Private 5G Networks for Connected Industries

Deliverable D7.2

First Intermediate Report

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1.0	30.09.2020	Version for submission

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List of Acronyms

3GPP	3^{rd} Generation Partnership Project
5G CONNI	5G for Connected Industries
ACIA	Alliance for Connected Industries and Automation
AMF	Access and Mobility Management Function
AP	Access Point
ATH	Athonet
API	Application Programming Interface
AR	Augmented Reality
AUSF	Authentication Server Function
CBRS	Citizens Broadband Radio Service
CEA	Commissariat à l’énergie atomique et aux énergies alternatives
CHT	ChungHwa Telecom
CNC	Computerized Numerical Control
COVID-19	Corona Virus Disease 2019
CPE	Customer Premises Equipment
CU	Central Unit
DFE	Digital Front End
DMTD	Dual-Mixer Time Difference
D-RAN	Distributed RAN, Distributed Radio Access Network
DU	Data Unit
DoA	Description of Action
E2E	End-to-End
ECC	ECoreCloud
eMBB	Enhanced Mobile Broadband
EML	Edge Machine Learning
ENI	Experimental Networked Intelligence
eSIM	Embedded SIM, Embedded Subscriber Identity Module
ETSI	European Telecommunications Standards Institute
FoF	Factories of the Future
FR1	3GPP Frequency Range 1
FR2	3GPP Frequency Range 2
gNB	Gigabit Node B, 5G Base Station
GTP	GPRS Tunneling Protocol
HARQ	Hybrid ARQ, Hybrid Automatic Repeat Request
HHI	Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute
IEEE	Institute of Electrical and Electronics Engineers
III	Institute for Information Industry
IIoT	Industrial Internet of Things
IMTC	Intelligent Machine Tool Center
ITRI	Industrial Technology Research Institute
I-UPF	Intermediate User Plane Function
KPI	Key Performance Indicator

MANO	Management and Orchestration
MAC	Medium Access Control
MEC	Mobile Edge Cloud
MEE	Mobile Edge Enabler
MEH	Mobile Edge Cloud Host
MIMO	Multiple Input, Multiple Output
MNO	Mobile Network Operator
MSD	Mean Squared Deviation
MQTT	Message Queuing Telemetry Transport
MVNO	Mobile Virtual Network Operator
NGMN	Next Generation Mobile Network
NFV	Network Function Virtualization
NMSE	Normalized Mean Square Error
NPN	Non-Public Network
NR	5G New Radio
NS3	Network Simulator Version 3
NSA	5G Non Stand Alone
OAM	Operation, Administration and Maintenance
PDCP	Packet Data Convergence Protocol
PHY	Physical Layer
PLL	Phase Locked Loop
PPS	Pulse Per Second
RAN	Radio Access Network
RLC	Radio Link Control
RRC	Radio Resource Control
RU	Radio Unit
SA	5G Stand Alone / Services and System Aspects
SAP	University La Sapienza
SBA	Service Based Architecture
SDN	Software Defined Networking
SMF	Session Management Function
TR	Technical Report
TS	Technical Specification
UDM	Unified Data Management
URLLC	Ultra-Reliable Low Latency Communication
UPF	User Plane Function
VNF	Virtualized Network Function
VR	Virtual Reality
VUCA	Virtual Uniform Circular Antenna Array
WP	Work Package
QoS	Quality of Service

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

The 5G CONNI project was started in October 2019 and announced to a broader public during the EU/Taiwan 5G/Beyond 5G Workshop held in Taipei in late October 2019. Substantial effort has been spent in the consortium in establishing a well working communication across companies, countries and cultures so as to enable focused progress in the project's technical work. During the last year, a good step towards the project's goal of demonstrating practical end-to-end industrial 5G applications in emerging new deployment models has been made as witnessed by the report at hand.

Just after the project's start, the COVID-19 pandemic posed an unforeseen challenge to all partners involved and the project itself. However, by swift action of the consortium members, impacts to the work plan could be identified early and by minor adjustments all work scheduled for the first reporting period could be completed within the time frame. Despite the lack of in-person events and meetings, both internal and external dissemination of the project has continued successfully with partners actively contributing to the scientific community (conference papers, talks and workshops), standardization and technical fora.

The technical work of the first reporting period was strongly focused on bringing together the views of industrial users and partners from the field of information and communication technologies. Taking a broader viewpoint beyond the pure application, the defined use cases and system architectures taking into account the overall industrial environment, both technical and organizational. In parallel, the investigation of radio propagation and network planning tools, as well as the development of enabling technical building blocks is going on and paving the way for the implementation phase starting in the second project year.

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

- WP1: A total of six innovative candidate use cases for demonstration have been identified and described, of which four were chosen for implementation and thorough investigation. For the selected use cases, as detailed analysis of functional and non-functional requirements was conducted. These results are captured in deliverable D1.1, see Sec. 1.2.1.2.
- WP2: Solutions for interconnectivity have been discussed on an architectural level. The identified and reviewed candidate architectures described in deliverable D2.1 offer flexibility in this regard.

- WP3: An empirical analysis of use cases selected for implementation at ITRI IMTC has been conducted.

1.1.1.2 Status of the objective

Work towards this objective is progressing well with a total of four innovative use cases being prepared for demonstration (three at ITRI IMTC, one at BOSCH). Currently, planning for their realization is underway with work on the implementation starting in the second project year as planned. Interconnectivity options have been included in the architectural planning early and will be detailed with a demonstration scenario in the final system architecture.

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

- WP3: Relevant scenarios for radio channel measurements have been defined and the required channel sounding system has been developed. In parallel novel radio mapping algorithms for coverage prediction were investigated. Practical radio planning by simulation based on the requirements identified by the use case analysis was carried out for ITRI's IMTC facility. See Sec. 1.2.3.2.

1.1.2.2 Status of the objective

Considerable work has been carried out towards this objective with solid preliminary results. Moving forwards towards practical measurements and implementations in the coming year, the partners are planning to combine and cross-validate their measurement and simulation results. Based on the current progress, it is expected that this objective will be met to a large extent within the next reporting period.

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 aiming to close technological gaps and create new building blocks for industrial 5G applications. Within the first reporting period, work towards this objective has been carried on in the following work packages:

- WP4: Industrial grade 5G radio access infrastructure and terminal equipment has been developed. Complementary, 5G core network software is being developed both on the European and the Taiwanese side of the consortium. An ETSI bump-in-the-wire local breakout solution for mobile edge computing has been developed along with resource allocation techniques for computational offloading of applications. The industrial demo uses cases are being prepared for integration with wireless communication and novel functionalities are being developed.

1.1.3.2 Status of the objective

The objective has been partially achieved, with first prototypes and methods in all four identified areas of technical enablers (radio access, core network, edge computing and industrial application) coming available as the result of WP4. Work continues rapidly on these developments to make them available for integration into the demonstrators within the second project year and thus fully meet the objective.

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

- WP1 & WP2: An analysis of stakeholder impact by different deployment models as well as of a broader collection of user stories for interactions with the private 5G system have been conducted. Based on this, suitable operator models and deployment strategies are currently being elaborated.

1.1.4.2 Status of the objective

As work on operator models in WP1 and WP2 has not yet concluded, yet, an analysis of regulatory requirements and existing regulation that would raise a need to be communicated to authorities is still pending. In the meantime, the consortium keeps monitoring regulatory activities for requests for input from the public relevant to private 5G networks.

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 objective is targeted by the bulk of activities planned for the integration and verification phase in WP5. As WP5 is scheduled to start with the beginning of the second reporting period, no focused work towards it has been carried out yet. However, the systematic empirical impairment analysis carried out already in WP3 as well as the radio planning results have laid the groundwork for achieving the objective.

1.1.5.2 Status of the objective

Although work on system integration in WP5 has not yet started, this objective has already been partially achieved by planning activities in WP3. When moving forward with integration activities in the second project year, this objective will be fully addressed.

1.1.6 Objective 6

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

1.1.6.1 Work carried out towards the objective

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

- WP6: Contributions by multiple partners to various standardization organizations (3GPP, ETSI MEC, IEEE) have been made. Visibility for the project has been created by organizing events in the academic sphere that allow for targeted dissemination of project results. The 5G CONNI vision will be presented in an accepted joint conference paper during IEEE GLOBECOM 2020 in Taipei.

1.1.6.2 Status of the objective

The objective has been fully met during the first project year. All partners have been engaging in active and open discussion, leading to a better mutual understanding of the application and wireless networking domains. Analysis of practical requirements for industrial private 5G deployments aides the development of the technical enablers, while planning for interconnectivity and sharing of components between European and Taiwanese partners emphasizes interoperability.

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 is subdivided into two tasks, one of them has been concluded (Task 1.1) and the other (Task 1.2) is currently active. While Task 1.1 covered the first two major goals above, Task 1.2 is currently addressing the aspects around operator models, i.e. the third major goal of the project. The main technical results that have been achieved by WP1 during the first year are:

- An in-depth review of related activities and documents of 3GPP, in particular TS 22.104, TR 22.261 and TR 22.804,
- The identification and analysis of innovative use cases, their description and documentation in D1.1, and an elaborate analysis of a subset of them with their associated requirements on 5G in an industrial setting,
- Selection of suitable use cases for proof-of-concept demonstrations, which will be built as part of the activities in Work Package 5 in the second year and onwards,
- The identification, analysis and documentation (in D1.1) of use case-unspecific functional requirements that are relevant in the context of private 5G network operation models for industries, and
- The submission and publication of the deliverable D1.1.

The specific technical activities conducted in each task are described below.

1.2.1.2 Work carried out & main results

1.2.1.2.1 Task 1.1: Use Case and Requirements Analysis

This task has started at the beginning of the project. After a careful consideration and review of current use case descriptions, predominantly in 3GPP documents, six innovative use cases have been identified and defined in this task to be relevant in the 5G CONNI context. Three out of these use cases have been selected for implementation in the technology verification site in ITRI and one has been selected for implementation at the BOSCH trial site. The general design, the functional and non-functional requirements on the 5G network, techno-economic benefits and implementation details of the three out of the six use cases have been comprehensively described in the first official deliverable D1.1 along with how they will be validated and demonstrated at the European and Taiwanese trial sites. The three use cases are

(1) Process diagnostics by CNC and sensing data collection,
(2) Using augmented/virtual reality for process diagnosis, and
(3) Robot platforms with edge intelligence and control.

The analysis of functional requirements revealed that, in total, 13 such requirements exist, of which four are shared among all three use cases. In addition, the non-functional requirements have been derived, which are found to be rather diverse because the use cases represent quite different scenarios, use case categories and traffic characteristics.

The three use cases that have been selected by ITRI for demonstrator implementation are

(1) Process Diagnostics by CNC and Sensing Data Collection: This use case requires eMBB capabilities of 5G network in the uplink direction. Various sensors will be

attached on the machine to collect all necessary physical quantities to analyze the machining process. In the meantime, the updated model parameters and threshold values will be transferred back to the on-line monitor system to fit the actual machining parameter. The architecture of this use case is shown in Figure 1.

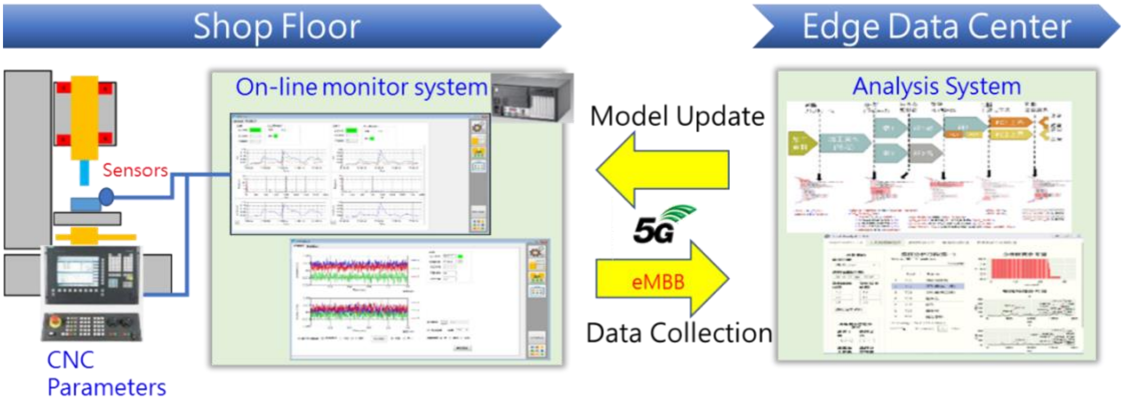


Figure 1: Components of the "Process Diagnostics by CNC and Sensing Data Collection" Use Case

(2) Using Augmented/Virtual Reality for Process Diagnosis: This use case tries to utilize the high data rate along with low latency properties of 5G communication and establish a wireless virtual reality or augmented reality system to help process engineers set up work pieces or monitor abnormal conditions during machining. The process engineer can observe machining conditions in a more intuitive way and shorten the trial-and-error process planning time. The illustration of this use case is shown in Figure 2.

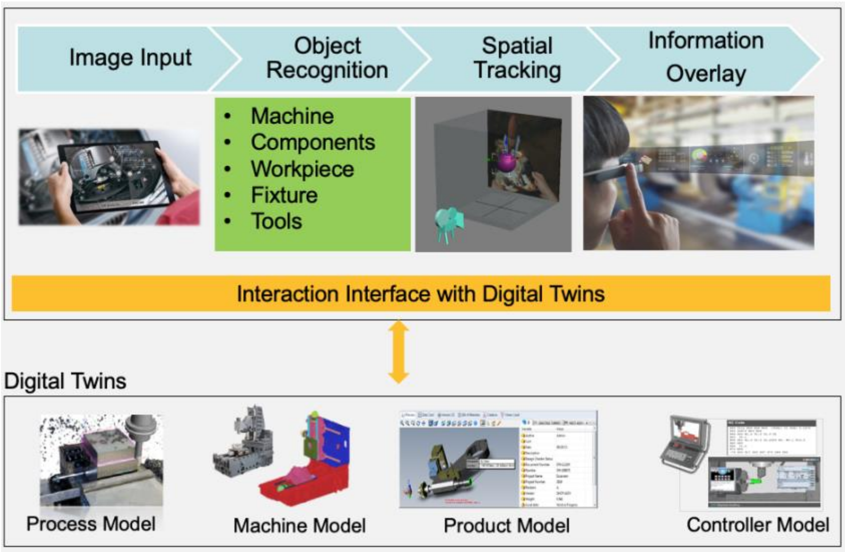


Figure 2: Components of the “AR/VR for Process Diagnosis” Use Case

(3) Cloud-based Controller for CNC: This use case consists of actuators, processes, and sensors, which are equipped at physical machines. A distributed motion controller implements the derivation of the motion commands generated by the interpolator module in the edge cloud, which are sent to the control loop to generate pulse commands to actuator. The high-level architecture is shown in Figure 3. Communication KPIs, such as service availability, reliability, packet error rate, end-to-end latency are crucial to this use case.

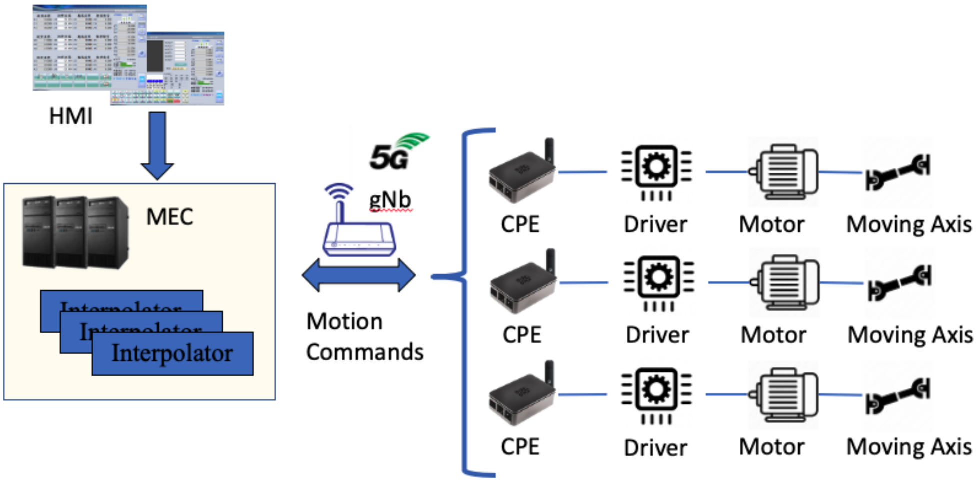


Figure 3: Illustrated Architecture of the Distributed Motion Control System for CNC

The use case that has been selected by BOSCH for demonstrator implementation is "Robot platforms with edge intelligence and control", whose high-level architecture description is depicted in Figure 4. This use case considers a mobile robot platform, e.g. a robot arm with a gripper hand, whose motion control functions are offloaded to a nearby edge cloud. 5G is considered to interconnect the robot arm with the backend, because exchanging motion control messages and feedback in the form of the current state of the machine necessitates fulfilling strict timeliness and reliability requirements. In addition, an additional sensor, e.g. a camera mounted onto the robot arm, is considered for the purpose of work piece inspection, whose data stream is also sent over a 5G link to the edge cloud.

In addition to the definition of functional and non-functional requirements, first conceptual designs have been created and initial investigations into more robust and reliable operation principles of safety-critical robot actions (e.g. arm movements), in case the 5G system performance varies over time or when network failures occur, have been conducted and documented. The further derivation of implementation details and the actual implementation are planned to start during the second year of the project.

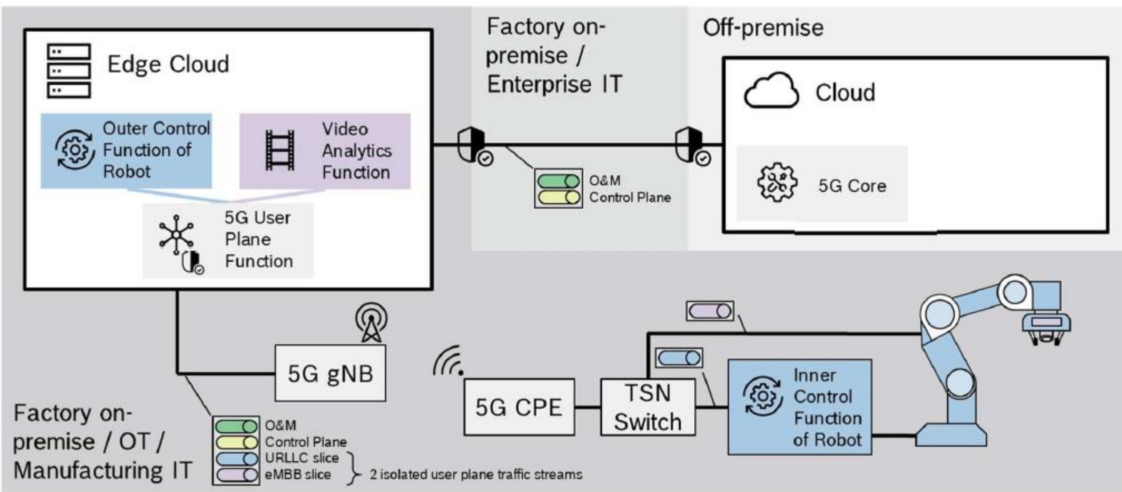


Figure 4: Architecture of the BOSCH use case.

1.2.1.2.2 Task 1.2: Requirements and Concerns Regarding Suitable Operator Models

This task has started in M6 and is currently ongoing with the main goal to identify and analyze requirements and concerns regarding operator models and to evaluate the individual aspects with respect to their criticality.

Because it is expected that deployment and network architecture models strongly interrelate with operator models, an initial investigation into use case-unspecific functional requirements that are mostly related to the network architecture design has been carried out. This resulted in a collection of 61 such requirements, which have been thoroughly described and documented. They are derived from 19 goals, which essentially correspond to a first collection of concerns regarding operator models. All of the 61 requirements can be grouped into eight categories, namely:

(1) Subscriber and identity management,
(2) Cyber-security,
(3) Monitoring and alerting,
(4) Slice and network management,
(5) Service availability,
(6) Access control,
(7) Voice services, and
(8) Charging.

The currently ongoing activities in this task are the following:

- Characterization and definition of operator models (which has already partly found its way into the definition of network architecture and, hence, deliverable D2.1, in particular, regarding involved stakeholders, ownership and governance),
- An analysis and description of the interdependence between operator and deployment models,
- The further collection of concerns and requirements regarding operator models,
- And the evaluation of the criticality of the aspects along with an evaluation template in preparation of Task 2.2 of Work Package 2.

1.2.2 Work Package 2

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

1.2.2.1 Status of the work package

In the first reporting period, focus was put on the analysis of stakeholder impact by different ownership and governance structures suitable for non-public 5G deployments. Working towards the work package’s objectives, the following results have been achieved:

- Definition and discussion of suitable architectures and associated operator models in a common ownership and governance framework
- Analysis of 5G system integration into enterprise processes by means of user stories
- Definition of the target architecture for the Taiwanese demo site
- Down-selection of target architecture for the European demo site
- Options for interconnectivity of both demo sites

These results have been documented in D2.1. Due to the COVID-19 pandemic emerging in the delivery timeframe of D2.1 and its immediate impact on the operations of project partners, delivery of D2.1 was delayed by four months. For a detailed discussion of COVID-19 impacts, see Sec. 0.

1.2.2.2 Work carried out & main results

1.2.2.2.1 Task 2.1: Architectural Design for Private 5G Networks

This task focused on defining several architectural models for 5G network deployment. In particular, different network architectures for network functions placement and management have been investigated and reported in deliverable D2.1.

The first part of D2.1 focused on the definition of network dimensions and roles of related stakeholders. This has been used to better define ownership and governance of the 5G network dimensions, according to the specific network architecture. Four different architecture types were taken into consideration and are displayed in Figure 5:

i) Fully Private Infrastructure
ii) MVNO Model
iii) Hybrid Model
iv) MNO’s Private Core Network using I-UPF
v) MNO’s Private Core Network using bump-in-the-wire

Discussions have followed regarding spectrum availability, which should be regulated depending on government bodies. About SIMs, the concept of eSIM has been introduced as a fitting asset for industrial mobile network contexts. Other relevant dimensions are: RAN, MEC platform, core network, applications, transport network and OAM system.

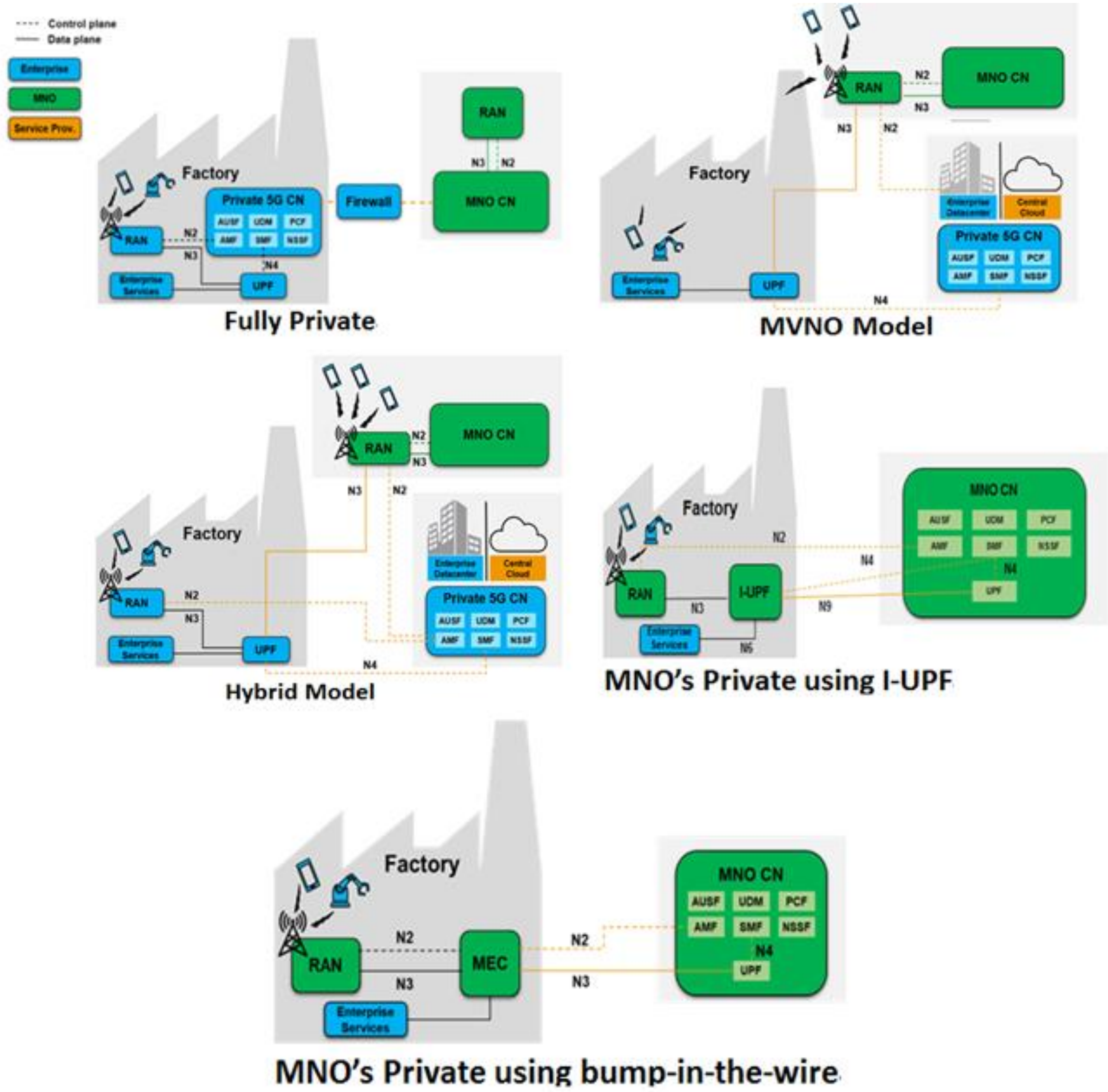


Figure 5: Five architecture options for private 5G networks

In order to accurately assess the impact of network architectures, a section related to user stories have been provided. This section made clear how to better specific the stakeholder impact of each network deployment model.

The core of this task was the definition of 5G private network architectures. In order to carry out with an appropriate design, four architecture options have been proposed, differentiating them according to which stakeholder is owning and governing the dimensions and where the premises are located. Three stakeholders have been defined for the scheme: MNO/MVNO, Enterprise and Service Provider. Three deployment locations have been defined: Edge Cloud (on-premise location), Enterprise Datacenter and Central/Public Cloud.

Based on the work conducted in this task and the discussions elaborated in D2.1, the target architectures for the demo were defined for the Taiwanese site and down-selected for the European site. Additional work was being done on the interoperability between the two demo sites. The results will be documented in deliverable D2.2, due in M15 of the project.

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

The goals of this task is the identification, design and analysis of deployment strategies and operator models. It is obvious that architectures and deployment and operation models are interrelated. Because of this, both Tasks 2.1 and 2.2 go hand in hand, while in Task 1.2 the concrete interdependence is currently being investigated.

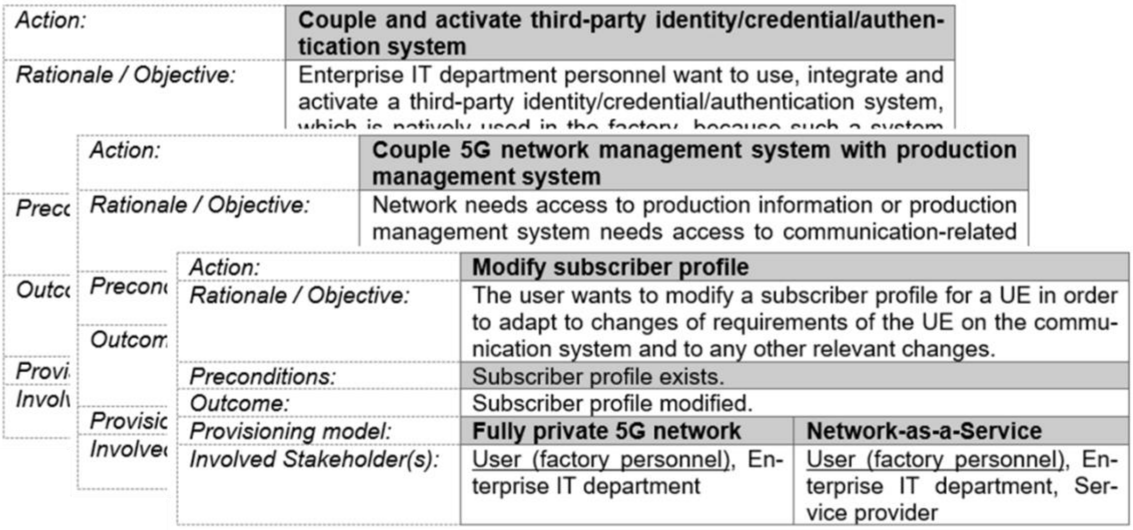
A joint, central aspect of the architecture, deployment and operation models, which has been identified in this task, is the interaction with the 5G System, in particular with respect to two important considerations:

(1) The concrete technical feasibility of an action by a certain stakeholder given technical and regulatory constraints, especially the ones in the context of connected industries, (which reflects on the suitability of a certain architecture) and
(2) The overall allocation of responsibilities and tasks among a number of different stakeholders, including factory personnel and a third-party service provider (which reflects on operation models).

In order to unravel this complex problem of model evaluation, the next step was to identify a number of user stories, 63 in total, which have been described according to

- Their rational,
- The preconditions and their expected outcome, and
- The involved stakeholders.

Three exemplary user stories are depicted in Figure 6.



Action:	Couple and activate third-party identity/credential/authentication system	
Rationale / Objective:	Enterprise IT department personnel want to use, integrate and activate a third-party identity/credential/authentication system,	

Action:	Couple 5G network management system with production management system	
Rationale / Objective:	Network needs access to production information or production management system needs access to communication-related	

Action:	Modify subscriber profile	
Rationale / Objective:	The user wants to modify a subscriber profile for a UE in order to adapt to changes of requirements of the UE on the communication system and to any other relevant changes.	
Preconditions:	Subscriber profile exists.	
Outcome:	Subscriber profile modified.	
Provisioning model:	Fully private 5G network	Network-as-a-Service
Involved Stakeholder(s):	User (factory personnel), Enterprise IT department	User (factory personnel), Enterprise IT department, Service provider

Figure 6: Three exemplary user stories out of the 63 defined.

The user stories were grouped into nine categories, namely

(1) Initial Setup of End Devices and Network,
(2) Subscriber Profile Management,
(3) Network Slice Management,
(4) Maintenance, Management and Operation,
(5) Data Confidentiality, Security and Safety,
(6) Private Communication,
(7) Accounting,
(8) Monitoring and
(9) Fault Management.

It was found that, from the different viewpoints of the 5G CONNI partners, different stakeholders should be involved in the respective actions. In order to consider this fact, the possible options of architectures and operation models are categorized coarsely into two “provisioning models”, which are “Fully private 5G network” and “Network-as-a-Service”. Then, per action, stakeholders have been defined for each of the two models, where the allocated responsibilities for the “Fully private 5G network” reflects the requirements and concerns of the OT industry and the ones for the “Network-as-a-Service” reflect the business models of the IT and telco industry.

As one of the subsequent steps in this task, the implementability of the user stories (among other criteria) will be used to evaluate the feasibility and suitability of the different architecture candidates and the operator models.

1.2.3 Work Package 3

Work Package 3 is dedicated to the application-centric planning, monitoring, operation and management of the private 5G network. The WP started in month 4, and during the first year of the project, activities from both tasks (T3.1 and T3.2) have been carried out. Within T3.1, HHI started setting up the channel sounder system for the measurements campaigns to be performed at BOSCH facilities. This task is carried out in collaboration with BOSCH, which started investigating some channel measurement scenarios. SAP developed a novel algorithm to build a connectivity map, starting from the investigation of a communication networks to infer the spectral efficiency of some links from sparse measurements over different links. ITRI started the work related to cell planning, performing ray tracing simulations, building a 3D model of the factory plant, including also traffic profile and preliminary results on coverage and throughput predictions. Alpha network has participated in this activity providing RAN component radio design. CHT started the investigation of T3.2 (private 5G network monitoring, operation and management). III has been attending the regular project meetings and discussing the planning, operation and maintenance of the private network which is designed for the industrial use cases with 5G CONNI partners.

1.2.3.1 Status of the work package

The activities of Work Package 3 started in month 4 of the project, and they end in month 34. Some activities only require theoretical efforts and algorithm developments, which have not been strongly affected by COVID-19 crisis. Other activities, such as channel measurements at BOSCH facilities, have been delayed due to the limited access to the plants, so that they will take place during the second year of the project. Nevertheless, the activity on the development of the channel sounder has been carried out in advance, so as to limit the delays.

1.2.3.2 Work carried out & main results

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

Task 3.1 is dedicated to the channel measurements, the connectivity map, capacity dimensioning and optimal placement of radio and sensing nodes. The activities carried out during the first year involve the setup of the channel sounding system for the measurements, the connectivity map with a focus on spectral efficiency, and cell planning with ray tracing and a 3D model of the factory, with preliminary results on coverage and throughput prediction.

Channel sounding system and measurements

A major item within this task is the investigation of the radio propagation conditions in the industrial environments which are targeted by the project. Although a channel model for a scenario called *Indoor Factory* has recently been standardized in 3GPP [1], both the vast variety of different industrial environments and their distinctions from those environments for which the standard channel models have been developed mandate further research. Within 5G CONNI, channel measurements with the goal of gaining deeper insight into the radio propagation conditions in industrial deployments will be conducted by HHI at 3.7 GHz (3GPP

Frequency Range 1 (FR1)) and 28 GHz (3GPP Frequency Range 2 (FR2)). The data obtained from these measurements may then also be used as input to the algorithms developed by 5G CONNI partner SAP. Apart from the targeted environment, the novel aspects of these investigations are inclusion of spatial resolution in the low-frequency measurements, providing for example angle-of-incidence information. At FR2 frequencies, diffuse/dense multipath propagation characteristics will be studied. In conjunction, both will allow an analysis of frequency dependencies in different parameters of interest.

In cooperation with BOSCH, three different scenarios have been defined for investigation:

1. Factory floor
   This scenario is intended to characterize the large scale parameter statistics throughout a factory floor. The measurement transmitter will be placed at representative radio head / base station locations and measurements will be collected from a large number of positions throughout the factory floor. This data will aid in refining the channel model, analyzing interference conditions, evaluating distributed RAN (D-RAN) benefits and serve as input to radio mapping algorithms.
2. Distributed antennas at machine tool
   In this scenario, measurements will be conducted for multiple antenna locations at a machine tool. This will help in characterizing the typical machine-to-base station channel and provide insight into possible diversity gains and methods to increase reliability.
3. Spatially resolved measurement in a confined production cell
   Within a typical production cell, spatially resolved measurements at FR2 frequencies will be conducted. This is intended to help realizing wirelessly connected sensors and actuators within densely packed machinery.

These measurements are planned to be conducted at a BOSCH manufacturing facility in the first half of the second project year, contingent on potential COVID-19 related access restrictions.

In preparation of the measurements, HHI has developed and manufactured a variant of its Virtual Uniform Circular Antenna Array (VUCA) spatial sampling system capable of measuring at FR1 frequencies. Furthermore, detailed investigations into metrological aspects of the measurement setup were begun using a newly defined generic reference plane model for channel sounders. By comparing model simulations and verification measurements at 25 GHz, HHI's digital correlative time domain channel sounder was demonstrated to achieve a close-to-optimum path loss dynamic range of 83.2 dB in a typical parametrization of the setup with a maximum measurable path loss of 143.2 dB. The findings of these studies are being prepared for publication and are available as preprint [2].

Another aspect that has been studied was the time synchronization of distributed measurement systems. When performing channel measurement in large or obstructed environments, maintaining time synchronization of both ends of the radio links is challenging. Conventional methods such as using cabled distribution of timing reference signals or GPS timing information are generally not applicable in industrial environments. To this end, HHI has adopted an approach using multiple independent and portable rubidium frequency standards. The commonly used approach to syntonize (i.e. align frequencies) and synchronize (i.e. align phases) of these frequency standards employs one pulse-per-second (1PPS) signals. However, this approach is not suitable for field measurements due to its large time constant. To alleviate this, HHI has investigated a synchronization approach using all-digital dual-mixer time difference (DMTD) detector based PLLs [3]. In a prototype implementation, an open-loop phase drift of typically 5 ns/h between two previously synchronized rubidium frequency standards could be demonstrated. This is close to the lower bound given by the used rubidium standard’s adjustment resolution. These results will be used at HHI to build a family of portable precision timing devices which will be used for measurements and timing related KPI verification within 5G CONNI.

Cell planning

This task is dealing with the planning of private 5G networks designed for the industrial use cases identified in WP1, which covers channel measurements in FR1 and FR2, connectivity map and cell planning. For the cell planning, ITRI have conducted 5G NR coverage and throughput predictions in frequency band n79. The simulation results provided insights into cell planning in terms of the optimal number and location of base stations. The simulations that have been carried out can be summarized as follows:

- The 3D Building Structure Modeling of the trial site has been conducted to form the basis for the accurate calculation of radio propagation prediction via ray tracing. In addition, the MIMO antenna patterns has been measured and imported (Figure 7).
- The traffic profile has been identified based on requirements of the use case “Using Augmented/Virtual Reality for Process Diagnosis”, namely downlink throughput, uplink throughput, number of users, mobility.
- The initial coverage and throughput predictions have been conducted to evaluate the performance of real-life network deployment. These initial results suggest ways to deploy 5G network in terms of the optimal placement of base stations.

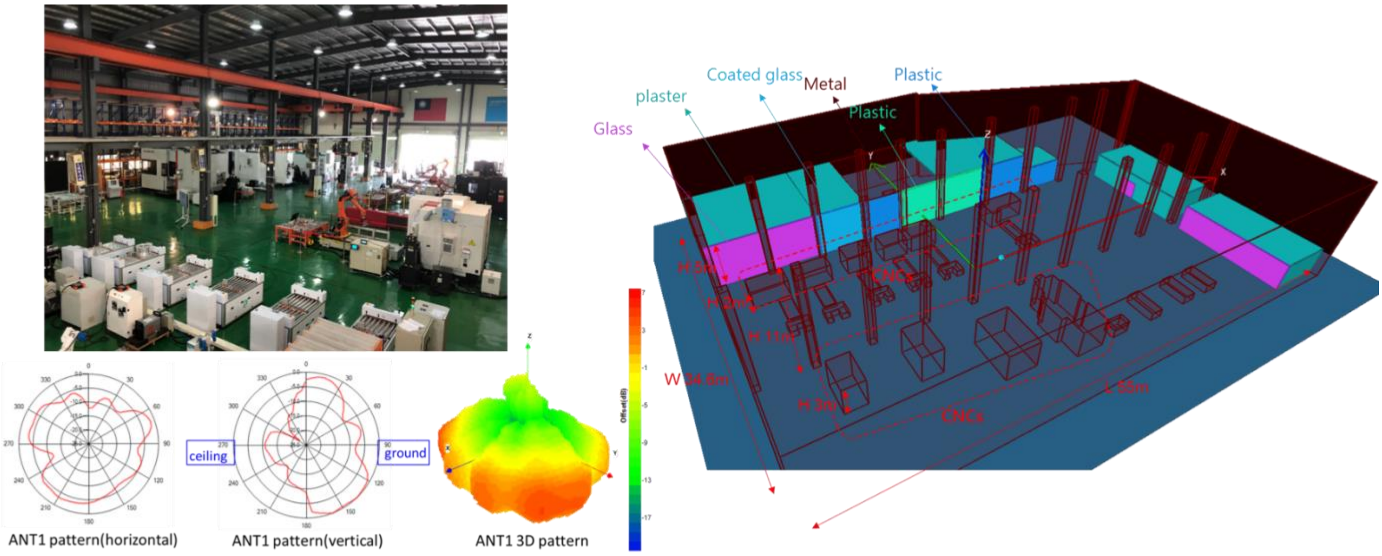


Figure 7: 3D Building Structure Modeling and antenna patterns

Connectivity map

One of the subtasks of T3.1 is dedicated to build a connectivity map including throughput, latency, and reliability, based on a limited set of measurements. In the first year, SAP developed a novel algorithm to build this map, which generalizes conventional graph-based approaches. In particular, given a communication network as in Figure 8, the goal is to infer the KPI's (e.g. throughput, latency, etc.) over a large number of links (the red arrows in Figure 8), starting from sporadic measurements of the same KPI's obtained over a limited number of links (the black arrows), to save time and complexity.

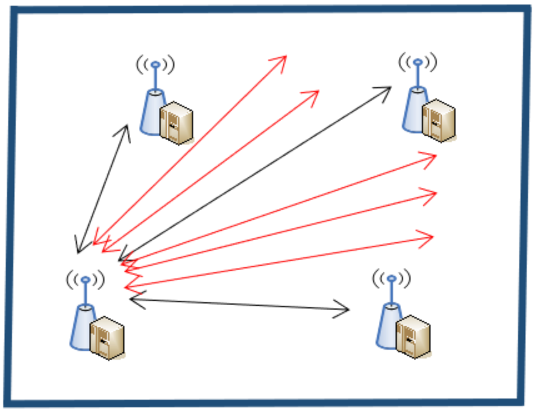


Figure 8: Example of a communication network for edge signal estimation

In the last few years, graph-based algorithms have received great attention in the signal processing community to estimate signals defined over the vertices of a graph. These methods exploit pairwise relations (captured by the edges of the graph) between the signals present on the nodes of the graph. However, in our setup, the signals of interest, e.g. throughput, latency, etc., are naturally associated to the edges of the graph. To solve the problem, we generalized the conventional approach by introducing simplicial complexes, which incorporate multiway relations, and developed algorithms to estimate edge signals from a subset of measurements. As a preliminary example, we applied our algorithm to estimate the spectral efficiency over non observed links of a network composed by 20 nodes, starting from the observation of the spectral efficiency over a subset of links. The scenario is depicted in Figure 9.

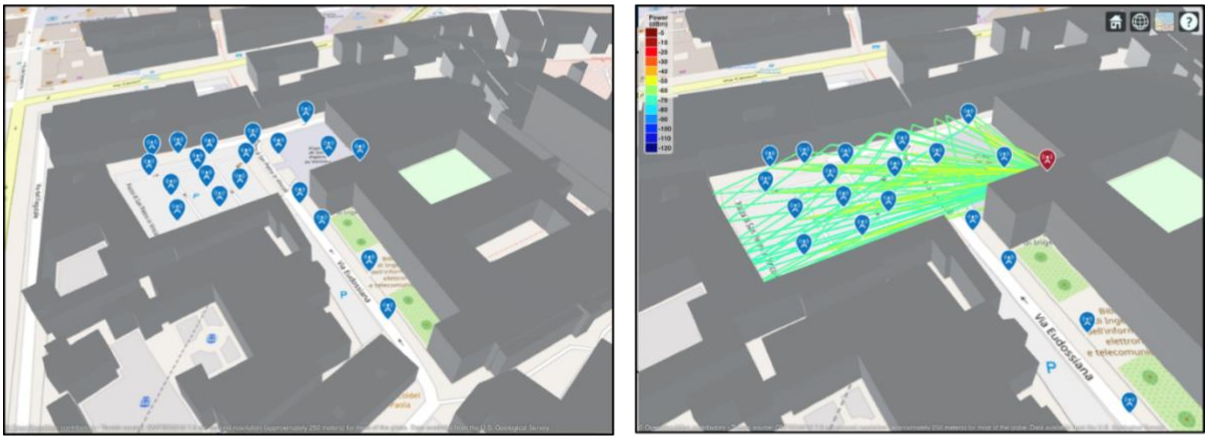


Figure 9: Ray tracing in a scenario with 20 AP located in the area around the basilica of San Pietro in Vincoli, Rome

Starting form sparse measurements, we estimate the edge signals over the non-observed links, and we show the performance in terms of Normalized Mean Squared Error (NMSE) in Figure 10, where our method is compared with a graph-based method. The NMSE is plotted as a function of the number of observed links. We can notice the non-negligible gain of the strategy based on simplicial complexes with respect to the graph-based approach. This is a preliminary result that opens the way to further investigations, including different scenarios (e.g. the factory plant), different signals (e.g. latency and reliability), and investigations on real measurement data.

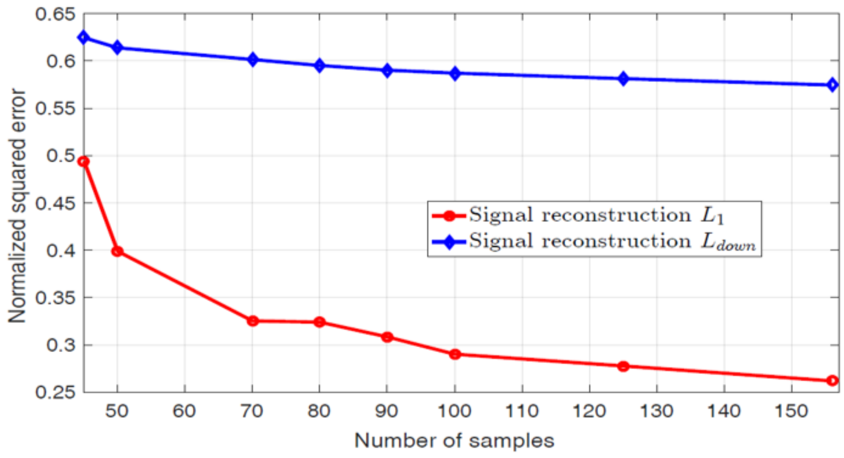


Figure 10: Normalized Mean Squared Error vs. number of observed links, comparing our method with a graph-based approach

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

The main activities of Task 3.2 involve the monitoring of network performance, the application centric radio and computation resource management, the mobility management of mobile inspectors with their association to mobile edge hosts for, e.g. computation offloading, and the definition of the network resource KPI's.

Application-centric optimization of radio and computation resources, with AP and MEH assignment

In Task 3.2, SAP has been working on the development of algorithms to optimize the use of communication and computation resources and in particular with the best association between mobile users, e.g. a mobile inspector, the radio access point and the mobile edge host, taking into account the overall delay associated to processing the data collected by the sensors and running in the MEC hosts.

Monitoring of network performance parameter relevant to I4.0 application

To make sure the operation and maintenance of specific industrial application will meet the KPI, an OAM and KPI monitoring system is being designed. Its implementation includes the management of Fault, Configuration, Performance and Security in this 5G end to end system. The specific KPI will be implemented with two requirements, one is from 3GPP specification, and the other is from the use cases (e.g., end-to end latency, service bit rate, time synchronization and secure remote access). With OAM and related KPI implemented in the 5G end-to-end system, users could monitor, configure the system and improve the efficiency of operation accordingly.

1.2.4 Work Package 4

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

1.2.4.1 Status of the work package

This work package started in March 2020. Alpha network has developed a 5G RAN system composed of a CPE and a gNB. CEA has designed an orchestrator and showed simulation results using NS3 for investigating how to enable deterministic URLLC services in task 4.1. III and ATH have developed a 5G core network in Task 4.2. ATH also has developed a MEC based on the hybrid architecture in smart industries. In Task 4.3, Chunghwa Telecom launched a MSA MEC and has developed a SA MEC prototype. ITRI has implemented three use cases prototype applications in task 4.4. The data collection and process diagnosis methods have been investigated and were demonstrated in a prototype implementation in one of the production cells targeted for the 5G CONNI demo. 3D models for these machines have been created for AR applications. The prototype of a cloud CNC controller has been developed and tested in a distributed network environment. SAP has developed an algorithm on dynamic resource allocation for wireless edge machine learning exploring energy-latency-reliability trade-off.

1.2.4.2 Work carried out & main results

1.2.4.2.1 Task 4.1: Radio Network Technical Enablers

The objective of Task 4.1 is the development of a radio network consisting of a 3GPP compliant CPE and gNodeB system based on the industrial use case generated by WP1. The main feature of 5G NR CPE developed by Alpha Networks are listed below:

- 5G NR Sub-6
- 2x GE Ethernet ports
- 1x RS232
- 1x DIDO (1DI, 1DO)

The 5G NR split gNobe is consist of RU, DU, and CU, and was developed by Alpha Networks.

- RU: the radio unit that handles the digital front end (DFE) and the parts of the physical (PHY) layer.
- DU: the distributed unit that sits close to the RU and runs the RLC, MAC, and parts of the PHY layer, and its operation is controlled by the CU.
- CU: the centralized unit that runs the RRC and PDCP layers.

Since the earliest phases of the New Radio study, it was felt that splitting up the gNodeB between Central Units (CUs) and Distributed Units (DUs) would bring flexibility. The distributed unit (DU) is responsible for real time L1 and L2 scheduling functions, and the centralized unit (CU) is responsible for non-real time, higher L2 and L3.

3GPP started studying different functional splits between central and distributed units. They have proposed 8 possible CU DU split options displayed in Figure 11:

1. Option 1 (RRC/PCDP 1A-like split)
2. Option 2 (PDCP/RLC Split 3C-like split)
3. Option 3 (High RLC/Low RLC split, Intra RLC split)
4. Option 4 (RLC-MAC split)
5. Option 5 (Intra MAC split)
6. Option 6 (MAC-PHY split)
7. Option 7 (Intra PHY split)
8. Option 8 (PHY-RF split)

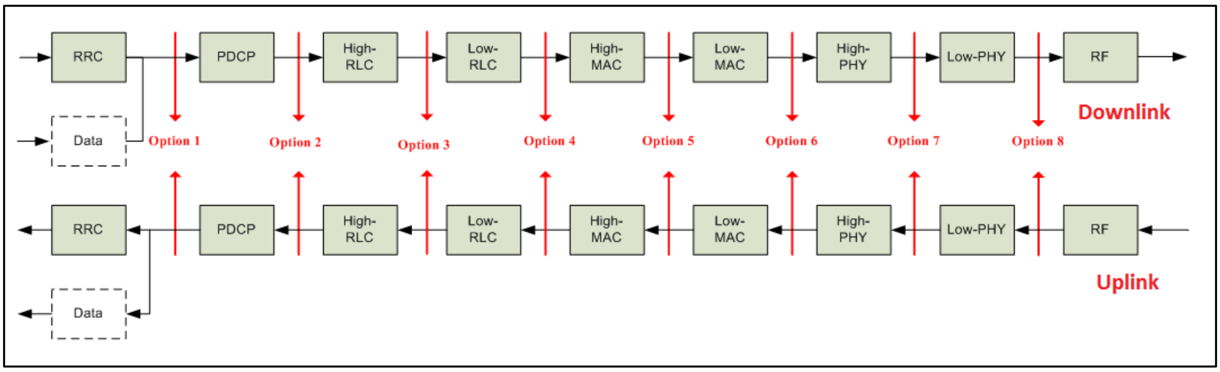


Figure 11: The proposed 8 possible CU DU split options

Some benefits of an architecture with the deployment flexibility to split and move NR functions between central and distributed units are below:

- Flexible hardware implementation allows scalable cost-effective solutions
- A split architecture (between central and distributed units) allows for coordination for performance features, load management, real-time performance optimization, and enables NFV/SDN
- Configurable functional split enables adaptation to various use cases, such as variable latency on transport

Alpha Networks has built the prototype of 5G NR gNodeB and CPE equipment, the end-to-end lab integration test is being conducted. The gNodeB and CPE will be deployed at ITRI IMTC at the end of month 15 to realize the selected use cases.

Moreover, CEA is investigating how to enable deterministic URLLC services. For that purpose, CEA has worked on a state of the art and the classification of available mechanisms enabling URLLC at RAN and Core. Many isolated mechanisms efficiently enhance reliability and reduce latency in Radio Access and Core Network. These mechanisms can exploit 5-D diversity:

(i) Modulation and Coding Scheme,
(ii) Time,
(iii) Frequency,
(iv) Spatial and
(v) Interface.

This investigation helps us to combine mechanisms to enhance reliability and latency in URLLC service and to provide deterministic URLLC services. It also highlights the need of a network orchestration designed to smartly combine the appropriate mechanisms and to dynamically and efficiently deal with the complex ecosystem of tenants, network slices with a diversity of service requirements and efficient usage of resources.

CEA has also defined a methodology to orchestrate the network by activating/deactivating/combining classified mechanisms taking into account the heterogeneity of services, the coexistence of the services, the dynamic evolution of the needs (e.g., traffic, number of users, QoS) and the changing environment (Figure 12).

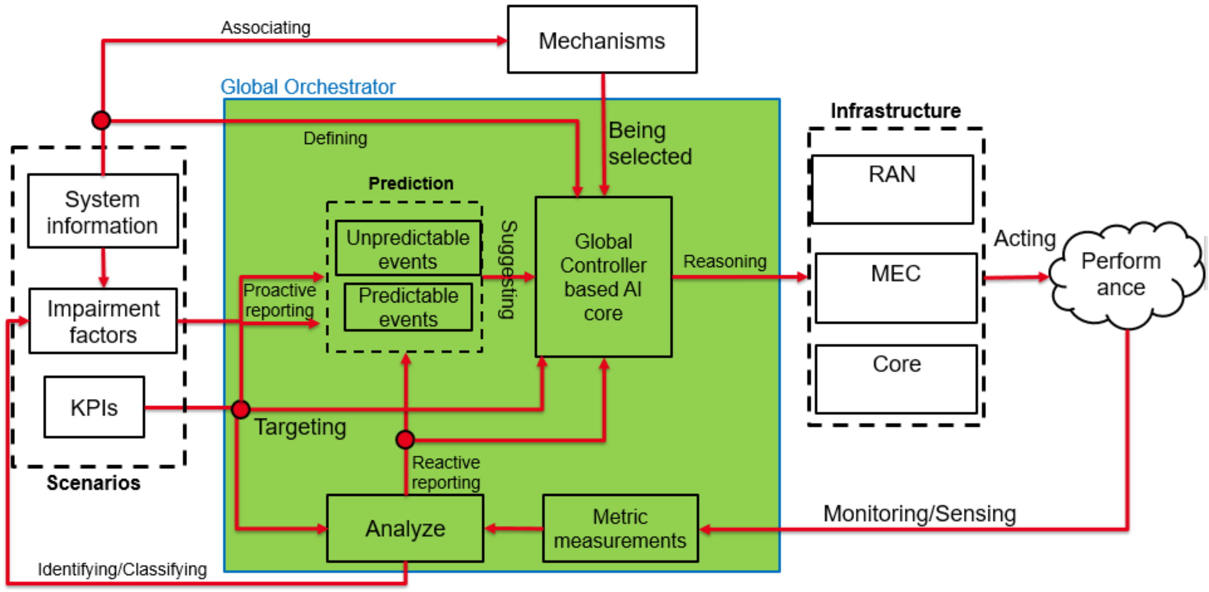


Figure 12: Framework to design a global orchestration

The desired functionalities of the proposed orchestrator are to measure the network state, to face to a myriad of (un-)predictable events and to smartly manage the entire network thanks to machine learning.

First simulations of 5G NR networks were done using NS3 in order to evaluate the impact of combined mechanisms and networks management for URLLC. CEA has evaluated end-to-end performance taking into account different network layers and the following mechanisms: adaptive MCS, redundancy (HARQ), numerology and MIMO.

1.2.4.2.2 Task 4.2: Core Network Technical Enablers

The task is focused on the development of the core network components to realize private local 5G networks to meet the envisioned industrial application requirements. A 5G core prototype including basic functions like AMF, SMF, AUSF, UDM, and UPF is meant to run as a set of VNFs. This way, a lightweight orchestration framework is investigated to implement the lifecycle management of the aforementioned virtual instances. Special focus has been reserved to the analysis and implementation of the SOL002 interface (see Figure 13), as per ETSI MEC, to enable orchestrators such as OSM to basically interact with the core VNF.

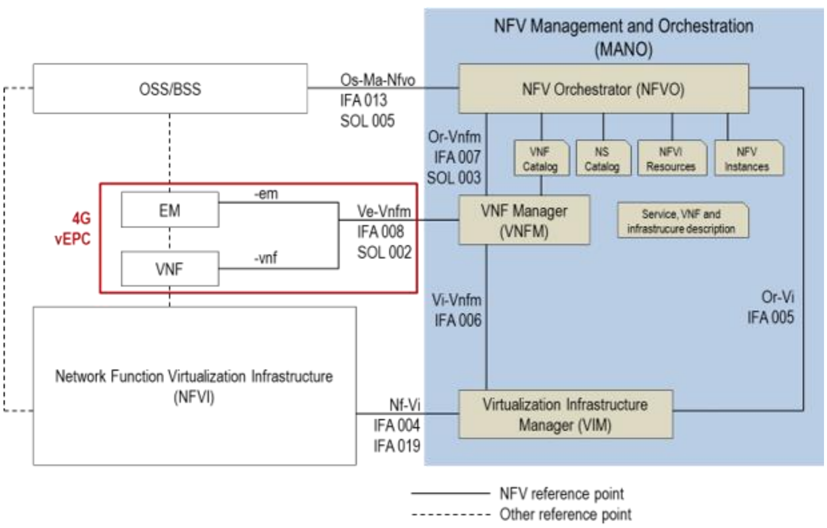


Figure 13: Overview of NFV Interfaces

On the Taiwan demonstration site, the 5G core network is designed for service-based architecture (SBA) and follows 3GPP Release 15+. The III-5GC implements the 5G components as standalone (SA) architecture as container-based with C/U split architecture. All the modules can be deployed on virtual machines on top of a large number of virtualization environments, and managed as a kubernetes platform (Figure 14).

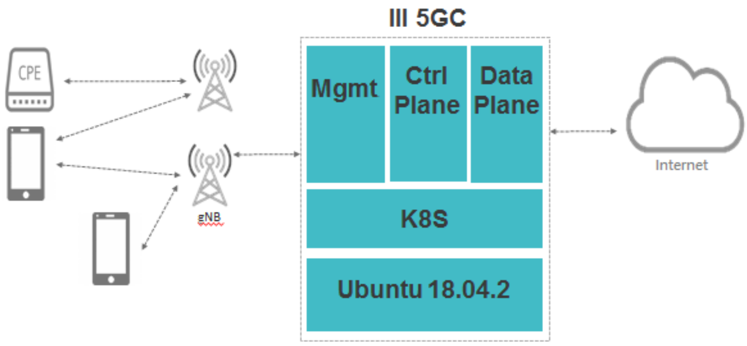


Figure 14: III-5GC Architecture

For supporting the industrial applications, the development especially focuses on data plane efficiency and system reliability. Thus, it supports both software and hardware solutions for data plane to enhance packet processing and load monitoring. By performing a set of tests, it has been found that the total throughput can achieve up to 20 Gbps and the data plane keeps a latency less than 1ms as shown in Figure 15.

	Previously Version 0.81								
	pkt size (Byte)	90		256		512		1024	
		Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
(bps)	Through-put	4.4G		11.5G		18.7G		19.3G	
Latency (us)	Min	224.102	225.849	296.952	301.776	217.541	215.969	263.545	266.04
	Avg	268.33	268.9	351.514	355.737	284.864	288.235	369.848	373.708
	Max	338.383	339.028	451.783	456.315	422.23	4233.912	498.692	501.689

Figure 15: Overview of Throughput and Latencies

1.2.4.2.3 Task 4.3: Mobile Edge Cloud Enablers

The objective of Task 4.3 is the development of 5G MEC technologies that support the requirements of smart factories in 5G eMBB and URLLC scenarios. MEC edge deployment designs are investigated, special focus has been reserved to the splitting of control and user plane functions in a hybrid-cloud way: 1) the control center, typically placed in the cloud, which acts as control plane manager and provides the configuration, provisioning and monitoring functions; 2) the edge node, located on-premise, which includes the UPF platform and forwards user traffic to/from RAN and local applications, thus it keeps the traffic local. This splitting enabled the definition of the hybrid network model, one of the four architectures defined in D2.1. Other solutions for traffic breakout at the edge are investigated, also based on the efforts produced in ETSI MEC.

ETSI bump-in-the-wire MEC cloud includes NFV infrastructure (ECoreCloud) and SDN network and Mobile Edge Enabler (MEE) VNF, as shown in Figure 16. MEC cloud uses SDN switch to route and mirror the traffic and uses EcoreCloud to manage MEE VNFs lifecycle task and the network routing among MEE and applications. MEE VNF provides traffic steering function, which selected data traffic can be offloaded locally. MEE VNF is divided into two modules. One is Control Plane Analyzer to handle control plane signal to get user contexts based on 3GPP TS36.413 R15 version; the other is data plane processor to process GTP packets based on 3GPP TS29.281 R15 version. The Non-standalone MEC which connects 5G commercial core network and new radio was launched in June 2020. We executed the interoperability test with Nokia and Ericsson 5G NR. Due to NSA model, the MEC must connect the 4G and 5G base stations, so all handover cases of NSA 5G network in NGMN specification were tested.

The remote centralized controller of this task is named ECoreCloud (ECC); it follows the ETSI MANO standard to manage and generate virtualized network functions (VNFs). ECC can support any VNF that uses ETSI MANO standard. Therefore, the MEC functions of task 4.3 have to be virtualized according to the ETSI MANO specification.

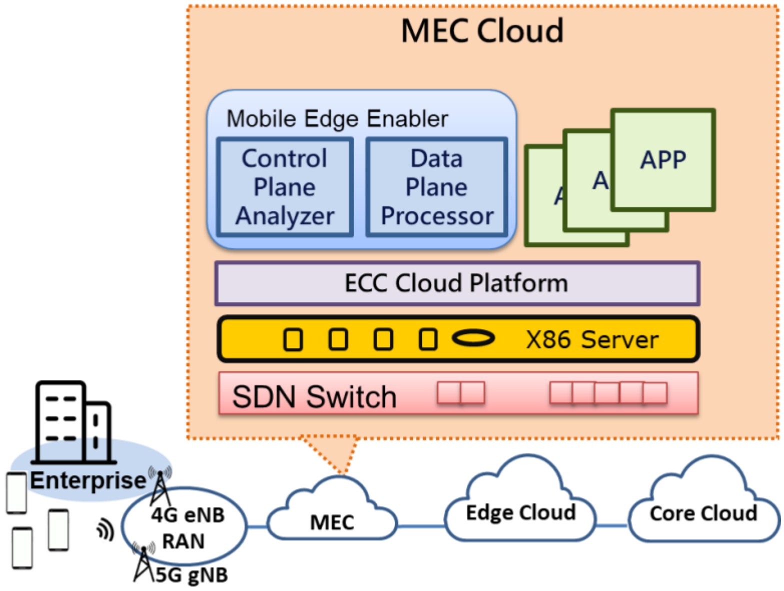


Figure 16: The architecture of bump-in-the-wire MEC cloud

We have developed the MEC 5G SA prototype that between 5G NR and core network, as shown in Figure 17. That will be released in November 2020. MEE Control Plane Analyzer is developed based on 3GPP TS38.413 R16 to handle NGAP protocol, and MEE Data Plane Processor is based on 3GPP 29.281 R16 to process GTP extension header packets.

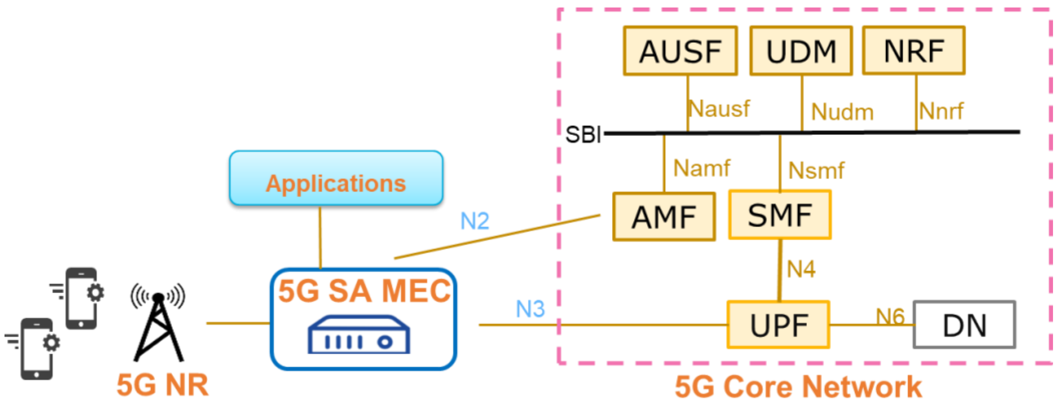


Figure 17: The architecture of MEC 5G SA version

1.2.4.2.4 Task 4.4: Industrial Application Enablers

The objective of this task is to rethink the network in a holistic manner by jointly optimizing all enabling technologies, namely radio (Task 4.1), core (Task 4.2), MEC platform (Task 4.3) and the use cases selected in Task 1.1 for a proof-of-concept demonstration. The initial plan of implementation of selected use cases has been proposed and the progress is described as follows:

- For the use case "Process Diagnostics by CNC and Sensing Data Collection", the data collection and process diagnosis has been investigated at one target cell and a three-axis accelerometer was attached to collect CNC data as well as sensing data for process data analysis.
- For the use case "Using Augmented/Virtual Reality for Process Diagnosis", the 3D model has been constructed for the target machine. The association of 3D model and CNC/sensing data via APIs has been under development. In particular, sensing data will be associated with corresponding 3D components to show process status information. For example, vibration levels can be shown on the 3D model of the spindle as color-coded contour. The prototype of this use case is expected to be demonstrated on upcoming IEEE GLOBECOM 2020. (Figure 18)

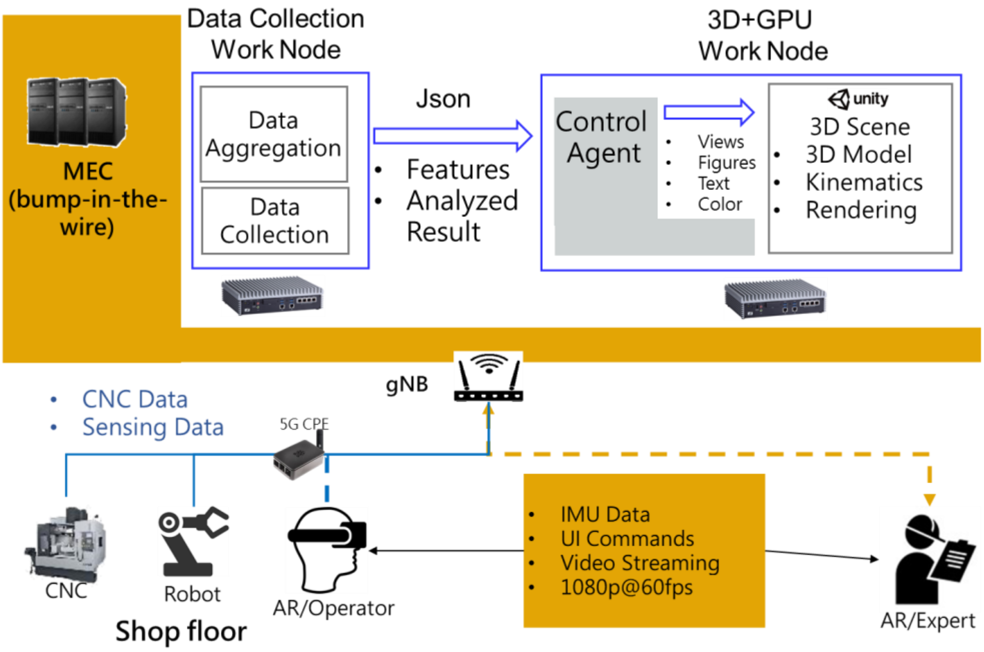


Figure 18: Prototype for the Using Augmented/Virtual Reality for Process Diagnosis use case

- For the use case "Cloud-Based Controller for CNC", the first version of the cloud-based CNC software has been tested under distributed network architecture (shown in Figure 19) where the motion command generation, motion command execution modules are separated.

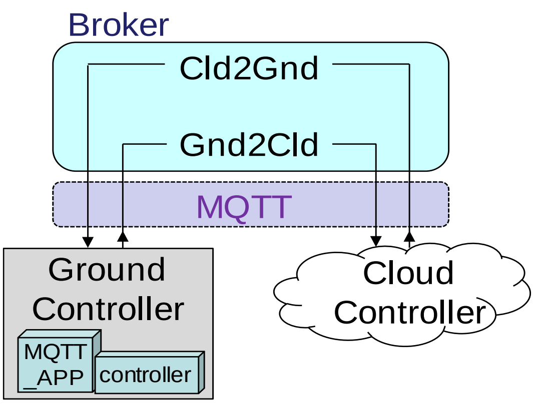


Figure 19: Architecture of the cloud CNC.

On the one hand, in task 4.4, devising computation offloading strategies to enable complex processing of data collected by mobile inspector is necessary in order to guarantee continuous monitoring and anomaly detection during industrial processes. The progress is described as follows:

- Dynamic resource allocation for computation offloading

One of the applications enabled by edge computing is the offloading of computational demanding programs from resource-poor sensors/machineries/mobile devices and nearby edge servers. A typical example in the smart factory is the processing of data collected by the industrial sensors for anomaly/fault detection, predictive maintenance, etc. Dynamic computation offloading refers to the case in which the sensors continuously collect data to be processed, which perfectly fits the industry use cases. Differently from the central cloud, MEC offers access to limited computational capacity at the edge of the network. The resulting resource management is a challenging problem, also due to the fact that computation resource optimization is naturally coupled to radio access resources. Indeed, when an application is offloaded, both a communication and a computation delay are experienced, which suggests a joint management of this resources in a holistic view of the system. Another challenge of this research topic is the fact that wireless channels and data arrivals are typically time-varying, with complex statistics which could be unknown in advance. During the first year of the project, SAP developed online resource algorithms for dynamic computation offloading, based on stochastic Lyapunov optimization, with the aim of reducing the energy consumption of the sensors, with guarantees on the average E2E delay, and reliability constraints on the probability that the E2E delay exceeds a predefined threshold. In this case, we refer to the E2E delay, as the time elapsed from the generation of a new data unit/subtask locally at the devices, until the result of this subtask is provided by the edge server. Stochastic Lyapunov optimization [4] allows to solve long-term optimization problems without assuming any knowledge on the statistics of data arrivals and radio channels. Without going into the mathematical details, the dynamic problem is approached by defining local communication queues at the sensors, containing data to be transmitted, and remote queues at the edge server, containing the amount of computations to be performed. Sapienza developed a low complexity algorithm able to:

1. Minimize the average energy consumption of devices
2. Guarantee a constraint on the average E2E delay
3. Guarantee a constraint on the probability that the E2E delay exceeds a predefined threshold

The algorithm requires the solution of a simple optimization problem in a per-slot basis, and is able to guarantee the constraints without any prior knowledge of the statistics of radio channels and data arrivals. The variables involved in the optimization are the transmit powers of devices and the CPU scheduling at the edge server. We now present some numerical results to assess the performance of the algorithm. As a first result, we show the energy delay trade-off, obtained by exploring the values of a Lyapunov parameter, denoted by V. In particular, theoretically speaking, by increasing this hyperparameter, the energy consumption decreases while the average E2E delay increases, until reaching the constraint imposed by the application. Then, in Figure 20, we show the trade-off obtained by increasing V, with our algorithm termed as *DyCO*. In particular V increases from right to left. As we can notice, the energy consumption decreases until reaching the desired constraint. The method is compared to a method that only forces the physical queues (communication and computation) stability. In particular, we can notice how this benchmark solution keeps on reducing the energy consumption, but not meeting the constraint on the average E2E delay, differently from our method, that finds the minimum energy that guarantees the constraints. As a second result, in Figure 21 we introduce the reliability constraint, and thus we plot the reliability function of the E2E delay, defined as $1 - CDF(E2E\ Delay)$, where CDF denotes the cumulative distribution function. Then, all the curves in Figure 21 represent the probability that the E2E delay exceeds the value on the abscissa. As we can notice, all devices meet their constraints, as shown in the plot with the circles around their respective values. Indeed, in this case, all devices have different requirements on the maximum E2E delay, but they all require not to exceed it 99 % of the time (10^{-2} reliability constraint).

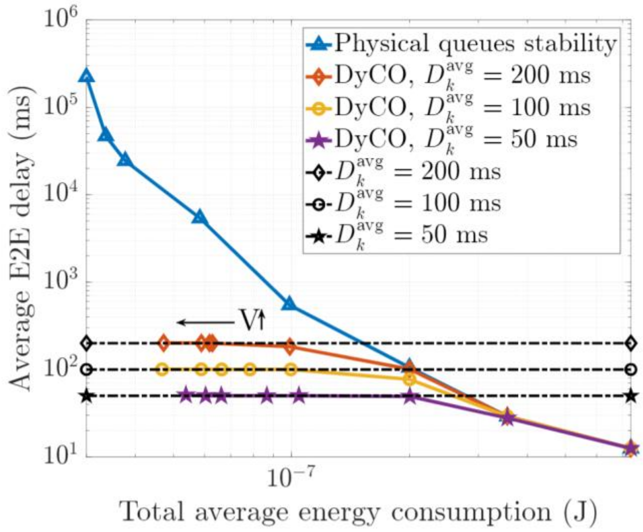


Figure 20: Average E2E delay vs. average energy consumption

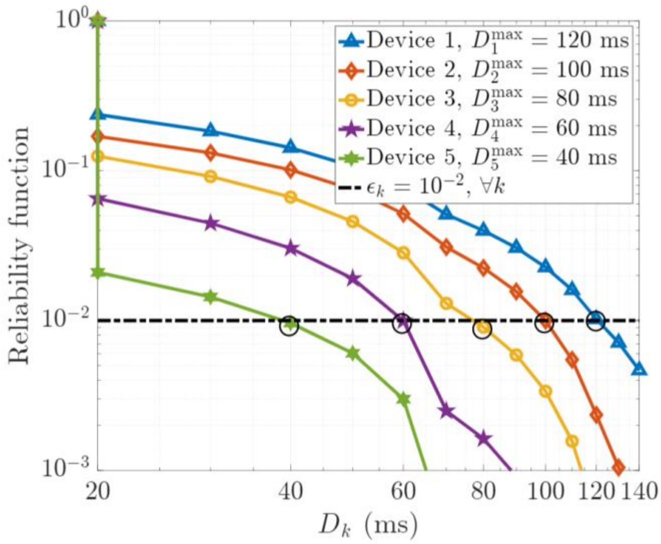


FIGURE 3.19: Reliability function

Figure 21: Reliability function of the E2E delay

- Dynamic resource allocation for edge machine learning

The work dedicated to dynamic resource allocation for computation offloading does not go into the details of the specific application, thus concentrating on the energy-delay trade-off. Instead, diving into the application, it is possible to introduce new performance measure, such as the accuracy of a certain learning task running at the edge server on data collected and transmitted by sensor devices. This opens a new research direction known as Edge Machine Learning (EML) [5], [6], [7], [8], [9], whose aim is to enable machine learning algorithms at the edge, by exploring the best trade-off between energy, latency and learning accuracy/reliability. Using the tools of stochastic Lyapunov optimization, Sapienza devised an online algorithm able to guarantee an average E2E delay and an average accuracy of an estimation task based on Least Mean Squares (LMS). The method does not require any prior knowledge of the statistics of data arrivals, radio channels, and data distributions. In particular, in this case, the accuracy is affected by the number of quantization bits used to encode the data. More bits lead to better accuracy but higher energy consumption, due to the longer payloads to be transmitted. Thus, the optimization variables are the devices' transmit power, the CPU scheduling at the edge server, and the number of quantization bits used to represent the data. As a preliminary result, in Figure 22 we show the energy delay trade-off of 5 sensors, each one requiring a different learning accuracy, defined as the Mean Squared Deviation (MSD) between the estimated parameter and its true value.

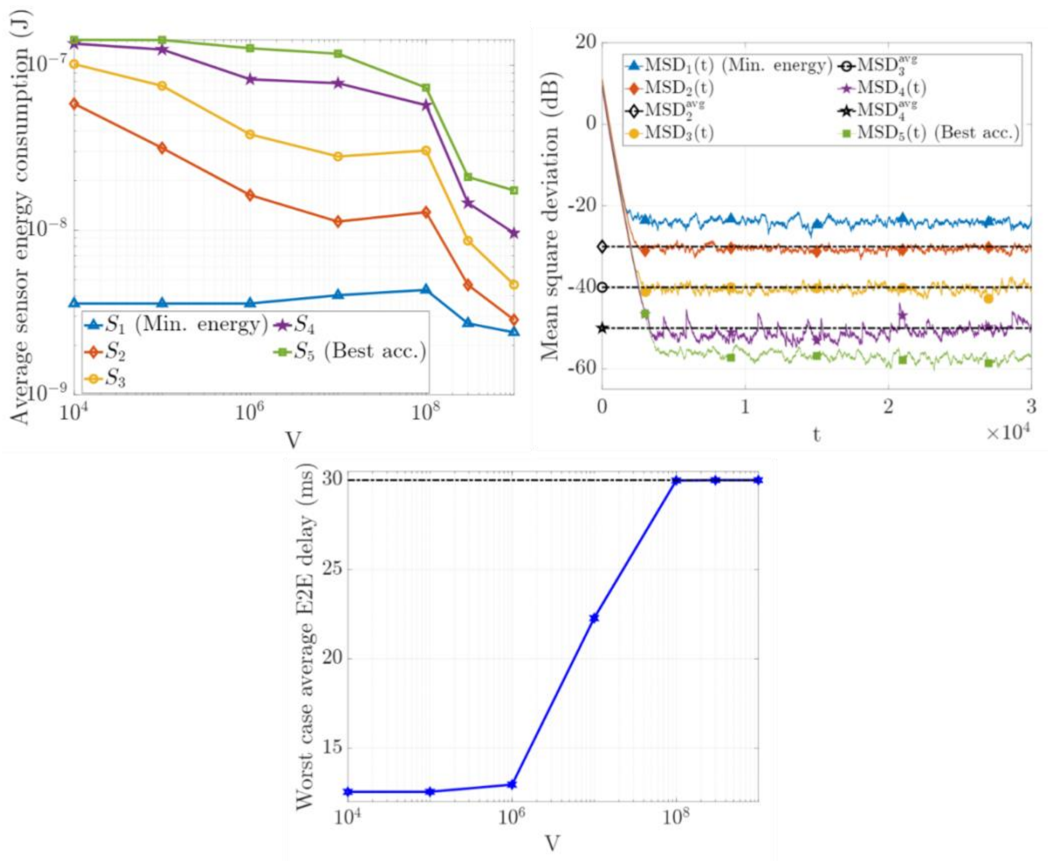


Figure 22: Energy-delay-accuracy trade-off

From the first subplot, we can notice how a tighter accuracy constraint leads to a higher necessary energy consumption, due to the higher number of bits to be transmitted, as expected. In this figure, two benchmark are shown: 1) Best accuracy (green curve, square marker), obtained by fixing the number of quantization bits to 8 (the maximum allowed value in this simulation); 2) Minimum energy consumption, obtained by fixing the number of quantization bits to 3 (the minimum allowed value in this simulation). The accuracy achieved by these two benchmarks is plotted in the second upper subplot, so that we can notice how the green curve converges to the lowest MSD, while the blue curve achieves the worst accuracy. The other curves are optimized to achieve a predefined target. We can notice how all devices achieve their required accuracies, represented by the horizontal dashed lines. Finally, in the third plot, we show the worst case average E2E delay, i.e. the maximum delay among all devices requiring the same average constraint set to 30 ms. Interestingly, thus delay does not exceed the maximum allowed value, as in the previous case about computation offloading. This represents a preliminary result on EML, and paves the way to the investigation of new trade-offs, applications and optimization strategies.

1.2.5 Work Package 5

This WP will start in the coming months and will utilize the results from WP2, WP3 and WP4 to build the multi-site end-to-end 5G test network and realize selected use cases from the domain of industrial manufacturing. It covers the steps from lab integration to field deployment, leading to a final demonstrator system used to verify the defined KPIs and validate 5G technologies for the industrial use case. The end-to-end system will be initially tested in a laboratory environment to analyze its interoperability and performance, then the experimentation will be tested in a real-world factory site.

1.2.5.1 Status of the work package

Not applicable.

1.2.5.2 Work carried out & main results

1.2.5.2.1 Task 5.1: Realization of the selected use cases

Not applicable.

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

Not applicable.

1.2.5.2.3 Task 5.3: E2E Performance Measurement and KPI Analysis

Not applicable.

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. While both tasks are ongoing over the whole project period, several results were achieved:

- The project website https://5g-conni.eu was published and populated with initial content
- Project corporate design and marketing material was developed
- Two workshops were planned
- Monitoring of 3GPP standardization is ongoing, contributions to ETSI MEC were accomplished
- The dissemination plan was developed and described in Deliverable D6.1.

Even though the established *status quo* for dissemination is heavily impacted by the COVID19 situation, the project consortium is adapting to the situation and is leveraging alternative means like online conferences, sessions and open access journals. The specific activities conducted in each task are described below.

1.2.6.2 Work carried out & main results

1.2.6.2.1 Task 6.1: Dissemination

The coordinator Fraunhofer HHI developed the project corporate design and project marketing material at the beginning of the project. The 5G CONNI public website was set up at the beginning of the project under the domain https://5g-conni.eu. On the website, news, deliverables and public dissemination information are published.

Each partner joined the kick-off meeting to discuss the dissemination events that we plan to attend, such as Mobile World Congress, EuCNC, IEEE GLOBECOM 2020, etc., but unfortunately most of the events were cancelled due to the COVID19 pandemic. The 5G CONNI project was officially announced to a broader audience from industry and academia during the joint EU-Taiwan 5G / Beyond 5G Workshop hosted by the 5G Program Office of the Taiwanese Ministry of Economic Affairs in Taipei. ITRI gave an overview of the 5G CONNI project and its value proposition for industries moving towards 5G-based wireless networking. The launch of the project was furthermore announced via a press release by the coordinator HHI.

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. HHI organized and submitted a workshop plan to IEEE GLOBECOM 2020 that was subsequently accepted, combined with a proposal by Nokia, to hold a workshop named *"Future of Wireless Access for Industrial IoT (FUTUREIIOT): Enabling Industry 4.0 Revolution"*. 5G CONNI partners submitted the workshop paper *"Beyond 5G Private Networks: the 5G CONNI Perspective"* to show selections of challenging use cases of private 5G network. HHI also organized the session of IIoT channel measurement and modelling in cooperation with 5G Channel Model Alliance (https://5gmm.nist.gov/) during VTC-Fall 2020. CEA also organized the 13th International Workshop on Evolutional Technologies & Ecosystems for Beyond 5G and 6G (WDN-5G&6G).

Several paper contributions in connection with the project were accepted at conferences and transactions and are listed in Table 1.

Type	Authors & Title
Journal	M. Merluzzi, P. D. Lorenzo, S. Barbarossa and V. Frascolla, "Dynamic Computation Offloading in Multi-Access Edge Computing via Ultra-Reliable and Low-Latency Communications," in IEEE Transactions on Signal and Information Processing over Networks, vol. 6, pp. 342-356, 2020, doi: 10.1109/TSIPN.2020.2981266
Journal	S. Barbarossa and S. Sardellitti, "Topological Signal Processing Over Simplicial Complexes," in IEEE Transactions on Signal Processing, vol. 68, pp. 2992-3007, 2020, doi: 10.1109/TSP.2020.2981920
Conference	F. Costanzo, P. D. Lorenzo and S. Barbarossa, "Dynamic Resource Optimization and Altitude Selection in UAV-Based Multi-Access Edge Computing," ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Barcelona, Spain, 2020, pp. 4985-4989, doi: 10.1109/ICASSP40776.2020.9053594
Conference	M. Merluzzi, P. D. Lorenzo and S. Barbarossa, "Dynamic Resource Allocation for Wireless Edge Machine Learning with Latency And Accuracy Guarantees," ICASSP 2020 - 2020 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), Barcelona, Spain, 2020, pp. 9036-9040, doi: 10.1109/ICASSP40776.2020.9052927
Conference (accepted)	E. Calvanese-Strinati, et al., "Beyond 5G Private Networks: the 5G CONNI Perspective", 2020 IEEE Globecom Workshops: IEEE GLOBECOM 2020 Workshop on Future of Wireless Access for Industrial IoT (FutureIIoT)

Table 1: List of paper contributions in connection with the project

Furthermore, novel technological approaches were communicated through (keynote) speeches at conferences and workshops. CEA participated in several keynotes, talks or tutorials:

- One keynote in IEEE CAMAD 2020 on 6G and industry 4.0 (https://camad2020.ieee-camad.org/2020/09/10/announcing-speakers/)
- Two invited talks on "6G: the next frontier of research" in 2nd 6G Wireless Summit 2020, and "When cloud meets 6G", 5G Italy
- Two tutorials on " When Clouds meet 6G: the academic, industrial and standard perspective" in EUCNC 2020 conference (https://www.eucnc.eu/2019/www.eucnc.eu/tutorials/tutorial-2/index.html) and on "6G: the next frontier, Academic, Industrial and Standard Perspective" in IEEE CCNC (https://ccnc2020.ieee-ccnc.org/program/tutorials#tut-01)
- One industrial seminar on "When clouds meet 6G: the academic, industrial and standard perspectives" in IEEE GLOBECOM 2019 (https://globecom2019.ieee-globecom.org/program/industry-program/industry-tutorialsseminars#its-08)

We have discussed the prototype architecture of Taiwan demo site at IMTC, as shown in Figure 23. This prototype architecture is for use case 2: *AR/VR for Process Diagnosis* that is described in D1.1, including III's 5G core network, ANI's 5G gNB and CPE, CHT's MEC and ITRI IMTC's AR application. We plan to record the video presented during Globecom 2020.

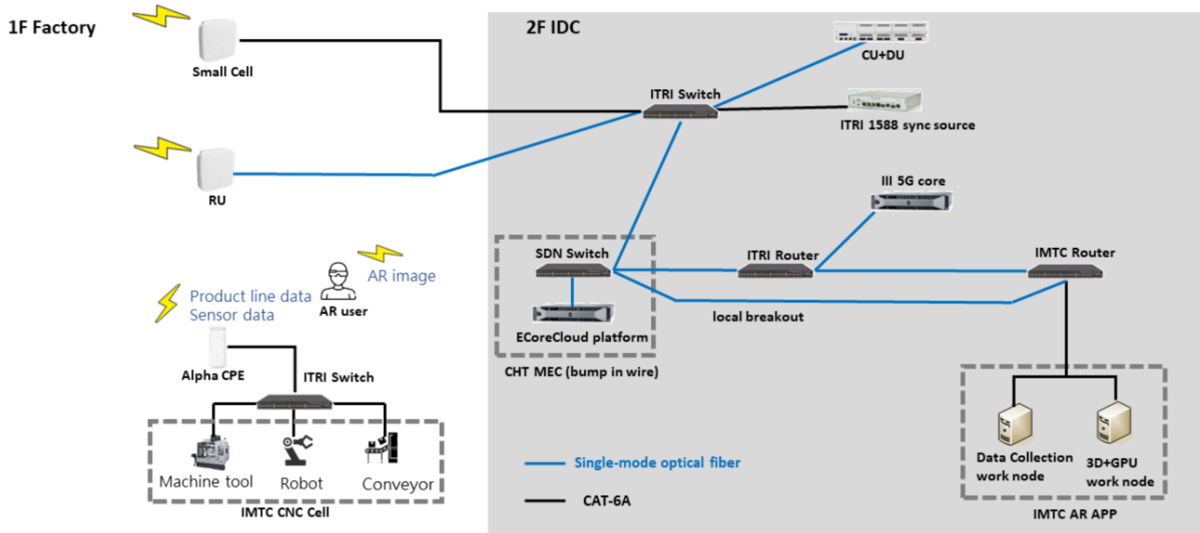


Figure 23: The prototype architecture of Taiwan demo site at IMTC

1.2.6.2.2 Task 6.2: Standardization & Regulation

The main objective of this task is the monitoring of and contribution to relevant standardization and regulation bodies. In the dissemination plan published in Deliverable 6.1, the consortium agreed to focus its work on the 3GPP Services and System Aspects (SA) and Radio Access Network (RAN) topic groups, and on the ETSI Mobile Edge Cloud (MEC), PLUGTESTS and Experimental Networked Intelligence (ENI) forums.

Several ongoing study and work items in 3GPP RAN are dealing with unlicensed access, dynamic spectrum sharing, edge applications and flexible local area data networks and are therefore highly relevant to the work in this project. Two items stand out and are being followed with special care: *Management of Non-Public-Networks* is a 3GPP Release 17 work item that defines management requirements for and roles in non-public networks (NPN) and specifies deployment scenarios, including those in factories. Special attention is given to provisioning and exposure of management functions, services and data. These topics are well aligned with the work in this project and the results of the work achieved in work package 2 will be leveraged in contributions to this work item.

Secondly, the Release 17 study item *Study on enhanced support of NPN* focuses on the credential and subscription handling in NPN. Onboarding and provisioning procedures will be defined and entities handling the subscription will be specified. These topics are very relevant to the 5G CONNI project and contributions are planned by the partners.

Even though 3GPP has already released a first version of a channel model supporting industrial scenarios, further investigations of the propagation characteristics are necessary. The consortium is actively planning extensive measurement campaigns at 3.7 and 28 GHz, and the results will be shared in the appropriate 3GPP topic groups.

The consortium is also tracking 3GPP activities in the SA topic group and has already submitted a contribution for core network enhancements. Furthermore, contributions to the work item DGS/MEC-0033 IoT API under ETSI MEC were done. The contributions are listed in Table 2.

Type	Target Group	Title of Contribution
CR	ETSI MEC DGS/MEC-0033IoTAPI(GS/MEC 033)	Update to Section 5.1 (IoT Service Introduction)
pCR	3GPP SA, FS_5MBS (TR23.757)	Local multicast service enhancement

Table 2: List of contributions to standardization groups

In addition to the standardization bodies, the consortium is also planning on participating actively at industry alliances. Targeted alliances are the CBRS Alliance, where partners are participating in weekly calls, and the Multefire Alliance and 5G ACIA with on demand attendance.

Finally, project partners are actively contributing to an IEEE working group developing a standard for channel sounder performance verification. The results of work package 3 will be leveraged in contributions to this working group.

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

Several months after the start of the project, the responsible person form ITRI (Dr. Shawkang Wu) left the project and another project member (Jack Luo) took over. 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.

1.2.7.2 Work carried out & main results

In the first year of the project, the following administrative and technical management tasks have been dealt within WP7:

1.2.7.2.1 Task 7.1: Administrative project management

Tools

In the first month of the project the following digital tools were acquired, set up, and hosted by HHI, 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, including improved audio and video equipment at HHI site
- 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

Furthermore, the project management team set up general consortium calls, which were biweekly in the starting phase of the project - due to the high administrative effort - and which are now monthly. There is also a dedicated project management call between HHI and ITRI, which takes place once every month. Further conference calls are technically motivated and are organized by the work package leaders. 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

The negotiation of the Consortium Agreement and the extension of the Grant Agreement were supported by the coordinators and could be finalized successfully. In addition to the standard Grant Agreement an amendment was put into force, which states the Taiwanese partners as full beneficiaries and not as third parties. This was necessary due to the strong wish of the consortium to emphasize and strengthen the contributions and the positions of the Taiwanese partners to reach a fair and balanced consortium.

Interfacing with funding agencies

The project coordinators are in perpetual communication with the EC and the Taiwanese funding agency as well as with the 5G Office in Taiwan. In particular, delays and risks caused by the COVID-19 pandemic where addressed. Furthermore HHI and ITRI attended a joint EU-TW workshop in Taipei, to discuss future collaboration topics. Unfortunately the follow-up workshop, which was planned to happen during Computex 2020, was canceled due to the COVID-19 pandemic.

1.2.7.2.2 Task 7.2. Technical project management

Project Meetings

In the first year of the project, one physical and one virtual meeting took place, which were organized by the project coordinators:

- Kick-Off Meeting in Berlin (December 3rd – 4th 2019)
- Virtual General Assembly (August 5th – 6th 2020)

Every meeting had a two day agenda, where especially the Kick-Off Meeting was a nice opportunity for partners from Taiwan and other European countries to experience the German Christmas Season.

Due to the COVID-19 pandemic, the scheduled General Assembly in line with the EuCNC Conference and further technical meetings could not take place. It is foreseen that the upcoming general assembly in line with the IEEE Globecom Conference in Taipei will also become a virtual event.

Figure 24: Kick-Off meeting at Fraunhofer HHI in Berlin, December 3rd - 4th 2019

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. It is planned to intensify the interaction with the external advisory board in the second year of the project.

Interfacing with standardization bodies

Currently the project is observing 5G standardization activities and is contributing to the work of different standardization bodies with the help of project partners who belong to the respective organizations, i.e. 3GPP, 5GACIA, ETSI-MEC, and IEEE. This work is coordinated and overseen by the project management team.

COVID-19 Risk Assessment and Risk Mitigation

Immediately after the COVID-19 outbreak in Europe and after the first national lock-downs a COVID-19 risk assessment was initiated by the project management team and communicated towards the EC. Although the implications of the COVID-19 pandemic on the project progress were severe in the first two quarters of 2020, it is expected that the project will catch up in the last quarter of this year. Luckily, the influence of the pandemic on the overall project goals could be mitigated and it is expected to be moderate and manageable.

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. Furthermore, the results of the evaluation were included in several paper contributions.

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

In order to provide a solid understanding on how to plan, deploy, operate and maintain a private 5G network in a factory environment, the 5G CONNI project will realize channel measurements of specific scenarios and model environments that are found in industrial applications. Based on these measurements, the project will develop suitable integration concepts and will validate 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 will be 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 are actively planning 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 had to be postponed. They are currently scheduled for M18 of the project. The measurement scenarios have been thoroughly planned, however, so that the measurements can take place as soon as access to the facilities is feasible again. Furthermore, extensive work was carried out towards radio planning and mapping. Simulations using ray-tracing techniques in 3D-modeled trial sites provided insights into cell planning based on the requirements of specific use cases. Novel algorithms to build connectivity maps based on (sparse) measurements were developed.

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

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

The work towards this expected impact is progressing as planned. Both the Taiwanese and European partners are on track with planning their respective demonstrators and the interconnectivity of the testbeds.

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

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

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

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

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

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

1.3.1 Impact on academia and research

The project is active in well-known academic conferences such as VTC, GLOBECOM, CAMAD, EUCNC and CCNC. In such conferences, the 5G CONNI project has been publishing key results in addition to holding keynotes and invited talks with a range of interested topics for researchers, and hosting workshops and tutorials related to private 5G and beyond in industrial environments. The partners are adopting to the challenging situation due to the ongoing COVID-19 pandemic by actively taking part in virtual online conferences and by considering alternative means of dissemination like open access journals.

1.4 Deliverables and milestones

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

Table 3: List of deliverables

No.	Deliverable Name	Work Packages	Due Date	Delivery Date
D1.1	Report on Use Cases & Requirements	WP1	31.03.2020	01.07.2020
D2.1	Intermediate Report on Private 5G Network Architecture	WP2	30.04.2020	04.09.2020
D6.1	Dissemination Plan & Project Website	WP6	31.12.2019	16.03.2020
D7.1	Project Handbook	WP7	31.12.2019	23.01.2020
D7.2	First Intermediate Report	WP7	30.09.2020	

Table 4: List of milestones

No.	Milestone Name	Due Date	Delivery Date	Means of verification
M1	Project website published	31.12.2019	19.12.2019	Website is accessible at https://5g-conni.eu

2 Update of the plan for exploitation and dissemination of result

No major updates to the project's general dissemination and exploitation plan as laid out in the grant agreement and the dissemination plan (D6.1) are required. Despite the challenges posed by the COVID-19 pandemic, external dissemination activities have continued successfully. In the second project year, extended effort will be spent on tapping into virtual dissemination opportunities.

The following paragraphs detail updates to the individual exploitation plans of each partner.

HHI

HHI is mainly focusing its dissemination work on contributions to relevant standardization and regulation bodies and on publishing in international peer-reviewed journals and conferences. The initial planned exploitation plan is still being followed and there are no substantial changes. Due to the impact of the COVID-19 pandemic on scientific conferences, HHI is focusing on virtual standardization meetings and conferences/workshops, and is targeting open access journal publications.

BOSCH

BOSCH has been following the initially planned exploitation plan and there are no updates to the plan itself. In fact, BOSCH has already achieved a good understanding of the operation and maintenance of private 5G networks, their different architectures, the fundamentals of operator models, and IT security requirements and solution approaches through the collaboration with the 5G CONNI partners during the first year. This along with the investigation on industrial 5G use cases further accelerates the identification of new business opportunities with regards to Industry 4.0 in general and 5G-enabled factories in particular.

ATH

For Athonet, this is not applicable at the moment.

CEA

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

SAP

SAP is currently disseminating 5G CONNI research related results through the publication of journal papers in high quality and impact journals, as well as conference papers in (mostly IEEE) conferences and workshops. During the first year of the project this dissemination plan led to the publication of 3 IEEE journal papers, 1 ETRI journal paper and 2 IEEE conference papers. Currently, there are three PhD students working on topics related to 5G CONNI. The results obtained within 5G CONNI will also open the possibility to introduce the topic in the education courses of students at the university, and to assign master and PhD thesis.

ITRI

There are no updates on the exploitation plan from ITRI. Based on the outcomes and deliverables that have been produced during the first year, the proof of concept is expected to be demonstrated on the upcoming IEEE GLOBECOM 2020.

ANI

For Alpha Networks, this is not applicable at the moment.

CHT

Chunghwa Telecom has executed 5G CONNI project following the exploitation plan in the proposal, and there is no change to the original plan. The MEC cloud non standalone version was launched, and MEC cloud standalone version prototype has been developed during the first year. Due to 5G CONNI project, we have better known the requirements, use cases, architectures, user stories and key enabling technologies of private 5G network in the smart factory. We will continue to develop the MEC cloud, which makes it more satisfied in the smart factory and accelerates the development of industrial applications in 5G technology.

III

For III, there is no update on the exploitation plan, and the work item proceeds as planned. In this year, we launch the SA 5GC for basic use cases and analyze the different types of private network architecture. We will keep developing the 5GC for industrial application scenarios in the 5G-CONNI project.

3 Update of the data management plan

Not applicable.

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

Not applicable.

5 Deviations from Annex 1 and Annex 2

5.1 Tasks

As shown in Sec. 1.4, most deliverables in the first reporting period have been submitted with delay. This was due to two influencing factors:

- Delayed project start: Since the project work plan was devised independently from the eventual starting date, the actual due dates for the deliverables were unknown in the planning stage. Due to the grant preparation phase taking longer than anticipated, the due dates for the first deliverables initially planned for project month M03 happened to fall on 31.12.2019. With most European partners having Christmas and New Year's holidays around that timeframe, deliverable production for D6.1 and D7.1 was shifted to January 2020.
- COVID-19 pandemic: The due dates for deliverables D1.1 and D2.1 fell directly into the onset stage of the COVID-19 pandemic. In that timeframe all countries involved in the project were under strict lockdown measures. Especially for the non-academic partners, a period of limited resource availability and short term priority readjustments followed. The impact on the project has been continuously tracked by repeated COVID-19 risk assessment questionnaires filled in by all partners. The resulting delays to the deliverables are in line with the reported resource availability by the involved partners.

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

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

Work Package 1

Partner	Description of work
HHI	N/A
BOSCH	Bosch is the leader of Work Package 1 and Task 1.1 on the European side and has been actively contributing to and coordinating the activities around 5G use cases and their requirements. In particular, BOSCH has developed the overall way of presentation and analysis of the use cases (e.g. functional and non-functional requirements in alignment with 3GPP definitions in 3GPP TS 22.104, TS 22.261 and TR22.804) and has deeply investigated and documented the requirements of UC-3 ("Robot Control Platform with Edge Intelligence and Control", D1.1 Section 3.3). BOSCH has also spent considerable effort in an elaborate collection, analysis and documentation of functional requirements beyond the use cases, which are related to security, management and operation of non-public network in connected industries/factories (D1.1 Section 5). These additional requirements are the first results of Task T1.2 ("Requirements and Concerns Regarding Suitable Operator Models") and will be the basis for the work in Work Package 2 ("Architecture & Operator Models"). BOSCH has also been the editor of D1.1.
ATH	Athonet participated to the WP1 calls. Some inputs have been provided to the deliverable D1.1, especially in section 2.2 where relevant use cases for functional requirements have been proposed. Also, the partner further contributed the definition of functional requirements. Finally, some reviews have been performed by Athonet on secs. 2.1.1 - 2.1.4 and 2.1.7. Athonet is contributing next to D1.2, which is planned for end 2020.
CEA	As the task leader of T1.2 (Requirements and concerns regarding suitable operator models), CEA has organized the T1.2 phone calls and is studying private 5G factory network requirements and evaluation methodology. CEA, will contribute to D1.2.
SAP	N/A
ITRI	As the task leader of use case and requirements analysis (Task 1.1), ITRI has identified and elaborated on four industrial uses cases and derived the associated functional and non-functional requirements. In particular ITRI has contributed to four use cases including UC1: Process Diagnostics by CNC and Sensing Data Collection, UC2: Using Augmented/Virtual Reality for Process Diagnosis, UC3: Shop Floor Asset Tracking Using On-board and On-premise Sensing Devices and UC4: Cloud-based Controller for CNC. UC1, UC2 and UC4 are selected for demonstrator implementations at the ITRI trial site. Details about these four use cases are described in D1.1. Implementation of the selected use cases are covered in Task 4.4. In addition, ITRI contributed to a publication on WP1 work: joint paper "Beyond 5G Private Networks: the 5G CONNI Perspective", submitted to IEEE Globecom 2020 workshop.
ANI	Alpha Networks has participated in WP1 conference calls. Alpha Networks has contributed to D1.1 in section 2.3, definition of Non-Functional Requirements.
CHT	Chunghwa Telecom contributed to D1.1 in the area of section 2.1 terminology to introduce and define essential terms including 5G new technologies, factory information technologies and industrial applications. Review section 2.3 definition of non-functional requirements and section 4 summary of the use case has been provided with some comments. Chunghwa Telecom has participated in the bi-weekly work package conferences and discussed use case requirements and use cases that 5G technologies can support. 3GPP specifications such as TR22.804,

Partner	Description of work
	TS22.104 and TS22.261 are studied for choosing the requirements for 5G CONNI use cases and requirements. Chunghwa Telecom also contributed to D1.2 in the area of suitable operator model. Some reference papers are reviewed for selecting the factors to evaluate the operator model.
III	III participated in the WP1 weekly calls, and analysis of innovative use cases and their associated requirements for 5G in an industrial setting. Also, gather the industrial use cases which contained in 3GPP TR 22.804 and along with the corresponding normative requirements collected in TS 22.261 and TS 22.104. III also has contributions for the deliverable D1.1, especially in section 2.4 descripting for the functional and non-functional requirements with 3GPP industrial use cases. III takes the reviews with chapter 3 targeted use cases part.

Work Package 2

Partner	Description of work
HHI	As work package lead of WP2, HHI has moderated the discussion on the 5G CONNI demonstration system architecture via regular conference calls and mailing list exchanges. As editor of D2.1, HHI was responsible for structuring the contributions from WP2 participants. The focus of this deliverable was laid on the stakeholders involved in private 5G networks as well as ownership and governance dimensions, creating a framework in which different network architecture options could be represented as a baseline for further discussions. To this deliverable, HHI contributed on topics related to regulation such as spectrum licensing.
BOSCH	In Work Package 2, BOSCH has been actively investigating involved stakeholders and their roles, as well as, corresponding ownership and governance dimensions for non-public 5G networks (see D2.1 Sections 2.1 and 2.2). For this, a number of BOSCH-internal experts have been consulted and interviewed, such that the different perspectives, e.g. on IT security, practicability for factory personnel, the plant owner, etc. are represented. This, in close collaboration with the 5G CONNI partners, led to the collection, analysis and documentation of user stories (D2.1 Section 2.3), which are mostly formulated from the “user” perspective, that is, realizing the user stories in the best manner would fulfill many factory personnel, plant owner and plant security requirements. BOSCH has also been investigating a number of 5G architectures (which are largely aligned with the ones documented in D2.1 Section 3) and their specific integration aspects, such that a 5G network can be compliant with BOSCH’s own IT infrastructure and IT security regulations. BOSCH has been contributing to many parts of D2.1, details can be found in the document’s revision history.
ATH	Athonet regularly attended phone calls for contributing to the WP2 user stories, architecture design (network function mapping) and deliverable D2.1 with focus on the sections of its competence. In particular, Athonet provided inputs into sections 2.2.2, 2.2.3 and 2.2.4 respectively related to SIMs, RAN and core assets. Then, two 5G network architecture options are deeply described and included into sections 3.1 and 3.2, with related ownership and governance details. This helped organize and harmonize the graphical elements for the final representative building blocks. Finally, Athonet provided edits/remarks through the document.
CEA	N/A
SAP	N/A

Partner	Description of work
ITRI	ITRI was involved in architectural design for private 5G networks (Task 2.1) and has been the editor of section 2.2.1 and 3.2 in D2.1. In section 2.2.1 ITRI provided information regarding spectrum allocation models in Taiwan. In section 2.1 we worked on the analysis of MVNO model in terms of architecture, stakeholder impact and cost implications. In addition, ITRI provided inputs to D2.1 on user stories from the operation and management (OAM) point of view, which covered elements integration, fault management, configuration management, performance management and self-optimization network.
ANI	N/A
CHT	Chunghwa Telecom contributed to D2.1 in the area of section 2.1.4 service provider's role, section 2.2.4 dimensions of 5G network ownership and governance for MEC platform and applications, section 2.3 some categories of user stories, and section 3 the bump-in-the-wire breakout option of MNO's private network model and the stakeholder impact and cost implications of MVNO model. Chunghwa Telecom has participated in the bi-weekly work package conferences and discussed 5G CONNI demo site architecture. In work package 2, we propose a bump-in-the-wire MEC model that will be implemented at Taiwan demo site.
III	III participates in the WP2 regular calls, and analysis the overall system and network architecture addressing the specific requirements of private 5G networks; also discuss the architecture for the European and Taiwanese trial site, as well as solutions for their interconnectivity. For D2.1 contributions, III is responsible for the section 3.4 the MNO's private network architectures and describing the architecture with stakeholder impact, and also have some cost implications.

Work Package 3

Partner	Description of work
HHI	HHI's activities in WP3 focused on developing the channel sounder to be used for measurements in the industrial environment of the demonstration site. Building on HHI's previous channel sounder developments, the majority of work was related to three areas: Firstly, to apply the virtual antenna array technique for directionally resolved radio channel measurements to frequency ranges relevant for industrial 5G, a new virtual uniform circular array antenna (VUCA) has been designed, engineered and manufactured. Secondly, one major challenge for distributed high-precision measurement systems such as radio channel sounders is to provide them with a precise and stable timebase. In order to build a distributed timing system for the planned measurements, HHI has investigated methods for highly accurate clock syntonization and synchronization. Finally, HHI worked towards the development of a universal channel sounder performance verification methodology. With respect to the specific performance metric of path loss dynamic range, new definitions have been provided and performance bounds have been derived by simulation for the class of digital correlative time domain channel sounders. With its implementation of this measurements principle, HHI was able to demonstrate a highly competitive performance with 83 dB path loss dynamic range and 143 dB maximum measurable path loss at 25 GHz. In cooperation with BOSCH, three different channel measurement scenarios have been defined which will be further investigated in WP3.
BOSCH	BOSCH has been investigating and analyzing a number channel measurement scenarios, which are of higher relevance. Three such scenarios have been discussed with HHI and chosen to be further studied in Work Package 3. Since

Partner	Description of work
	the outbreak of the COVID-19 pandemic, access to factory environments and information exchange with factory stakeholders have been limited, such that the channel measurement campaigns are planned for a later stage and more efforts have been put into the work in Work Packages 1 and 2.
ATH	N/A
CEA	N/A
SAP	From the European side, Sapienza University of Rome is the leader of WP3 and its all tasks (T3.1 and T3.2) along with ANI from the Taiwanese side. As leader of the WP, Sapienza has moderated all the conference calls, which took place regularly on a monthly basis starting from April 2020. From a technical point of view, during the first year, Sapienza has concentrated on the development of novel algorithms to build connectivity maps based on sparse measurements, which is one of the goals of Task 3.1. In particular, the goal is to measure a certain quantity (throughput, latency, etc.) over a subset of link of a communication network, to infer the same quantity over non observed links. This is performed thanks to a learning algorithm based on Simplicial Complexes, a generalization of graphs that take into account multi-way relations (signals over the links of a graph). Preliminary results have been produced on the inference of the spectral efficiency of a subset of links, using data obtained with a ray tracing technique.
ITRI	ITRI was involved in Task 3.1 “Application-centric Planning of Private 5G Networks” and contributed to cell planning to determine the number and location of 5G base stations (gNBs). We built trial-site 3D structure modeling and imported MIMO antenna patterns for coverage predictions using ray tracing techniques. In addition, we’ve considered the traffic profile to conduct throughput predictions to evaluate the performance of real-life network deployment. The simulation results provided insights into cell planning based on the requirements of the use case.
ANI	Alpha Networks has participated in WP3 regular monthly conference call. Alpha Networks has contributed Task 3.1 cell planning and simulation by RAN component radio design.
CHT	Chunghwa Telecom has participated in WP3 regular monthly conference call and knew the main activities of each partner. Chunghwa Telecom has focused on Task 3.2 private 5G network monitoring, operation and management.
III	III has been attending the regular project meetings and discussing the planning, operation and maintenance of the private network which is designed for the industrial use cases with CONNI partners.

Work Package 4

Partner	Description of work
HHI	N/A
BOSCH	N/A
ATH	Athonet attended the WP4 calls, especially as task leader in Tasks 4.2 and 4.3. In T4.2, Athonet is working on the 5G components of the private networks to be deployed and on the NFV-like orchestration development on OSM for the core network part; in T4.3, the solution for MEC deployments for hybrid architecture and mobile edge computing is under development and testing.
CEA	As WP4 Leader, CEA has organized regular WP4 phone call and has moderated the discussion about 5G CONNI technical enablers for industrial application. CEA is investigating how to enable deterministic URLLC. For that purpose, CEA has worked on a state of the art and the classification of available mechanisms

Partner	Description of work
	enabling URLLC at RAN and Core. CEA has also defined a methodology to orchestrate the network by activating/deactivating/combining classified mechanisms. In tasks 4.3 and 4.4, CEA has collaborated with SAP on the development of algorithms for the minimization of the energy consumption in networks endowed with mobile edge computing capabilities. In particular, CEA worked with SAP on the joint allocation and orchestration of the heterogeneous (radio and computation) resources of the network, with a particular focus on the optimization of the duty cycles of the network elements, subject to quality of service constraints.
SAP	Sapienza participates in Tasks 4.1, 4.3 and 4.4. Also, it is leader of T4.4 from the European side. Within WP4, Sapienza has developed algorithms for dynamic resource allocation to enable application computation offloading from sensor/machineries/mobile users to nearby edge servers. The goal is to allow resource poor devices such as industrial sensors to run sophisticated applications, such as massive data analytics for anomaly detection, predictive maintenance, etc. The first class of algorithms focuses on a generic application for computation offloading, taking into account the latency requirements, but not going into the details of the specific application to be run at the edge server. They focus on the best energy-delay trade-off. These algorithms are based on stochastic Lyapunov optimization, a tool that allows to solve difficult long-term optimization problems with unknown statistics of data arrivals and wireless channels, with low complexity, enjoying theoretical guarantees. The second class of algorithms considers the specific needs of the application in terms of accuracy. In particular, these are developed under the umbrella of a recent research topic known as Edge Machine Learning (EML). EML refers to machine learning algorithms running at the edge of the network. In particular, the difference with traditional machine learning, is the fact that data need to be sent from sensors/mobile devices to an edge server running the machine learning algorithm, with low energy consumption and within low latency, without drastically scarifying the performance in terms of learning accuracy. Then, the aim is to explore the best trade-off between energy, delay, and learning accuracy.
ITRI	ITRI was the leader of Task 4.4 “Industrial Application Enablers”. This involved the actual implementations of the use cases defined in D1.1. Two CNC machines have been selected to implement two use cases: “Process Diagnostics by CNC and Sensing Data Collection” and “Using Augmented/Virtual Reality for Process Diagnosis”. Various sensors have been installed on these machines in order to collect process data for diagnosis. 3D models for these machines have been created for AR applications. The prototype of cloud CNC has been developed and tested under distributed network environment where the motion command generation and execution are coordinated via a MQTT broker.
ANI	Alpha Networks has participated WP4 calls. Alpha Networks is task leader in Task 4.1. In T4.1, Alpha Networks is continuously working on RAN system consisting of CPE and gNodeB, which comply with 3GPP standards. The end to end integration testing is ongoing. The RAN and CPE system will be deployed at ITRI IMTC as by the end of 2020 as demonstrator implementation.
CHT	Chunghwa Telecom, as work package 4 leader on “Technical Enablers for Industrial Applications”, collected the development progress of 5G network components and industrial applications progress of each partner and investigated the trend of 5G new technologies that maybe be implemented in 5G CONNI project. Chunghwa Telecom has participated in WP4 regular four weeks conference call. Chunghwa Telecom leads Task 4.3 mobile edge cloud enablers to provide the 5G bump-in-the-wire MEC platform that consists of ECoreCloud

Partner	Description of work
	(ECC) NFV platform and Mobile Edge Enabler (MEE) VNF. Chunghwa Telecom developed MEC 5G non-standalone version to support EUTRA-NR Dual Connectivity (EU-DC) packet process and interoperability test with Nokia and Ericsson 5G New Radio. MEC 5G non-standalone version supports multiple handover scenarios. ECC platform created MEE VNF, applications and network connections. Chunghwa Telecom has developed MEC 5G standalone prototype to decode and correlate N2 interface and process GTP extension header.
III	III participates in the WP4 regular calls, and implements the 5G components as standalone (SA) architecture as container-based with C/U split architecture in T4.2. All private local 5G network components are meant to run as Virtual Network Functions (VNFs) in a virtualized environment will be implemented to meet industrial application requirements.

Work Package 5

Not applicable.

Work Package 6

Partner	Description of work
HHI	HHI's activities related to dissemination of the 5G CONNI project included creation of the corporate design, hosting the project website, creation of templates and graphics for internal and external use and creation of printed marketing material (flyers and roll-up displays). To increase visibility in the scientific community, HHI is co-organizing a workshop on industrial IoT at IEEE Globecom 2020 and, in cooperation with the 5G mmW Channel Model Alliance, a session on industrial channel measurement and modeling during at IEEE VTC-Fall 2020. Furthermore, contributions to the 5G CONNI vision paper submitted to IEEE Globecom were made. In standardization, HHI closely follows and participates in 3GPP meetings relevant to the project. Also, HHI is actively contributing to an IEEE working group developing a standard for channel sounder performance verification, leveraging the results from WP3.
BOSCH	BOSCH has been contributing to Tasks T6.1 and T6.2. In particular, BOSCH has co-authored the paper "Beyond 5G Private Networks: the 5G CONNI Perspective", which is submitted to IEEE GLOBECOM 2020 Workshop on Future of Wireless Access for Industrial IoT. BOSCH is also closely following 3GPP activities with respect to non-public networks and the outcomes of related study and work items.
ATH	Athonet contributed to Tasks 6.1-6.2, as well to the Deliverable D6.1. Athonet has co-authored the paper submitted to IEEE Globecom "Beyond 5G Private Networks: the 5G CONNI Perspective", and to the keynote on 6G and Industry 4.0 applications at the IEEE CAMAD conference in collaboration with 5G CONNI partners. Athonet also contributed to the work item DGS/MEC-0033 IoT API, under ETSI MEC.
CEA	CEA led and actively contributed to the 5G CONNI joint paper submitted to IEEE Globecom. CEA was also responsible of D6.1 deliverable on Dissemination plan and project website. Moreover,CEA has organized or participated to events promoting 5G CONNI project (e.g., presentation in 5GItaly on 5G and 6G cloud for private networks, industrial tutorial on 6G cloudification in IEEE Globecom 2019 and IEEE CCNC2020, keynote on 6G and IIOT in IEEE CAMAD 2020)
SAP	Sapienza has co-authored IEEE Globecom paper "Beyond 5G Private Networks: the 5G CONNI Perspective", and has contributed to the keynote on 6G and Industry 4.0 applications at the IEEE CAMAD conference. S. Barbarossa has

Partner	Description of work
	given a plenary talk at Graph Signal Processing Workshop. Also, Sapienza has presented 2 conference papers at IEEE ICASSP 2020, and has produced 4 journal papers (3 IEEE and 1 ETRI), already accepted, plus 2 IEEE journal papers under review (1 in collaboration with CEA).
ITRI	As the work package contributor, ITRI has contributed to a joint paper on industrial use cases and the associated requirements for IEEE Globecom workshop 2020. Moreover, ITRI has been coordinating the prototype demonstration of the AR use case for IEEE Globecom 2020 to disseminate the preliminary results.
ANI	Alpha Networks contributed to Globecom 2020 joint paper for section 3, OAM and Dynamic KPIs Monitoring of key enabling technologies. Alpha Networks has participated the bi-weekly Taiwan site conferences and discussed the prototype demo architecture at ITRI IMTC for Globecom 2020 demo video of the AR process diagnosis use case.
CHT	Chunghwa Telecom contributed to Globecom 2020 introductory paper for section 3 MEC and network slicing and orchestration of key enabling technologies. Chunghwa Telecom has participated in the bi-weekly Taiwan site conferences and discussed the prototype demo site architecture at ITRI IMTC for Globecom 2020 demo video of the AR process diagnosis use case. Collection the specifications of 5G core, RAN and applications assist in 5G MEC prototype SA version integration.
III	III has co-authored the paper “Beyond 5G Private Networks: the 5G CONNI Perspective” for IEEE Globecom 2020. III also has been continuously tracking the 3GPP activities on SA2 meetings, and six contributions for core network enhancement were submitted.

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. To provide a framework in which partners may cooperate and communicate successfully, HHI has produced a Project Handbook (D7.1) and hosts the project’s mailing lists and cloud data storage. HHI is hosting monthly management calls with the assistant Project Coordinator at ITRI as well as consortium calls. Two two-day consortium meetings were organized, one of which took place at HHI’s Berlin facilities and the other had to be held virtually due to the COVID-19 pandemic. HHI also closely collaborated with the project’s Technical Manager at ITRI on technical project management, contributing to monitoring of progress in individual work packages and quality assurance by overseeing creation of deliverables and subsequent reviews. An important portion of HHI’s management work was related to the EU-Taiwan cooperation aspect of the project, moderating the discussion between both sides of the consortium. Furthermore, by actively engaging in conversation with both EC and the 5G Office and attending joint events, HHI is contributing to a sustained cooperation. In response to the ongoing COVID-19 pandemic, HHI has taken measures to find and communicate possible risks to the project early.
BOSCH	BOSCH has been participating in the regular project meetings, the kick-off workshop and the virtual general assembly, and has contributed to the project deliverables and reports.

Partner	Description of work
ATH	Athonet contributes to the planned project reports in collaboration with 5G CONNI partners.
CEA	CEA has been participating in the regular project meetings, the kick-off workshop and the virtual general assembly, and has contributed to the project deliverables and reports.
SAP	Sapienza contributes to the planned project report, has participated to the Kick-off meeting, the monthly consortium meetings and the first virtual General Assembly.
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 organized 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 participated in project meeting, kick-off meeting, monthly meeting, and 2020 virtual GA. Alpha Networks has contributed to 5G CONNI delivery report in collaboration with other partner.
CHT	Chunghwa Telecom has participated in monthly general meeting to know the organization issues and the progress of each work package. Chunghwa Telecom attended the kick-off two days meeting in Germany on Dec. 2019 to discuss the plan work of each work package. Chunghwa Telecom attended Virtual General Assembly meeting to discuss the work carried out by each partner.
III	III has been attending the regular project meetings such as kick-off meeting, conference workshop and virtual general assembly, and has contributed to the documents and tasks in each work package.