonstration factory in early 2022 and integrated into 5G CONNI's overall international multi-site network. HHI provided remote integration support to BOSCH's application experts and focused on performance optimization of the deployed network. At HHI's Berlin site, a gNodeB supplied by Alpha Networks was integrated with an edge UPF by Athonet and connected to a public cloud control plane provided by Athonet, thus realizing a hybrid network deployment. Each deployment was made accessible to the common provisioning system developed and deployed by III in Taiwan.
BOSCH	In the course of the third project year, BOSCH has put primary focus on the further development, implementation and evaluation of the two use cases, Robot Platform with Edge Intelligence and Control and Remote Expert. For the first use case, the robot use case has been extended by introducing a motion planning framework to showcase a manufacturing workpiece inspection demonstration. Two camera systems have been integrated in the setup, which are capable of showcasing its interaction with the robot controller in the edge cloud to carry out quality inspection of workpieces on the one hand, and intrusion detection for safety purposes on the other. The setup has been integrated with the private 5G network and extensively tested in terms of network and application performance in a lab environment first and then brought to a BOSCH plant later for validation and evaluation in a real factory environment. In addition, the "European part" of the Remote Expert use case has also been implemented, integrated with the private 5G network and tested in a lab environment. Finally, also this use case was brought to a BOSCH factory for final validation and evaluation.
ATH	As the leader of WP5 and co-leader of Task 5.1, Athonet organized and conducted the regular monthly meetings, coordinated the network and use case deployments of the EU, TW, and cross-site setups, and led the writing of deliverables D5.2 and D5.3, all in collaboration with the other WP partners. Concerning Task 5.1, Athonet participated in the completion of the 5G private network deployment at the EU sites (BOSCH and HHI's premises). This involved the configuration of the on-cloud 5G core network instance made available to partners for the end-to-end network integration and the installation, configuration, and shipment of the edge node with user-plane functionalities delivered to HHI. In addition, Athonet collaborated with HHI, III, and ITRI to develop and deploy the unified user provisioning system for the EU and TW 5G network instances. Moreover, Task 5.2 and 5.3's activities saw Athonet involved in the in-lab and on-site testing and validation of the deployed solutions, with a specific focus on the 5G core network and its integration with the radio access network and user equipment of the EU sites.
CEA	CEA contributed to deliverables 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	SAP worked on checking how some of its algorithms developed in WP3 and WP4 could be adapted to the scope for the demonstrator.
ITRI	In this work package, ITRI has been working on the integration of 5G with two vertical applications, namely "Combined UC-1/UC-2: Process Diagnosis Using Augmented/Virtual Reality with CNC and Sensing Data Collection" and "Additional UC: Cloud-based Controller for Fixture System". For Combined UC-1/UC-2, the impact of various network impairments on the user experience has been

	evaluated. In addition, the remote rendering technique has been used to transport the video stream of rendered scene to the tablet via 5G. For the additional UC, the cloud controller has been virtualized to the MEC platform so that the OTT application can be managed and monitored. The cloud controller has to send a series of motion commands to the ground controller to reduce the vibration during the milling process in a timely manner via 5G.
ANI	In the third project year, ANI not only integrated the N79 RU, but also integrated the N78 RU and performed the IoP with ATHONET 5GC. The 5G RAN, including CPE, N79 RU and CDU passed the basic verification items and contributed to field trial on Taiwan side. In the field trial, ANI co-worked with partners to fine tune performance for each of the use case of Process Diagnosis Using Augmented/Virtual Reality with CNC and Sensing Data Collection described in WP5.
CHT	Chunghwa Telecom contributed to D5.2 internal review process. Chunghwa Telecom has also assigned to be one of the reviewers of D5.3. Chunghwa Telecom has participated in WP5 regular monthly conference calls to discuss the EU-TW architecture and assisted in integration tests for the MEC platform.
III	A unified centralized provisioning system has been implemented by III, to practically implement the authentication modules that are shared between the TW and the on-cloud centralized 5GC instances. From the 5GC architectural perspective, such an implementation choice has two main benefits: ensuring redundancy of critical subscription data (physically available at both continental sites) and improving the performance of the control plane network functions (NFs) of the TW setup (making the UDM always locally reachable). The result is shown on D5.2 and D5.3.

Work Package 6

Partner	Description of work
HHI	HHI contributed to WP6 with four conference publications: • "Over-the-Air Verification of Angle-of-Arrival Estimation in Millimeter-Wave Channel Sounders" at VTC2021-Fall • "Channel Measurements and Large Scale Parameter Estimation in a Production Hall" at VTC2021-Fall • "A Reference Model for Channel Sounder Performance Evaluation, Validation and Comparison" at EuCAP 2022 • "Angle-Resolved THz Channel Measurements at 300 GHz in an Industrial Environment" at VTC2022-Spring and a talk "Best Practices for Rigorous Millimeter-wave Channel Sounding" at AP-S/URSI 2022. Furthermore, HHI coordinated production of audiovisual material of the project's demonstrators for distribution to various audiences. HHI continues to host the project website, providing all publicly released material and documentation. Finally, HHI acted as work package lead for WP6.
BOSCH	BOSCH is further closely following 3GPP activities with respect to non-public networks, security and the outcomes of related study and work items. In addition to this, 6G research and innovation projects, incl. publicly funded projects, have been initiated and granted, for which the outcomes of the 5G CONNI project provided a substantial basis. Of particular importance here are the concept of network-of-networks and subnetworks.
ATH	Athonet contributed to Task 6.1 and 6.2 and participated in the writing of D6.3. In particular, Athonet distributed flyers of the project at the 5G World event, held in London (UK) from Sept. 21st to 23rd, 2021. Further, Athonet hosted the UPTIME conference, held on Jan. 26th and 27th, 2022, at Villa Marconi, Bologna

	(Italy), where a dedicated session focused on EU funded projects. 5G CONNI was presented and discussed. In addition, Athonet presented some of the project's activities at the following seminars: • Dec. 20th, 2021: "5G Network Slicing: Athonet's Perspective and Testing Tools," organized by the Bicocca University of Milan (Italy). • May 11th, 2022: "5G Networks in Action – The Private Mobile Era," organized by the Federico II University of Naples (Italy) as part of the 5G Academy. • May 13th, 2022: "5G Networks in Action – The Private Mobile Era," organized by the Bicocca University of Milan (Italy). Moreover, Athonet co-authored the following papers: • M. Maman et al., "Beyond private 5G networks: applications, architectures, operator models and technological enablers," EURASIP JWCN, n. 195 (2021), Dec. 2021. • M. Merluzzi, N. di Pietro, P. Di Lorenzo, E. Calvanese Strinati, and S. Barbarossa, "Discontinuous Computation Offloading for Energy-Efficient Mobile Edge Computing," IEEE Trans. Green Commun. Netw., vol. 6, no. 2, pp. 1242-1257, June 2022. • A. Ishaq et al., "Service-Based Management Architecture for On-Demand Creation, Configuration, and Control of a Network Slice Subnet," in Proc. IEEE NetSoft, Milan (Italy), June 27th – July 1st, 2022. The latter was a demo paper, and the corresponding proof-of-concept was presented at the conference on June 29th, 2022. Finally, Athonet contributed to the work item DGS/MEC-0033 IoT API, under ETSI MEC ISG. Athonet ATH continued its work started in the previous reporting periods on the IoT API specifications with a series of submitted items accepted by the standardization group. Moreover, ATH gave a presentation and demonstrated a prototypical MEC IoT Service at the ETSI IoT Week, held in Sophia Antipolis (France) between Oct. 10th to 14th, 2022.
CEA	CEA is actively participating to dissemination activity with the publication of several paper to international conferences: EUCNC 2022 (Toward URLLC with Proactive HARQ Adaptation), VTC Spring 2022 (Early Decision Maker for HARQ Procedure in Beyond 5G Networks) and IEEE PIMRC 2022 (Dynamic Resource Scheduling Optimization for Ultra-Reliable Low Latency Communications: From Simulation to Experimentation). CEA has also submitted a paper to IEEE ICC 2023 (Hybrid Radio Resource Management for Ultra-Reliable Low Latency Communications based on Multi-Agent Reinforcement Learning). CEA also collaborated with SAP on a journal paper in IEEE Transactions on Green Communications and Networking (Lyapunov-based Optimization of Edge Resources for Energy-Efficient Adaptive Federated Learning). CEA has published a patent on early decision maker for URLLC and is submitting another one on deterministic optimization. Moreover, CEA has organized or participated to events promoting 5G CONNI project (e.g., summer school, Workshops and Tutorial)
SAP	SAP actively participated to the dissemination activities by delivering a number of invited speeches at EuCNC Workshop on Semantic and Goal-Oriented Communications, 2022, FITCE International Congress, Sep. 2022, and to the 5G-Italy event. SAP published two journal papers on the IEEE Transactions on Green Communications and Networking, in collaboration with CEA, a journal paper on the EURASIP Journal on Advances in Signal Processing, submitted a journal paper to the IEEE Communication Magazine, 2022, and it is submitting very soon a paper, co-authored with HHI, to the IEEE Wireless Communication Letters. SAP has also presented papers related to 5G CONNI to two international conferences: EUSIPCO 2022 and ICASSP 2022.

ITRI	As the work package contributor, ITRI has worked with Taiwanese partners to showcase the inter-site use case (Remote expert support for process diagnosis) at EU-Taiwan Joint 6G SNS Workshop. In addition, ITRI has contributed to the joint paper on monitoring and alerting functions for APNOMS 2022.
ANI	N/A
CHT	Chunghwa Telecom submitted to the APNOMS conference paper cooperating with ITRI. Chunghwa Telecom also contributed to D6.3 in the area of section 3.2 partner update. Chunghwa Telecom also attended EU-Taiwan Joint 6G SNS Workshop, and assisted to prepare the AR remote expert demonstration.
III	On Nov 15, 2022, an EU-Taiwan joint 6G SNS Workshop was held by III and ITRI, Dr. Thomas Haustein, head of department of department wireless communications and networks on Fraunhofer HHI, share the 5G CONNI results and future plan on-line.

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 continued to host monthly management calls with the assistant Project Coordinator at ITRI as well as consortium calls. Two two-day consortium meetings were organized, the first of which had to be held virtually due to the COVID-19 pandemic. The second meeting, also encompassing the final demonstrations of the developed use cases was held in a hybrid format with the European and Taiwanese side each meeting physically and connection via video conference. 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.
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). The final project general assembly has been organized by BOSCH in December 2022, which took place in a hybrid manner with the European partners being physically present.
ATH	Athonet contributed to the planned project reports in collaboration with the other 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	SAP participated to the project meetings, review meeting and virtual general assembly, and contributed to the project deliverables and reports.
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 and the progress of each work package. Chunghwa Telecom attended Virtual General Assembly meetings to discuss review meeting preparation, network integration of use case and final project demonstration issues.
III	III attends regular WP meetings, virtual GA meetings and review meetings to report the progress and discuss the integration issues with 5G CONNI partners.

Annex II: Request for Extension

The 5G CONNI project was started in October 2019 and currently is within the third year of its planned duration. With the onset of the global COVID-19 pandemic in early 2020, around month 5 (M5) of the project, restrictions imposed by governments and companies, especially relating to individual mobility and workplace access, presented challenges to implementation of the project's work plan, some of which persist to this day. Their impact has been discussed in detail in the project's periodic reporting.

While the impacts could be largely mitigated with respect to the activities of Work Packages 1 – 4 as of today, overall implementation and system integration activities of WP5 are still affected by delays, caused by a combination of resource availability issues, travel restrictions, restricted site/lab access and overall affected business processes. This also led to under-spending on part of some project participants as compared to the initial resource planning (as highlighted in the second review report).

The 5G CONNI consortium remains confident that its goal of demonstrating an international end-to-end 5G testbed for the selected industrial use cases may still be achieved. However, combined with the ongoing activities of Work Packages 3 and 4 in parallel, implementation of the corresponding tasks presents itself challenging.

It is for these reasons, that the 5G CONNI consortium has decided after careful consideration to **propose an extension of the project's duration by 3 months**, i.e., to cover the full calendar year 2022, by an amending the Grant Agreement appropriately. Specifically, it is proposed to extend the duration of Work Packages 5 – 7 and consequently shift their associated deliverables and milestones by the same amount of time. This measure will allow compensating for the delays and addressing underutilization of resources incurred in the first two years of the project.

The technical aspects of the work plan remain unchanged. A projected timeline for the end-to-end integration activities assuming the proposed extension is given below.

End-to-End Testbed Integration Time Plan (to be reported in D5.2)

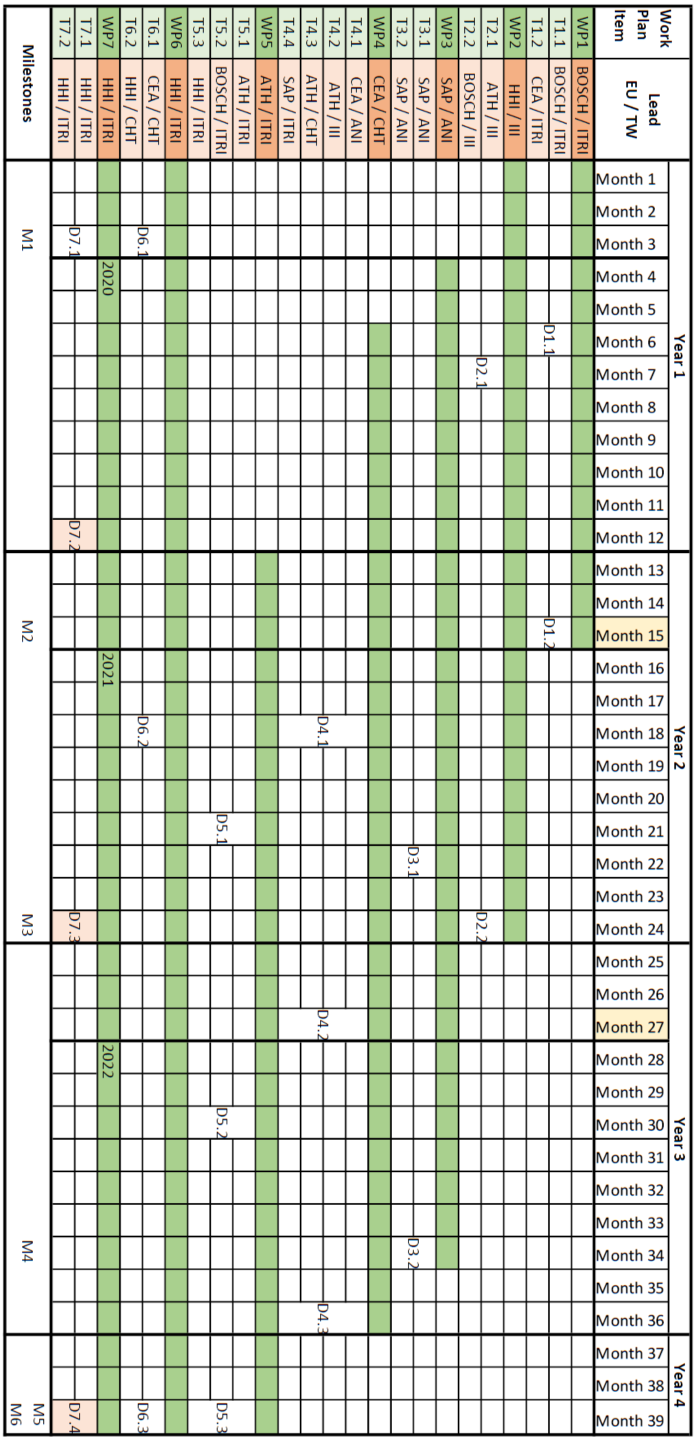
Task	Task owner (in bold) and responsible partners	Labs	Deadline	Notes
Integration of centralized UE provisioning with III and ATH's 5G core	**III**, ATH, ITRI	III, ATH	End of Aug. 2022	The web portal developed by III is able to provision subscription data into III and ATH's UDMs via RESTful APIs.
Start of inter-site use case integration	**ITRI**, BOSCH	ITRI, BOSCH	End of Sep. 2022	Start of inter-site use case implementation at trial site.
Start of D5.3 preparation	**ALL**	N/A	End of Sep. 2022	/
E2E testbed validation	**ITRI**, ANI, III, CHT, BOSCH, ATH, HHI	ITRI, BOSCH	End of Oct. 2022	Validation of the EU-TW end-to-end 5G testbed with the inter-

				site use case and final performance measurement.

The proposed changes to the work plan, milestones and delivery dates are outlined below.

GANTT Chart

The following updated GANTT chart shows the proposed extension and changed deliverable and milestone due dates:



List of Milestones

Mile-stone No	Milestone Name	Related Work Pack-ages	Due Date	Means of Verifica-tion
M1	Project Website published	WP6	M03	D6.1
M2	5G CONNI trial system archi-tecture definition, including use cases, requirements and oper-ator models	WP1, WP2	M15	D1.1, D1.2, D2.1
M3	Specification and first imple-mentations of key building blocks finished. Channel measurements finished.	WP2, WP3, WP4	M24	D2.2, D3.1, D4.1
M4	Real world trial site deploy-ment and use case integration finished	WP3, WP4, WP5	~~M34~~ M37	D3.2, D4.2, D5.2
M5	Successful performance vali-dation in real world production environments, KPI analysis concluded	WP4, WP5	~~M36~~ M39	D4.3, D5.3
M6	Final Workshop held[1)]. Consol-idation of dissemination, stand-ardization and exploitation ac-tivities	WP6	~~M36~~ M39	Event took place[1)], D6.3

1) Format and venue of final workshop is contingent on restrictions due to COVID-19 pandemic

List of Deliverables

No	Deliverable Name	WP No	Lead Par-ticipant	Type	Dissemina-tion Level	Deliv-ery Date
D1.1	Report on Use Cases & Re-quirements	1	BOSCH	R	PU	M06
D1.2	Report on Relevant Require-ments and Concerns Regard-ing Suitable Operator Models	1	BOSCH	R	PU	M15
D2.1	Intermediate Report on Private 5G Network Architecture	2	HHI	R	PU	M07
D2.2	Final Report on Private 5G Net-work Architecture and Operator Models	2	HHI	R	PU	M24
D3.1	Report on Measurements & Network Planning Methodology	3	SAP	R	PU	M22
D3.2	Report on Network Perfor-mance Analysis, Maintenance and Monitoring	3	SAP	R	PU	M34
D4.1	Initial specification and imple-mentation of the building blocks	4	CEA	R	PU	M18
D4.2	Final specification and imple-mentation of the building blocks	4	CEA	R	PU	M27

D4.3	Specification and implementation of advanced functionalities	4	CEA	R	PU	M36
D5.1	E2E In-Lab System Integration Report	5	ATH	R	PU	M21
D5.2	E2E In-Factory System Integration Report	5	ATH	R	PU	~~M29~~ M30
D5.3	E2E Performance Measurements and Analysis	5	ATH	R	PU	~~M36~~ M39
D6.1	Dissemination Plan & Project Website	6	CEA	R	PU	M03
D6.2	Intermediate Report on Dissemination and Standardization	6	HHI	R	PU	M18
D6.3	Final Report on Dissemination and Standardization	6	HHI	R	PU	~~M36~~ M39
D7.1	Project Handbook	7	HHI	R	Confidential	M03
D7.2	First Intermediate Project Report	7	HHI	R	PU	M12
D7.3	Second Intermediate Project Report	7	HHI	R	PU	M24
D7.4	Final Project Report	7	HHI	R	PU	~~M36~~ M39

Annex III: Response Letter to Second Review Report

Fraunhofer HHI

Fraunhofer Institute for Telecommunications,
Heinrich Hertz Institute, HHI

Executive Directors
Prof. Dr. rer. nat. Martin Schell
Prof. Dr.-Ing. Thomas Wiegand

Einsteinufer 37
10587 Berlin

Sven Wittig
Wireless Communications and Networks
Phone +49 30 31002-448 | Fax +49 30 31002-001
sven.wittig@hhi.fraunhofer.de
www.hhi.fraunhofer.de

Fraunhofer Heinrich Hertz Institute | Einsteinufer 37 | 10587 Berlin

European Commission
Directorate-General for Communications Networks,
Content and Technology

Berlin, February 28, 2022

Subject: Horizon 2020 Framework Programme; Project: 861459 — 5G CONNI; Project review report

Dear all,

In response to the draft review report we received on the above-mentioned project, we make the following observations:

- The review report claims that there is underspend reported by all project partners. We cannot see that this claim is supported by the reported resource utilization with exception of the beneficiary [redacted]. As there appears to be a misunderstanding, we want to highlight that the resource utilization tables represent an annualized comparison (i.e., target PMs for the relevant reporting period calculated based on percentage of WPs falling into that period) and a comparison of the current overall utilization vs. plan for the project. Likewise we want to stress that the statements by [redacted] included in the periodic report relate solely to personnel costs being reported in a different category than given in Annex 2 (in line with their established and certified accounting practices; the deviation is due to an error in the preparation of the grant agreement) and do not address a purported underspend in any way. A respective statement has only been given by [redacted] in the first periodic report.
- For deliverable D3.1, the inclusion of measurement results for the 300 GHz band is requested. It is our understanding that the project deliverables shall represent the current status of implementation and the results available at the point at which they are submitted. Thus, the consortium intended and continues to intend to include the requested results in their entirety in the next scheduled deliverable of the related work package instead of retroactively amending an already submitted deliverable. We respectfully ask for confirmation of that course of action.
- For deliverable D5.1, it is stated that information on the status and plan for deployment activities is missing. We want to highlight that the scope of the deliverable is "In-Lab Integration" as stated in the document's title, thus the reported activities and results do not relate to the deployment of the end-to-end system. A roadmap for the integration of both continental sites has been reported in the deliverable. A detailed report on the timeline and status of the end-to-end in-factory deployment will be included in D5.2 in line with the document's scope. We propose to revise D5.1 such to more clearly present the scope of activities and their relationship with the overall work plan as well as the deployment activities reported in D5.2.

Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V., München
Executive Board
Prof. Dr.-Ing. habil. Prof. E. h. Dr.-Ing. E. h. mult. Dr. h. c. mult. Reimund Neugebauer, President
Prof. Dr. rer. publ. ass. iur. Alexander Kurz
Dipl.-Kfm. Andreas Meuer

Cheques and transfers payable to:
Deutsche Bank, München
Account 752193300 **BLZ** 700 700 10
IBAN DE86 7007 0010 0752 1933 00
BIC (SWIFT-Code) DEUTDEMM
V.A.T. Ident No. DE129515865
Tax Number 143/215/20392

Subject: Horizon 2020 Framework Programme; Project: 861459 — 5G Berlin, February 28, 2022

- The review report inaccurately mentions "plans" of the partner [redacted] to file two patents. We want to clarify that these patent applications are indeed already filed. However, no detailed information may be given prior to their publication by the patent office due to confidentiality.

The consortium will carefully consider the remaining suggestions and requests given in the review report and work diligently towards their implementation.

Sincerely,

Sven Wittig

2 | 2

Annex IV: Editor's Replies to Request for Revision of D5.1

Cover Letter

Dear Officer,

We would like to thank you for the valuable feedback on our deliverable. We have carefully gone through the received comments and replied to them, applying the necessary changes throughout the document. We hope that these modifications satisfy the expectations of the Officer.

Please find below the detailed replies; we look forward to your feedback.

Best regards,

Marco Centenaro (Athonet – Editor of D5.1), on behalf of the authors

Replies to Officer's Comment

Comment

'This deliverable describes the end-to-end system in a lab environment, conducting connectivity and interoperability tests between European and Taiwanese sites. In general, the descriptions of the configurations are sufficient. However,

a. it contains very limited information about the actual status of the deployment and
b. it does not include a clear and detailed plan of the activity.

Both shall be added.'

Editor's Reply

The activities towards the integration of the E2E 5G system are divided into 3 steps:

1. Design, verification, and testing of the 5G system components, comprising radio access network (RAN), 5G core (5GC), multi-access edge computing (MEC) servers, and over-the-top (OTT) applications in each partner's (or group of partners') laboratory environment;
2. Integration of communication system components to create European (EU) and Taiwanese (TW) continental testbeds;
3. Integration of the E2E intercontinental testbed, implementation of the use case, and performance assessment.

At the time of writing D5.1, WP5 partners were in the middle of step 1 of the integration activities, performing assessment tests or preliminary integration of components. All these activities were taking place (or, if not started yet, were planned to take place) in each partner's laboratory or across a group of partner's laboratory environments. The actual status of this in-lab work was reported in detail in Section 4 ('System Integration'), which includes the list of envisioned tests to be performed on the hardware and software components described in Section 3 ('Hardware and Software Setup'). Thus, in order to respond to item a in the Officer's comments, we included the above mentioned considerations in the Introduction section of the revised D5.1.

The activities of step 1 (and partially step 2) were planned on a continental basis, and the time plans for the European partners and Taiwanese partners were reported in tabular form in Sections 4.1.1 and 4.2.3, respectively. Each table featured tasks, task owners, deadlines, and explanatory notes. Thus, in order to respond to item b in the Officer's comments, in the revised

D5.1 we clarified the time plans by distinguishing between task owner and responsible partner, and we added a new column to indicate the actual laboratory or group of laboratories wherein the activities were taking place (or, if not started, where they expected to take place). We want to remark that these tables will be included, updated, and extended in the upcoming D5.2 based on the integration activities and results obtained after the conclusion of D5.1.