H2020 5G-Coral Project

Grant No. 761586

D6.2 – Final Project Report (Corresponds to the technical part of the Second Periodic Report)

Abstract

This deliverable presents a summary of the technical work performed during the Second Period of the 5G-CORAL project (from 01/09/2018 to 31/08/2019). This summary will be included and extended with the impact and resource management summary in the Second Periodic Report.

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Disclaimer

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Executive Summary

This deliverable presents the technical advances performed during the second and last reporting period of the project. Although titled "Final Project Report" initially, we report only on the second period of the project in this deliverable, which will be followed up with the official Final Periodic Report at the end of October 2019.

It is important to highlight that the deadline of D6.2 is the 31st of August, the final data for use of resources is still not available at the end of this month. The full financial information will be included in the Final Periodic Report in October 2019, which will include the data provided by the partners in their Form C.

This document includes a description of the technical work carried out by beneficiaries and overview of the progress in the second year of the project, including the objectives, the work performed by work package, and the deliverables and milestones.

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

1.1 Objectives

Obj. 1 WP1	Develop a system model that includes use cases, requirements, architecture, and business models to design and validate the 5G-CORAL solution	
Target R&D topic	**Progress towards target**	**Deliverable**
Identify and prioritize use cases, deployment scenarios, and requirements for the design and demonstration of 5G-CORAL solution.	For this R&D topic, no updates/changes have been identified with respect to the 1st Periodic Report (covering Project's activities from September 2017 to August 2018). Activities in Project's Y2 impacting this R&D topic were 1) the analysis of the State-of-the-Art for both the performance metrics and technical features taken into account in each of the 5G-CORAL use cases; 2) the identification of the future directions of the 5G-CORAL solution for improving the applicability of the solution itself to the already selected use cases as well as new potential ones, in particular on-device Artificial Intelligence (AI) and Machine Learning (ML) as well as private wireless networks.	D1.1, D1.2 and D1.3
Develop the 5G-CORAL architecture leveraging on existing industrial frameworks for NFV, SDN, MEC, and fog computing.	For this R&D topic, no updates/changes have been identified with respect to the 1st Periodic Report (covering Project's activities from September 2017 to August 2018). In fact, during the validation process, no further modifications to the reference architecture as described in previously-submitted WP1 deliverables have been identified (or deemed as necessary): at this time of the Project, the work conducted is basically on the internal characterization of EFS and OCS (out of WP1 scope). However, in D1.3, a functional characterization of interfaces which are relevant for the EFS-OCS interactions was performed and an example of how the OCS deploys an Application/Function in the EFS – together with the procedural steps performed by the involved Application/Function entities and by the EFS Service Platform – was reported. Finally, D1.3 also addresses the possible deployment options of the 5G-CORAL use cases by considering how the OCS manages heterogeneous virtualization platforms (i.e. Virtual Machines, containers and native applications) depending on the respective necessities and requirements.	D1.1, D1.2 and D1.3
Develop the 5G-CORAL system framework for supporting convergence between the multiple RATs envisioned.	5G-CORAL use cases have been developed in a framework where multiple RATs interwork for the sake of improving their achievable, use case specific performance. The WP1 activity to address this R&D topic within the considered reporting period was mainly on the identification	D1.1 and D1.3

	of the involved RATs for each of the use cases. D1.3 reports the results of such activity, highlighting that each use case makes use of at least two RATs (both 3GPP and non-3GPP).	
Define step-based procedures and techniques for enabling incremental deployment of 5G-CORAL solution into existing networks.	This work has been conducted in the Project's Y2 (and reported in D1.3) by taking the viewpoints of both the telecom operator and the Vertical company into account. For the former, the analysis initially considered current 4G networks (EPC-based, with LTE RAT) where initial deployments of Edge and Fog solutions have to be necessarily designed as add-ons on top of the existing network. Incoming 5G systems, instead, will be designed to efficiently support Edge and Fog since the beginning, so to flexibly achieve both high performance and quality of experience. When it comes to the Vertical company, the benefits in terms of security, user access control and service provisioning which could derive when deploying the 5G-CORAL solution within the Company's premises were analysed.	D1.3
Develop business models involving all stakeholders of the 5G-CORAL value chain, such as operators, vendors, service/application/cloud providers, facility owners, end users, etc.	For this R&D topic, no updates/changes have been identified with respect to the 1st Periodic Report (covering Project's activities from September 2017 to August 2018). The work conducted, however, was exploited for characterizing the applicability of the 5G-CORAL solution in the context of private wireless networks from the business point of view: private networks can then be seen as a type of telecom services, with the telecom operator acting not only as the connectivity provider but also as the Edge and Fog system provider, hence providing a private network service to a Vertical company (e.g. the enterprise, which plays the role of the Edge and Fog application/service end-user). Finally, to complete the initial considerations of D1.2 regarding the federation mechanisms in 5G-CORAL, the identification of the business requirements from each of the player in the 5G-CORAL ecosystem was performed in order motivate the need of such mechanisms.	D.12 and D1.3
Verification	**Status**	**Deliverable**
Use cases, scenarios, requirements, and architecture (including building blocks and logical interfaces) used in the design WPs (WP2/3/4) and contributed to standards.	For this R&D topic, no updates/changes have been identified with respect to the 1st Periodic Report (from September 2017 to August 2018).	D1.1 and D1.2
Business models presented and assessed at a dedicated workshop for exploitation of 5G-CORAL technologies	5G-CORAL business models have been developed in Project's Y1. Business-related exploitation of the 5G-CORAL technologies were presented during the EuCNC 2019 in Valencia	D5.2

attended by various stakeholders.	(Spain) within the "*Emerging 5G Business Models: Opportunities for SMEs and large companies – lessons from 5G PPP*" workshop. In particular, for 5G-CORAL, the speech "*Enabling new SME business models by leveraging novel federation and zero-touch technologies, through network softwarization in 5G-CORAL*" was presented by TELCA.	

Obj. 2 WP2	Design virtualized RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	
Target R&D topic	**Progress towards target**	**Deliverable**
Explore the virtualisation of RAN functions in the EFS for multiple RATs, develop their requirements, and assess their merits from an access convergence viewpoint	WP2 investigated the feasibility of having one radio network infrastructure, instead of parallel network deployments, to several multiple Radio Access Technologies (RATs), namely: IEEE 802.15.4, LoRa and NB-IoT. The communication protocol stacks (i.e. lower layers like L1/L2 and higher layers like L3) for the various RATs were virtualized in the EFS and shared a single Radio Head (RH) via a common fronthaul. WP2 investigated the latency and capacity requirements of the fronthaul for different functional splits of the RAT communication stacks; and explored fronthaul compression by reducing the number of bits per IQ sample. WP2 also explored the virtualization of RAN functions using the following virtualization technologies: LXD/LXC containers, Docker containers, KVM virtual machines, etc.; and assessed the merits of baseband softwarization, such as: increasing network flexibility, reducing network cost, and increasing system scalability. Additionally, WP2 investigated and implemented the following: virtualized IEEE 802.11 access point using HostApd LXC/LXD container, virtualized LTE HSS, MME & SPGW) using KVM virtual machines and Docker container.	D2.1, D2.2
Specify EFS services for collection, aggregation, publishing, and use of radio and network context information by applications and possibly virtualized functions	WP2 designed and verified an EFS service platform that provides an API framework through which both EFS and non-EFS applications and functions can publish and subscribe to various services. The EFS service platform performs Authentication, Authorization and Accounting (AAA) of EFS and non-EFS applications and functions that publish and/or subscribe to the EFS service(s). The EFS service platform also maintains a service registry to track all of the services consumed by the applications and functions. WP2 adopted MQTT Broker as a reference implementation of the EFS service platform where each EFS service was essentially an API with multiple topics that authorized applications/functions can publish to and/or subscribe to receive notifications from. WP2 specified and developed nine EFS services to support the 5G-CORAL use cases, namely: iBeacons indoor localization service, rplidar indoor localization service, Wi-Fi information service, LTE OAI based radio	D2.1, D2.2

	network information service, IEEE 802.15.4/LoRa/NB-IoT IQ data service, user orientation service, telemetry service, warning service and train proximity service.	
Develop EFS functions using EFS services from multiple RATs and the transport and core networks in support of access convergence	EFS Functions are software entities made up of at least one atomic entity deployed in EFS for networking infrastructure. WP2 implemented 9 EFS functions to support the 5G-CORAL use cases, namely: virtual 802.11 access point, vMME, OAI vEPC (MME, HSS, SPGW), OAI LTE eNodeB, IEEE 802.15.4 communication stack, LoRa communication stack, BLE iBeacons communication stack, SD-WAN function and User classifier function.	D2.1, D2.2
Develop EFS applications using EFS services from multiple RATs and the transport and core networks to improve network KPIs and user QoE	WP2 adopted the microservice-based design to develop EFS applications, i.e., the EFS applications were implemented as microservices; with each microservice as a separate entity with no dependency on other microservices. The microservices implemented the logic of the EFS applications and interacted with each other and communicated via network calls, consequently each EFS application exposed an application programming interface (API) to communicate in collaborative way. WP2 developed 15 EFS applications to support the 5G-CORAL use cases, namely: Robot intelligence, Real-Time Messaging Protocol (RTMP) acquisition, Tile encoding, DASH segmentation, DASH client, Tile segmentation and decoding, Image Recognition, Job Dispatcher, Interference Analyzer, Collision Avoidance, Vehicle Breakdown Notification, Emergency Vehicle Approaching, PoS Database, PoS Web App and Video Streaming. The experimental results regarding network KPIs and user QoE are detailed in deliverable D2.2.	D2.1, D2.2
Verification	**Status**	**Deliverable**
Develop a proof of concept for the EFS (prototype, TRL 3) and demonstrate EFS functions, services, and applications, with at least two coordinated RATs	WP2 adopted the MQTT broker and messaging as a reference implementation to develop 7 proof of concepts for the EFS, namely: Robotics, Virtual Reality (VR), Augmented Reality (AR), Multi-RAT IoT, Connected Car, SD-WAN and High-Speed Train. (see deliverable D2.2 for a detailed description of the PoC). Three of the seven proof of concepts demonstrate EFS functions, services, and applications, with at least two coordinated RATs, namely: Multi-RAT IoT PoC (IEEE 802.15.4, LoRa and NB-IoT), AR PoC (IEEE 802.11 and iBeacons/BLE), Connected Car PoC (LTE and IEEE 802.11). The first proof of concept for the EFS was publicly demonstrated in November 2018 at the Nangang Shopping Mall (Taipei, Taiwan) and subsequently at MWC 2019 (Barcelona, Spain) and EuCNC2019 (Valencia, Spain).	D2.1, D2.2, D4.1, D4.2
Validate selected EFS components through a	EFS components were integrated in the Shopping Mall testbed in Taiwan for the showcase in November 2018.	D2.1, D2.2, D4.1, D4.2

system verification in the integration testbeds from WP4		

Obj. 3 WP3	Design an Orchestration and Control system (OCS) for dynamic federation and optimized allocation of 5G-CORAL EFS resources	
Target R&D topic	**Progress towards target**	**Deliverable**
Extend existing industrial frameworks for NFV, MEC, and fog to best suit dynamic environments where EFS resources are volatile	A set of requirements has been defined for the OCS considering dynamic environments. The resulting OCS architecture is based on NFV and MEC components/interfaces. In order to support heterogeneous resources, which are not considered in NFV and MEC, OCS adopts a plugin-based architecture to unify the compute, storage and communication fabric end-to-end. Moreover, in order to support mobile and volatile resources, OCS adopts a distributed key-store storage to distribute the state and information across the network in such a way the partial failure or disappearance of the resources running the OCS components (e.g., VIM, EFS Resource Orchestrator, etc.) does not affect the functioning of the overall OCS.	D3.2
Develop federation mechanisms for EFS resources belonging to multiple owners and subject to different technical, business, and administrative requirements	The discovery and integration of heterogeneous resources has been investigated for multiple RATs. A set of extensions has been defined for those RATs to enable the uniform advertisement of resource capabilities across multiple RATs. A mechanism has been defined for the federation of resources between different administrative domains, allowing the on-demand request and lending/borrowing. This enables the reconfiguration of control and data planes (not management plane) across distinct administrative domains.	D3.1, D3.2
Develop interfaces for automated deployment of EFS functions and applications	A descriptor has been defined for the EFS Stack, which enables the integrated and automated deployment of EFS functions, EFS applications, and EFS services. The EFS Stack information model is the result of the integration and extension of ETSI NFV, ETSI MEC, and TOSCA descriptors. The resulting information model has been defined for Orchestrator-VIM interaction (see D3.1) and Orchestrator-user/OSS interaction (see D3.2) encompassing the fog characteristics (e.g., volatility, location, hardware-specific, etc.).	D3.1, D3.2
Integrate the EFS with central clouds to enable instantiation and migration of virtual functions and applications between the EFS and central clouds	The work done with the descriptor started considering Cloud environments. Specifically, the information model of TOSCA, which stands for *Topology and Orchestration Specification for Cloud Applications*, has been considered in the definition of the EFS Stack descriptor. The Orchestrator architecture adopts a plugin-based architecture, allowing to extend the OCS support for multiple clouds. Moreover, many commercial clouds leverage TOSCA as information model, thus ensuring the compatibility between information models.	D3.1, D3.2

Develop orchestration and control algorithms for elastic placement and migration of EFS functions and optimised allocation of EFS resources	Algorithms for elastic placement in federated environments have been proposed and evaluated. Specifically, the total lifetime cost of ownership has been considered by a placement algorithm suited for volatile and constrained environments. Moreover, the total cost/profit has been considered in a placement algorithm suited for federated environments.	D3.2
Verification	**Status**	**Deliverable**
Develop a proof of concept OCS prototype (TRL 3) to prove and demonstrate: (1) Federation mechanisms in static and dynamic scenarios; (2) Orchestration algorithms aimed at reducing latency for EFS functions and applications; and (3) Aggregation and offloading mechanisms for the best use of multiple RATs in the EFS	The development of an OCS prototype has started under the framework of Fog05 from ADLINK. An open-source release is available on GitHub. Fog05 enjoys the status of Eclipse foundation project. Fog05, which plays the role of the VIM, adopts the plugin-based architecture for very distributed deployments to allow applications and functions to be managed, monitored and orchestrated. A first proof of concept was publicly demonstrated at EuCNC2018 (Ljubljana, Slovenia) and in November 2018 at the Nangang Shopping Mall (Taipei, Taiwan). A prototype of the EFS Stack and Resource Orchestrator was later developed by ADLINK and UC3M under the name of f0rce (i.e., fog orchestration engine) and contributed as open source to the fog05 repository on GitHub. Finally, the fog05 and f0rce projects have been tested and integrated during the ETSI 4th NFV Plugtests for ETSI OSM and various VNF vendors interoperability.	D3.1, D3.2
Validate selected OCS components through a system verification in the integration testbeds from WP4	OCS components have been integrated in the Shopping Mall testbed in Taiwan (e.g., for the showcase on 2nd of November 2018).	D4.1, D4.2

Obj. 4 WP4	Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
Target R&D topic	**Progress towards target**	**Deliverable**
Customise existing testbeds in Taiwan to meet the needs of 5G-CORAL proof-of-concept in large-scale deployments	The Shopping Mall testbed adopted several components to facilitate the requirements of 5G-CORAL as follow: **Fog nodes:** Fog nodes are considered the backbone of 5G-CORAL concept. Fog nodes provide limited computation power behind the access points, helping in decreasing the latency and increasing the throughput. In the mall, Fog Nodes are deployed behind every Access Point (AP). The idea behind the deployment is to provide immediate computation to incoming requests from the end user devices and sensors **Local Edge Server:** The 5G-CORAL concept is based on hierarchical computing infrastructure. Constrained Fog nodes represent the last ¼ mile tier of volatile and mobile resources, whereas Edge represents the last mile (or few miles) static computing platform tier. In the mall, Fog nodes connect to the edge node (local edge server),	D4.1, D4.2

	in order to offload low latency demanding computing tasks that cannot be handled immediately by them. **Remote Edge Datacentre:** To meet the significant processing power required to run certain applications, such as Virtual Reality (VR), a third tier involving a powerful remote edge datacentre is added. This remote datacentre is a few tens of miles away from the mall. It consists of a number of powerful computing machines able to handle the most power-demanding computing tasks, such as coding, decoding, stitching, etc.	
Integrate and validate EFS and OCS in large-scale testbeds, such as shopping mall, high-speed train, and connected cars	Several PoC has integrated and validated EFS and OCS in shopping mall testbeds. For example, micro-services based design in a multi-tier computing model of Fog/Edge nodes integrated through a unified orchestration and control system. Also, in the shopping mall, robotics fog-assisted PoC utilize an indoor environment characterized by scattered fog computing devices and wireless connectivity, and then cooperative delivery of large items with fog-assisted robots Latency-sensitive task. This PoC reuse of existing infrastructure for supporting the robots and validate the EFS and OCS.	D4.2, D2.1
Demonstrate and trial multi-RAT access convergence and low latency applications, such as augmented reality and car safety, in real-world scenarios involving real users	Most of the PoC focuses on the multi-RAT access coverages but, it is important to highlight the Multi-RAT IoT PoC. In the Multi-RAT IoT, the main idea is to investigate the possibility to have one radio network infrastructure (instead of parallel network deployments) to serve multiple IoT RATs. The IoT baseband functions are centralized and cloudified to an Edge Cloud environment. This has been showcased in Taiwan Trail 2018. And currently, working to integrate more RAT and show the benefits of increasing network flexibility, reducing network cost and increasing scalability.	D4.2, D2.2
Evaluate the performance of 5G-CORAL solution in the field through measurement of relevant KPIs on data rates and latency in low and high mobility environments	Initial measurement already shown in D4.1, and currently working to finalize the results and updated into D4.2. Besides, several KPI has been addressed for every PoC in D1.3 as reference of State of art.	D4.1, D4.2, D1.3
Verification	**Status**	**Deliverable**
Proof of concept experiments in Taiwan in a commercial 8,000 square meters shopping mall area with up to 15 people per 100 square meters	Four live demos were demonstrated at Taiwan's showcase in November 2018. First, Augmented Reality (AR) Navigation PoC to provide a continuous indoor AR navigation experience for the users in the shopping mall. The objective is to augment the user recorded video frames with a navigation arrow to its desired destination. The user will see a guiding line grounded in the real-world image displayed on his screen so that it will remind a real object, i.e. a pointer, to the desired destination. Moreover, users will be able to see shop	D4.1, D4.2, D3.2, D2.2

	promotions on their screen whenever they pass by the store. These special offers will enhance the shopping experience for the mall's client. Second, The Virtual Reality (VR) PoC aims at showcasing the benefits of a 360° video live streaming service delivered by several 360° cameras located in specific points of interest inside a shopping mall. The main motivations for using this technology can range from offering an ultimate experience to users attending a live event, such as celebrity appearances, contests and sporting events, to help relieve overcrowded situations that can occur when a live event attracts a significant number of people in a limited space. In such cases, a 360° video live cast can offer the opportunity for everyone inside a shopping mall to watch the live event panoramically and cut the crowd management cost. Third, Robotic fog assistance PoC is based on delivering goods/products from storage rooms to the shops in the shopping mall. Since large items would need multiple robots to carry them to a shop, the idea of the demo is to show synchronous cooperation between multiple robots, carrying a single item. In particular, a dedicated virtual network for the robots would be created in which the intelligence of the robots would reside. Fourth, The IoT Multi-RAT PoC develops two RATs with 6LoWPAN (i.e. IEEE 802.15.4 [14]) and NB-IoT at an edge server/PC. In the testbed at the shopping mall, SDR-based radio heads for the PoC design. The multi-RAT IoT radio head is designed with two USRPs (one used for 15.4 and the other used for NB-IoT) connected to one mini-PC handling the fronthaul interface sending and receiving IQ samples to/from the edge PC. In the testbed, we demonstrate end-to-end connectivity for 15.4. For NB-IoT, an SDR-based terminal.	
Proof of concept experiments in Taiwan with high-speed (up to 300km/h) moving small cells in 12-coach trains along a 40km high-speed rail track.	An in-lab testbed has been created at ITRI campus emulating the high mobility characteristics to perform the experiment. First video of the work presented at Taiwan's showcase in November 2018. A final version for group handover in high-mobility PoC including required software/hardware components performed and show a reduction in signalling up to 50%. Besides, the service migration for a group of users was developed and can serve the high-speed train passengers when they move from train to stain and it will provide the minimum interruption. Where the downtime is less by 36%. Obviously, adopting the 5G-Coral architecture for a high-speed train, where an edge unit is placed near the end user, will reduce the signalling to the core network and achieve low latency	D4.1, D4.2, D3.2, D2.2

	for moving network. This is especially true when users are switching from onboard the high-speed train into the train station. Also, this will allow service continuity while transiting from the train into the train station.	
Proof of concept experiments in Taiwan in a connected car testbed targeting at low latency communications for moving vehicles.	The intended goal of the connected car testbed is to validate the developed technologies of 5G-CORAL by allowing low latency communications and computation offloading near the user, supporting time critical services to the users. To proof the 5G-CORAL concepts and technologies, the testbed consists of an Edge and Fog Computing System (EFS), the support for integration with an Orchestration and Control System (OCS), including also its interworking with other non-EFS components such as legacy 4G LTE eNBs. Initial planning was set for the connected car PoC including required software/hardware components. This has been largely done by AZCOM in Italy, the initial safety use case was demonstrated at Taiwan's showcase in November 2018. More features and hardware components added safety connected car PoC. In particular, novelties the Road Side Unit (RSU), which is the MintBox Mini 2 Pro (MBM2 Pro), this is fog CD that works as WiFi virtual access point, providing a secondary RAT. Also, on the RSU an additional instance of the broker MQTT is deployed to reduce e2e latency since with WiFi AP enables a local routing of the EFS services. In summary, reliability is increased since vehicles receive messages and warning from both the brokers from different and independent RATs.	D4.1, D4.2, D3.2, D2.2

Obj. 5 WP5	**Disseminate and contribute 5G-CORAL results into international research and innovation venues to pave the way for their successful exploitation**	
Target R&D topic	**Progress towards target**	**Deliverable**
Develop an outreach communication and dissemination of 5G-CORAL results to all stakeholders including researchers, industrials, and general public	Communication activities have been steered towards ensuring an up-to-date communication on the project concept and results to the large public through various tools including web portal, social networks, videos, interviews, leaflets, posters and magazine articles.	D5.1, D5.2
Develop a proactive standardisation plan including roadmaps, intellectual property creation, and contribution to relevant standards	Maximizing the impact of the project innovations on present and future standardization and industry forums has been set as a key objective in order to help create opportunities for commercial exploitation of the project outcomes.	D5.1, D5.2
Develop a plan for exploitation of 5G-CORAL results into value creation for all stakeholders during the project lifetime and beyond	To achieve tangible exploitation of its findings and results during the course of the project and afterwards. Various forms of exploitation are targeted including pre-commercial proof-of-concepts (PoCs) and commercial products, innovations and new features adopted into standards, and new services.	D5.1, D5.2

Verification	Status	Deliverable
Measured impact through metrics relevant to each type of activity (e.g., number of citations, number of patent applications, number of standard contributions with adoption status, surveys for feedback from stakeholders, etc.).	Year 1 achievements of dissemination, communication, standardisation, and exploitation activities and a plan for Year 2 were reported in D5.1. Year 2 achievements and future plans for were reported in D5.2.	D5.1, D5.2

1.2 Explanation of the Work carried per WP

1.2.1 WP1: 5G-CORAL system design and business perspectives

The main objective of 5G-CORAL's WP1 is to develop a system model – which includes use cases, requirements, architecture and business models – to design and validate the 5G-CORAL solution from both the technical and the commercial viewpoints. In other words, WP1 established the framework for the technology development conducted in technical work packages, i.e. WP2 and WP3, and for system verification and validation in WP4.

WP1 work is split into two tasks:

- Task T1.1 - *Use cases, requirements, and business perspectives*: led by TI and started at M1 (September 2017), this task ended at M12 (August 2018, i.e. at the end of the Project's Y1)
- Task T1.2 - *5G-CORAL system design*: led by UC3M and started at M3 (November 2017), this task ended at M21 (May 2019). WP1 activities performed during Project's Y2 have been conducted under this task responsibility.

At the time of writing this Report, WP1 submitted its last deliverable (in addition to D1.1 [1] and D1.2 [2] already submitted during the first year of the Project), i.e.:

- *D1.3 – 5G-CORAL refined system design and future directions* (M21, May 2019) – This deliverable targets the final 5G-CORAL system design, the definition of both procedures and techniques for incremental deployment of the 5G-CORAL platform into existing networks as well as the identification of the future directions of the 5G-CORAL solution.

1.2.1.1 T1.1 Use cases, requirements, and business perspectives

T1.1 ended at M12 (August 2018), i.e. at the end of Project's Y1. No activities related to this task have been conducted.

1.2.1.2 T1.2 5G-CORAL system design

T1.2, devoted to the design of the system model and architecture framework, continued during the second year of the Projects focusing on the remaining system-level aspects that were not previously addressed. To be specific, WP1 focused on (and reported in deliverable D1.3 [3]) the final 5G-CORAL system design, the definition of both procedures and techniques for incremental deployment of the 5G-CORAL platform into existing networks as well as the identification of the future directions of the 5G-CORAL solution. The key achievements of this activity are:

- Identification of the business requirements from each of the player in the 5G-CORAL ecosystem – the ones previously identified and extensively described in D1.2 [2] , i.e. the telecom operator, software vendors, Over-The-Top (OTT) service providers, Cloud providers, hardware vendors and Vertical companies – which can be used to motivate the need to have federation mechanisms in 5G-CORAL. Such mechanisms allow the above-mentioned players to create business relationships aiming at extending or creating new end-to-end services by importing external features or resources (being used for other services) from already deployed Edge and Fog systems. Federation is beneficial for all the business players targeting to expand their footprint, introduce new service spectrum, increase their competitiveness and keep track of increasing customer expectations.

- Analysis of the State-of-the-Art for both the performance metrics and technical features taken into account in each of the use cases belonging to the scenarios foreseen in 5G-CORAL, i.e. the Shopping Mall (low mobility scenario), the Connected Cars (medium mobility scenario) and the High-Speed Train (high mobility scenario). This analysis has been conducted in order to establish a "bridge" towards the activities in WP4 related to the use cases' demonstrations and Proof-of-Concepts (PoCs), in order to have a baseline with respect to which the performance improvements and/or system enhancements achieved when adopting the 5G-CORAL platform can be assessed.
- System level refinement of the 5G-CORAL architecture, hence leaving the details of the internal characterization of both EFS and OCS to the corresponding WPs. Basically, the validation process within the Project has not identified the need for further modifications to the reference architecture, which is still the same as described in D1.2 [2] . Moreover, since the 5G-CORAL platform has been designed having the convergence of multiple RATs in mind, the identification of the RATs exploited by each use case was performed exploits a summary of how each use case makes use of multiple RATs is also reported. The system-level interaction between EFS and OCS was also specified (along with the identification of the relevant interfaces being involved) by defining the procedural steps according to which the OCS deploys a certain Application/Function in the EFS in order to allow for another Application/Function to make use of the services provided by the previously deployed EFS Application/Function.
- Definition of both procedures and techniques for the incremental deployment of the 5G-CORAL solution into existing networks, taking the viewpoints of both the telecom operator and the Vertical company into account. For the former, the analysis considered both current 4G networks (with Edge and Fog necessarily deployed as add-ons) as well as incoming 5G systems (which will efficiently support Edge and Fog since the beginning). For the Vertical company, instead, how the deployment of the 5G-CORAL solution within the Vertical premises might be beneficial in terms of security, user access control and service provisioning was assessed.
- Identification of the future directions of the 5G-CORAL solution for improving the applicability of the solution itself to the already selected use cases, along with the possibility to adopt the 5G-CORAL framework for other promising use cases, such as on-device Artificial Intelligence (AI) and Machine Learning (ML). The compliance of the 5G-CORAL platform with respect to the key trends of the incoming years, that is, position with respect to Cloud, bandwidth cost savings, proper handling of Internet-of-Things (IoT) applications, Service Based Architecture (SBA) design approach and development of AI-based services was also evaluated.

In addition to the above and according to the outcome of the 5G-CORAL first technical review related to the Y1 activities of the Project, WP1 also worked on the following:

- Assessment (on a use case basis) of the OCS capability to manage heterogeneous virtualization platforms (i.e. Virtual Machines (VMs), containers and native applications). This allowed to demonstrate that the 5G-CORAL architecture is able to support multiple virtualization platforms properly, chosen according to the characteristics of the resources being involved.

Technical and business-related evaluation of the 5G-CORAL solution when applied in the context of a private wireless networks, i.e. a local network that uses dedicated radio equipment to service a premise with specific applications and services, working either in licensed, unlicensed or shared spectrum. The analysis considered both current networks (LTE with EPC) as well as upcoming 5G systems and it was demonstrated that the 5G-CORAL solution peculiarities – i.e. the use of heterogeneous Edge and Fog resources, multi-RAT convergence, service-based architecture as well as broad, open and business-oriented ecosystem – will be fully exploited in the context of the 5GS due to Edge and Fog being supported since the beginning.

1.2.2 WP2: 5G-CORAL edge and fog computing

The 5G-CORAL Edge and Fog Computing System (EFS), developed in WP2 (lead by IDCC), is a logical system subsuming Edge and Fog resources that belong to a single administrative domain. The main differences between an edge resource and a fog resource lie in their i) computing capabilities (a fog resource is more limited than an edge resource), ii) mobility (a fog resource may be mobile whereas an edge resource is assumed stationary), and iii) availability (a fog resource may have intermittent availability compared to an edge resource which is always available). The EFS constitutes the following components.

- EFS Virtualization Infrastructure (EFS-VI): The EFS virtualization infrastructure (EFS-VI) is the totality of the hardware and software components that build up the environment in which EFS entities (i.e. EFS applications, EFS functions and EFS service platform) are deployed, managed and executed. The EFS-VI is geographically distributed across several locations and composed of Fog nodes and Edge nodes.
- EFS entities, namely: EFS applications, EFS functions, the EFS service platform and their respective entity managers. An EFS entity is comprised by at least one atomic entity. An atomic entity is an unpartitionable computing task executed in the EFS.
  - EFS Function: A software entity comprised of at least one atomic entity deployed in EFS for networking infrastructure.
  - EFS Application: A software entity comprised of at least one atomic entity deployed in EFS for end users and third parties.
  - EFS Entity Managers: Analogous to the ETSI NFV element managers, the EFS entity managers are responsible for FCAPS management of the EFS service platform, Functions and Applications. This includes configuration management, fault management, Security management, accounting and collecting performance measurement results.
  - The EFS Service Platform: A logical data exchange platform constituting: (1) Data storage to keep the collected information from applications/functions and edge/fog resources. (2) Messaging/communication protocols to gather/provide information from/to applications/functions and edge/fog resources.

The following highlights the main achievements of WP2 regarding the design and validation of the 5G-CORAL Edge and Fog Computing System (EFS).

- Identified the EFS requirements, derived from the 5G-CORAL system requirements. The EFS requirements were grouped into two categories, namely: 1) requirements pertaining to the EFS virtualisation infrastructure (EFS-VI) and 2) requirements pertaining to the EFS entities.
- Developed the EFS architectural design, compliant with ETSI MEC and ETSI NFV frameworks, but with two notable extensions, namely: 1) the EFS virtualisation

infrastructure (EFS-VI) extends the ETSI Network Functions Virtualisation (ETSI- NFV) reference architecture to incorporate mobile and volatile resources that have different levels of availability, mobility, storage, computing, networking and power capabilities and 2) the EFS entities extend the ETSI-NFV network functions to include EFS applications and an EFS service platform.

- Provided a detailed description of the following: EFS internal and external interfaces, EFS workflows and the EFS data models.
- Designed the EFS entities following the microservice-based design paradigm as opposed to monolithic software design principles, i.e. the EFS atomic entities are independent of the microservices.
- Conducted a comprehensive survey, analysis and experimentation of the EFS Service platform messaging/communication protocols, i.e. NATS, DDS, MQTT, Zenoh and Kafka REST.
- Developed a reference EFS design for 5G-CORAL use cases, namely: IoT Multi-RAT Gateway, Robotics, Virtual Reality (VR), Augmented Reality (AR), Connected Cars, SD-WAN, and High-speed Train. The design decomposed each use case into the constituent EFS entities and described their respective interworking(s).
- Verified the feasibility of EFS reference design through software implementation and experimentation evaluation of seven 5G-CORAL use cases.
- Conducted a study and experimentation of EFS resource monitoring.

1.2.2.1 T2.1 Design and validation of EFS Functions

Task 2.1 mainly focused on the design and evaluation of EFS functions, i.e. software entities made up of at least one atomic entity deployed in EFS for networking infrastructure. The EFS functions were designed as Virtualized Network Functions (VNFs) and implemented using several virtualization technologies (LXD/LXC, Docker, and virtual machines) depending on their requirements. For instance, the IEEE 802.11 virtual access point (vAP) was designed and developed using LXD containers because of the need to access Kernel features related to the physical network interface card (NIC).

Task 2.1 investigated and validated the virtualization of communication protocol stacks of several cellular and non-cellular Radio Access Technologies (RATs), namely: IEEE 802.15.4, LoRa, NB-IoT and IEEE 802.11. In addition to radio access EFS functions, T2.1 also addressed the virtualization of a number of core network and transport EFS functions, such as the: Evolved Packet Core (EPC), Mobility Management Entity (MME), Home Subscriber Server (HSS), Serving/Packet Data Network Gateway (SPGW) and the Software Defined Wide Area Network (SD-WAN) function.

T2.1 identified, designed and implemented prototypes of EFS functions for each of the 5G-CORAL use cases. Table 1-1:, presents a summary of EFS functions, detailed descriptions of these functions are available in deliverables D2.1[4] and D2.2 [5] .

Table 1-1: EFS Functions

EFS Function	Description
Virtual Wi-Fi Access Point (IEEE 802.11).	EFS function enabling infrastructure-to-robot communication which is essential for robot navigation. Commands to control the robot are sent over the Wi-Fi connections. Designed and packaged as an LXD VNF.

iBeacons Localization estimation (BLE).	Estimates the relative position in an indoor environment based on iBeacon reference signals. Designed and packaged as a Docker container VNF.
IEEE 802.15.4 communication stack.	Full IEEE 802.15.4 stack implementation supporting 3 frequency channels from PHY layer to application layer. Designed and packaged as a Docker container VNF.
LoRa communication stack.	LoRa: PHY and MAC layer implementation. Designed and packaged as a Docker container VNF.
NB-IoT communication stack.	NB-IoT downlink PHY (NPSS, NPDSCH) implementation with a simplified upper layer implementation. Designed and packaged as a Docker container VNF.
SD-WAN	SD-WAN function acts a virtual gateway to establish a secure virtual network (control and data plane traffic flows) across different domains. Designed and packaged as a KVM virtual machine VNF.
Virtual Mobility Management Entity (vMME).	In LTE, MME is the main entity that handles control signaling. Derived from the NextEPC framework. Designed and packaged as an LXD VNF.
Virtual Evolved Packet Core (vEPC)	LTE core network constituting: HSS, MME and SPGW. Derived from Open Air Interface. Designed and packaged as a KVM virtual machine VNF.
eNodeB	LTE RAT derived from Open Air Interface. Designed and packaged as a PNF.

1.2.2.2 T2.2 Design and validation of EFS Services

Task 2.2 mainly focussed on the design of the EFS service platform that hosts the EFS services. The EFS services were designed following the microservice-based design paradigm as opposed to monolithic software design principles. The microservice-based design structures the EFS services as a collection of loosely coupled autonomous software modules working together. Each EFS service is a separate entity with no dependency on other EFS services. The EFS services interact with each other and other EFS applications and functions via network calls, i.e. application programming interface (APIs). Due to the distributed nature of the EFS and the mobility and volatility of EFS resources, T2.2 adopted the publish/subscribe API design (Figure 1-1:).

The EFS service platform provides the API framework through which both EFS and non-EFS applications and functions can publish and subscribe to various services e.g. localisation service, radio network information service (RNIS), etc. EFS and non-EFS applications and functions may publish and/or subscribe to one or more topics, maintained by EFS service(s). The EFS service platform performs Authentication, Authorisation and Accounting (AAA) of EFS and non-EFS applications and functions that publish and/or subscribe to the EFS service(s). The EFS service platform also maintains a service registry to track all the services consumed by the applications and functions. Each EFS service is essentially an API with multiple topics that authorised applications/functions can publish to and/or subscribe to receive notifications from. Therefore, the EFS service platform is an API as a service (APIaaS), a subset of Software as a Service (SaaS).

T2.2 also conducted comprehensive survey and analysis of potential publish/subscribe messaging/communication protocols suitable for the EFS Service platform reported in deliverables D2.1 [4] and D2.2 [5] . A key outcome of this study was the recommendation of NATS and Zenoh as the most apt EFS Service platform messaging/communication protocols. Table 1-2:, presents a summary of EFS services, detailed descriptions of these services are available in deliverables D2.1 and D2.2.

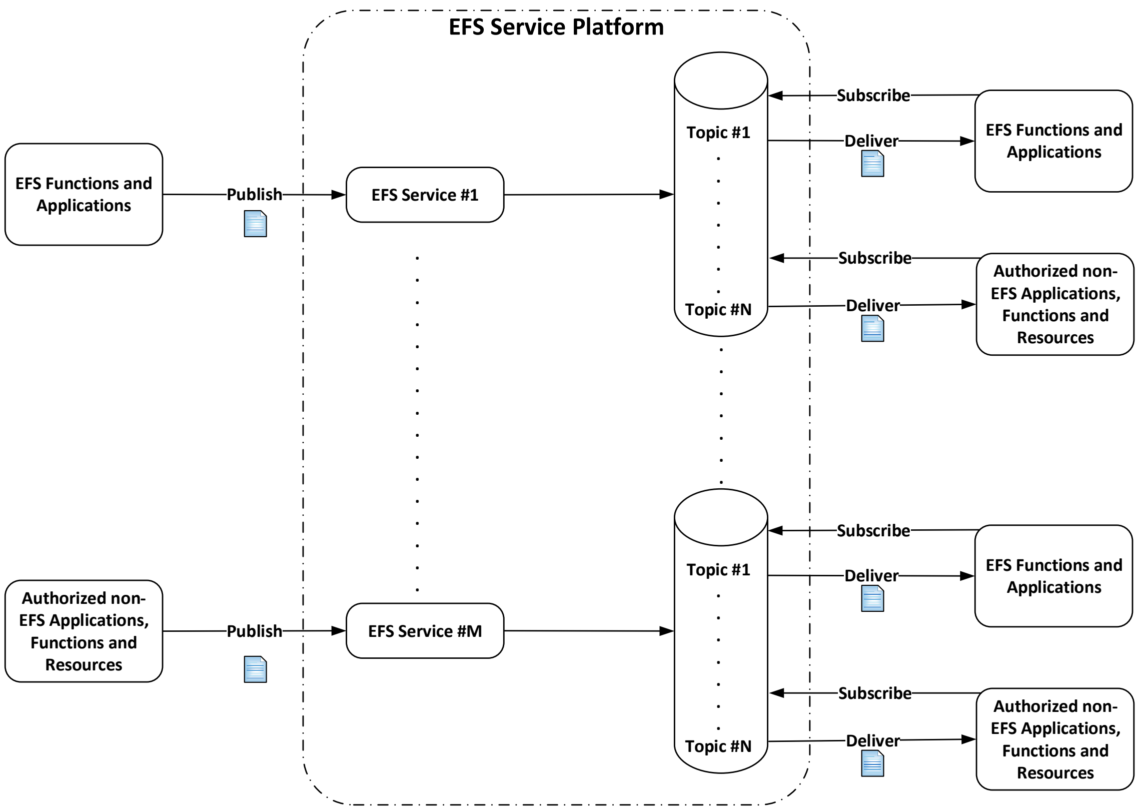

FIGURE 1-1: PUBLISH/SUBSCRIBE MESSAGING AMONG EFS ENTITIES

TABLE 1-2: EFS SERVICES

EFS Service	Description
iBeacons indoor localization service.	This service estimates the vicinity of the device to the iBeacon, and when the location of the iBeacon is known, the approximate location of the device.

	iBeacon localization data includes iBeacon ID and signal strength.
rplidar indoor localization service.	This service estimates the vicinity of the device (e.g. robot) using LIDAR mapping.
Wi-Fi information service	EFS service which provides Wi-Fi network information for each connected client (e.g., a robot) data regarding: the signal level; transmission and reception bit rates; number of retransmission and packet losses at data link level; and number of successfully transmitted/received bytes and packets.
LTE OAI based radio network information service.	EFS service that provides LTE radio network information containing parameters such as: wideband channel quality indicator, buffer status reports, power headroom report, serving cell index, etc.
IQ data service.	EFS service that provides PHY-layer IQ samples from the communication-stack EFS functions. In the PoC testbed, the IQ samples are published by the IEEE 802.15.4 communication-stack function following the MQTT protocol via an MQTT broker, as one implementation example.
User orientation service.	EFS service responsible for selecting which tile has to be sent to the UE based on the orientation information provided by the orientation client. The selected tile is communicated to the DASH client.
Telemetry service.	EFS service that provides telemetry messages that include vehicle characteristics (length and width), vehicle speed, location, etc.
Warning service	EFS service that provides warnings in the event of an approaching emergency vehicle.
Train proximity service.	EFS service that provides the approximate location of a moving train.

1.2.2.3 T2.3 Design and validation of EFS Applications

Task 2.3 focused on the design and evaluation of EFS Applications, i.e. a software entity comprised by at least one atomic entity deployed in EFS for users and third parties. Analogous to the EFS services developed in task T2.2, the EFS applications were likewise designed following the microservice-based design paradigm as opposed to monolithic software design principles. The benefits of a microservice-based EFS design include.

- A single EFS application can be deployed independently of the rest of the system. This allows to deploy some of the EFS applications at the edge or fog while keeping others at distinct locations.
- Microservices permit the use of different technologies (e.g. programming languages) inside each EFS application; additionally, the software stack within each EFS application can be

freely replaced while keeping the API towards the other EFS applications and services the same.

- Adapting existing EFS applications does not require refactoring of the whole EFS application.
- Microservices permit scaling of only those EFS applications that need scaling while keeping the rest untouched.
- Microservices provide better fault isolation, i.e. if one EFS application fails, the others continue to function.
- With microservices, it is easy to integrate with 3rd party applications into the EFS.
- Microservice-based EFS applications can easily be implemented using containers or virtual machines.
- Microservice-based design of EFS applications inherently provides isolation of the individual EFS applications thus simplifying the security-related design.

T2.3 also identified EFS services relevant to each EFS application for instance considering the Robotic use case; the EFS robot intelligence application consumes data provided by both the localization and Wi-Fi information services.
T2.3 identified, designed and implemented prototypes of EFS Applications for each of the 5G-CORAL use cases. Table 1-3:, presents a summary of EFS applications, detailed descriptions of these applications are available in deliverables D2.1 and D2.2.

TABLE 1-3: EFS APPLICATIONS

EFS Applications	Description
Robot intelligence application	EFS application in charge of controlling and guiding the robot towards the point of interest. The application computes the optimum path for a robot to reach the point of interest.
Real-Time Messaging Protocol (RTMP) acquisition	EFS application responsible for performing the RTMP acquisition enabling persistent connections and low-latency communications.
Tile encoding	EFS application to perform the tiled 360 video encoding. It processes the data stream coming from the RTMP acquisition application and provides the DASH segmentation module with the tiled encoded data stream.
DASH segmentation	EFS application in charge of segmenting the data stream encoded by the tile encoding application through DASH, which is consumed by the DASH client application
DASH client	EFS application to reassemble DASH segments sent by the DASH segmentation application. The output data is then sent to the decoding application.
Decoding	EFS application performing the decoding of tiled video streams sent by the DASH client. The decoded video stream is then delivered to the composition EFS application.
Composition	EFS application responsible for re-composing tiled video streams into 360 video frames at the client side.
Image Recognition application	EFS application that detects objects in an image.

Interference analyser	EFS application that uses the IQ samples from the subscribed IQ data service and analyses IQ samples to increase the knowledge and understanding about the radio environment and interference conditions.
Collision avoidance application	EFS application that processes the telemetry messages in order to warn the user(s) about collision risks.
Vehicle breakdown notification	EFS application responsible for generating and publishing warnings in the event of a hazardous malfunction being detected.
Emergency vehicle approaching	EFS application responsible for warning the user(s) in the event of an approaching emergency vehicle.
Point of Sale (PoS) database	EFS application that records an inventory of the PoS customers.
Point of Sale (PoS) web application	EFS application that provides a user interface to the PoS system.
Video streaming server	EFS application responsible for streaming video content.

1.2.3 WP3: 5G-CORAL orchestration and control system

The 5G-CORAL architecture is based on the ETSI MEC and ETSI NFV frameworks, where a mix of physical and virtualized resources available in the fog and edge tiers is considered to implement an ETSI NFV compliant infrastructure. The Orchestration and Control System (OCS) developed in WP3 (led by UC3M) is a logical system in charge of composing, controlling, managing, orchestrating, and federating one or more EFS(s). In the following we detail the OCS components:

- A Virtualisation Infrastructure Manager (VIM) comprises the functionalities that are used to control and manage the interaction of the service platforms, functions, and applications with the edge and fog resources under its authority;
- An EFS Manager is responsible for the lifecycle management (e.g. instantiation, update, scaling and termination) of the service platforms, functions, and applications in the EFS;
- An EFS Orchestrator is in charge of the orchestration and management of edge and fog resources and composing the EFS. An EFS Orchestrator comprises an EFS Resource Orchestrator and an EFS Stack Orchestrator. An EFS Resource Orchestrator supports accessing the edge and fog resources in an abstracted manner independently of any VIM. An EFS Stack Orchestrator is responsible for the EFS Stack lifecycle management operations (e.g. instantiation, update, query, scaling and termination);
- An EFS Stack can be viewed architecturally as a forwarding graph of functions and/or application interconnected by supporting edge and fog resources and/or service platforms. An EFS Stack extends the ETSI NFV Network Services by also considering interconnections with applications and service platforms;
- An EFS Stack Descriptor extends the ETSI NFV Network Service Descriptor by also considering applications and service platforms in addition to network functions. It describes the requirements and interconnections of one or more EFS Functions and EFS Applications between them or with the EFS Service Platform;
- An EFS Entity Descriptor extends and combines ETSI NFV VNF and ETSI MEC App descriptors to uniformly describe the various characteristics of EFS Functions, EFS Applications, and EFS Service Platform. EFS Entity Descriptors are referenced and included into an EFS Stack Descriptor.

1.2.3.1 T3.1 Federation and integration of EFS resources

While the first reporting period of Task 3.1 mainly focused on the discovery and automatic advertisement of resources targeting their integration in the EFS, the second reporting period mainly focused on the federation of resources between different administrative domains. Federation can be considered a key feature of the OCS for optimizing function and application deployment and efficiently placing EFS Entities (e.g., functions and application) into convenient locations, such as in proximity of the users requesting them. As a matter of fact, a single EFS infrastructure may introduce deployment limitations due to the lack of resources and reduced user accessibility, with consequent negative impact on CAPEX and OPEX.

In order to overcome such limitations, administrative domains close to each other can benefit from taking part in a federation based on a trusted cooperative peer-to-peer model. Figure 1-2 shows an example of resource federation between three administrative domains. In this example, Domain A requests the peering domains an additional resource which is then granted by Domain B. The above federation process will not only expand the overall footprint of the administrative domains participating in the federation, but it will also increase the profits of the members involved and fairness in profits/revenue can be prevented by encouraging all the participants to share the total profit. As a result, we assessed how federation can help operators significantly reduce deployment and operational costs (see D3.2 [7] for detailed results).

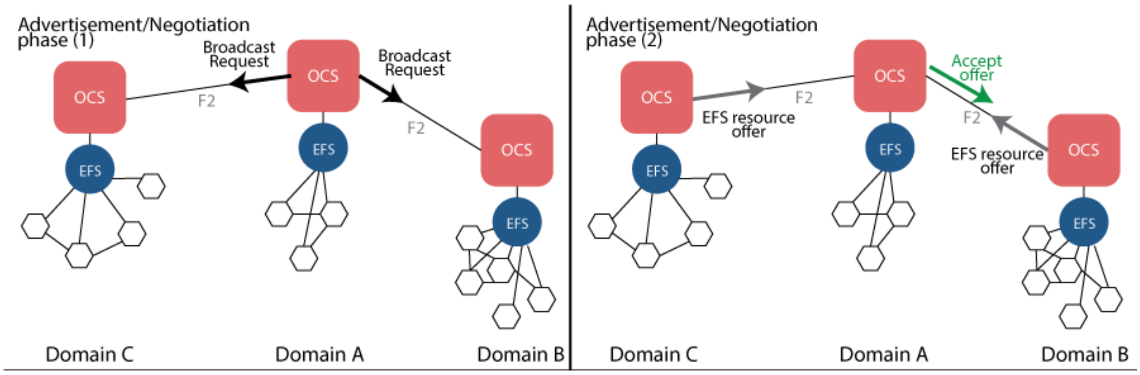

FIGURE 1-2: OCS FEDERATION INTERACTION - ADVERTISEMENT/NEGOTIATION PHASE

Additionally, Task 3.1 analysed most prominent orchestration solutions emerged from open-source communities, research projects and standardization groups, with the goal of assessing their benefits and their limits with respect to the 5G-CORAL framework and OCS requirements (see D3.2 [7] for a detailed analysis). Specifically, the 5G-CORAL non-functional requirements for the OCS are far from being met by current orchestrators. Particularly, today's implementations are tailored to datacentre environments where resources are fixed, and high bandwidth is available. However, this assumption is not true for fog and edge environments where heterogeneous resources are geographically distributed. This makes it difficult to support OCS deployment on low-end devices which may also be mobile and distributed across multiple locations.

To tackle this problem, the 5G-CORAL OCS adopts a novel key-value store concept, which allows to distribute the various OCS components (and sub-components) and their state (i.e., data) across different technologies and networks, along the cloud-to-thing continuum. Differently from traditional key-value stores, in 5G-CORAL data are globally accessible and local replication is not required. Furthermore, we assessed the advantages of adopting a distributed VIM, capable of managing resources hosted by heterogeneous nodes, particularly by resource-constrained and mobile nodes. The architecture of the VIM agent running on the EFS resources and the various distributed storages are illustrated in Figure 1-3. Differently from a centralized VIM, the distributed VIM ensures more flexibility and agility in monitoring, tracking and provisioning resources sitting on different logical layers, namely, cloud, edge, fog and terminals. Moreover, to overcome issues generated by the resource volatility, we introduced the storage decomposition in actual and desired storage, such that service instantiation/termination, polling and any other lifecycle operations can be successfully carried out even when devices are out of coverage or connectivity is disrupted. In turn, this allows the OCS to instantiate and terminate EFS applications, having an accurate visibility of the resources available and taking into account their volatility.

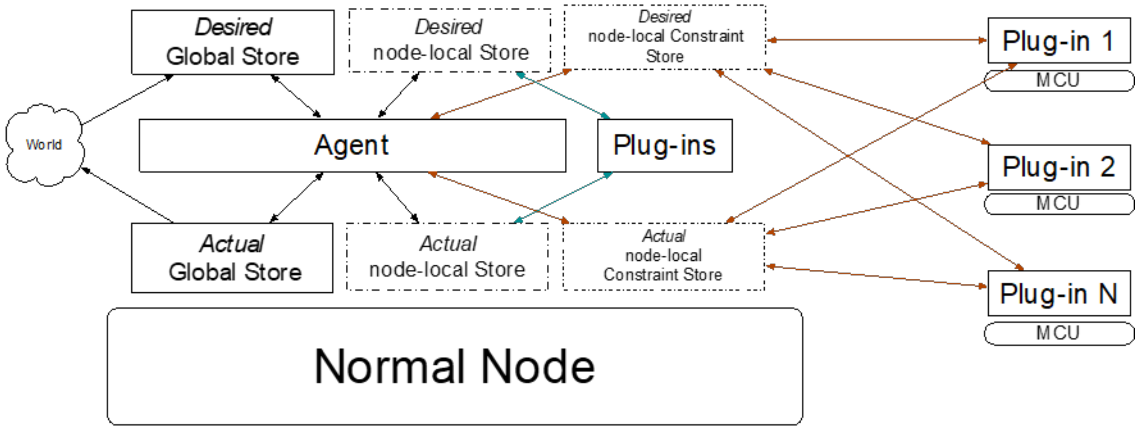

FIGURE 1-3: DISTRIBUTED VIM AGENT AND STORAGES

1.2.3.2 T3.2 Control and management of EFS functions and applications

Task 3.2 focuses on the definition of the EFS Stack which can be architecturally viewed as a forwarding graph of functions and/or application interconnected by supporting edge and fog resources and/or service platforms. The first reporting period mainly focused on the definition of the EFS Entity descriptor as required by the VIM. However, in order to allow the automatic deployment of EFS Stacks on the 5G-Coral infrastructure, an EFS Stack Descriptor has been designed for the EFS Stack and Resource Orchestrator during the second reporting period of Task 3.2. As a result, , the EFS Stack allows to harmonize and extend the ETSI MEC and ETSI NFV information model by collecting information describing the edge and fog environment, such as I/O devices, network interfaces and location constraints. The complete details and the information model of the EFS Stack Descriptor are available in D3.2 [7] . The EFS Stack Descriptor is provided to the EFS Stack Orchestrator which, in collaboration with the EFS Resource Orchestrator, takes care of the deployment of the different applications/functions on the available resources. The EFS Stack Descriptor specifies the requirements and interconnections of one or more EFS Functions and EFS Applications between them or with the EFS Service Platform. In turn, the EFS Resource Orchestrator performs a mapping of those requirements onto the underlying infrastructure via a placement algorithm. A placement algorithm for fog environment has been developed in Task 3.3 (see later).

The EFS Stack descriptor has been experimentally validated and results show that the hypervisor is the main factor contributing to the overall deployment time. Figure 1-4 shows that container-based virtualization technologies (i.e., Docker and LXD) are ~6 times faster in deploying and executing the EFS App compared to a virtual-machine based hypervisor (i.e., KVM). Moreover, the image footprint of LXD is ~5 times smaller than Docker. Finally, in these tests we have considered the image to be pre-provisioned on the compute node. However, in a realistic scenario the image should be provisioned on-demand on the compute nodes. In case of limited or intermittent network connectivity and storage space, LXD would be a better choice compared to Docker.

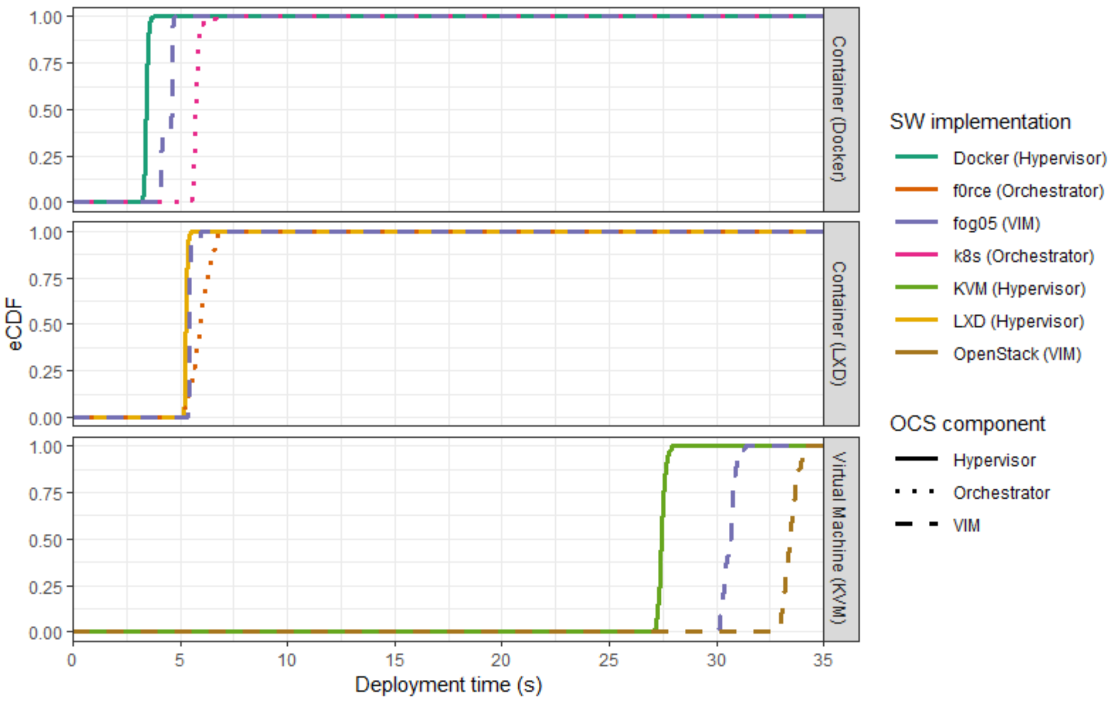

FIGURE 1-4: EXPERIMENTAL DEPLOYMENT TIME OF AN EFS STACK WITH AN ATOMIC EFS APPLICATION

1.2.3.3 T3.3 Orchestration of EFS resources

The first reporting period of Task 3.3 mainly focused on the definition of a Finite State Machine (FSM) for EFS Atomic Entities, including MIGRATION, TAKING_OFF and LANDING states to support migration process (see D3.1 [6] for details). The second reporting period of Task 3.3 focused on a novel migration mechanism for container based EFS Entities targeting downtime minimization. Container migration can be classified into stateful and stateless. In stateless migration (a.k.a. *cold* or *offline* migration), the state of the container is not preserved when the container is relocated to the destination node. In the case of stateful migration (a.k.a. *live* migration), the state of the container is retained when the container is restored at the destination node. There are three schemes of stateful migration as follows:

- **stop-and-copy:** freezes the container, checkpoints its state, copies the container image and its state to the destination then restores the state from the checkpoint;
- **pre-copy:** performs iterative state checkpointing while the container is running till the amount of in-memory change is at minimum, then concludes with a shorter stop-and-copy;
- **post-copy:** performs a short stop-and-copy to move essential state data, then starts the container at the destination and retrieves the rest of the data when required.

Specifically, we develop and implement a pre-copy migration scheme (see D3.2 for details) based on LXC, checkpoint and restore in user space (CRIU), and remote file synchronization (rsync). Figure 1-5 shows the experimental downtime of stop-and copy (sc) and pre-copy (pc) migration schemes. The left y-axis represents the observed downtime while the right y-axis shows the size of the accumulative checkpoint files in megabytes for the respective container type and migration scheme. The results clearly show that the sc exhibits higher downtime and variation compared to the developed pc scheme. As such, the proposed pc migration scheme reduces the downtime by approximately 21% when compared to the current state-of-the-art.

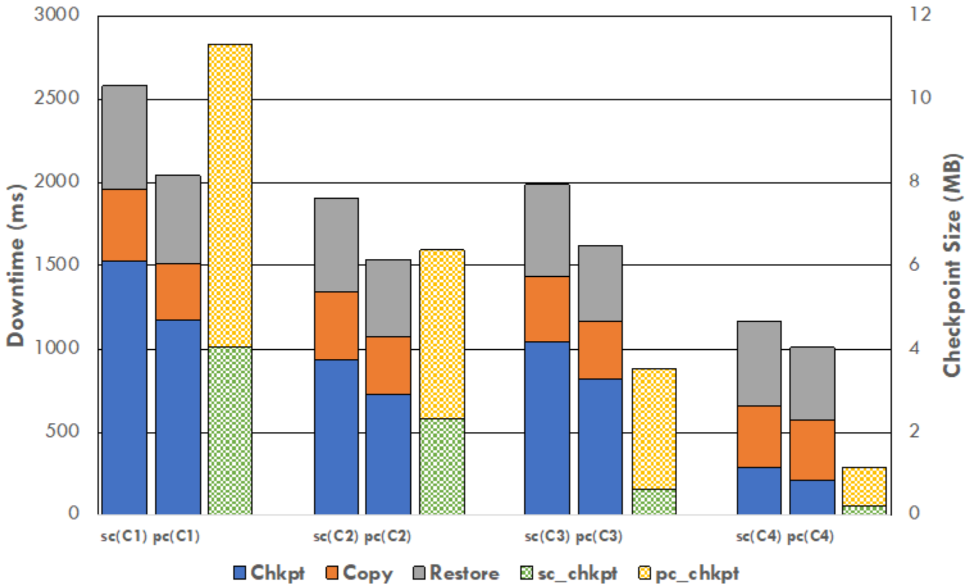

FIGURE 1-5: MIGRATION DOWNTIME COMPARISON BETWEEN STOP-AND-COPY (SC) AND PRE-COPY (PC) SCHEMES FOR DIFFERENT CONTAINERS

Additionally, Task 3.3 proposed and evaluated a placement algorithm for edge and fog environment considering the volatility and pricing of different types of resources (see D3.2 for the model and algorithm details). Our conclusion is that introducing volatile resources in the EFS infrastructure significantly increases the total cost of ownership of the EFS Stack. In other words, the adoption of volatile resources in the 5G-CORAL platform makes a negative impact on OPEX and CAPEX. Therefore, we advocate the usage of edge resources, since the lack of volatility lowers the EFS Stack lifetime cost, while volatile fog resources may be utilized in certain scenarios, where volatility does not affect the OCS operations. For instance, in a shopping mall setting, fog resources may be more persistent due to the limited space, thus ensuring good availability in a certain time frame. By contrast, operational costs may significantly rise in different situations, such as the high-speed train and connected-cars scenarios, where mobility may lead to connection drops and service disruptions. In such circumstances, we recommend the deployment of edge resources, which can guarantee higher reliability and longer availability.

Finally, Task 3.3 addressed the agile deployment and reconfiguration of RATs and multiple communication channels from an OCS perspective. Specifically, in 5G-CORAL RATs are handled as EFS functions, resulting in rapid instantiation, termination and migration. As an example, robots can benefit from Wi-Fi coverage through virtual APs deployed by the OCS, or low-latency D2D connectivity can be reliably provided for robots that needs to be coordinated. This is possible thanks to the context information available at the edge, which is delivered to the EFS manager by means of EFS services. As we demonstrated (see D3.2 for details), the ability of deploying multi-RAT solutions is mission-critical in robotics use cases, as robots need to be able to exploit short-range D2D connectivity to navigate and maintain coordination with high accuracy, particularly in high-interference conditions as illustrated in Figure 1-6. In such scenario, the 5G-CORAL OCS can quickly react and reconfigure the network connections by relying on the information stored in the EFS.

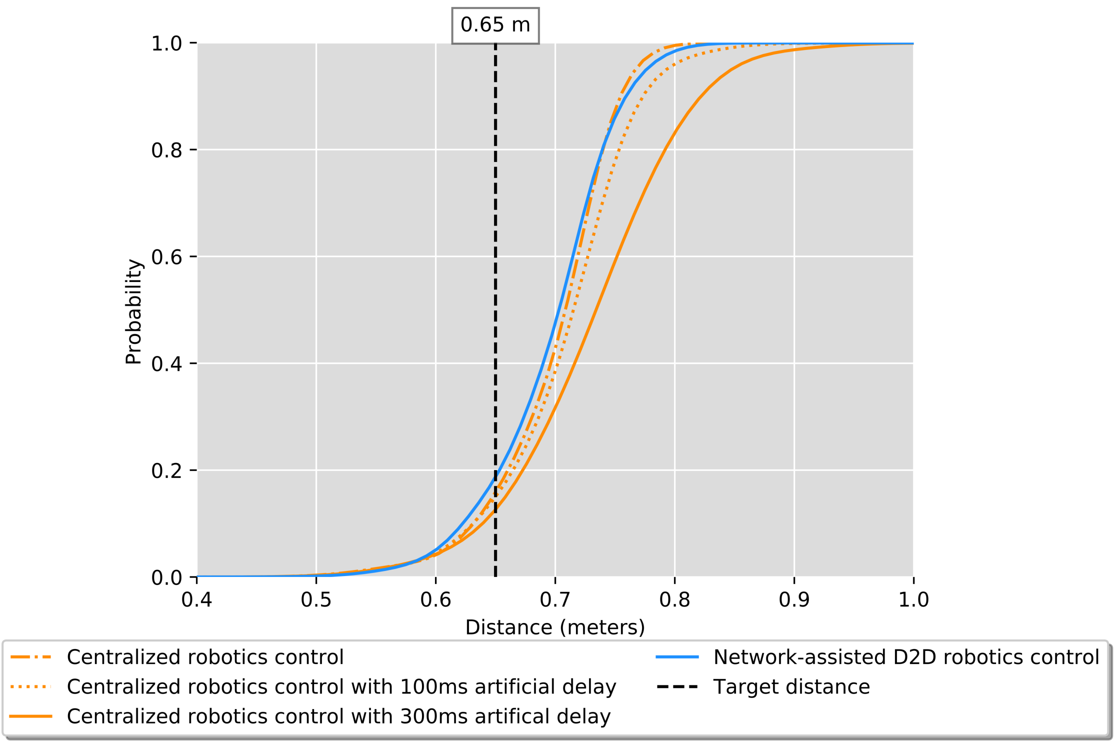

FIGURE 1-6: EXPERIMENTAL CDF OF DISTANCE BETWEEN TWO ROBOTS FOR CENTRALIZED AND NETWORK-ASSISTED D2D ROBOTICS CONTROL

1.2.4 WP4: 5G-CORAL demonstration and trials

ITRI is leading the WP4, covering the demonstration and Trials of the 5g-CORAL project. The main objective of 5G-CORAL's WP4 is to evaluate the merits of 5G-CORAL solution through of proof-of-concepts (PoCs) featuring high-throughput and low-latency demanding applications at the vicinity of the end-user and in real-world environments. The goal of WP4 is to integrate the technology components developed in WP2 and WP3 in the available testbeds of the project. This integrated platform will be used to experimentally validate all these components together into real world multi-functional testbeds. This has been demonstrated in Taiwan Trail 2018 (Nangang Shopping mall, Taipei). Also, it included 7 PoCs defined based on the use cases of WP1. In WP4, the most promising technologies from WP2 and WP3 are used as baseline to develop PoCs. In particular, we have presented three individual real-world test sites to experiment with the various PoCs and report meaningful performance measures highlighting the added-value of 5G-CORAL solution. Three real-world testbeds are defined in this testbed namely Shopping Mall, (ii) HST/ITRI Campus; and (iii) TIM/AZCOM Connected Cars. The testbeds provide a solid foundation for the assessment and evaluation of the technology solution being developed within 5G-CORAL. In aforementioned testbed, It highlights the technologies and infrastructures to be integrated in each site and presents the corresponding integration plan. Also, for each PoC, we show the relation with project objectives, relation with use case, Software and Hardware configuration, ways to measure performance metrics and interim results.

We then presented seven PoCs, namely: Augmented Reality Navigation, Virtual Reality, Cloud Robotics, IoT Multi-RAT Gateway, Group Handover in High-Speed Train, Connected cars and SD-WAN. We presented the physical and logical architectures of each PoC, as well as detailed specifications for the integration and deployment of the individual components comprising each PoC. Integration and validation were also presented. Various PoCs have been demonstrated in EuCNC'18, EuCNC'19, MWC'19, ICT'19 and Computex'19 under development in the 5G-CORAL project. Moreover, each PoC has been evaluated and validated through various performance metrics defined in D1.3. Then, it is planned to show EFS and OCS competent integrated in selected PoC planned in October 2019.

1.2.4.1 T4.1 Definition and setup of testbeds

For the first year, WP4 has been working exclusively on T4.1: "Definition and setup of testbeds". This task consolidates the definition of the testbeds along with the demonstrations plan. This task consolidates the testbeds used in the project, demonstration plans and understanding of the available technologies from the 5G-CORAL partners. The definition and setup of testbed are (i) Shopping Mall, (ii) HST/ITRI Campus; and (iii) TIM/AZCOM Connected Cars. In WP4, testbed setup is defined with the available technologies from the partners in accordance to the architecture defined in the WP1. Demonstration plans with respect to the three different testbeds have been defined with the linkage to the uses cases defined in the WP1 and Targeted KPIs. Regarding the interaction with the rest of the project, WP4 worked closely together with WP1, WP2 and WP3 and identified the key architectural components used in the demos. All the initial demo results have been extensively collected D4.1. Also, we provided a detailed mapping of PoCs functionalities with the outcomes of WP1 (use cases and requirements) and the required 5G-CORAL building blocks defined in WP2 (EFS entities configuration) and WP3 (Orchestration and control system).

1.2.4.2 T4.2 Integration and experimentation

This task has finished on Month 18. The main milestone for this task Developed Demonstration and Trials Plans for 2018. In particular, WP4 has validated multiple PoC in Taiwan trials in November 2018 at the Shopping Mall test site (Taiwan) based on the components presented in D4.1 [8] . This included identification, implementation and integration of necessary components for the demonstration/trials. Besides, preliminary results are reported of each PoC in D4.1. The features of each PoC are summarized in Table 1-4: Taiwan Trial PoC features.

TABLE 1-4: TAIWAN TRIAL POC FEATURES

PoCs	Key features
PoC #1 – Augmented Reality Navigation	Cooperative computing among Fog CDs
PoC #2 – Virtual Reality	Multi-tier Hierarchical computing of Fog/Edge
PoC #3 – Fog-assisted Robotics	Intelligent control following the moving robots
PoC #4 – Multi-RAT IoT	Multi-RAT convergence and virtualization
PoC #5 – SD-WAN	On Demand federation of resources
PoC #6 – High-Speed Train	Fog assisted control unit for the handover and service migration of group of users: The core following group of users
PoC #7 – Connected Cars	Moving Fog CD and distributed computing

Several example of PoC experiments have also been showcased in EuCNC2018 and EuCNC2019, as highlighted in Table 1-5.

TABLE 1-5: POC IN EUCNC'18

PoC	Description	Format	Involved Partners
Cloud Robotics	Deploying the robot resources on edge devices and control the robots remotely by placing the robotic intelligence in the network, assisted by the WiFi infrastructure	Live Demo	UC3M, IDCC, Adlink
Multi-RAT IoT	Initial implementation of Multi-RAT IoT Gateway, highlighting the feasibility of virtualizing the communication stacks of two IoT RATs, IEEE 802.15.4 and NB-IoT. In the demo, IEEE 802.15.4 implementation was also integrated with a LWM2M server, showcasing the end-to-end LWM2M IoT capability.	Live Demo	EAB, SICS
Augmented Reality	Augmented reality live navigation was demonstrated used to navigate the user to the destination. Localization service was deployed in the fog nodes to detect the current position of the users and using it to navigate the user.	Video	ITRI, NCTU
High-Speed Train	Initial version of Group handover for users was demonstrated.	Video	ITRI
Connected Cars	Development status was shown, highlighting the alerts regarding the safety risk.	Video	Azcom, TI

1.2.4.3 T4.3 Demonstration and trials

In T4.3, mature experiment results for PoCs were reported for example, Integration, development and experimentation of network assisted D2D feature are depicted for Robotics PoC. In addition, delay and throughput measurements of the multi-channel SDR implementation of 802.15.4 in Multi-RAT PoC. Besides, end-to-end system performance is captured for On-Board Unit (OBU) of Connected Car PoC. Moreover, developing and integrating distributed computing to AR PoC. It is important to note that several PoC owners used Eclipse fog05 in their experimentation. This help to demonstrate the OCS and EFS feature of the diverse PoC adopted in 5G-CORAL. Besides, the measurement results are collected and compared it with the state of art defined in D1.3. Notable, final demo Plans has been addressed in detail for the selected PoCs. Lastly, several PoCs has been presented in EuCNC 2019 and Computex 2019. It is important to highlight the key achievements of each PoC as follow:

- PoC #1 – Augmented Reality Navigation: This PoC focus on the distributed computing of the limited resource Fog nodes. Distributed computing distributes the incoming job or dispatches it to another fog node (available), if the area is crowded with the users. This allows the utilization of the resources in the EFS, increasing in number of handled requests. In AR PoC, user captures the Point of Interest and send it over the Fog Node for the image recognition, then provides navigation to Points of Interests (POIs). If the Node is overloaded, then distributed computing will guarantee the user experience. This PoC minimize computing latency by processing image recognition and navigation tasks at the EFS. Also, it overcome Single Point of Failure (SPF) by centralized distributed computing mechanism.

- PoC #2 – Virtual Reality: This PoC focuses on reducing the E2E latency experienced by the VR user by offloading complexity and processing load from both the server and the terminal. In this respect, a large amount of latency has been reduced from 26 seconds, measured during Year-1 trials, down to 8 seconds. Further improvements are anticipated by replacing the streaming engine with a more optimized streaming solution. In addition, 5G-CORAL platform on top of Fog05 contributed into a significant reduction in the time spent by the orchestrator in setting up and taking down the end-to-end video streaming service. Besides, the VR service decomposition into multiple microservices (EFS apps and functions) increases flexibility and unlocks more deployment options, on top of an agile multi-tier EFS stack deployment managed by Fog05.
- PoC #3 – Fog-assisted Robotics: This PoC focus on network assisted D2D function for robot-to-robot communication and the EFS mobility function. Also, localization EFS Service was integrated to tracks the robots estimated 2D position and make it available over the EFS Service platform. These adopted features allow to extend continues connectivity for the mobile robots. On the other hand, OCS is responsible for lifecycle management (e.g. instantiation, query and termination) of the EFS functions. This PoC decreased the end-to-end reaction time by moving the intelligence in the edge, use of the context information in order to predict misbehaviours, react, and coordinate the robot movements by exchanging data over the D2D channel.
- PoC #4 – Multi-RAT IoT: This PoC focus on multi-RAT convergence and virtualization using software defined radio. Implementations of IEEE 802.15.4, LoRa and NB-IoT stacks have been softwarized and separated into radio head and edge parts, where the latter can be instantiated as needed using edge computing. The components are "dockerized" and integrated in a testbed. IQ/Data wideband samples are made available as an EFS service from the 802.15.4 radio head, which is used by an interference analyser EFS application. This PoC showcase the feasibility of implementing Multi-RAT IoT stacks in EFS, which indicates better scalability for supporting high IoT connection density. Some of the features are adopted in Contiki-NG open-source project.
- PoC #5 – SD-WAN: This PoC focus on provide a simple PoS application with roaming capabilities. The PoS Terminal roaming across domains, while PoS service is uninterrupted and QoE maintained. This PoC showcase static federation mechanism, host mobility service to locate PoS Terminals across domains and traffic delivery optimization by means of offloading. The resource of SD_WAN were integrated to orchestrator, which has the global view of the whole set of resources, either federated or not. The resource orchestrator is able to place EFS applications more precisely where offloading capabilities are required. This PoC improved latency, bandwidth and jitter by moving applications closer to the user/consumers. Also, moving applications closer to user allows service providers to serve more end users in the same area due to the increase capacity and reduced latency at the Edge/Fog. reducing bottlenecks caused when application traffic moves from user’s terminal to the cloud.
- PoC #6 – High-Speed Train: This PoC focus on improving on-board user experience by reducing the interaction with on-land base stations. Furthermore, edge networks and virtualization technologies are utilized to bring services closer to the traveling users. Adopting 5G-CORAL platform as EFS and OCS contribute to overcome the signalling storm and backhaul latency challenges to maintain a continuous service. In high-speed train POC, we propose a mobile service continuity solution, which includes a group handover and application migration schemes. Our experimental results show that the proposed schemes

can reduce the control signals and migration downtime by 50% and 36%, respectively. This PoC showcase the container-based migration and mobility services.

- PoC #7 – Connected Cars: This POC focus on adopting 5G CORAL architecture to guarantee a lower and more stable latency compared to the legacy-centralized architecture. In this POC, it has been seen that the payload size is reduced by 82% compared to state of Art. In the following Figure 8 11 the comparison of the CDF of the latency measurements done of the three protocols are depicted. In this PoC, Latency is low and stable since EFS app service and function are placed on the OBU and RSU. Also, RSUs can be used to serve small area, reducing congestion and bottleneck i.e. in traffic jam situation. Finally, E2E latency lower bound is represented by the RAT latency, using more suitable RAT, DSRC or C-V2X or 5G NR to contribute toward 1ms target.

1.2.5 WP5: Communication, dissemination, standardization and exploitation

To aim at generating a maximum impact of the project on all the various stakeholders is the key objective of WP5, led by NCTU. The main activities in this Work Package are related to achieve an outreach communication and dissemination, a proactive standardization, and a sound exploitation plan during the project lifetime and beyond.

WP5 is structured in two tasks. The first focus on communication and dissemination activities. The second focus on standardization and exploitation activities. The activities undertaken are reported in two deliverables, namely D5.1 for the Year 1 (from 01 September 2017 to 31 August 2018) and D6.2 for the Year 2 (from 01 September 2018 to 31 August 2019).

In Year 1, WP5 deployed a range of activities to accompany the accelerated technology development in the technical work packages. These activities resulted in key achievements highlighted below:

- A noticeable presence at Mobile World Congress 2018, with a full program including demonstrations, panel, invited talks, videos, leaflet, and press release.
- An active communication and dissemination through 15 talks and panels, and 2 organized workshops, in addition to press releases, videos, and interviews.
- A significant record of scientific peer-reviewed publications with 12 articles published or accepted for publication in reputed IEEE and ACM journals/magazines and conferences proceedings.
- A significant boost in the number of contributions submitted to standardization forums, with 27 contributions submitted in various groups, such as IETF and ETSI.
- A proactive identification of key innovations from the project together with precommercial proof-of-concepts, and a new product (Fog05) from 5G-CORAL partner ADLINK, which all bear a good potential for further exploitation.

In Year 2, WP5 continued its full range of activities and added further achievements to this period noticeably:

- A noticeable presence at Mobile World Congress 2019, with a full program including demonstrations, panel, invited talks, videos, leaflet, and press release.
- A booth and workshops at EuCNC 2019, with demonstrations, panel, invited talks, videos, and press release.
- 5 open source contributions to various groups and 15 contributions submitted to standardization forums.
- Addition of 13 more publications, 15 talks, and 6 workshops organized.
- Delivery of videos and video interviews on 19 demonstrations showcasing the technological innovations developed within the project.

Cumulatively over the project lifetime from 01 September 2017 to 31 August 2019, the project exceeded on all metrics set for the targeted objectives. An impressive record of activities has been achieved as highlighted below:

- Over 42 normative contributions feeding into key standardization specifications such as: IETF 6TiSCH, IETF SFC, ETSI MEC, and ETSI NFV.
- 21 peer-reviewed publications in IEEE and ACM proceedings, journals and magazines, over 30 talks and panels delivered at key events, and nearly 8 workshops and special sessions (co-) organized.
- Over 24 demonstrations exhibited at various events including at the flagship Mobile World Congress both in 2018 and 2019, ICT 2018, Computex 2019, WCNC 2018 and 2019, and at the EC conference EuCNC in 2018 and 2019.
- Proactive communication through blogs, press releases, video interviews, and leaflets, all actively promoted through various channels and social media.

1.2.5.1 T5.1 Communication and dissemination

In this period (M13-M24), the following communication and dissemination activities are undertaken:

1) 6 workshops held, 1 in Nangang, 1 in CoNEXT 2018, 1 in ICT 2018, 1 in WCNC 2019, and 2 in EuCNC 2019

2) 6 posters have been provided in conferences

3) 5 videos have been provided in Nangang, Computex 2019 and EuCNC 2019

4) 13 conference papers accepted by WCNC 2019

5) 15 public presentations mentioning 5G-CORAL

1.2.5.2 T5.2 Standardisation and exploitation

In this period (M13-M24), the following standardization and exploitation activities are undertaken:

1) 15 standard contributions to ETSI and IETF

2) 5 open source contributions which are FogO5, f0rce (fog orchestration engine), 5G infrastructure generator, Contiki-NG, and the pylxd project.

3) 4 booths hosted in ICT 2018, MWC 2019, Computex 2019, and EuCNC 2019

4) Total 19 demonstrations

1.2.6 WP6: Project Management

The management of the project, dedicated WP in the DoA, is led by UC3M. The main activities in this Work Package are related to ensure that the project runs successfully, that the partners collaborates each other and the technical objectives are achieved taking care of the time and the costs of the project. The project coordinator (PC) administered the financial contribution, allocating it between the beneficiaries, and activities in accordance to the Grant Agreement. The payments have been done with no delay. The PC kept the records and financial accounting and informed the Commission of the distribution of the financial contribution of the Union. The PC verified consistency between the reports and the project tasks and monitors the compliance of beneficiaries with their obligations.

During the second period, the only deliverable due to this Work Package corresponds to this document D6.2. Besides, during this period, the Milestone MS6.3 has been achieved, corresponding to the delivery of all the results of the project on their due time.

Although already reported in the previous Periodic Report document, during the second period of the project there has been one single amendment which started the 1st of September 2018. We repeat the information of this amendment in the following for completeness:

Amendment 2 (September 2018):

1. **Partial takeover of SICs by RISE**

   The RISE institutes Innventia, SP, and Swedish ICT (SICs) have merged to become a stronger research and innovation partner. Through their international collaboration programmes with academia, industry, and the public sector, they ensure the competitiveness of the Swedish business community on an international level and contribute to a sustainable society. So, RISE Research Institutes of Sweden is fully owned by the Swedish state.

2. **Change the lead beneficiary in MS2.2, SICs to RISE**

   We change the lead beneficiary, from SICs to RISE of the Milestone: MS2.2-Software implementation of 5G-CORAL EFS functions, services, and applications ready for initial integration in WP4. The due date is in M16.

3. **Update SICs to RISE WP & Task PM allocation**

	SICS	RISE
WP1 - 5G-CORAL system design and business perspectives	**5**	**5**
T1.1 Use cases, requirements, and business perspectives	2	2
T1.2 5G-CORAL system design	3	3
WP2 - 5G-CORAL edge and fog computing system	**16**	**13**
T2.1 Design and evaluation of EFS functions	5	7
T2.2 Design and evaluation of EFS services	5	5
T2.3 Design and evaluation of EFS applications	6	1
WP3 - 5G-CORAL orchestration and control system	**0**	**0**
T3.1 Federation and Integration of 5G-CORAL resources	0	0
T3.2 Control and Management of 5G-CORAL functions and applications	0	0
T3.3 Orchestration of 5G-CORAL resources	0	0
WP4 - 5G-CORAL proof of concept	**9**	**12**
T4.1 Testbed definition and setup	1	1
T4.2 Integration and experimentation	3	5
T4.3 Demonstration and trials	5	6
WP5 - Communication, Dissemination, Standardization, and Exploitation	**3**	**3**
T5.1 Communication and Public Relations	1	1
T5.2 Dissemination, Standardization, and Exploitation activities	2	2
WP6 - Project Management	**0**	**0**
T6.1 Project administrative, financial, and legal management	0	0
T6.2 Technical coordination, Innovation and Quality management	0	0
Total	**33**	**33**

4. Update PM of SICs & RISE effort distribution

	SICs (01/09/2017 - 31/08/2018)	RISE (01/09/2018 - 31/08/2019)
WP1	**3.5**	**1.5**
WP2	**6.63**	**6.37**
WP3	**0**	**0**
WP4	**4.52**	**7.48**
WP5	**2.01**	**0.99**
WP6	**0**	**0**
TOTAL	**16.66**	**16.34**

5. Include IDG as linked Third Party to IDCC

IDCC had a transfer of personnel (namely Giovanni Rigazzi) from the London office to Berlin office premises. Giovanni Rigazzi has been working on 5G-Coral and will continue to work on 5G-Coral out of his new position at InterDigital Germany (Berlin). The short name of the IDCC linked Third Party is IDG and has the following PIC number 909294200.

InterDigital Germany GmbH (Berlin) was established by InterDigital in 2017 as an addition to InterDigital Europe Ltd (London) to expand InterDigital business in Europe and Germany in particular. IDG focuses on R&D collaborations with national German and regional European partners on areas such as 5G and beyond, next generation video, and IoT.

The new allocation of PMs per Task considering the Third-party inclusion is the following:

Personnel (Person-Months): Total = 52 PMs.
- InterDigital Europe Ltd: 40 PMs
- InterDigital Germany GmBH: 12 PMs

Travel: Total = 35400 Euros
- InterDigital Europe Ltd: 25400 Euros
- InterDigital Germany GmBH: 10000 Euros

Other Goods and Services: Total = 3000 Euros.
- InterDigital Europe Ltd: 3000 Euros
- InterDigital Germany GmBH: 0

Total Direct Costs: 338,000.00 Euros
- InterDigital Europe Ltd: 288,400.00 Euros
- InterDigital Germany GmBH: 88,000.00 Euros

Total Indirect Costs: 94,100.00 Euros
- InterDigital Europe Ltd: 72,100.00 Euros
- InterDigital Germany GmbH: 22,000.00 Euros

6. TELCARIA new PM cost

TELCARIA has a minor PM cost: 3.548 €/PM. So, they increase PM from 40 to 62 and the new PMs distribution will remain as follows:

	TELCARIA	**TELCARIA**
WP1 - 5G-CORAL system design and business perspectives	***7***	***7***
T1.1 Use cases, requirements, and business perspectives	3	3

T1.2 5G-CORAL system design	4	4
WP2 - 5G-CORAL edge and fog computing system	**12**	**18**
T2.1 Design and evaluation of EFS functions	2	6
T2.2 Design and evaluation of EFS services	4	6
T2.3 Design and evaluation of EFS applications	6	6
WP3 - 5G-CORAL orchestration and control system	**13**	**19**
T3.1 Federation and Integration of 5G-CORAL resources	8	8
T3.2 Control and Management of 5G-CORAL functions and applications	2	5
T3.3 Orchestration of 5G-CORAL resources	3	6
WP4 - 5G-CORAL proof of concept	**4**	**14**
T4.1 Testbed definition and setup	0	0
T4.2 Integration and experimentation	2	8
T4.3 Demonstration and trials	2	6
WP5 - Communication, Dissemination, Standardization, and Exploitation	**4**	**4**
T5.1 Communication and Public Relations	1	1
T5.2 Dissemination, Standardization, and Exploitation activities	3	3
WP6 - Project Management	**0**	**0**
T6.1 Project administrative, financial, and legal management	0	0
T6.2 Technical coordination, Innovation and Quality management	0	0
Total	**40**	**62**

Furthermore, during the second period there has been a change in the PM cost of AZCOM, requiring an increase of PMs dedicated to the project from 21 to 32, with the following new allocation of resources:

WPs	Former allocation of PMs	New allocation of PMs
WP1	1	2
WP2	3	8
WP4	15	20
WP5	2	2
Total	*21*	*32*

After discussing with the Project Officer, it was decided to consider these new numbers for the book keeping of resources without opening a new amendment for it.

1.2.6.1 T6.1 Project, administrative, financial and legal management

In this period (M13-M24) the project held 5 meetings, 2 virtual and 3 physicals:

- 1st Virtual meeting on 3 of October 2018: This meeting was organized with the main objective of the preparation of the exhibition and workshop held in Nyangang Shopping Mall and the preparation of the review to be held on December 2018.
- 2nd Virtual meeting on the 25th of January 2019: This meeting was organized with the main objective of analyzing the feedback from the reviewers and prepare the actions to be held during the second period of the project.

- 5th Plenary meeting on 31st of October to 1st of November 2018 in Hsinchu, Taiwan, hosted by NCTU: During this project meeting the project focused on technical discussion of the open points in the development of the platform, considering the lessons learnt from the shopping mall deployment.
- 6th Plenary meeting on 21-22 of February 2019 in Berlin, Germany, hosted by ITRI: This meeting focused on the discussion of the evaluation needed for the D2.3, D3.3 and D4.3. Basically, the definition of the KPIs to be measured and the methodology to do it.
- 7th Plenary meeting on 13-14 of June 2019 in Madrid, Spain, hosted by UC3M: Final project meeting, we discussed mainly the development and measurement of each PoC, for their inclusion on D4.3 and their showcase in the final review. In addition, we did a session on conclusions of the technical design WPs and open points to be tackled in the future.

In addition to the above meetings, weekly technical remote meetings (per WP) were held to allow synchronization between the different partners using a collaborative tool for audioconferences (GoToMeeting). During the conference calls several topics are discussed related to activities which illustrated the WPs update in the period. In a shared calendar, the remote meetings were planned to inform all the partners of the date and hour.

A report of the project progress in terms of technical activities and resources allocation is planned each three months by means the Quarterly Management Reports.

Regarding the communication tools, we used mainly two mechanisms, the 5G-Coral website and the different social networks:

- The 5G-Coral website is available from the beginning of the project (http://5g-coral.eu/). The Twitter account @5G_CORAL has a total count of 597 followers (at June 2019) and had published more than 1046 tweets.
- The Project has also a LinkedIn account https://www.linkedin.com/in/5g-coral/ with more than 200 visualizations of the profile in the last 90 days (June 2019).
- Our YouTube Channel[1] has published 13 videos in total (not including the videos to be recorded in the last review event) showing the different demos done during the 5G reference conferences as EuCNC, MWC, etc. These videos have a total of 1200 visualizations as shown in Figure 1-7
- Finally, we have continuing updating the web page with the translation of key sections of the web site to Chinese to reach a broader audience.

[1] available at https://www.youtube.com/channel/UCMSZg98gLicD_BPzTCAaS8Q

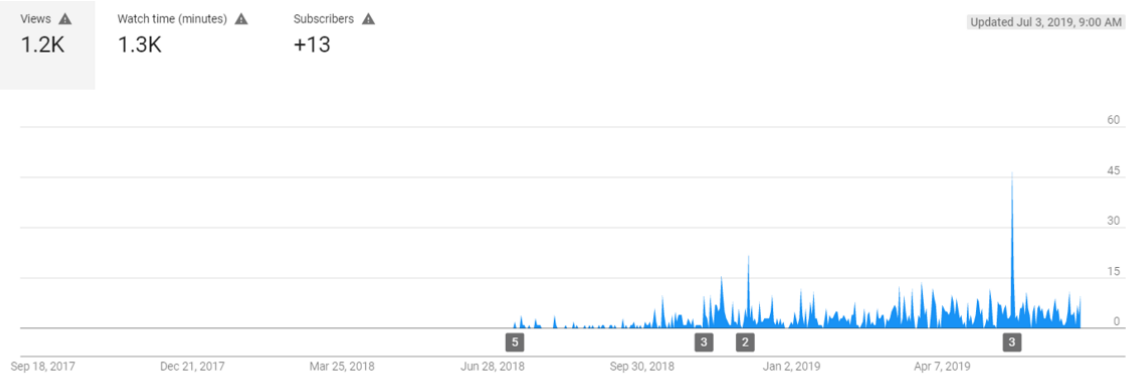

FIGURE 1-7: YOUTUBE CHANNEL VISUALISATION TIMELINE

1.2.6.2 T6.2 Technical coordination, Innovation and Quality management

This task is led by ITRI as Taiwanese Technical Manager and UC3M and EAB participate as Project Coordinator and Innovation Manager. ITRI as the Taiwanese Technical Manager, leads the technical innovations, together with IDCC (European Technical Manager), for the project and coordinating the work of all WPs. UC3M as Project Coordinator ensures the project progresses towards its objectives. EAB as the Innovation Manager has monitored the innovation and exploitation activities.

As part of this task, EAB as innovation leader will produce the different answers to the innovation questionnaire provided by the EC.

1.3 Explanation of the work carried per WP and per-partner

WP1: 5G-CORAL system design and business perspectives		
T1.1 Use cases, requirements, and business perspectives	This task finished on M12, therefore no activity was done in the second period.	
T1.2 5G-CORAL system design	UC3M	Work towards the architecture refinement for federation, contribution to D1.2 (Federation and cloud robotics business considerations and software vendors business perspective analysis) Refinement of 5G-CORAL architecture considering WP2 and WP3 feedback. Contribution to deliverable D1.3 (business requirements of software vendors justifying federation, state of the art performance metrics for fog-assisted robotics use case, OCS management of heterogeneous virtualization platforms and future directions of fog-assisted robotics use case)
	TI	Editorship, reviewer and contributor of D1.3. In particular, TI provided business requirements of the telecom operator, deployment considerations of the 5G-CORAL technical solution into existing networks from the telecom operator's perspective, applicability of the 5G-CORAL solution in the context of private networks and future directions of the Safety use case.
	TELCA	TELCA contributed to analyzing the SoA for OTT Providers with a 5G-CORAL business perspective contributed to Deliverable D1.2 and further studying the business requirements that OTT providers might demand from 5G-CORAL platform, which was contributed to D1.3. Additionally, TELCA did a deep dive analysis of the deployment options for the SD-WAN use case scenario and an analysis of the state of the art for performance metrics (KPI) identification and future directions for the use case.
	EAB	Together with RISE SICS, EAB contributed to the joint work between WP1 and WP2 regarding the definitions of EFS data model and EFS APIs on the refined 5G-CORAL architecture. EAB also contributed in D1.3 regarding 5G-CORAL business requirements and the refined system design, performance KPIs and future directions of the Multi-RAT IoT use case.
	SICS	RISE SICS contributed to the alignment of the work in WP2 on the EFS API and data models with the WP1 work on the refinement of the overall 5G-CORAL architecture and system design, as well as, the alignment with the OCS development in WP3. RISE SICS also contributed to defining performance metrics and making a deployment analysis for the Multi-RAT IoT use-case. Both activities were carried out in close collaboration with Ericsson. RISE SICS furthermore reviewed Deliverable 1.3.
	IDCC	IDCC contributed to D1.3 and reviewed the document. Also, IDCC analyzed business requirements of cloud providers and provided reference values for the KPIs related to the VR PoC. Finally, IDCC carried out a preliminary state-of-the-art review on on-device Artificial Intelligence (AI) and Machine Learning (ML), which will be considered as future work.
	ITRI	ITRI has ccontributed and reviewed to Deliverable D1.3. These contributions include HST use case and AR use case KPIs for:

		State-of-the-Art values for the performance metrics, OCS management of heterogeneous virtualization platforms in AR use case, Deployment of the 5G-CORAL HST use case and AR use case future directions. Active participation in the Architectural design of the 5G-CORAL System.
	ADLINK	ADLINK contributed in the analysis between possible different implementation of the system, providing input in the differentiation between a distributed implementation and a centralized one, with emphasis in the different management overhead.
	NCTU	NCTU contributed input for analyzing business requirements for vertical companies in D1.3.

WP2: 5G-CORAL Edge and Fog computing system (EFS)		
T2.1 Design and Validation of EFS Functions.	EAB	Further developed NB-IoT stack for stability improvement and FH rate reduction. Developed LoRa stack with multi-channel capability and improved preamble detection. Together with RISE SICS, further developed 802.15.4 stack with enhanced stability, improved performance by RF parameter tuning and improved echo filtering based on preamble detection, and reduced delay by improved RH-Edge transport. Multi-channel capability was also developed.
	IDCC	As WP2 leader, coordinated the software implementation of 5G-CORAL EFS functions towards EFS version 2, particularly addressing Multi-RAT convergence aspects. As WP2 leader, coordinated the study activity addressing the mechanisms by which EFS Functions discover and register to EFS Service(s). In both the Robotic and VR use cases, continued the integration of the OAI LTE network functions (core and radio) into the EFS. As TM, revised and reviewed the D2.2 for quality assurance.
	TELCA	Telcaria initially contributed to the design and validation of EFS functions in two use cases: infotainment and safety use cases. Reformulating the vehicular use case to match to the official 5G-CORAL definitions for Function, Service and Application. Additionally, TELCA has led the SoA of messaging systems, protocols and service platforms, which was contributed to deliverable D2.1. Furthermore, TELCA performed an analysis for available VIMs (fog05, Kubernetes) which will be suitable to deploy EFS applications, functions and services and further designed and developed the SD-WAN and WiFi AP functions for docker and LXC virtualisation technologies, capable of being deployed by Kubernetes or fog05.
	SICS	Together with EAB carried out further development of the 802.15.4 communication stack. The reliability was improved by

		developing methods for improved echo filtering, RF parameter tuning and MAC parameter tuning. The RH-Edge interface latency was reduced with preamble detection and UDP transport replacing Zero-MQ based TCP transport. Multi-Channel capability was also developed with the ability to communicate with terminal devices on three channels.
	AZCOM	Azcom has integrated the secondary RAT in the demonstration setup. To do so, a Road Side Unit (RSU) has been introduced in the design, where a virtualized WiFi 802.11 a/c access point has been deployed. On the OBU, Azcom integrated the WiFi modem's driver and interfaces into the embedded Linux OS. Azcom has also contributed to the D2.2.
	ITRI	ITRI has contributed to D2.2. This cover the Refined EFS design for 5G-CORAL HST and AR use-cases. Also, it includes evaluation of distributed computing AR (DAR) performance on TX2 and Pi3. Besides, the evaluation of DAR performance on LXD and native application. ITRI provide the vMME function performance and how it reduces the signaling storm. Also, ITRI contributed into Integration efforts of: Localization Module and Image Recognition Module at EFS side. Integration of Localization module into AR Navigation APP at user side. S10 message implementation. Inter-MME handover implementation, Handover triggering function, User classifier implementation, S10+: Handover of group of users function implementation, UE emulator to support high-speed train use case.
	ADLINK	ADLINK has collaborated with partners providing support in the design of the EFS functions, in particular in the design of the descriptors.
	NCTU	NCTU has completed one iBeacon localization module for the AR navigation app. It can achieve up to 1m accuracy by fusing iBeacon signals and IMU data and one iBeacon localization module for robotics, which supports the MQTT protocol
T2.2 Design and Validation of EFS Services.	IDCC	As WP2 leader, coordinated the software implementation of 5G-CORAL EFS services towards EFS version 2, particularly addressing Multi-RAT convergence aspects. As WP2 leader, coordinated the study activity addressing the mechanisms by which EFS Services are discovered by EFS Function(s) and Application(s). As WP2 leader, coordinated the study of the refinement of EFS of publish/subscribe messaging, to include a comparison of: Zenoh, DDS, NATs, MQTT and Kafka REST. Progressed the implementation and integration of the LTE RNIS.
	TELCA	TELCA lead the Design, integration and validation of Prometheus/Graphana/node_exporter as an EFS monitoring platform, including the analysis of all possible monitoring metrics, finally preselecting a set of them based on the EFS and OCS

		requirements. Furthermore, TELCA designed, developed and validated the host mobility service, capable of detecting the migration of UEs from different APs in real-time and across domains.
	SICS	RISE SICS developed an EFS service where IQ samples from the radio receiver is published over the EFS MQTT broker. The purpose is to enable the implementation of various EFS functions or applications that analyse the samples, for example, to find a channel with low interference. Furthermore, RISE SICS worked on the EFS services workflow and the EFS API with message data models, including their design and specification relating to the MEC standards for Deliverable 2.2.
	AZCOM	Azcom has deployed a MQTT broker on the RSU in addition to the one in the edge (close to the LTE eNB) in the TI's Lab. The two brokers have been setup in a bridge configuration to increase redundancy and consequently the reliability of the system. Azcom has also contributed to the D2.2.
	ITRI	ITRI has contributed to the updated design and functional validation work of Navigation services in AR use case. Also, ITRI has contributed to train proximity service in high-speed train use case.
	ADLINK	ADLINK has collaborated with partners providing support in the design of the EFS services, in particular in the design of the descriptors.
T2.3 Design and Validation of EFS Applications.	IDCC	As WP2 leader, coordinated the software implementation of 5G-CORAL EFS applications towards EFS version 2, particularly addressing Multi-RAT convergence aspects. As WP2 leader, coordinated the study activity addressing the mechanisms by which EFS Applications discover and register to EFS Service(s).
	TELCA	SD-WAN use case involves a PoS service, where initially the open-source WallacePoS was integrated to the SD-WAN use case. Finally, TELCA redesigned PoS service by separating the Customer and Inventory database from the business logic application (PoS WebApp). The previous application used (WallacePoS) was very sensible to latency between the Customer and Inventory database and the business logic application. So, a preliminary PoS WebApp was developed and validated with the necessary functionalities required for the use case.
	EAB	Jointly with RISE SICS, an Interference Analysis application was developed utilizing the received IQ samples via the subscribed IQ/data service. It showed the feasibility to capture the interferences in the air.
	SICS	RISE SICS designed and implemented a simple EFS application that showed the feasibility of capturing channel noise and interference from captured IQ data samples. The radio receiver publishes IQ samples to the IQ/data service which the application subscribes to over the EFS service platform.
	AZCOM	Azcom has continuously updated the application used in the connected car testbed after every trial done both in the TI's Lab and on the field trial in Turin. Azcom has also contributed to the D2.2. Studies on different encoding protocols, other than JSON, have been done.

	ITRI	ITRI has contributed to the design Restful API between AR Application and Image Recognition Module.
	ADLINK	ADLINK has collaborated with partners providing support in the design of the EFS applications, in particular in the design of the descriptors.

WP3: 5G-CORAL orchestration and control system		
T3.1 Federation and integration of EFS resources	UC3M	Leading WP3, organizing and chairing WP3 weekly calls. Initiated and steered the discussion on monitoring procedures from OCS perspective. Leading the federation discussion and proposal. Proposed resource federation procedures which have been contributed to D3.2. Finalization of resource federation procedures which have been contributed to D3.2. Final design and implementation of the EFS Resource Orchestrator. Validation of EFS Resource Orchestrator for automated.
	IDCC	IDCC tested potential federation and integration techniques through its VR PoC. Specifically, IDCC aimed to federate different server machines with the goal to share a single streaming engine license, which is essential to the VR demo execution.
	TELCA	As task leader TELCA acted as liaison with T2.1 were TELCA analyzed the possible integration of EFS resources into the OCS, contributing to the edge and cloud characterization technical aspects concerning the OCS and the Resource discovery analysis were SoA analysis of discovery protocols, which are capable of providing dynamic discovery of resources. Additionally, TELCA analyzed the possible metrics to be measured and under which conditions should they be monitored, for the IoT Gateway and the SD-WAN use cases. Furthermore, TELCA analyzed how the SD-WAN use case could be suitable to demonstrate the federation between EFS domains. Designing, developing and demonstrating the federation protocol to be used by F2 interface and its communication with the rest of 5G-CORAL architecture components.
	ITRI	Contribution to D3.1 on the dynamic resource discovery, dynamic resource discovery via zigbee and bluetooth, protocol survey on service location protocol. RESTful API specification support for Localization Function. Provided input regarding resource discover of High-speed train and AR use cases in D3.1. Reviewed D3.1
	ADLINK	ADLINK in close collaboration with UC3M provided inputs and initial implantation for the EFS Resource Orchestrator
	NCTU	Completed the work on profit maximization in a federated environment, including methology, modeling, analysis, and numerical results and advanced resource provisioning in federated EFSs, including methology, modeling, analysis, and numerical results.
T3.2 Control and management of EFS functions	UC3M	Initiated and steered the discussion on orchestrators alternatives and related support from edge and fog perspective. Survey on Cloudify orchestrator and his support from edge and fog perspective

and applications		Refinement of the EFS Stack information model. Initial design and implementation of the EFS Resource Orchestrator. Initial validation of EFS Resource Orchestrator. Initial design and implementation of the EFS Manager. Initial validation of EFS Manager. Contribution to Deliverable D3.2. (Federation section, Editor of the deliverable, OCS validation of Network assisted D2D) Refinement of the EFS Stack information model. Final design and implementation of the EFS Manager for fog-assisted robotics. Final validation of EFS Manager. The results have been contributed to Deliverable D3.2.
	IDCC	IDCC contributed to editing D3.2. In particular, IDCC supervised a state-of-the-art review of most popular orchestrators and identified missing features that have been addressed in the 5G-CORAL OCS. Furthermore, IDCC supported the OCS experimental validation and pinpointed the main lessons learnt throughout the project.
	TELCA	TELCA has further extended the SD-WAN Controller and SD-WAN manager by adding new functionalities such as roaming, offloading and secure end to end communications support leveraging IPsec. Additionally, TELCA has contributed to fog05 (official repository) in two topics: i) the integration of Open Virtual Switch as a network driver and ii) the automatic creation of Linux bridges in case theses were missing.
	ITRI	ITRI has contributed to Deliverable D3.2 regarding Orchestrator survey and analysis, monitoring procedure design and analysis for AR. In particular, survey on resource discovery protocol (SDP), survey on Orchestrator (ARIA TOSCA). Also, ITRI contributed in the design of monitoring procedure for AR Navigation use case and monitoring procedure for High-speed train use case.
	ADLINK	ADLINK provided an analysis of ETSI OSM as part of the state-of-the-art analysis on orchestrators. Implementation of the distributed VIM as an OpenSource project
	NCTU	Co-authoring with other 5G-CORAL partners a WCNC 2018 conference paper reporting the goal of 5G-CORAL and authoring two WCNC 2019 papers that report our work on 5G-CORAL.
T3.3 Orchestration of EFS resources	UC3M	Participation in the discussion regarding the modelling of resources. Design of a dynamic application and function placement algorithm and contribution to D3.2. Initial validation of the placement algorithm. Refinement of a dynamic application and function placement algorithm and contribution to D3.2. Final validation of the placement algorithm, including the open source release of graph generator for 5G infrastructure and edge/fog deployments for simulation purposes. Validation of network assisted D2D for fog-assisted robotics has been performed.
	TELCA	TELCA has built and validated a demonstration scenario where Kubernetes is the EFS orchestrator, which in order to comply with 5G-CORAL and the SD-WAN use case requirements, Kubernetes was deployed using the “multus-plugin” and with a modification in its K8 “bridge” plugin, providing plain L2 connectivity between entities. Additionally, TELCA lead the monitoring procedures subtask were each partner defined what novel and relevant

		functionalities must be included to the OCS (leveraging 5G-CORAL monitoring platform), TELCA gathered information from all partners and extracted common and specific features of all use cases. Furthermore, TELCA has designed and developed a preliminary Resources Orchestrator only implementing the necessary components required for the federation demonstration and its corresponding federation interface designed in T3.1.
	ITRI	ITRI developed a pre-copy migration scheme for relocating EFS function and applications. Provided support to lightweight virtualization technology including system and application level containerization. Introduced enhancements to the migration scheme through low-latency computing and fast storage. ITRI has utilized Jetson TX2 support for virtualization (Docker, LXC and LXD).
	ADLINK	ADLINK provided input for a distributed design on an OCS orchestrator and implementation of some enabling technologies.
	NCTU	Completed the survey of the Open Source Network Function Virtualization Orchestrator (OPNFV) in terms of the architecture, requirements and mapping with 5G-CORAL OCS.

WP4: 5G-CORAL Demonstration and Trials		
T4.1 Definition and setup of testbeds	This task finished on M12, therefore no activity was done in the second period.	
T4.2 Integration and experimentation	IDCC	IDCC integrated all the components necessary to support the VR PoC and carried out a preliminary measurement campaign to obtain insights on the system performance. Moreover, IDCC aimed to reduce the end-to-end latency by upgrading the server with a high-end storage unit. Finally, IDCC assessed the system performance under non-stationary conditions by placing the video source on top of a mobile robot and verified the successful delivery of the video content over a Wi-Fi IEEE 802.11ac channel.
	UC3M	Development of all the platform for the Fog Assisted Robotics use case, including EFS, OCS, Robotics application, migration of virtual AP and multi-RAT. Participation in D4.2 and in multiple demonstrations.
	ADLINK	Development of the distributed VIM, providing support to partners using the distributed VIM in their experimentation
	NCTU	Completed one iBeacon localization module for the AR navigation app. It can achieve up to 1m accuracy by fusing iBeacon signals and IMU data and one iBeacon localization module for robotics, which supports the MQTT protocol
	ITRI	Executed the Shopping Mall testbed setup for Taiwan trial allowing 4 live demo and 3 video demo showcasing.
	TELCA	TELCA initially integrated Kubernetes as possible OCS resource orchestrator for the SD-WAN federation demonstration during the first-year project review. However, in order to comply with the use case requirements, TELCA integrated the EFS resource orchestrator designed and developed in T3.3, the static federation protocol (T3.1) and merged the SD-WAN PoS service components (T2.3) into the PoC testbed. Furthermore, TELCA finally validated their correct operation as a whole in a joint

		testbed composed of two simulated 5G-CORAL domains, demonstrated in EUCNC 2019 5G-CORAL booth.
	EAB	Jointly with RISE SICS, the following are achieved. LoRa Radio Head and Edge software programs are developed and added into the integrated PoC testbed. IEEE 802.15.4, NB-IoT and LoRa software programs are "dockerized" and integrated in one setup, where they can run simultaneously. An MQTT broker is added to the testbed, acting as the EFS service platform. And the Interference Analyzer application is developed and added to the testbed. Final integration tests and Interference Analyzer tests are performed. The results show that the performance is not impacted by running multiple IoT RATs simultaneously at the Edge and thus proves the concept of Multi-RAT IoT use case.
	SICS	RISE SICS has achieved the following together with EAB: "Dockerized" and integrated the 802.15.4, LoRa and NB-IoT EFS functions in one setup where the functions can run simultaneously. An EFS service platform (MQTT broker) is added to the testbed. The Interference Analyzer EFS application is developed and added to the testbed, together with the IQ/data EFS service. Final integration tests along with tests for Interference Analyzer application are conducted. The results show the simultaneous execution of multiple IoT RATs at the Edge does not impact the performance proving the concept of the Multi-RAT IoT use case.
	AZCOM	Azcom has integrated the secondary RAT in the OBU and designed a virtual access point on a Road Side Unit. Latency measurements have been done in the TI's Lab. Moreover, a field trial with cars has been carried out with the support of TIM. Azcom has also integrated Kubernetes as a possible OCS resource orchestrator. Azcom has also contributed to D4.2.
	TI	The activity initially related to the performance analysis of the MQTT broker connection to the Azcom On-Board Unit (OBU) after the integration process within the TILab's LTE network. Then the focus was on the integration of a Road Side Unit (RSU) in the TILab's LTE Network. Furthermore, the performance of the system with two MQTT brokers (one connected to 4G network and a second one connected to the RSU) have been analyzed and validated.
T4.3 Demonstration and trials	UC3M	Demonstration of the "Fog-assisted Robotics" use case in the shopping mall in Taipei, Taiwan. Fog Assisted robotics demonstration at European Microwave Week (EuMW 2018) Fog Assisted robotics demonstration at Ericsson Innovations Days
	ADLINK	Providing technical support to partners during their trials. Contributed to "Fog-assisted Robotics" demonstration and "VR" demonstration.
	NCTU	Completed one MEC deployment prototype and published it in USENIX HotEdge 2018; Published one IEEE WCNC Workshop

		2018 paper, we coauthor with other 5G-Coral partners, to disseminate the 5G-Coral's integrated edge and fog system architecture; Published one IEEE BMSB 2018 paper, we coauthor with other 5G-Coral partners, to disseminate the 5G-Coral's edge and fog system with Multi-RAT converge
	TELCA	TELCA contributed with a video demo of the SD-WAN federation use case in the shopping mall event in Taiwan. Moreover, TELCA demonstrated the SD-WAN federation use case during the first-year review in Vienna and finally TELCA participated in EUCNC 2019 5G-CORAL booth to demonstrate a preliminary OCS and EFS system, where static federation, roaming, and offloading was demonstrated as a live demo.
	ITRI	ITRI has developed and integrated distributed computing to AR Navigation system. Integrates the SD node of DAR system into one of the fog nodes. The AR APP is modified to test and show the user plane latency of the DAR system. Fog05 is installed on TX2 successfully. Also, ITRI has deployed LXD containers using Fog05 and Implemented container migration for the HSR use-case in ITRI testbed. In Taiwan Trail 2018, ITRI has deployed of ibeacons in Nan-Gong Global Mall for AR Demo. ITRI lead the preparation of November 2018 Taiwan. AR Navigation Live Demo in Taiwan Trail, Video Demo for High-speed train use case in Taiwan Trail.
	EAB	Jointly with RISE SICS, the PoC under continuous development was successfully demonstrated in the shopping mall trial in Taiwan in November 2018 and in ICT 2018 in Vienna in December 2018, as well as in the midterm project audit. The integrated PoC will be shown and tested in the end of October 2019 in Taiwan in the final 5G-CORAL trial.
	SICS	RISE SICS together with Ericsson successfully demonstrated the Multi-RAT PoC as part of the Taiwan shopping mall trial, and then in Vienna at ICT2018 and the project review. The Multi-RAT PoC is currently being enhanced incorporating the work on LoRA and the multi-channel 802.15.4 SDR implementation in preparation for the demonstration at the final project review.
	AZCOM	Azcom has participated to the EUCNC 2019 in 5G-CORAL booth showing the connected car PoC as a live demo. This was accompanied by a video and a poster showing the complete description of the architectural solution, the results achieved in these two years and a field trial using real cars. Azcom will provide a summarizing video for the final review in Taiwan. Azcom has also contributed to D4.2.
	TI	For this task, TI was involved in the integration of both MQTT broker and RSU within the commercial network for a field trial.

WP5: 5G-CORAL Communication, Dissemination, Standardization and Exploitation		
T5.1 Communication and dissemination	UC3M	The article “Enhancing Edge robotics through the use of context information” has been accepted and presented at the CONEXT workshop session. The article “Modelling MEC scenarios with inhomogeneous hard-core point processes” has been submitted and accepted to the Transaction on Broadcasting. Organisation of the 5G-EM Workshop, EuCNC EU Taiwan workshop with Clear5G and EuCNC booth.

	Fog Assisted robotics demonstration at European Microwave Week (EuMW 2018) Fog Assisted robotics demonstration at Ericsson Innovations Days
EAB	Demonstration of the Multi-RAT PoC together with RISE SICS at ICT2018 in Vienna, December 5th, 2018 Conference paper published: Saptarshi Hazra, Simon Duquennoy, Thiemo Voigt, Peng Wang, Chenguang Lu, Daniel Cederholm. Handling Inherent Delays in Virtual IoT Gateways. In The 15th International Conference on Distributed Computing in Sensor Systems (DCOSS), Santorini Island, Greece, May 29 - 31, 2019.
IDCC	Demonstrated the VR use case and prepared a 5G-CORAL leaflet and a video highlighting 5G-CORAL use cases, all of which were successfully presented at the Mobile World Congress ‘19 Published an extended abstract titled, “A Distributed Fog/Edge Computing Solution for Enhanced 360-degree Video Streaming Services”, accepted at WWRF ‘19 Published an extended abstract titled, “Architecture for Wireless Intelligence and Data Service Provisioning”, submitted to WWRF ‘19 Demonstrated a joint showcase with 5G-TRANSFORMER and, prepared a video and poster for the EUCNC ‘19 exhibition in Valencia, in June ’19, titled “360^0 Immersive Telepresence: Remote Robotic Control” Issued a press release on the same joint showcase at EUCNC ‘19: INTERDIGITAL PARTICIPATES IN 5G SLICING AND ULTRA-HIGH THROUGHPUT DEMONSTRATIONS Progressed plans for joint demonstration with Abo Akademi University (To take place in August ‘19) - Exhibition Progressed plans for joint demonstration together with BT and 5TONIC (to take place towards the end of 2019) - Exhibition Presented Technical Manager project progress status at the plenary meeting in Madrid June ‘19 – Presentations "5GEN: A tool to generate 5G infrastructure graphs", submitted to IEEE CSCN, track on Access Network, Edge Computing and Transport for 5G - June ‘19 – Publications. Published a paper and presented it after been accepted at “An Edge and Fog Computing Platform for Effective Deployment of 360 Video Applications”, at the IEEE WCNC’19, CLEEN workshop – Marrakech, Morocco Presented a “UAV standardization survey” for TTA SPG35
SICS	Master thesis: Saptarshi Hazra, “Timing delay characterization of GNU Radio based 802.15.4 network using LimeSDR”, KTH Royal Institute of Technology, Stockholm, Sweden. Three SICS internal seminar presentations on 5GCORAL project work: “Virtualized RAN for IoT Networks” (15th January 2019), “5G Coral- Overview and next steps” (22nd January 2019), and “SDRs for Virtualized IoT Gateways” (17th May 2019).

		Presentation at company ASSA ABLOY: “Introduction to GNU Radio and SDR”, 20th March 2019. Paper accepted and presented: Saptarshi Hazra, Simon Duquennoy, Thiemo Voigt, Peng Wang, Chenguang Lu, Daniel Cederholm. Handling Inherent Delays in Virtual IoT Gateways. In The 15th International Conference on Distributed Computing in Sensor Systems (DCOSS), Santorini Island, Greece, May 29 - 31, 2019.
	AZCOM	Azcom has disseminated 5G-CORAL results in multiple events during the project lifetime, including EUCNC 2018, MWC 2018 and EUCNC 2019 with a booth. Azcom has also contributed to some paper inside 5G CORAL project and disseminated 5G CORAL events in social media (Linkedin). Azcom has also contributed to D5.2
	ITRI	ITRI has submitted a journal paper to IEEE Transactions on Network Science and Engineering. Also, submitted a conference paper to IEEE PIMRC (Accepted). ITRI Presented “ARNAB: Transparent Service Continuity across Orchestrated Edge Networks” paper in GLOBECOM’18. Also, ITRI presented “5G-CORAL platform and proofs-of-concept” on TelecomsRadar. Published Journal paper in ITRI ICL Lab regarding 5G-CORAL, definition, goals, challenges and testbeds. Contributed to the join paper “An Integrated Virtualized convergence” for the BMSB 2018 conference. Contributed to the three WCNC workshop papers. Presented a talk in the OpenFog consortium on “Edge and Fog Integration for the future 5G-Communication”
	ADLINK	ADLINK disseminate the results of the project in the Eclipse IoT opensource community
	NCTU	WP5 leadership Administrative outputs related to the project Editor of Deliverables Draft posters and leaflets for communication and dissemination activities Maintenance of SVN repository for communication and dissemination documents Published various publications related to the project
	TELCA	TELCA has disseminated 5G-CORAL results in multiple events during the project lifetime, including REDIMadrid conference 2018, t3chfest 2019 and EUCNC 2019 with a booth and the participation to Emerging 5G Business Models workshop. Additionally, TELCA disseminated most of 5G-CORAL events and video demonstrations in social media (Twitter).
T5.2 Standardization, Open Source and exploitation	UC3M	Attendance to ETSI MEC weekly calls. Serving as rapporteur for the ETSI MEC024 Work Item on network slicing. - Contribution to IETF: "Network Virtualization Research Challenges" (draft-irtf-nfvrg-gaps-network-virtualization-10) passed conflict review. Expected to be published as RFC early in 2019.

		- Contribution to IETF: "Proxy Mobile IPv6 extensions for Distributed Mobility Management". New version (draft-ietf-dmm-pmipv6-dlif-03) submitted in October and presented in IETF 103 (Bangkok). - Contribution to IETF: "Overview of Edge Data Discovery" (draft-mcbride-edge-data-discovery-overview-00) submitted in October and presented in IETF 103 (Bangkok). - Contribution to IETF: "Link-Layer Addresses Assignment Mechanism for DHCPv6" (draft-bvtm-dhc-mac-assign-02) submitted in October. Currently in IETF WG adoption call. Contribution of f0rce (i.e., fog orchestration engine) to Eclipse Fog05 project based on the work done in WP3 on the OCS. Open source publication of 5GEN, a tool for generating 5G network infrastructure graphs
	EAB	Some internal exploitation activities interacting with relevant Ericsson product units for technology and concept transfer. Contributions to D5.2 regarding to exploitation activities and plans.
	ITRI	Provided the final exploitation plan for AR-PoC into D5.1. Reviewed Chapter 2 and 3 of D5.1. Contributed the information regarding IEEE SA in call for IEEE P1934. Also provided the upcoming two workshops about OpenFog. Open source for inter MME handover-NextEPC
	SICS	The previously submitted Internet-drafts have received several updates during the year: draft-chang-6tisch-msf-02, "6TiSCH Minimal Scheduling Function (MSF)", was adopted by the IETF 6TISCH WG and published as draft-ietf-6tisch-msf-00 on August 21, 2018. It has then been updated to -01 on October 22, 2018, and lately to -04 on July 2, 2019 and is on the path to becoming an IETF standard. draft-tiloca-6tisch-robust-scheduling, "Robust Scheduling against Selective Jamming in 6TiSCH Networks", was updated to version -01 on December 17, 2018 and to -02 on June 10, 2019. 6TiSCH is defining IPv6 over TSCH, a time-slotted channel hopping mode for IEEE 802.15.4 wireless networks proving the service needed for industrial automation and process control. Most of the 5GCORAL use-cases fall into these classes of IoT applications, and thus 6TiSCH is an important technology for the project to consider. For these classes of IoT applications, we anticipate that 6TiSCH is run in the EFS as an EFS function.
	ADLINK	ADLINK is leading the Eclipse fog05 opensource project, major contribution to this project comes from the work done in 5G-CORAL
	NCTU	WP5 leadership Administrative outputs related to the project Editor of Deliverables

		Maintenance of SVN repository for standardization documents and exploitation videos
	TELCA	TELCA, has participated in the exploitation of 5G-CORAL results adding SD-WAN service, as a beneficiary of the 5GCORAL platform, where features such as, federation, offloading and roaming across multi-domains have been integrated into Telcaria product release roadmap. Additionally, TELCA contributed to the open source community by contributing to the Eclipse foundation project Fog05, with the work done in T3.2.

WP6: Project Management		
T6.1 Project administrative, financial and legal management	UC3M	Task leadership Administrative coordination among partners Editor of the Periodic report Editor of Deliverables, QMR and presentation templates Relationship with the European Commission Edition of QMR04 report Management of budget Management of collaborative tool for audioconferences (Gotomeeting) Maintenance of SVN repository for working documents Maintenance of mailing lists Maintenance of web hosting Maintenance of Twitter project account Maintenance of Linkedin project account Maintenance of Instagram project account Publication of 5G-CORAL news in the website, linkedin, Instagram, YouTube and twitter
	ITRI	Administrative coordination among partners for Taiwan Trail 2018 Plenary Meeting Organisation (Kick off meeting, Taiwan) Plenary Meeting Organisation (November 2018, Taiwan) Plenary Meeting Organisation (February 2019, Berlin) Audit Meeting Organisation (October 2019, Taiwan) Attendance to plenary meeting in Madrid (December 2017), plenary meeting in Sweden (March 2018) and the plenary meeting in Turin (June 2018), Audit Meeting in Vienna (December 2018) and plenary meeting in Madrid (June 2019).
T6.2 Technical coordination, innovation and Quality management	UC3M	WP7 leadership, leader of Project Board
	EAB	Innovation manager
	IDCC	European Technical Manager
	ITRI	Reviewed deliverables submitted end of August 2018 and end of May 2019. Editorial of D2.2 and D4.1. Prepared the status for Taiwanese partners in several Face to Face meetings. Management tasks related to WP4 leadership.

1.4 Deliverables

All Deliverables have been delivered in due time.

#	Name	Delivery date
D1.1	5G-CORAL initial system design, use cases, and requirements	28/02/2018
D1.2	5G-CORAL business perspectives	31/08/2018
D1.3	5G-CORAL refined system design and future directions	31/05/2019
D2.1	Initial design of 5G-CORAL edge and fog computing system	31/05/2018
D2.2	Refined design of 5G-CORAL edge and fog computing system and future directions	31/05/2019
D3.1	Initial design of 5G-CORAL orchestration and control system	31/05/2018
D3.2	Refined design of 5G-CORAL orchestration and control system and future directions	31/05/2019
D4.1	5G-CORAL testbed definition, integration and demonstration plans	31/08/2018
D4.2	5G-CORAL proof of concept and future directions	31/08/2019
D5.1	Communication, dissemination, standardization and exploitation achievements of Y1 and plans for Y2	31/08/2018
D5.2	Communication, dissemination, standardization and exploitation achievements in Y2 and cumulated with Y1, along with plan beyond the project duration	31/08/2019
D6.1	Project portal and communication channels	30/09/2017
D6.2	Final project report	31/08/2019

1.5 Milestones

All Milestones have been achieved in due time:

#	Milestone name	Delivery date
1	MS1 – Use cases, requirements, and initial system design	**01/03/2018**
2	MS1.1 – Identification of the initial 5G-CORAL use cases and requirements	**01/12/2017**
3	MS1.2 – Design of the initial 5G-CORAL system	**01/03/2018**
4	MS1.3 – Identification of the 5G-CORAL business perspectives	**01/09/2018**
5	MS1.4 – Refinement of the 5G-CORAL system according to technical and business development plans from the different stakeholders and identification of future directions	**01/06/2019**
6	MS2 – 5G-CORAL EFS and OCS initial design	**01/06/2018**
7	MS2.1 – Design of the initial edge and fog computing system	**01/06/2018**
8	MS2.2 – Software implementation of 5G-CORAL EFS functions, services, and applications ready for initial integration in WP4	**01/01/2019**
9	MS2.3 – Evaluation and validation of 5G-CORAL edge and fog computing system and identification of future directions	**01/06/2019**
10	MS3 – 5G-CORAL testbed definition, integration, demonstration and trials plans	**01/09/2018**
11	MS3.1 – Design options for initial orchestration and control system	**01/06/2018**
12	MS3.2 – Software implementation ready for the initial 5G-CORAL manager, orchestrator, and VIM integration in WP4	**01/01/2019**
13	MS3.3 – Evaluation and validation of 5G-CORAL orchestration and control system and identification of future directions	**01/06/2019**
14	MS4 – 5G-CORAL EFS and OCS first software implementation	**01/01/2019**
15	MS4.1 – Design of initial testbeds configuration and setup	**01/01/2018**
16	MS4.2 – Refinement of design and setup options for the testbeds	**01/09/2018**

17	MS4.3 – 5G-CORAL testbeds operational for demonstration and trials	**01/03/2019**
18	MS4.4 – 5G-CORAL integrated demonstration and trials and identification of future directions	**01/09/2019**
19	MS5 - 5G-CORAL testbed ready, starting of integration, demonstration, and trials	**01/03/2019**
20	MS5.1 – Definition of the initial communication, dissemination, standardization, and exploitation plans	**01/03/2018**
21	MS5.2 – Definition of communication, dissemination, standardization, and exploitation for Y2 based on the activities of Y1	**01/09/2018**
22	MS5.3 – Demonstration at Large event in Europe, 2019	**01/06/2019**
23	MS5.4 – Demonstration at Large event in Asia, 2019	**01/09/2019**
24	MS5.5 – Definition of communication, dissemination, standardization, and exploitation activities beyond the project lifetime based on the activities of Y2	**01/09/2019**
25	MS6 – 5G-CORAL system design, business perspectives, EFS and OCS final implementations	**01/06/2019**
26	MS6.1 – Project introduction and communication channels	**01/10/2017**
27	MS6.2 – Y1 project deliverables and milestones addressed (M12, Lead: UC3M).	**01/09/2018**
28	MS6.3 – Y2 project deliverables and milestones addressed	**01/09/2019**
29	**MS7 – 5G-CORAL demonstration, trials and identification of future directions**	**01/09/2019**

1.6 Follow-up of recommendations and comments from previous review

Following the review meeting, the project started to tackle each of the comments received from the reviewers. In the following we present the different actions undertaken to address each of them:

It is recommended to focus the project effort and prioritize the current list of use-cases / PoCs focusing on the most promising ones from a business as well as technical perspective rather than replicating some demonstrations already performed (e.g. the car demo in Turin) or implementing minor enhancements. For instance a performance trade-off analysis for the VR 360° use case could be of utmost interest (with or without EFS / OCS). Conversely, the connected car and high-speed train scenarios could be eventually deemphasized.

Following reviewers' recommendations, the project has focused on developing four out of the seven use cases showcased in the first review. The following list presents the evolution planned of each demonstration that will be showcased in the final review:

- Navigation through Augmented Reality: ITRI is developing a new version of this use case focusing on the development of intelligent algorithms for the distribution of the load between different Fog nodes. Current implementation employs a linear programming approach for the load balancing algorithm. Work towards the development of an AI approach is also under development.
- Multi-RAT IoT Gateway. During the reporting period the following improvements have been done to this specific demonstration: i) LoRa Radio Head and Edge software programs are developed and added into the integrated testbed. ii) Multi-channel capability has been implemented in IEEE 802.15.4 Radio Head and Edge software programs. iii) IEEE 802.15.4, NB-IoT and LoRa software programs are dockerized and integrated in one setup, where they can run simultaneously. iv)An MQTT broker is added to the testbed, acting as the EFS service platform. v) IQ/Data service are implemented and integrated in the IEEE 802.15.4 Radio Head software, which can publish wideband IQ samples to the MQTT broker following the MQTT protocol. And final vi) Interference Analyzer application is developed on the Edge. It subscribes the IQ/Data service from the MQTT broker using the MQTT protocol and perform noise and interference analysis.
- VR 360^0 Immersive Telepresence: Remote Robotic Control. This use case was evolved by merging the Robotics use case and the VR use case to realize a mobile 360-degree camera on top of the Turtlebot robot with a wireless 802.11ac connection. The improved use case show cases the following features.
    - Two simultaneous network slices with contrasting connectivity Profiles, namely: 1) E2E 360 video streaming slice across three tiers of computing nodes (Low, medium and high ends), i.e. eMBB and 2) E2E robotic control and actuation slice, i.e. URLLC.
    - Video streaming from Mobile 360^0 camera to remote worker location, at a fraction of the bandwidth.
    - Remote robotic control and actuation based on the received video stream.
    - OCS automated deployment of the eMBB and URLLC slices (Fog05).
- Fog Assisted Robotics: This use case has been evolved considering the use of multi-RAT, the use of federation for the use of resources in the central cloud (leveraging on the SD-WAN demonstration) and on the migration of the virtual functions through the Fog subsystem. Multi-RAT is being used on improve the coordination of the movement and the deployment of the robots in different scenarios with a broad range of coverage. The migration of functions, and specifically virtual APs has been largely improved, by developing a container with pre-configure IEEE 802.11r credentials, which allow for fast BSS transition of the robot in a follow me cell scenario.

Regarding the other use cases, AZCOM is continuing the evolution of its use case by integrating multi-RAT in the vehicle on-boarded MEC, TELCA has integrated its demonstration into the Fog Assisted Robotics use case and ITRI has finished the development of the train use case. These demonstrations will not be shown in Taiwan final review to better focus development resources in the four main use cases of the project.

The presence of private network operators shall be included in the business analysis.

This point has been added as a separated section (section 5.3) in D1.3. A summary is provided in the following:

The deployment flexibility of the 5G-CORAL solution allows the solution itself to be easily applied to several use cases (often having contradictory sets of requirements when compared to each other) encompassing also the so-called private networks. This is due to the overall distributed system composed by Edge and Fog nodes whose characteristics in terms of computing/storage/networking capabilities, heterogeneity, and ownership can be exploited for deploying a private network fulfilling the needs of a specific application (e.g. a business-critical production process within an enterprise). A private (wireless) network can be defined as a local network that uses dedicated radio equipment to service a premise with specific applications and services, working either in licensed, unlicensed or shared spectrum. By focusing on specific requirements, the private network can be tailored for more optimized performance (e.g. low latency). Private networks can be deployed in several flavors, basically depending on the enterprise's requirements in terms of latency, reliability and security. These requirements can be fulfilled when considering private networks based on the current Evolved Packet System (EPS) and, easier, with the upcoming 5G System (5GS). Examples of EPS-based initiatives exploiting LTE radio access are the MulteFire Alliance for dedicated LTE networks deployed in the unlicensed 5GHz band and the CBRS Alliance which developed a private, TDD-based LTE network deployed in the US Citizen Broadband Radio Service (CBRS) shared band. However, the use in 5GS of a cloud-native and virtualized core network (i.e. 5GC) characterized by a high degree of modularity of its functionalities will allow to exploit the concept of Network Slicing, i.e. the technological enabler for configuring end-to-end logical virtual network instances – each optimized to the specific functional requirements of a customer or application – more quickly and at lower costs than designing and deploying traditional dedicated networks. The 5G-CORAL solution peculiarities – i.e. the use of heterogeneous Edge and Fog resources, multi-RAT convergence, service-based architecture as well as broad, open and business-oriented ecosystem – will be fully exploited in the context of the 5GS as Edge and Fog will be supported since the beginning for achieving both high performance and quality of experience.

It is also recommended to align the contributions to standardizations with the timeline of the corresponding standards.

A revised standardization roadmap has been added to D5.2 where we are dealing with this issue. Updated standards roadmap includes mapping of status of the innovations of the project to the standards timeline and their status within their time plan.

A deep dive analysis in case the system operator uses the OCS to manage heterogeneous virtualization platforms (VM, container and native bare metal) shall be performed in WP1.

We have addressed this topic on D1.3, specifically in section 4.2. A per use case analysis of the possible OCS implementations is done in this section.

A short update of the exploitation plan is provided in D5.1. However, a more substantial update of the individual exploitation plan per beneficiary would be desirable.

D5.2 has been updated with a substantial plan for the exploitation of results per partner.

1.7 Bibliography

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