H2020 5G-Coral Project

Grant No. 761586

D4.1 – 5G-CORAL testbed definition, integration and demonstration plans

Abstract

This deliverable presents the initial plan to design the 5G-CORAL testbed sites by integrating the developed technological components and deriving the demonstration scenarios relevant to the different 5G-CORAL use cases. With this goal, it first describes the experimentation sites to be used for integration, verification and validation of the 5G-CORAL solution. Secondly, demonstrations/ Proofs-of-Concept are defined for each use case along with corresponding performance evaluation frameworks. Finally, the next steps for executing on the integration and demonstration plans are outlined.

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Disclaimer

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List of Acronyms

3GPP	3rd Generation Partnership Project
6LoWPAN	IPv6 over Low power Wireless Personal Area Networks
AP	Access Point
API	Application Programming Interface
APP	Application
AR	Augmented Reality
ARP	Address Resolution Protocol
ATM	Asynchronous Transfer Mode
AVRCP	Audio/Video Remote Control Profile
BLE	Bluetooth Low Energy
CD	Computing Devices
CPU	Central Processing Unit
D2D	Device to Device
DC	Data Centre
DDS	Data Distribution Service
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name System
EFS	Edge and Fog computing System
EPC	Evolved Packet Core
ePDG	Evolved Packet Data Gateway
ESS	Extended Service Set
ETSI	European Telecommunications Standards Institute
ET	End Terminal
GPS	Global Positioning System
GUI	Graphical User Interface
HTTP	HyperText Transfer Protocol
HTTPS	HyperText Transfer Protocol Secure
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
IoT	Internet of Things
KPI	Key Performance Indicator
KVM	Kernel-based Virtual Machine
L2CAP	Logical Link Control and Adaptation Protocol
LAN	Local Address Network
LTE	Long Term Evolution
LXD	Next generation system container manager
MAC	Media Access Control
MEC	Mobile Edge Computing
MQTT	Message Queuing Telemetry Transport
NAT	Network Address Translation
NFV	Network Function Virtualisation
NS	Network Service
NSD	Network Service Descriptor
OBU	On Board Unit
OCS	Orchestration and Control System
OI	Organisation Identifier
OS	Operating System
OSS	Operation Support System
P2P	Peer to Peer
PHY	PHYsical layer
QoS	Quality of Service
RAM	Random Access Memory
RAN	Radio Access Network
RAT	Radio Access Technologies
ROM	Read-Only Memory
ROS	Robot Operating System
RSU	Road Side Unit
UE	User Equipment
UUID	Universally Unique IDentifier
V2I	Vehicle to Infrastructure
V2N	Vehicle to Network
V2V	Vehicle to Vehicle

V2X	Vehicle to Anything
VM	Virtual Machine
VNF	Virtual Network Functions
VR	Virtual Reality
WP	Work Package

Executive Summary

An ultimate goal for 5G-CORAL is to integrate, validate and demonstrate the technological components developed in WP2 and WP3. This first deliverable of 5G-CORAL Work Package 4 focuses on the testbed definitions, integration and demonstration plans. It first defines the 5G-CORAL real-world sites and provides the initial plans for deploying and integrating components into those real-world sites. Later this deliverable describes Proofs-of-Concept (PoCs) for each case defined in WP1 and provides the ways to implement PoCs into defined 5G-CORAL sites.

The key achievements in this deliverable are highlighted below:

- Real-world integration and evaluation sites description, i.e., (Shopping Mall, High-Speed Train, and Connected Cars), including available technologies and services that the partners of the 5G-CORAL contribute to the project.
- Initial integration plan of the technologies and services into those sites.
- Identification of the PoCs derived from the 5G-CORAL use-cases defined in WP1.
- Initial planning of the PoCs per use case, their description, the technologies and relation with project objectives.
- A roadmap of each PoC throughout the timeline of the project.
- An evaluation framework to measure the performance metrics of each PoC.

1 Introduction

One of the key objectives of 5G-CORAL 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 [1] and WP3 [2]. This integrated platform will be used to experimentally validate all these components together into real world multi-functional testbeds. This will be done by means of executing the PoCs based on the use cases defined in WP1 [D1.1]. The testbeds are three namely (1) Shopping Mall, (2) Connected Cars, and (3) High-Speed Train. They represent environments where the mobility factor spans from low (Shopping Mall), to medium (Connected Cars), and further next to high (High Speed Train).

This deliverable D4.1 presents a description of the testbeds and also defines all the PoCs related to the use cases that will be deployed and tested in these testbeds during the project.

Section 2 describes the testbeds in real-world environments. It highlights the technologies and infrastructures to be integrated in each site and presents the corresponding integration plan for the Year 1 of the project.

Section 3 describes the initial planning of the PoCs relevant to the use cases defined in WP1. 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. Required technological components developed in WP2 and WP3 are also highlighted in this section.

Section 4 describes a first demonstration milestone. This section highlights the PoC demonstrated at the European Conference on Networks and Communications (EuCNC) 2018.

Finally, **Section 5** concludes with the next steps for the integration and evaluation of the defined PoCs in the three testbeds.

2 Description of the Testbeds

This chapter describes the test sites, which are located in the real-world environments. It highlights the technologies and infrastructures to be integrated in each site and provides an overall overview of the technologies to be integrated in each test site.

2.1 Shopping Mall

2.1.1 Description

The Shopping Mall testbed is located in Taipei, Taiwan. It provides facilities for performing experiments and pilot deployments in realistically dense scenarios, both regarding infrastructure and users. The testbed is approximately 8,000 square meters wide with around 120 shops and attracts up to 15 people per 100 square meters. The testbed also allows users to take part in the demonstration trials. Shopping Mall testbed was launched in early 2014 to test the D2D technologies by enabling wireless backhaul.

The testbed offers suitable environment to test 5G-CORAL solution in a multi-RAT deployment scenario thanks to the various population of users, devices and sensors co-existing in the mall. Computation offloading, network offloading and mission-critical services are envisioned to be demonstrated in this testbed. For example, IoT gateway and AR navigation will take advantage of the vicinity of computing resources in the mall for offloading heavy processing tasks from end-user devices/sensors to the Edge/Fog computing devices. This is to leverage the low latency communication between the end-user devices and the Edge/Fog devices in the mall.

2.1.2 Overview of Integrated Components

The testbed aims at integrating several technological components which will support the deployment of various experiments to verify and validate the 5G-CORAL solution in the mall environment. A functional diagram of the testbed is depicted in Figure 2-1.

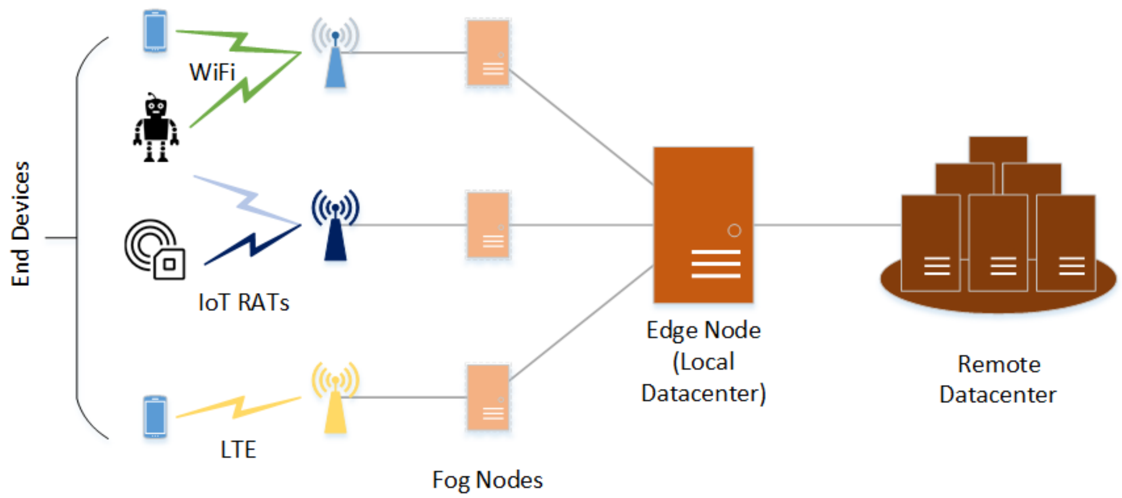

Figure 2-1: Integrated Technologies in the Shopping Mall Testbed

Different types of hardware and software components are deployed in the shopping mall to realise the 5G-CORAL infrastructure. Different types The APs of different wireless radio technologies are deployed in the shopping mall to generate a multi-RAT environment. Specifically, they include small cells and IEEE 802.11 APs, which are deployed to provide LTE and Wi-Fi connectivity, respectively. Various sensors are also enabled, such as Bluetooth iBeacons, temperature sensors, etc. The devices of end terminals (ET) include smartphones, robots, and wearables such as VR glasses. To facilitate a variety of functions, the ETs collect sensor information and deliver it to Multi-RAT IoT GW via different RATs. We elaborate on each of key hardware/software components below.

- **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. Functions and applications utilize container virtualization to be hosted in the Fog nodes deployed. NVidia based Jetson TX2 [3] is used as the reference fog node. Table 2-1 reference hardware details of a Fog node are reported below:

TABLE 2-1: REFERENCE SPECIFICATIONS OF A FOG NODE

Processor	Dual-core Nvidia Denver2 + Quad-core ARM Cortex-A57
Memory	8 GB LPDDR4, 128 bit
Mass Storage	32GB eMMC 5.1 Flash
Video	4kp60 H.264/H.265 encoder & decoder

- **Local Edge Server:** The 5G-CORAL concept is based on a 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), in order to offload low latency demanding computing tasks that cannot be handled immediately by them. Local edge server aims to provide the best quality of edge service to the Fog nodes. Table 2-2 depicts the reference hardware details of a local edge server.

TABLE 2-2: REFERENCE SPECIFICATIONS OF A LOCAL EDGE SERVER

CPU	Intel Core i7-7700
GPU	NVidia Pascal GTX 1080
Memory	DDR4 16GB
SSD	M.2 PCI-E x4 128G SSD
HDD	1TB SATA3 HDD

- **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. The remote edge datacentre is connected to the mall through fixed line or wireless broadband connections ensuring very high throughput (few hundreds of Mbps) and low latency (few tens of milliseconds). Communication between the remote datacentre and the entities operating in the mall, e.g. cameras, fog nodes and VR end-devices, is established through TCP/UDP socket connections.
- **End Terminals:** End Terminals acts as End devices, which are the receiving end of the network. Such End Terminals will include Smartphones, sensors, wearables such as VR glasses, robots, etc. Key ETs are described below:
  - **iBeacons:** They are Bluetooth-based sensors which are commonly used to provide location information to users. It relies on a simple concept that the stronger wireless

signal strength an end device observes from an iBeacon, the smaller the distance is between them. To enable each iBeacon to represent a small area, we divide the walkway of the shopping mall into grids. Thea grid of squares and place one iBeacon in a grid. Each square has the side length and the width of each grid element is 1 meter. In each square, an iBeacon station is centred and hung at the ceiling, as shown in **Figure 2-2**. **Figure 2-3** shows the locations of the deployed iBeacons. Our approach is mainly based on iBeacon RSSI path loss fused with triangulation to determine the position of each mobile device. The major advantage is that iBeacons have much easier and cost-effective deployment compared to WiFi-based localization solutions. However, the weakness is that the signal strengths of iBeacons may vary over time in a complicated indoor environment due to interference. As a result, we seek to leverage both sensors and Augmented Reality (AR) application to improve the localization accuracy.

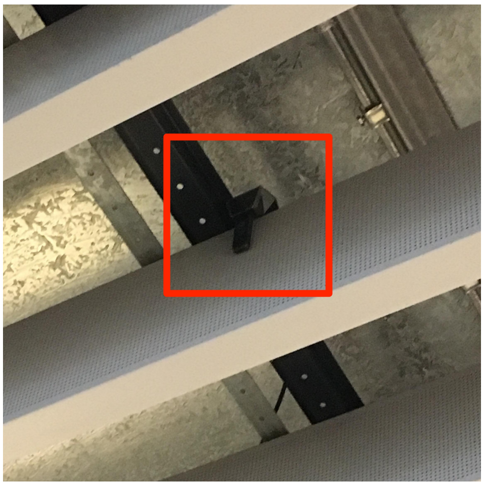

Figure 2-2: iBeacon deployed in the shopping mall

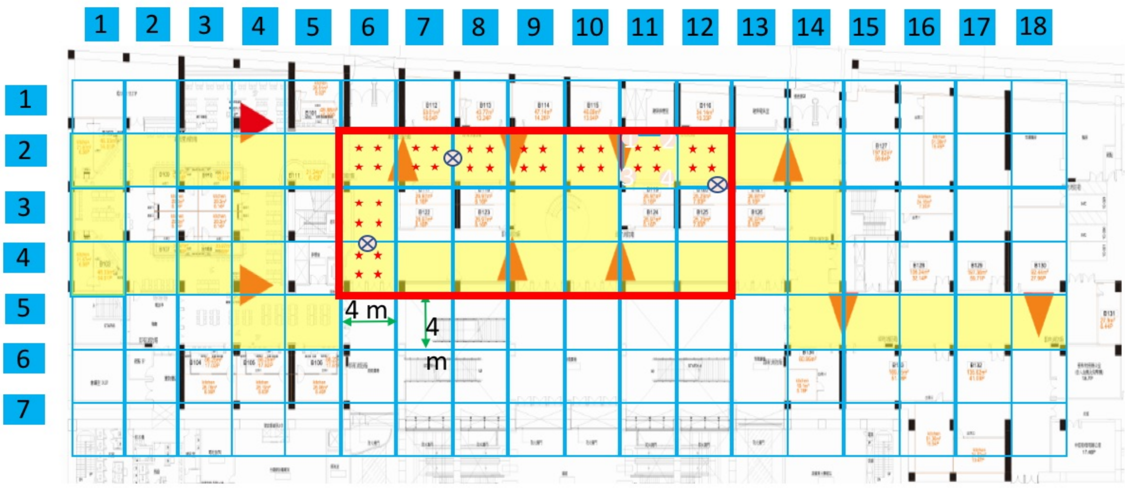

Figure 2-3: represents iBeacon locations in the shopping mall

- **IMU (Inertial Measurement Unit) Sensors on Mobile Devices:** Due to the interference and the obstacles in the indoor environment, the localization accuracy obtained based on the iBeacons can be very coarse. IMU sensors assist with the iBeacons-based localization.

- **Localization Service:** In the mall testbed, indoor localisation is of paramount importance to most applications. To this purpose, a localisation service is offered in the mall leveraging the multi-tier computing infrastructure deployed. Two applications are deployed in the Fog nodes, one is the localization server and the other is the AR image recognition system. For the localization server, we utilize database systems to store mapping information and the sensor values updated from the devices. Mobile devices update their location information to the localization server periodically. After calculation, the localization server responds to the mobile devices with the corresponding coordinates. The localization server also supports third party applications such as robot controller to query locations of a certain device. The Localization Service utilizes iBeacons, IMU sensors and image recognition to evaluate accurately the current location of the user. Currently localization service is in its first phase and deployed in the shopping mall with the help of RESTful APIs, whereas second phase aims to port this localization service into the MQTT. To validate the performance of our localization approach, we deployed it in the shopping mall. 10 iBeacon stations and 10 fog computing nodes were used to preform testing of our indoor positioning framework. Using iBeacons only we could deliver 4m * 4m position accuracy. We will further improve our positioning accuracy down to 1m * 1m based on the assistance of IMU sensors and mobile AR.

2.2 Connected Cars

2.2.1 Description

Vehicular communications have been developed as a part of the ITS, which pursues to improve safety and efficiency through intelligent transportation by incorporating different information.

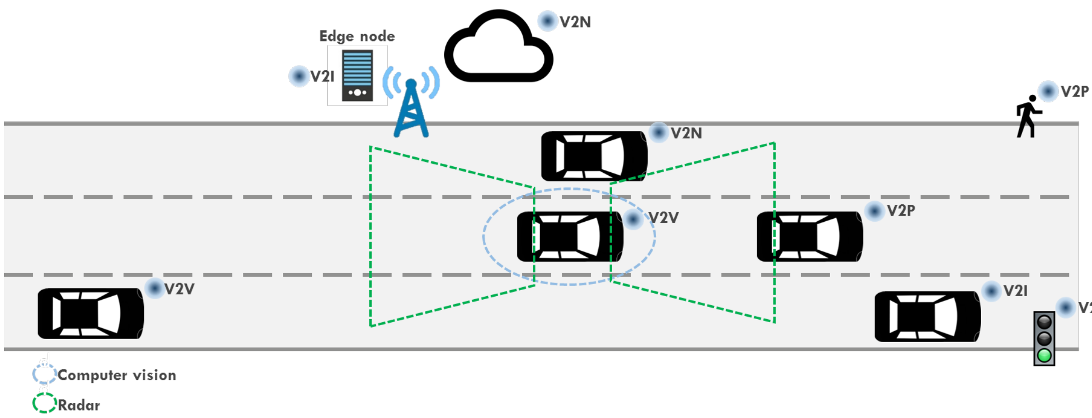

Figure 2-4: Vehicular Communications

As depicted in Figure 2-4, vehicular communications are achieved with the combination of vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), vehicle-to-network (V2N) and vehicle-to-pedestrian (V2P) communications. Vehicular communications add significant value to Advanced Driver Assistance Systems (see Figure 2-4):

- improved safety: NLOS awareness in case of intersections and critical weather conditions;
- traffic optimization;
- improving driving experience delivering new services based on the collected data.

The connected car testbed will be exploited for implementing mainly those use cases which cover the general connected cars communication where the 5G-CORAL technologies are configured to run also on the vehicles (see Figure 2-4). In this scenario data regarding speed, direction and position are collected from vehicles, these data could be used in different ways for improving the cars safety. With the suggested testbed setup, it is possible to think of a number of use cases:

- Roadworks reporting
- Weather conditions reporting
- Emergency vehicles approaching
- Position tracking
- Collision avoidance

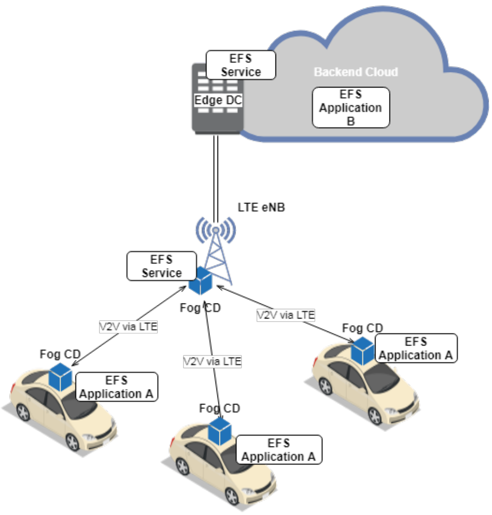

Figure 2-5: Connected cars testbed architecture

Some of the mentioned use cases require low latency communication that cannot be guaranteed by legacy networks according to the 4G LTE e2e latency figures reported in Table 2-3 [4].

TABLE 2-3: 4G LTE PING RESULTS IN THE WORLD

4G LTE Ping results in the world	
Best 10%	21-43 ms
Median	33-75 ms
Worst 10%	47-200 ms

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.

2.2.2 Overview of Integrated Components

Following initial developments and integration activities performed in Azcom Labs, the testbed components provided by Azcom are being used for the testbed in TI Labs located in Turin (Italy) with the support of TI, as depicted in Figure 2-6.

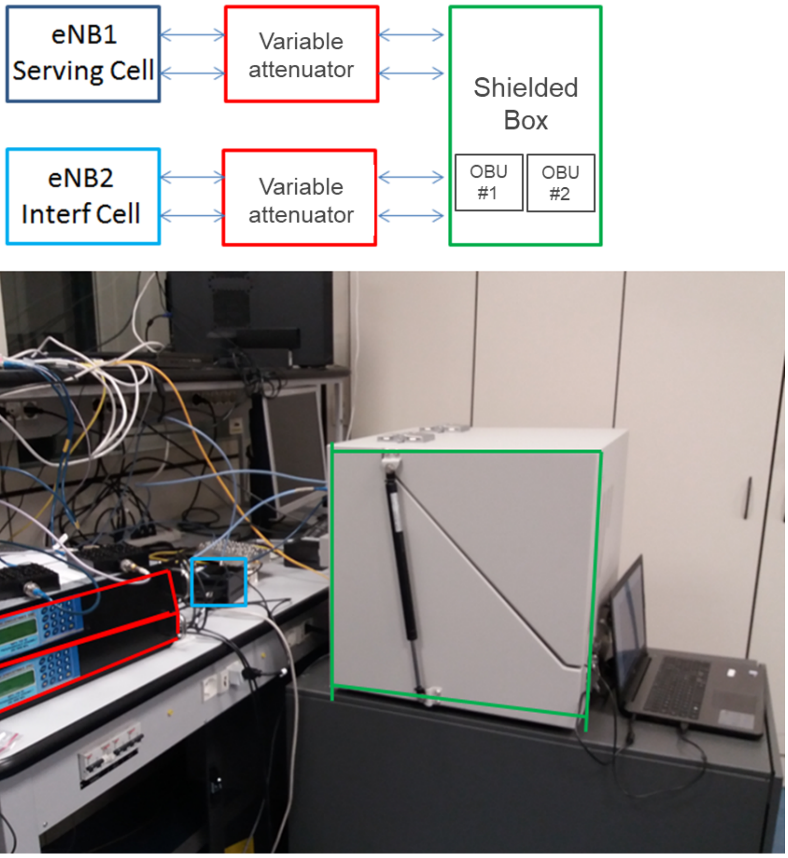

Figure 2-6: Initial setup of the connected car Testbed at TI wireless lab in Turin

The testbed in TI will has been realized to both assess the feasibility as well as to perform additional tests (e.g. with different radio configurations or testing configuration that could not be replicated in the fied-trial).

The TI wireless lab is involved in the integration activities to analyse the impact of radio propagation conditions and the network load on the capability of collision avoidance. Figure 2-7 shows a generic description of TI wireless lab where several subnetworks are available. Each subnetwork is associated with a specific eNB vendor and all the eNBs can access to the lab datacentre (Edge-DC or MEC server) where several EPC services are available and a Network Management service, which is used for the radio nodes monitoring and control.

In the TI lab, the following components are used for connected car testbed as explained below:

- **On-board unit (OBU):** the OBU, provided by Azcom, is a vehicular Fog node, which is configured to run safety applications also on the vehicles. The OBUs, after the termination of the radio access layers, will communicate using the MQTT protocol with the MQTT Broker that will be installed on either the Edge-DC or MEC server and the Cloud-DC as shown in Figure 2-7. The detailed OBU description and specifications are reported in Section 3.6.5.
- **eNBs:** both open source eNB (exploiting Openeairinterface Software [5]) or commercial nodes can be used in these tests. The already supported Core Networks are instantiated also in a central datacenter (Central/Cloud-DC) in order to verify the collision avoidance performance with different Core Network distances from the edge/MEC node.

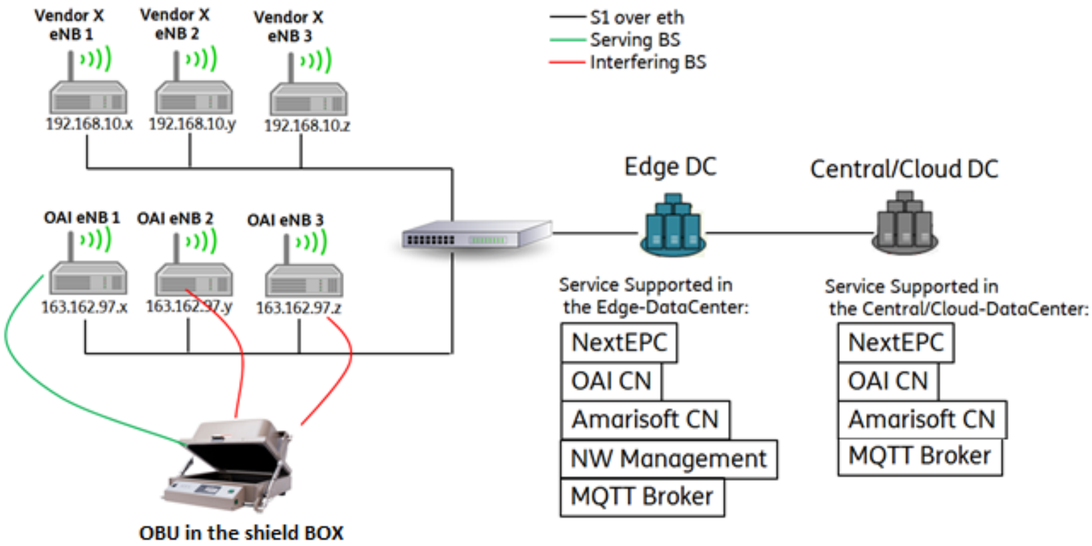

Figure 2-7: TI Lab architecture for OBU Test

As illustrated in Figure 2-7 in the TI wireless lab a shield box can be connected via RF cable to several eNBs in order to create a controlled radio environment inside the box. Two Azcom OBUs can be placed inside the shied box where both useful and interfering signals can enter through RF connectors. This controlled environment will allow to monitor the collision avoidance performances when:

- Different Channel Quality (CQI/SINR) occurs in the RAN connection: the OBU signal is transmitted/received simultaneously with other interfering user connections (different eNBs transmitting over the same frequency)
- Different Radio Channel Load: the OBU signal is transmitted/received simultaneously with other user connections served by the same network node.
- Different S1 link Load/Latency: the Load/Latency over S1 can impact the OBU performance in the collision detection. The increase of latency/traffic load over S1 can be higher when the Core Network runs in the central datacenter (Central/Cloud-DC)

- **Core Network (EPC)**: initially NExtEPC has been selected to act as a core network in the connected car testbed, but other options can be evaluated according to the results of the experimentation activities.
- **End terminal and car emulator**: an external laptop is used for visualizing and collecting the experimental data. Moreover, it can also run the simulation software which can generate additional connected car messages (GPS and OBDII tracks) emulating also more complicated scenarios without increasing the number of physical OBUs.

A real-world field trial could also be foreseen at the end of the PoC laboratory experimentation activities. If feasible, only specific vehicle models will be chosen since the developed OBD II interface is car-specific. Moreover, some security aspects should be considered carefully (driver safety, municipal regulations …) as well as issues related to the demonstration of the testbed (i.e. how to communicate the results of the demo to external people, third parties).

2.3 High-Speed Train

2.3.1 Description

The Taiwan High-Speed Train Testbed was established in 2010. Initially, it served the WiMAX technology, and in 2014 4G–LTE technology deployment was initiated, and a total solution of 4G-LTE system was introduced for full-line deployment. Currently, this testbed is successfully deployed over 30 km and is used on daily basis. It is located between the Hsinchu Station and the Taoyuan Station. Currently, the following equipment is deployed on the roadside over the span of 30 km, including 10 eNBs and 16 sets of Analogue-RoF (A-RoF). The entire signal is routed back to the core network located in the server rack in the ITRI campus, which is connected to the RAN by a subscriber line and currently performs all the essential tasks of 4G-LTE. Furthermore, the high-speed train testbed adopts two-hop architecture [6] as depicted in Figure 2-8, which means that on-board small cells are for radio access of user equipment used by passengers mainly, while the roadside base stations are the points of access for the on-board outbound gateway, also known as customer premise equipment (CPE), which provides mobile backhaul for on-board small cells.

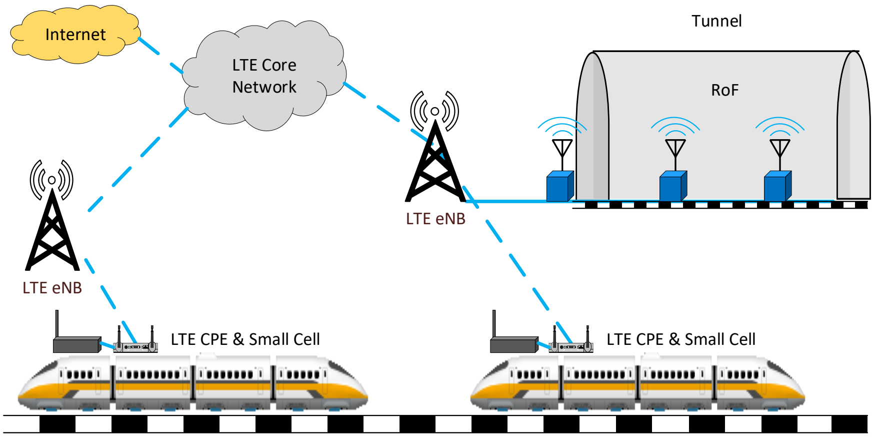

Figure 2-8: High-speed Train testbed

Nevertheless, to provide a satisfactory Quality of Service (QoS) for passengers on-board is still very challenging in the high mobility case. Mobile communication services will be affected due to unstable radio signal between CPE on train and base station along the rail. The 5G-CORAL solution can help improve the QoS by bringing the core network to the edge and limit the huge signalling from hundreds of passengers on-board the train. Ultimately, the intermittent wireless disconnection will reduce significantly and open the door for new services while enjoying traveling by high-speed train.

2.3.2 Overview of Integrated Components

In 5G-CORAL, the main focus will be on the specific use case of mobility scenarios where massive signalling from frequent handovers are expected due to a large number of end users and sensors on board the train. Therefore, local virtual MMEs will be deployed on the Fog nodes to cope with the huge amount of signalling envisioned at such a high speed. Such Fog nodes are deployed on board the train and can also be used to host some specific core functions, such as local breakouts, to enable the storage and consumption of contents locally without the need of going through the train's backhaul connection. Moreover, service migration from on board the train to on land (train station) will contribute to lower latency and better QoS for end users.

For this testbed, the first step toward integrated fog/edge components is to develop an emulated environment in ITRI's lab mirroring the commercial high-speed train in two-hop architecture as shown in Figure 2-9 and Figure 2-10. Obviously, it will not be feasible to integrate fog/edge function, service and application directly into the commercial testbed. The replicated inlab high-speed train testbed can be utilized to measure different E2E measurement as baseline and provide the necessary PoC for any field trial testing. Moreover, NextEPC [7] which utilizes Rel-13 LTE core network was used inlab testbed to build the core network. Commercial small cells acted as eNB for both on-board and on land.

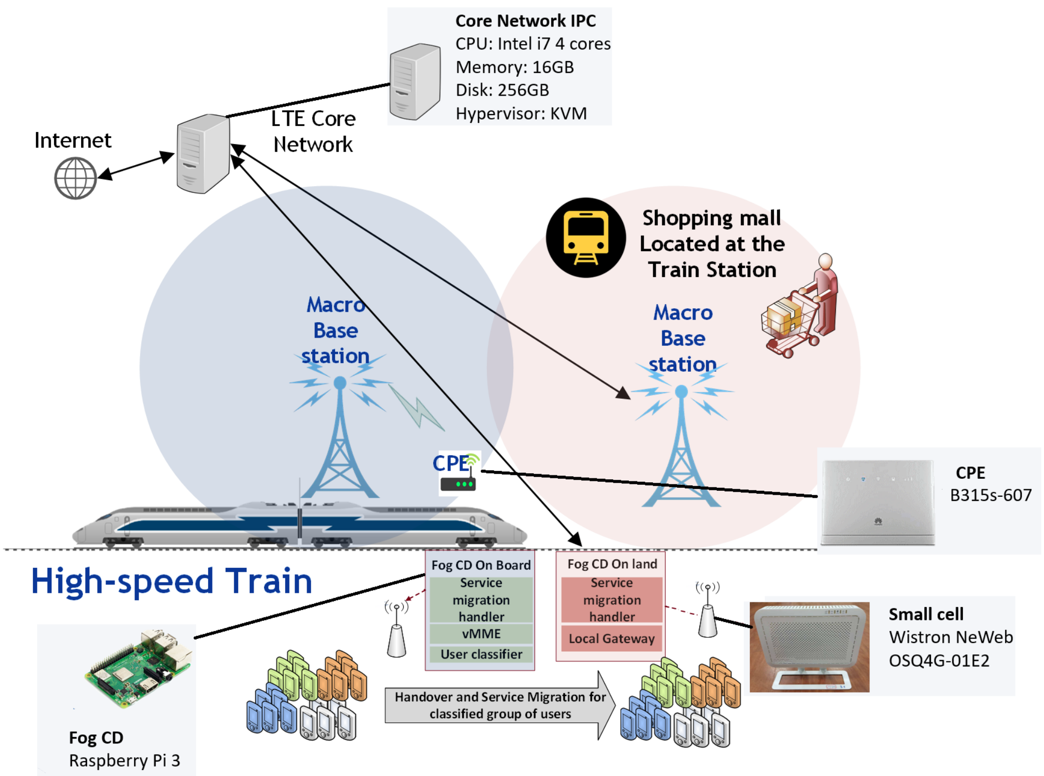

Figure 2-9: Initial in Lab high-speed train testbed for 5G-CORAL

Figure 2-10: In Lab high-speed train testbed at ITRI Hsinchu

In the ITRI lab, the following components are used for high-speed train testbed as explained below:

- **Fog Node:** it is the main component deployed and represent the vMME on board. It is a modified version from NextEPC's MME, and it is responsible about several services and functionalities of EFS such as receives handover triggering from MME, user classifier function based on QoS. Currently, it used Raspberry Pi 3 [8] as the reference fog hardware. But it is possible also to use the NVidia based Jetson TX2 mentioned in Table 2-1.
- **Small Cell:** it is used for high-speed train with the reference specification as shown in Table 2-4. Where, one small cell will act as eNB on-board the train. Another small cell will act as on land Macro base station, which has the capability to change RSSI and can emulate the high-speed train signal degradation.

Table 2-4: Reference Specifications of Small Cell

Processor	Qualcomm FSM9955
Operational frequency	Band 7
Software version	LTE REL9
Model	Wistron NeWeb OSQ4G-01E2
DL/UL	80/40Mbps

- **CPE:** - it is a gateway between on board and on land eNB/small cell, also it can act as an WiFi AP. The reference specification is shown in Table 2-5.

Table 2-5: Reference Specifications of CPE

Operational frequency	Band 7
coverage	Up to 250 meters
WiFi	supports WiFi 802.11b / g / n
Mobile network	LTE-CAT4
Model	B315s-607

- **UE Emulators:** - it emulates multiple UEs with different QoS requirements such as video streaming.
- **Core Network (EPC)** – it is a computer with the reference specification shown in Table 2-6 has NExtEPC to act as a core network in high-speed train demo. it installs each entity is installed in different VMs based on KVM. It is also responsible to send handover triggering message to vMME.

Table 2-6: Reference Specifications of Core Network computer

CPU	Intel i7 4 cores
Memory	DDR4 16GB
OS	Ubuntu, KVM
HDD	256GB

In the first year of 5G-CORAL, we focused mainly on the most challenging part that is the vMME including modifications of S1/S10 handover process and tested its performance compared with the baseline measurement. MME belongs to the core network of LTE. However, in high-speed train use case which faces lower signal strength due to the mobility of the train, deploying local MME as part of the edge/fog will be an advantage towards better user experience for passengers. Also, utilizing virtualisation environment will help to add or subtract some of the original MME functionalities at the edge based on the demand of passengers in the high-speed train. As part of preparing in-Lab testbed, vMME was installed on Raspberry Pi which acts as fog node and located on the train. Also, core network components (MME/SGW/PGW/PCRF) were installed as 4 different VMs, and HSS was installed at another PC as shown in Figure 2-11.

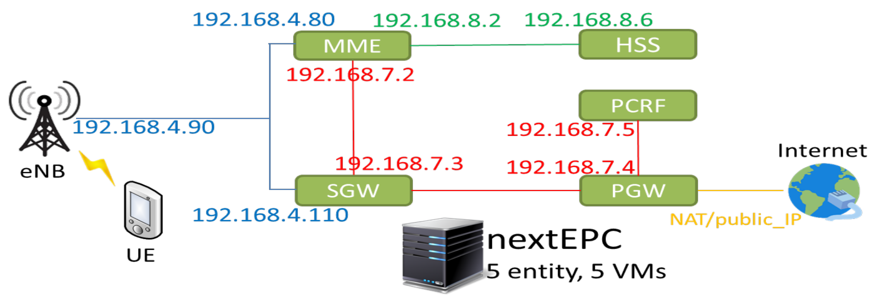

Figure 2-11: Example of IP setting for each VM

Several experiments have been carried out to emulate the real high-speed train testbed. In particular, vMME on top of Fog nodes and commercial small cell have been deployed behind CPE. Besides, current efforts are targeting the integration of 5G-CORAL functionalities, services and applications into the Fog nodes on board and on land.

3 Proof-of-concepts

3.1 PoC#1: Augmented Reality Navigation

3.1.1 Description

This PoC focuses on Augmented Reality (AR) Navigation 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 promotions on their screen whenever they pass by the store. These special offers will enhance the shopping experience for the mall's client.

To realize this scenario, End Terminal (ET) in our case a smartphone accesses the WiFi access point (connected to a Fog CD) which allows installation of the AR Navigation application. A video of a shopping mall alley or a landmark (e.g. store logo, mall information sign) is captured by the device's camera. Chosen frames from the video are sent to the Image Recognition application residing at the WiFi gateway. The IR app performs the analysis of the incoming frames in order to detect location of the ET. At the same time, the AR Navigation app transmits beacon signature data that it registered from nearby iBeacons devices distributed around the shopping mall. This data is in turn fed to the Localization function which estimates the location of the ET in parallel to Image Recognition (IR) app. In order to maximize precision of the localization, two modules (IR app and Localization function) interact with each other exchanging location estimates. This process, in addition to improving location evaluation, aims at decreasing computational burden. Indeed, IR application might decrease the size of the database to explore if rough location of the ET is known. It is the location estimated from the beacon signals that allows the IR app to select relevant portion of the database and hence decrease latency but also improve precision. The precise location is then fed back to the localization function which releases it back to the ET. Once the AR Navigation app receives the location of the user, it displays position and direction on the mall map (as part of the application GUI).

In order to ensure that the IR module operates within given latency constraints under various loads (different numbers of client ETs), the workload can be distributed to multiple fog CDs, not necessarily the closest one. This allows to utilize the resources available within the fog system to increase the number of handled user requests and shorten the latency required to serve the user requests. Distributed Computing System (DCS) consists of many Distributed Computing Modules (DCMs). DCM tightly collaborates with IR function that might be deployed on the same Fog CD. DCM receives AR image computation request from the IR function. The incoming AR request (video frame) is dispatched in form of tasks among the neighbouring DCMs/fog nodes (see Figure 1). The dispatching is based on real-time load measurements of the DCM as well as load of neighbouring DCMs. The dispatching process is performed in distributed manner meaning that every DCS is aware of the load of its neighbours.

To realize the AR Live Navigation scenario, several components needs to be deployed in the shopping mall. Mapping of the AR Components in the shopping mall is illustrated in Figure 3-1 and the EFS entities are shown in the Figure 3-2. The Image Recognition server is deployed in the Fog Node. It receives the image from the End-terminal and localizes the current user position, enabling navigation to a destination. iBeacon and IMU sensors detect the ET, if present in their coverage and reports to the Fog node, which further helps to improve the precision of the user's position. Virtual AP helps the ET to connect to the local area network of the shopping mall. ET receives the localization EFS service, which further helps in the client-side AR Live Navigation App to navigate itself to the destination.

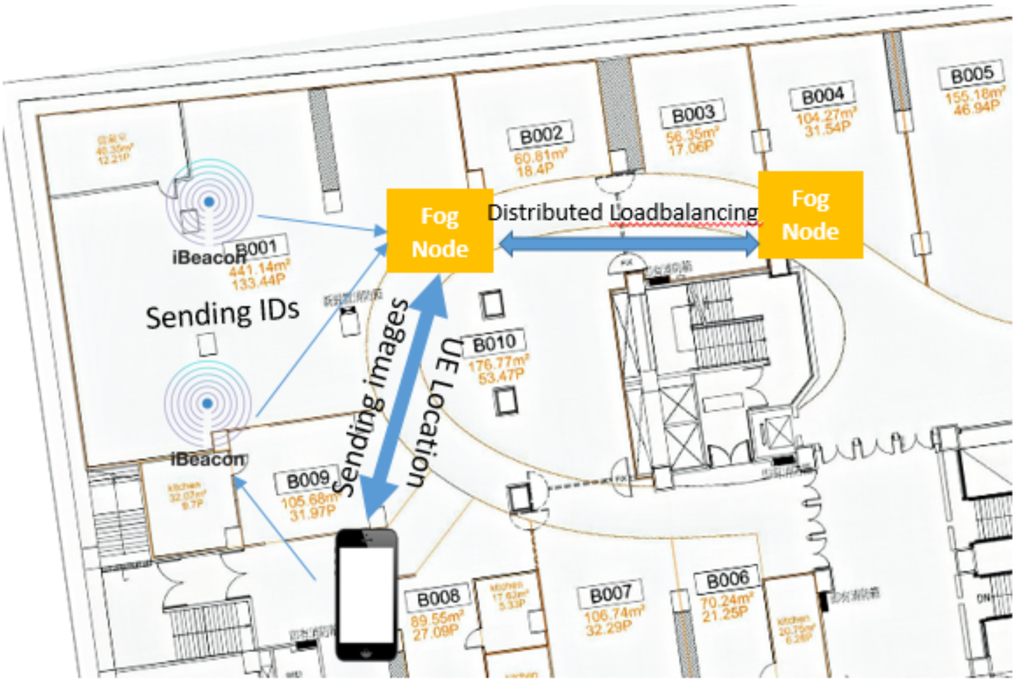

FIGURE 3-1: AR LIVE NAVIGATION NETWORK

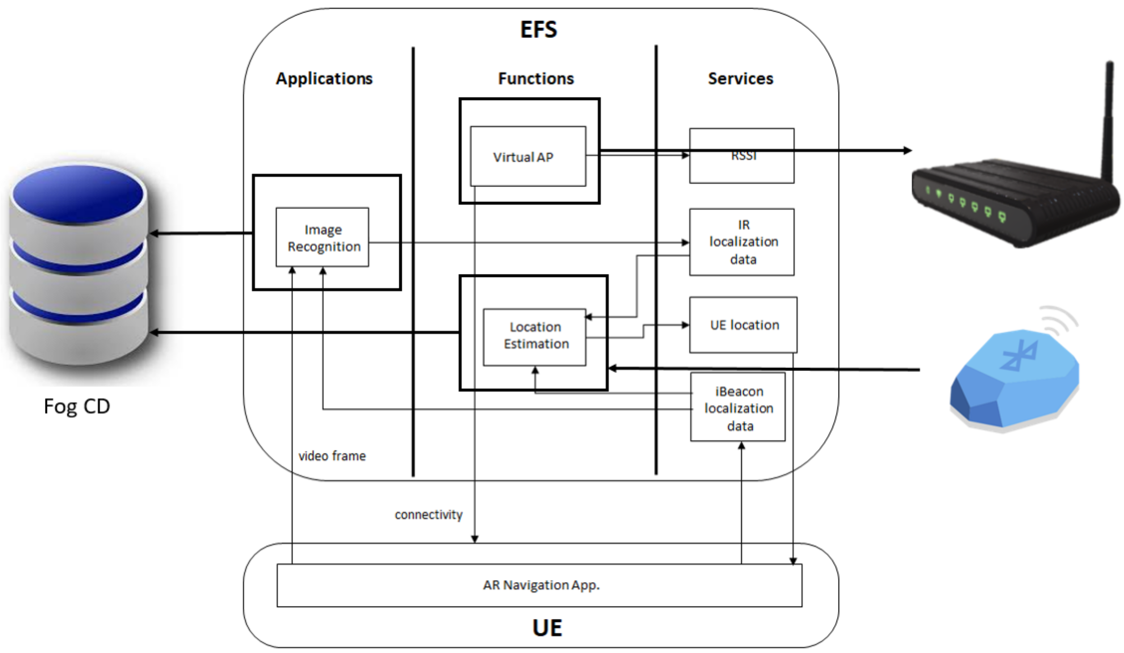

FIGURE 3-2: EFS ENTITIES CONFIGURATION FOR AR USE CASE

3.1.2 Relation with Project Objectives

Table 3-1 highlights the relation of Augmented Reality Live Navigation demo with the project objectives.

TABLE 3-1: POC#1 RELATION WITH PROJECT OBJECTIVES

Project Objectives	How will this PoC address the project objectives
Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	
R&D Topic 1: *Network-assisted D2D function* for discovery and communication of proximity networking and computing resources.	D2D protocols will be used over the wireless links between Fog nodes to discover the nodes and distribute the jobs among the multiple nodes.
R & D Topic 2: *Network-offloading function* that enables device and core network offloading by running some of its functions in the EFS.	User will be able to offload the computation task (image recognition) to the Fog node available in the vicinity. Tasks are also offloaded to the neighbouring Fog nodes if the primary Fog node is not able to support the incoming request.
Verification: Validate selected EFS components through a system verification in the integration testbeds from WP4.	Components will be integrated and verified in the Shopping Mall Testbed.
Objective 3: Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources	
R & D Topic 1: Develop interfaces for automated deployment of EFS functions and applications.	OCS allows automated deployed of IR application as the user comes into the vicinity of the Fog node.
Verification: Validate selected OCS components through a system verification in the integration testbeds from WP4.	Components will be integrated and verified in the Shopping Mall Testbed.
Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
R & D Topic 1: Integrate and validate EFS and OCS in large-scale testbeds, such as shopping mall, high-speed train, and connected cars.	AR Navigation will be demonstrated in the Shopping Mall Scenario.
R & D Topic 2: 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.	Low latency application "AR navigation" will be demonstrated in the real-world shopping mall testbed.
Verification: 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.	Demonstration of AR navigation in the Shopping Mall testbed.

3.1.3 Initial Performance Metrics

Table 3-2 provides an initial list of performance metrics which will be measured through the experiments using this AR navigation PoC. Additional metrics are being considered and interim results are being obtained from the ongoing experiments. These will be reported in the next deliverable.

TABLE 3-2: POC#1 PERFORMANCE MEASURES/METRICS

Performance metrics	Description	Way of measurement
Latency	Round trip time between issuing a command from an ET and execution from a Fog CD	Time difference between execution of a command and receiving the acknowledgement from the Fog CD.
Delay	Communication delay between the Fog CDs (for distributed computing)	Dummy packets can be time stamped and distributed among Fog CDs or simply ping
Process Power by Segmented Database	Time required by a Fog node to complete a job	Starting and Ending time can be time-stamped to obtain the samples
Localization Precision	Error between true location points and obtain location points	A testing path will be set based on true location points to evaluate the error. Location of the recorded reference points with true location will give us the error.

3.1.4 Relation with Use Case

The AR PoC is directly related with the indoor navigation using AR use case defined in WP1 [9].

3.1.5 Software/Hardware Configuration

This AR PoC requires several hardware components to run the software elements. These components are listed below:

- **Fog Node –** Fog node will be used to host the intelligence of the application, that is the image recognition algorithms and the localization modules for AR navigation. Localization modules will help determine the current precise location of the user. The Fog node will have an interface to an Access Point. The Fog node is pre-built (e.g., Jetson TX2 Module [3]) with the support containers (LXC, LXD, and Docker).
- **Access Points (APs) –** One or more hosting devices shall support virtualization and have 802.11 cards for providing wireless connectivity. A lightweight virtual AP will be created for the AR navigation users to connect.
- **Gateway –** Single hosting system with Internet connectivity. A DHCP server would run on top and the device would act as a gateway for the nodes experiencing the AR navigation.
- **Smartphones/Wearables –** End devices such as smartphones or smart glasses will be used for AR Navigation.
- **iBeacons** [10] **–** the Bluetooth low energy devices are deployed in the shopping mall to detect the presence of a user. Mass deployment of iBeacons helps the fog node to determine the precise location of the user. End devices such as Smartphones listen to signals from the beacons in the mall and transmit the information with area ID to the Fog node.

3.1.6 Required 5G-CORAL Building Blocks

Table 3-3 provides an exhaustive list of 5G-CORAL EFS and OCS building blocks (sub-system) to form a working AR live navigation PoC.

TABLE 3-3: POC#1 REQUIRED 5G-CORAL BUILDING BLOCKS

Sub-system	Component's Name	Description
EFS	Image Recognition	An **Application** to recognize the incoming features from a pre-defined distributed database.
EFS	Location Estimation	A **Function** of iBeacon localization, IMU (Inertial Measurement Unit) and Image Recognition to precisely localize the current position of the user.
EFS	Localization Service	**EFS Service** -The density of visitors supports the system to initiate the demo scenarios and where to operate. The localization service provides significant information for the user to navigate and reach the desired location in the shopping mall.
EFS	Navigation system	**EFS Service** - Navigation system for the robot to navigate through the Shopping Mall
OCS	Instantiation	A **OCS Component** to Instantiates EFS sub-systems from a given catalogue. It also instantiates virtual AP to a Physical AP.
OCS	Monitoring	**OCS Component** reporting monitoring/statistics information (Current Resource usage) of the containers/Neighboring Fog nodes.
Non-EFS	ET AR navigation application	Captures frame of the objects and send it to the Fog Node in a pperiodic fashion to navigate itself to the destination.

3.1.7 Interim Results

Figure 3-3 illustrates the result depicting the processing time in millisecond. Fog node utilized in this experiment is Jetson TX2 [3] .The processing time is the time taken by the Fog node to process the image recognition process for the AR application. The following chart represents the processing time received by the Fog node by with and without segmentation of the database. Two tests are performed namely (i) with Segmentation and, (ii) without segmentation with 500 samples each as depicted in Figure 3-3. Segmentation of the database is achieved by the iBeacon id received with the request. iBeacon node segments the zone which helps to segment the database and provides indexing in quickly identifying the picture. It can be clearly seen that segmentation has improved processing time by ten times.

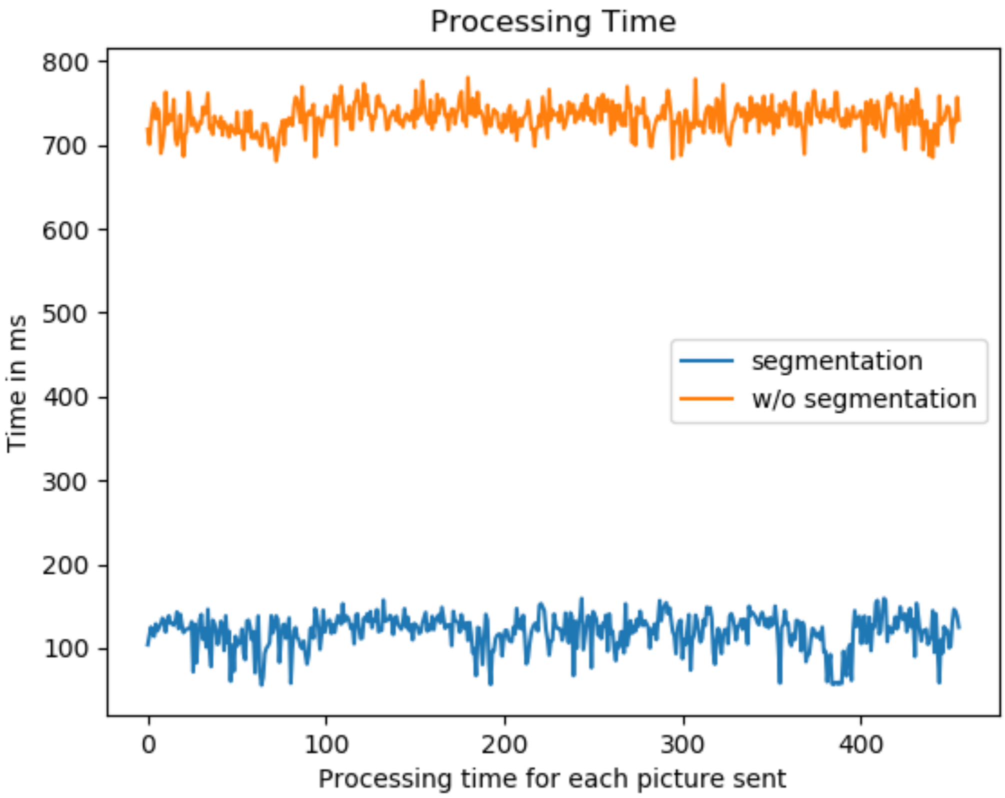

Figure 3-3: Processing Time Comparison with and w/o Segmentation in the Fog Nodes

3.1.8 Integration and Validation Timeline

Table 3-4 shows the integration and validation timeline of the AR PoC.

Table 3-4: POC#1 Timeline

Description	AR Navigation
Q1 – 2018	• Developed Software building blocks (e.g., Image Recognition, iBeacon, GUI)
Q2 - 2018	• Integration of Map with iBeacons and g-sensor (Location Estimation) • Developed new GUI with Map with user-tracking feature • Integration of Distributed Computing System with Image Recognition Application
Q3 - 2018	• Virtualization of image recognition and distributed computing System and localization • Integration of Location Estimation with Image Recognition • Development of Localization APIs • Implementation of virtual AP + Early lab tests
Q4 – 2018	• Integration of Distributed Computing, Image Recognition and Localization • Early lab tests for Container based Migration • Implementation of Distributed computing for dispatching image recognition jobs. • Shopping Mall Trial for the Augmented Reality Navigation

Q1 - 2019	• Optimize localization and GUI to get precise location • Integration with OCS • Automated deployment of application in static scenarios • Identification of the user's mobility
Q2 - 2019	• Exposing Monitoring data to OCS • Automated deployment of applications in dynamic scenarios • Verification of distributed computing in the AR scenario
Q3 - 2019	• Final Integration and assessment in real world shopping scenario

3.2 PoC#2: Virtual Reality

3.2.1 Description

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.

However, the 360° video delivery implies high bandwidth consumption and low latency requirements which are hard to achieve in conventional wireless networks. One of the solutions to reduce the bandwidth consumption consists of employing a viewport adaptive streaming technology. This technique relies on the clients' viewing orientation and aims to deliver the portion of the 360° video (e.g., viewport) being watched by the user in high quality/resolution, whereas the rest is delivered in low quality/resolution. Figure 3-4 shows the building blocks of the 360° video delivery service at the server side. Furthermore, viewport adaptive streaming is currently supported by the latest MPEG VR standard, Omnidirectional Application Format (OMAF), and MPEG video streaming standard Dynamic Adaptive Streaming over HTTP (DASH). Yet, tile-based High Efficiency Video Coding (HEVC) transcoding/encoding adds extra computational complexity to the system, as tiled video streams have to be decoded and re-composed into 360° video frame at the client side, which adds computation into the devices and may not be supported by legacy devices. An illustration of the building blocks employed at the client side is presented in Figure 3-5.

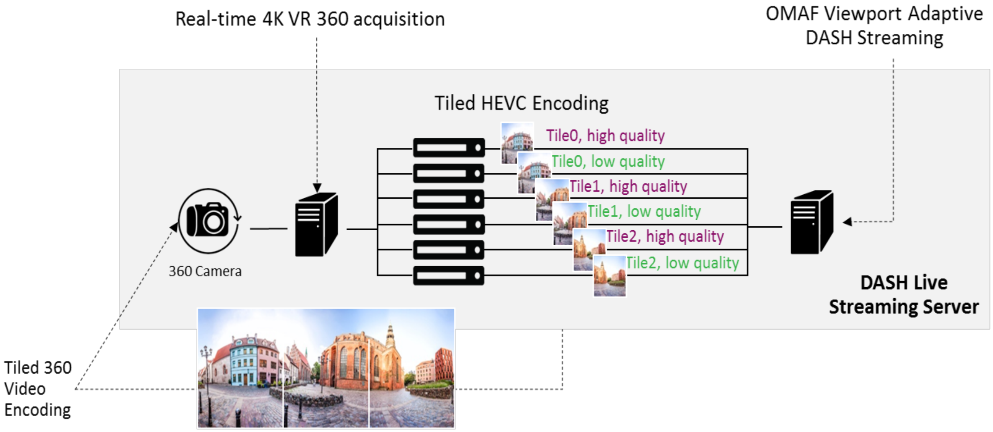

Figure 3-4: Architecture of the 360° video delivery (server side)

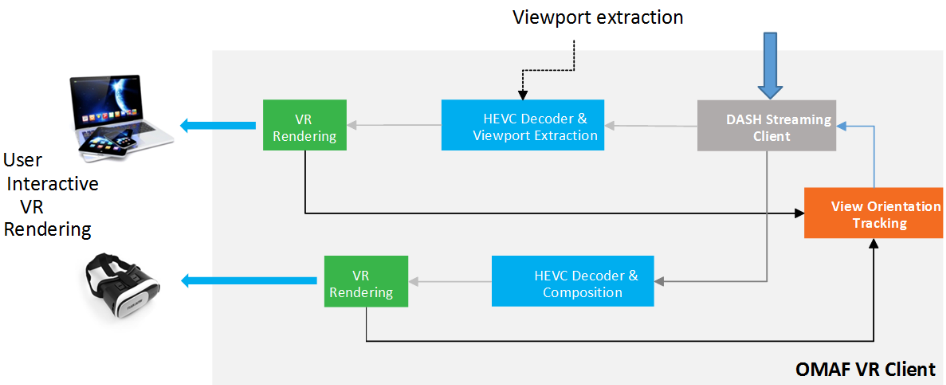

Figure 3-5: Architecture of the 360° video delivery (client side)

To cope with such technical challenge, a distributed fog computing scenario is proposed consisting of multiple fog nodes offloading the burden of computing from the mobile devices. As shown in Figure 3-6, a number of fog nodes deployed in the shopping mall communicate with the VR clients with the goal of collecting the viewing orientation of each end user and enabling the viewport adaptive streaming, while an edge datacentre, i.e., local edge server, is in charge of decoding, composing and forming the 2D viewport video. Finally, at the top tier, a more powerful remote edge computing system can handle most computationally complex tasks, such as Real-Time Messaging Protocol (RTMP) acquisition, tiles encoding and DASH live segmentation. Figure 3-7 lists all the EFS entities involved in this use case and shows a possible mapping between entities and computing substrates.

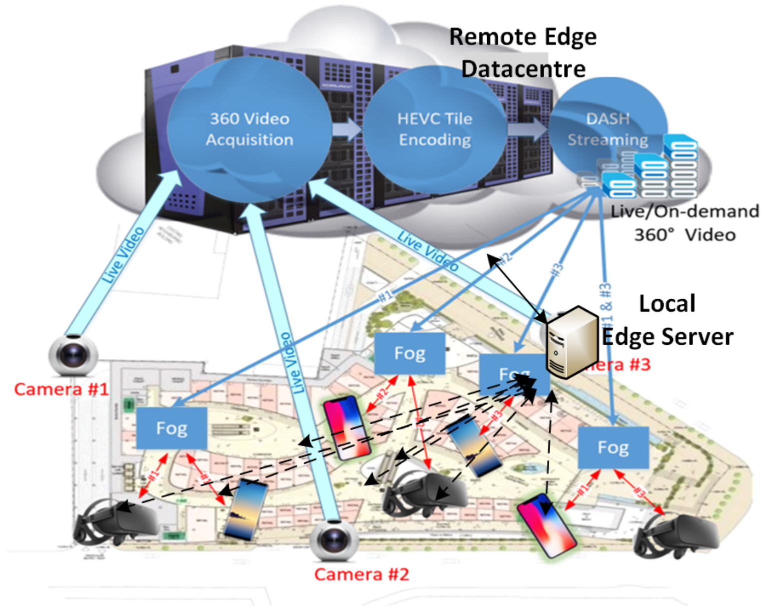

Figure 3-6: 360° video streaming network system

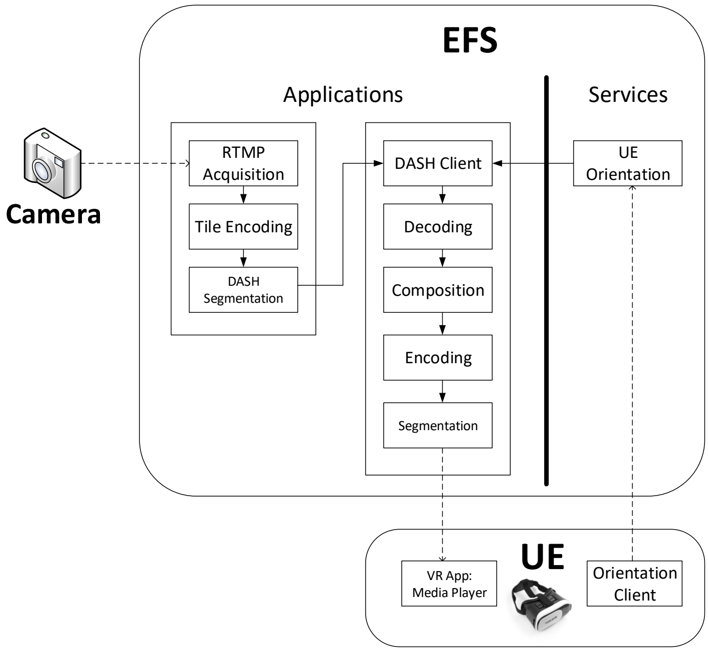

Figure 3-7: EFS entities configuration for the VR use case

3.2.2 Relation with Project Objectives

TABLE 3-5 shows the relation of project objectives with the VR PoC.

TABLE 3-5: POC#2 RELATION WITH PROJECT OBJECTIVES

Project Objectives	How will this PoC address the project objectives
Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	

R&D Topic 1: *Network-assisted D2D function* for discovery and communication of proximity networking and computing resources.	Service discovery will be ensured through the deployment of D2D proximity service discovery protocols among all the network nodes.
R & D Topic 2: *Network-offloading function* that enables device and core network offloading by running some of its functions in the EFS.	Multiple fog nodes will be deployed closer to the end users with the goal of performing specific computing tasks next to the them.
Verification: Validate selected EFS components through a system verification in the integration testbeds from WP4.	The specific EFS components will be integrated, tested and validated by means of a proof of concept inside a shopping mall in Taiwan.
Objective 3: Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources	
R & D Topic 1: Develop orchestration and control algorithms for elastic placement and migration of EFS functions and optimised allocation of EFS resources.	An orchestration solution will be developed and adopted to conveniently distribute computing tasks between fog nodes and edge data centres as well as migrate the tasks based on traffic load and user mobility.
Verification: Validate selected OCS components through a system verification in the integration testbeds from WP4.	All the OCS components needed for this use case will be validated through a proof of concept showcased inside a shopping mall in Taiwan.
Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
R & D Topic 1: Integrate and validate EFS and OCS in large-scale testbeds, such as shopping mall, high-speed train, and connected cars.	The VR use case will be demonstrated inside the shopping mall in Taiwan.
R & D Topic 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.	Relevant KPIs will be measured through a demonstration in real-world conditions.
Verification: 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.	The VR demonstration will be carried out in the shopping mall scenario.

3.2.3 Initial Performance Metrics

TABLE 3-6 shows the initial performance metrics list. Highlighted performance metrics will be measured using the VR PoC.

TABLE 3-6: POC#2 PERFORMANCE MEASURES/METRICS

Performance metrics	Description	Way of measurement
Bandwidth	Viewport adaptive streaming approach reduces the bandwidth required to stream 360-degree video while maintaining the same viewing experience.	Measure the bandwidth (mbps) required to stream 360-degree video, with and without viewport adaptive streaming.
Service Setup Time	Service setup time refers to the time it takes for the OCS to instantiate and provision all the VR components, distributed across the EFS, to produce an E2E VR service.	Record and analyze the time-stamps of the OCS instantiation commands and EFS acknowledgement responses.
Delay	Communication delay among: Fog CDs, Local DC, Remote DC and VR clients.	Using ping.

3.2.4 Relation with use case

The VR PoC is related to a new use case added in WP1 D1.2. This use case showcases an immersive VR experience with specific requirements in terms of data rate and latency.

3.2.5 Software/Hardware Configuration

A list with Software and Hardware components employed in the Virtual Reality demo is provided as follows:

- **Remote edge datacentre**: high-performance server machines executing most of the computing tasks needed to run the VR application. It will be equipped with a powerful graphic card capable of handling VR processing power requirements.
- **Local edge server**: server machine located inside the shopping mall capable of processing some of the VR computing tasks. It will be equipped with a high-end graphic card to support the VR computational requirements.
- **Fog nodes**: several fog nodes will be deployed in the shopping mall and connected to different points of attachment, such as LTE small cells and Wi-Fi access points. Depending on their capability, more or less complex computation will be hosted on these devices.
- **360° video cameras**: it captures and records the 360° video and delivers the video live streaming to the real-time acquisition server running on the EFS. Several Insta360 Pro cameras will be installed in the shopping mall and located in specific points of interest.
- **Smartphone (ET)**: it will host the media player app as well as the camera selection app, which enable the video streaming consumption and the selection of the point of interest, respectively. Furthermore, the orientation client will be running on the ET and will be communicating with the DASH client application in the EFS.
- **Laptop + VR headset**: it operates similarly to the ET with the additional capability of delivering a 360° immersive experience. The headset will be connected to a laptop which will communicate with the wireless points of attachment.
- **Wi-Fi AP/LTE small cells**: these two solutions will enable the communication between ETs, fog nodes and edge servers. Several Wi-Fi APs and LTE small cells will be deployed in the shopping mall to ensure reliable and low-latency data transfer between the different entities.

3.2.6 Required 5G-CORAL Building Blocks

Table 3-7 presents an exhaustive list of 5G-CORAL EFS and OCS building blocks that constitute the Virtual Reality (VR) PoC.

TABLE 3-7: POC#2 REQUIRED 5G-CORAL BUILDING BLOCKS

Sub-system	Component's Name	Description
EFS	RTMP acquisition	**EFS application** responsible for performing the RTMP acquisition enabling persistent connections and low-latency communications. It consumes data provided by the camera and sends the output data stream to the tile encoding application.
EFS	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.
EFS	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
EFS	DASH client	**EFS application** to reassemble DASH segments sent by the DASH segmentation application. The output data is then sent to the decoding application. This application also uses the ET orientation information provided by the ET orientation service, which provides the user's view angle.
EFS	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.
EFS	Composition	**EFS application** responsible for re-composing tiled video streams into 360 video frame at the client side. This component receives tiled video streams decoded by the decoding EFS function.
EFS	ET orientation	**EFS service** responsible for selecting which tile has to be sent to the ET based on the orientation information provided by the orientation client. The selected tile is communicated to the DASH client.
OCS	EFS service platform manager	**OCS component** in charge of managing the orientation service deployed on the fog nodes. For this purpose, Fog05 will be used to manage the service lifecycle.
OCS	EFS App/Func Manager	**OCS component** responsible for managing multiple EFS applications required to run the VR streaming. For this purpose, Fog05 will be used to manage the application lifecycle.
Non-EFS	VR App media player	SW component running on the ET and on the laptop connected to the VR headset. It shows the VR multimedia content after being decoded and processed by the appropriate EFS elements.
Non-EFS	Orientation client	SW component responsible for informing the ET orientation service of the current ET orientation status, so that the viewport adaptive streaming service can be efficiently executed.
Non-EFS	Camera streaming	SW component interfacing with the 360 camera. It is mainly employed to instantiate a 360 live video streaming session with the edge data centre server.

3.2.7 Interim Results

Figure 3-8, presents a breakdown of the average service setup time for the VR PoC. The E2E VR PoC was distributed across multiple Edge and Fog resources and orchestrated using Fog05. Initial results reveal a total E2E service setup time of approximately two minutes, i.e. 117 seconds.

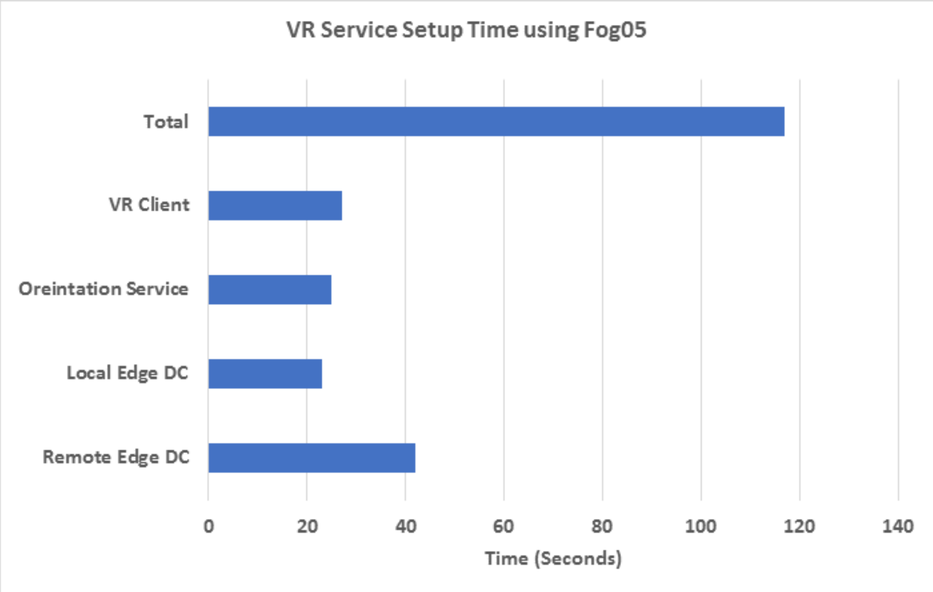

FIGURE 3-8:BREAKDOWN OF THE AVERAGE SERVICE SETUP TIME FOR THE VR POC.

3.2.8 Integration and Validation Timeline

Table 3-8 shows the VR PoC integration and validation timeline.

TABLE 3-8: POC#2 TIMELINE

Description	VIRTUAL REALITY
Q1 – 2018	• Identification of key building blocks characterizing the VR application
Q2 - 2018	• Evaluation of different options for EFS entity deployment • Initial development of APIs for the ET orientation service • Preliminary tests conducted on the designated fog nodes
Q3 - 2018	• Integration of the ET orientation service APIs into the EFS • Initial testing of Fog05 capability of instantiating the orientation service and performing live migration • First demonstration of the VR PoC at EuMA conference (Madrid, Sept 2018)
Q4 – 2018	• Installation and testing activities inside the shopping mall in Taiwan • Shopping mall trials in Taiwan
Q1 - 2019	• Identification of new EFS services capable of running on fog nodes • Development of APIs to enable new EFS services, such as DASH coding, segmentation, decoding, etc.

3.3 PoC#3: Cloud Robotics

3.3.1 Description

The Cloud Robotics PoC consists of two demo scenarios: cleaning robots and delivery robots. The idea of the cleaning robots scenario is to have robots that would autonomously clean an area of the shopping mall. The robots would clean periodically based on the density of visitors (people) in a given area of the shopping mall or manually triggered by a shopping mall employee upon an incident e.g., broken glass in some area. For this scenario to be realized, a dedicated virtual network would be created for the robots, to isolate their operation and enable a third-party company to deal with the day to day operations. The robots would be connected to the (virtual) network with the intelligence of the robots residing in the network. At start the robots would be in idle state, connected to the network and out of sight for the shopping mall visitors. The EFS would trigger (periodically or event-based) the cleaning of a certain area (e.g., where there are less visitors). For the sake of presentation, this can be manually predetermined area. The robots would use the localization service to navigate their way to the cleaning area. Then the robots would clean the area and return by navigating back to the initial position. This demo scenario can be realized with single or multiple robots.

The second demo scenario 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. Similarly, to the first demo scenario, a dedicated virtual network for the robots would be created in which the intelligence of the robots would reside. At start the robots are in idle state (maintaining the network connection) located in the storage room. An employee would manually initiate the transportation of a large items from the storage room to a shop. Two (or more) robots would form a fleet using Wi-Fi and Bluetooth technology. The Wi-Fi would be used for infrastructure-to-robot communication assisting the robots for navigation and establishing Bluetooth robot-to-robot connection. The Bluetooth connection would be established for robot-to-robot or Device-to-Device (D2D) communication for low-latency connection and maintaining better coordination (e.g., moving in formation). Upon establishing the fleet (formation) the large item is loaded on the robot. The robots deliver the item to the destination while maintaining the formation. Once the item is delivered, the robots break the formation and navigate back to the idle location.

As described in the previous section, in order to realize the Cloud robotics scenario, several components need to be deployed. All EFS entities are shown in the Figure 3-9. The Virtual AP EFS function is deployed in the APs of the shopping mall to enable isolated network for the robots. The Robot brain EFS application is deployed as single instance on a Fog CD in the shopping mall. It is the core EFS application that includes navigation and control functionalities. The Robot Navigation App consumes the localization EFS service, processing and delivering the real-time location of the robots to the Robot Control App. The Robot Control App by obtaining the location information and sensor data from the robots, issues navigation directions or other commands to the robots.

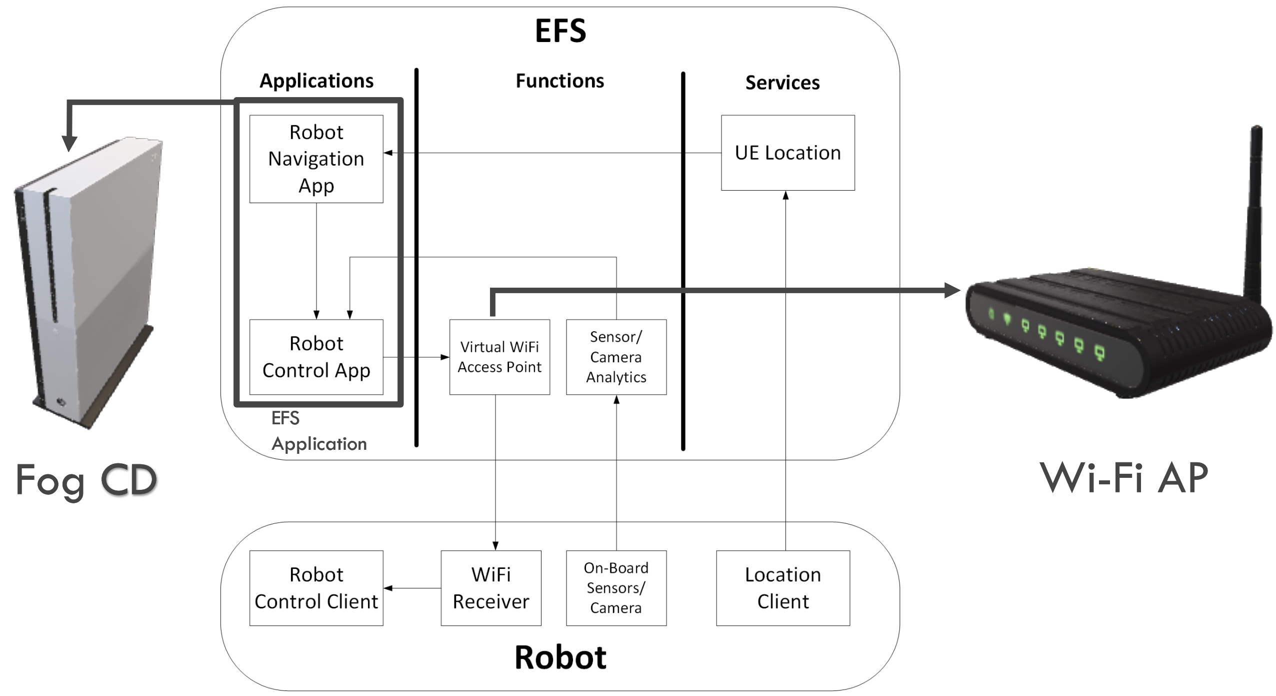

FIGURE 3-9: INTERCONNECTION OF EFS ENTITIES IN CLOUD ROBOTICS USE CASE

3.3.2 Relation with Project Objectives

Table 3-9 shows the relations of the two demos of Cloud Robotics PoC with the 5G-CORAL project objectives.

TABLE 3-9: POC#3 RELATION WITH PROJECT OBJECTIVES

Project Objectives	How this demo will tackle the project objectives
Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	
R&D Topic 3.2: Authentication functions for facilitating session continuity, aggregation, and offloading across multiple RATs	Demo 2: Bluetooth D2D is authenticated and established via WiFi
R&D Topic 3.3: Network-assisted D2D function for discovery and communication of proximity networking and computing resources	Demo 2: Bluetooth D2D used for local control feedback loop between the robots
R&D Topic 3.4: Network-offloading function that enables device and core network offloading by running some of its functions in the EFS	Demo 1 and 2: Robot intelligence moved in the EFS
Verification: Validate selected EFS components through a system verification in the integration testbeds from WP4	Components will be integrated and verified in the Shopping Mall Testbed
Objective 3: Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources	
R & D Topic 3: Develop interfaces for automated deployment of EFS functions and applications	Demo 1 and 2: all the components composing the robot service are automatically deployed

R & D Topic 5: Develop orchestration and control algorithms for elastic placement and migration of EFS functions and optimised allocation of EFS resources	- Demo 1: main intelligence over WiFi but close to the edge to reduce robot reaction time - Demo 2: main intelligence over WiFi for high-level fleet coordination and local feedback on the robot via Bluetooth D2D
Verification: Validate selected OCS components through a system verification in the integration testbeds from WP4	Components will be integrated and verified in the Shopping Mall Testbed
Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
R & D Topic 2: Integrate and validate EFS and OCS in large-scale testbeds, such as shopping mall, high-speed train, and connected cars	Both robot demos integrates EFS and OCS and will be demonstrated on the large-scale testbed of the Shopping Mall Scenario
R & D Topic 3: 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.	Demo 1 and 2 demonstrate multi-RAT access convergence, it's not augmented reality and car safety, but edge robotics is equally valid
Verification: 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.	Demonstration of the Robot demo in the Shopping Mall testbed

3.3.3 Initial Performance Metrics

Table 3-10 provides an initial list of performance metrics which will be measured through the experiments using both demos of the Cloud Robotics PoC.

TABLE 3-10: POC#3 PERFORMANCE MEASURES/METRICS

Performance metrics	Description	Way of measurement
Delay	Communication delay between the Fog CDs and the robots	Using ping to reach the robot
Low-latency	The latency between issuing a command remotely (from the robot intelligence application) and execution of the command by the robot	The time between issuing the command and receiving the acknowledgment from the robot.
Deployment time (of APs)	The time it takes to create the new APs in the Fog CDs using the hostapd.	The time between issuing the operation and successful deployment.
Migration time	The time it takes to migrate the robotic intelligence from the central point, closer to the edge. As well as the time it takes to migrate from one to another Fog CD, due to mobility of the robots.	The time between issuing the operation and its completion.
D2D deployment time	The required time to establish D2D Bluetooth connectivity between two	The time between initiating the operation and the pairing between two robots.

	robots, using the WiFi as infrastructure-assistance.

3.3.4 Relation with Use Case

The Cloud Robotics PoC is mainly related with the use case UC3.7: "Robotic-assisted shopping mall" defined in WP1, implementing the cleaning and items delivery demos.

3.3.5 Software/Hardware Configuration

This PoC requires the following hardware devices to run different software components:

- **Robots –** The first demo scenario can be realized with a single robot, whereas for the second scenario (item delivery) at least two robots are needed to present the robot-to-robot coordination and moving in formation. The robots would be pre-built robots (e.g., Robotnik – Turtlebot [11] equipped with various sensors (Kinect and/or camera) with software component running on top the Robot Operating System (ROS). The Turtlebot robot is shown on Figure 3-10 on the left. On Figure 3-10 on the right are shown the Lego Mindstorm robots used in the demonstration described in Section 4.1.1.

FIGURE 3-10: TURTLEBOT ROBOT (LEFT) AND LEGO MINDSTORM EV3 ROBOTS (RIGHT)

- **Access Points (APs) –** One or more hosting systems (devices) that can support LXD and have 802.11 cards. The host device would run *hostapd* inside LXD containers in order to create new 802.11 access points. The newly created access points use the same (existing) physical interface. The LXD containers are based on the Alpine Linux (lightweight Linux distribution for cloud environments).
- **Gateway –** Single hosting system with Internet connectivity that supports LXD/KVM. A DHCP server would run on top and the device would act as a gateway for the robots' end-to-end service.
- **Intelligence point –** Single or multiple host devices that support KVM. The robots' intelligence is stored and run on these devices. The devices would be responsible for migration of the intelligence when is needed.

3.3.6 Required 5G-CORAL Building Blocks

Table 3-11 presents the 5G-CORAL (OCS and EFS) building blocks through which the Cloud Robotics PoC is implemented.

TABLE 3-11: POC#3 5G-CORAL BUILDING BLOCKS

Sub-system	Component's Name	Description
OCS	Instantiation of functions	**EFS function** - Automatic instantiation. Configuration of the WiFI AP, deployment and instantiation of the Robot App into the robot.
OCS	Mobility	**EFS Function** - Mobility of the Access Point (AP) configuration, control functions and robotic intelligence.
OCS	RNIS (LTE+WIFI)	**EFS Function** - Leveraging on LTE and WiFi Radio Network Information Service to initiate deployment or migration.
EFS+OCS	D2D Network assisted	Implementation of the Bluetooth Network Encapsulation Protocol (BNEP) is implementation of **EFS function** that enables transferring another protocol stack's data (e.g., IP) via an L2CAP channel between robots.
EFS+OCS	Navigation system	**EFS Service** - Navigation system for the robot to navigate through the Shopping Mall
EFS	Localization service	**EFS Service** -The density of visitors supports the system to initiate the demo scenarios and where to operate. The localization service provides significant information for the robot to navigate and reach the desired location in the shopping mall.
EFS	EFS robotic intelligence application	Implementation of the robotics intelligence to be placed in the EFS system as **EFS application**. In other words the robotic intelligence would reside in the network as EFS application which is required to accomplish all the demo scenarios.

3.3.7 Interim Results

This section presents the results from the demonstration of the Robotic PoC (Section 4.1.1). Figure 3-11 presents deployment time and termination time of the cloud robotics EFS Stack. The cloud robotics EFS Stack is deployed on two Raspberry Pi devices. The results are extracted from 100 deployments/terminations. The statistical results are shown in Table 3-12 The EFS Stack (Section 2.3 – Deliverable 3.1) is composed of a brain EFS application, a gateway EFS function and a virtual access point EFS function. The EFS application and EFS functions are delivered in a form of LXD containers.

TABLE 3-12: STATISTICAL CHARACTERISTICS OF CREATION & TERMINATION OF ROBOTIC EFS STACK

Operation	Mean (s)	5th pctl (s)	95th pctl (s)	Mode (s)	Median (s)	Std (s)
Create	9.24	7.60	10.38	7.60	9.03	0.88
Terminate	20.82	11.98	28.52	11.66	21.09	5.26

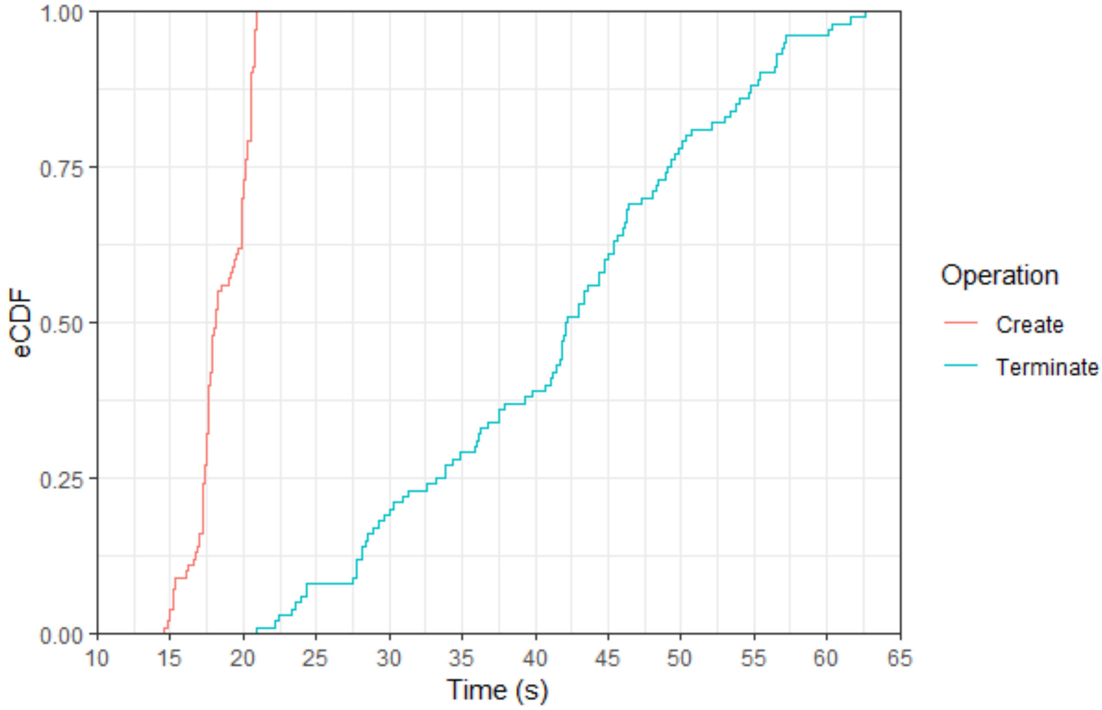

FIGURE 3-11: CREATION TIME & TERMINATION TIME OF CLOUD ROBOTICS EFS STACK IN THE FOGO5

Additional results extracted from the demo are the delay between the Fog CDs and the robot. Figure 3-12 shows the delay over 100 ping requests. Table 3-13 presents the statistical results of the delay measurements.

TABLE 3-13: STATISTICAL RESULTS OF THE DELAY (MS) BETWEEN FOGCD AND ROBOT

Parameter	Mean (ms)	5th pctl (ms)	95th pctl (ms)	Mode (ms)	Median (ms)	Std (ms)
RTT (ping)	6.08	4.33	7.95	5.95	5.95	1.23

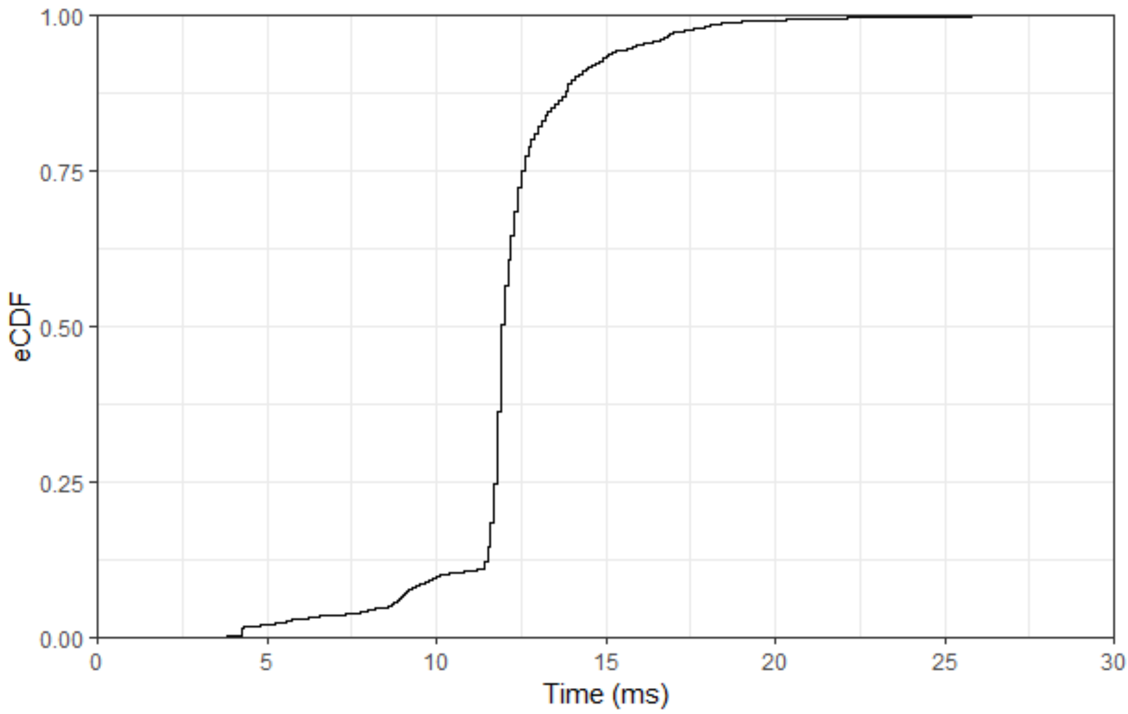

FIGURE 3-12: DELAY TIME (MS) BETWEEN FOG CD AND ROBOT

3.3.8 Integration and Validation Timeline

The timeline plan is to have a fully functional demo by end of October 2018. Initial demo presentation is shown on the EuCNC conference in June 2018 (Section 6.4.1).

TABLE 3-14: POC#3 TIMELINE

Description	Cloud Robotics
Q1 – 2018	• Research and planning of the PoC hardware/software components
Q2 - 2018	• Building fully functional demo for EuCNC 2018 conference • Demo built with small Lego Mindstorm robots

Q3 - 2018	• Expanding small demo to Turtlebot robots
	• Developing the PoC for trial in Taiwan
	  ○ Navigation using LIDAR
	  ○ Localization using iBeacons+WiFi

Q4 – 2018	• Installation and testing activities inside the shopping mall in Taiwan • Shopping mall trials in Taiwan
Q1 - 2019	• Finalizing open points and issues from the Taiwanese trial
Q2 - 2019	• Integration of MEC in the PoC • Developing demo for EuCNC 2019 conference
Q3 - 2019	• Installation and testing activities inside shopping mall • Final shopping mall presentation • Demo presentation on Sigcomm 2019/ CoNEXT 2019 conference

3.4 PoC #4: IoT Multi-RAT

3.4.1 Description

The IoT Multi-RAT access system introduces a technology-agnostic IoT access system, for future-proof IoT support. It follows the Cloud-RAN approach, centralizing baseband processing at the Edge in EFS. The system comprises of three parts: radio heads, Ethernet network and edge cloud, as shown in Figure 3-13. The radio heads are in charge of transmitting and receiving radio signals. It is connected to a (or several) communication stack, running on the EFS in an Edge cloud. Each communication stack is in charge of modulating/demodulating the radio signals for one RAT, as well as of handling all upper layers. For example, in the 6LoWPAN [12] case for instance, it runs IEEE 802.15.4, 6LoWPAN, RPL [13], etc.

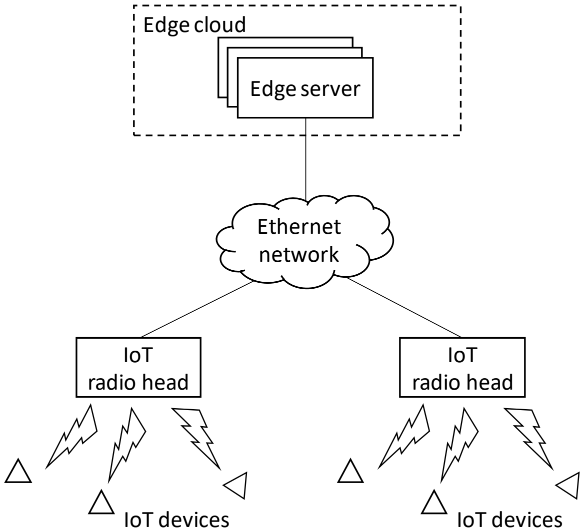

Figure 3-13: Illustration of a multi-RAT IoT access system

The IoT Multi-RAT PoC testbed is designed to explore the possibilities, investigate the implementation issues and showcase the feasibility. Figure 3-14shows the testbed setup. In the testbed, we aim to develop two RATs with 6LoWPAN (i.e. IEEE 802.15.4 [14]) and NB-IoT at an edge server/PC. In the testbed, we use 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. The communication stacks of 15.4 and NB-IoT are running on the edge PC for baseband processing of the IQ samples of the two RATs. Currently, the communication stacks are implemented with GNURadio [15] for PoC design. For NB-IoT, we mainly focus on the PHY implementation and investigation. For 15.4, we aim to develop full stack of 6LoWPAN. In the testbed, we will use real IoT devices (Zolertia Firefly), to demonstrate end-to-end connectivity for 15.4. For NB-IoT, an SDR-based terminal will be developed with the focus on PHY implementation.

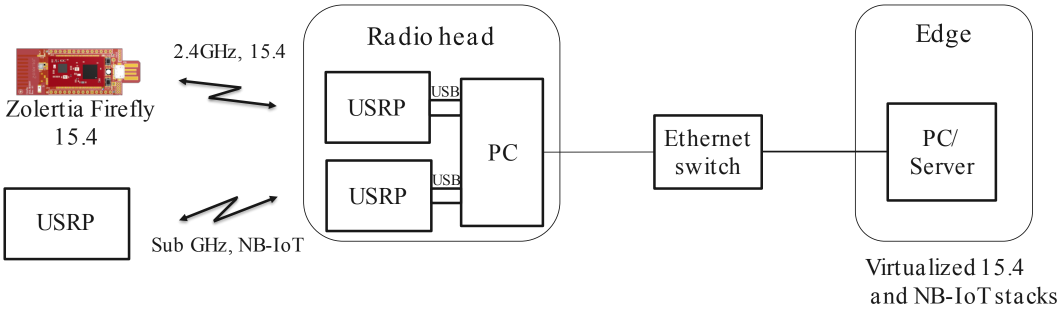

FIGURE 3-14: POC#4 SETUP OF MULTI-RAT IOT

Figure 3-15 shows the implementation diagram for 15.4. The implementation builds on GNURadio for IEEE 802.15.4 and signaling between AP and Edge, and on Contiki-NG [16], for upper-layer stack implementation. The Edge node will be running an RPL border router, offering connectivity to IoT devices in the vicinity of the radio head. Thanks to RPL, the connectivity can even extend over multiple low-power wireless hops. The setup will also involve several IoT devices (Zolertia Firefly, as shown in Figure 3-15). A photo of the current PoC prototype can also be seen in Figure 3-16.

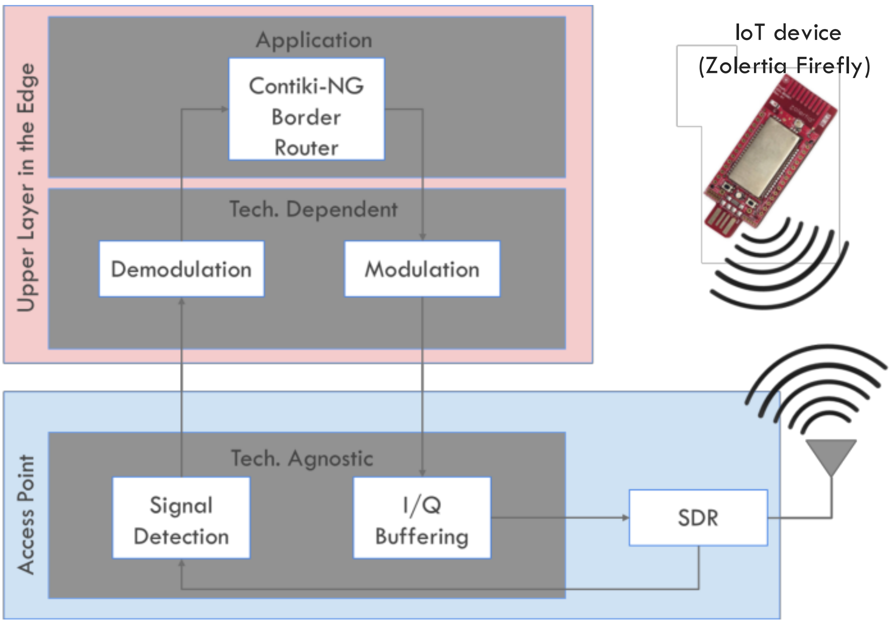

FIGURE 3-15: 15.4 IMPLEMENTATION EXAMPLE

3.4.2 Relation with Project Objectives

Table 3-15 shows the relations of the IoT Multi-RAT PoC with the 5G-CORAL project objectives.

TABLE 3-15: POC#4 RELATION WITH PROJECT OBJECTIVES

Project Objectives	How this PoC will tackle the project objectives
Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	
R&D Topic 1: *Multi-RAT convergence function* to optimise the traffic delivery across the multiple RATs (e.g., selection, aggregation, offloading).	The PoC is primarily focused on multi-RAT access for IoT. Multiple RATs such as NB-IoT and 15.4 stacks are softwarized and centralized at one edge node. The communication stacks are virtualized. It shows the IoT

	access convergence with multi-RAT processing aggregation.
Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
R & D Topic 2: Integrate and validate EFS and OCS in large-scale testbeds, such as shopping mall, high-speed train, and connected cars	The PoC validates the EFS components involved, in the shopping mall context.
R & D Topic 3: 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.	Demonstrated multi-RAT access convergence for IoT applications, i.e., low-power wireless, including NB-IoT and multi-hop mesh with IEEE 802.15.4.

3.4.3 Initial Performance Metrics

Table 3-16 shows the initial performance metrics list. Highlighted performance metrics will be measured using the VR PoC.

TABLE 3-16: POC#4 PERFORMANCE MEASURES/METRICS

Performance metrics	Description	Way of measurement
Communication latency	The end-to-end latency between a wireless node one hop from the AP and the communication stack residing at the Edge.	Ping from border router at the Edge towards wireless node.
Communication throughput	The end-to-end datarate achievable between a wireless node one hop from the AP and the communication stack residing at the Edge.	Continuous UDP transmission from border router at the Edge towards wireless node. Node reports measured data rate via a serial port used as means of measurement.
SNR	For NB-IoT, SNR (signal to noise ratio) at the receiver can be measured.	Measure SNR by software implementation with GNURadio.
PER/BER	For NB-IoT, packet error rate (PER) and bit error rate (BER)	Measure PER/BER by software implementation in GNURadio.

3.4.4 Relation with Use Case

This PoC is mainly related with the IoT Multi-RAT use case [D1.1].

3.4.5 Software/Hardware Configuration

The required hardware and software components are listed below:

- **Radio head:** the radio head is the physical radio interface for the virtualized communication stacks. It is implemented using USRP B210 mounted on miniPC. We are also investigating the possibility to use the LimeSDR platform, which is cheaper, thus allowing larger scale experimentation. The SDR is connected to a mini PC such as Intel NUC. The mini PC runs GNURadio software components for connectivity with communication stack software on the Edge PC.
- **Edge PC:** act as an Edge cloud node. We currently use an Intel NUC PC (i7-6670HQ CPU, 8GB DDR4 Memory, 500GB SSD).
- **IoT devices:**
    - For 15.4, several Zolertia Firefly boards are used.
    - For NB-IoT, an SDR-based terminal comprising of one USRP B210 and a mini PC.

- **Ethernet connectivity:** Gigabit Ethernet connection between the AP and the edge PC.
- **Communication stack software:** the communication stack is virtualized and runs on the edge PC. For virtualization, we use Docker to run the containers. The containers contain (1) the GNURadio software components for connectivity with the AP, (2) the GNURadio software components for IEEE 802.15.4 PHY and NB-IoT support, and (3) the Contiki-NG communication stack (IEEE 802.15.4 MAC and above incl. 6LoWPAN and RPL).

3.4.6 Required 5G-CORAL Building Blocks

Table 3-17 shows an exhaustive list of 5G-CORAL EFS and OCS building blocks that constitute the IoT Multi-RAT PoC.

TABLE 3-17: POC#4 REQUIRED 5G-CORAL BUILDING BLOCKS

Area	Component's Name	Description
EFS Function	IoT Communication Stack	Network layers of the various RATs (e.g. 15.4 and NB-IoT), and upper layers (e.g. 6LoWPAN)
EFS Function	IoT Performance Enhancement	Interference mitigation and other schemes that improve performance of IoT communication.
EFS Function	IoT Localization Estimation	Localization estimation from low-level radio signal data. IoT access points (or anchors) are sensing and using the information to estimate object location from their emissions.
EFS Service	Communication metadata	The raw radio signals (IQ data), form the communication stack. Covers a variety of frequencies and RATs.
EFS Service	Localization service	The localization service to detect the position of the devices.
EFS Application	User navigation	Guides a user in e.g. the shopping mall, through their smart phone.
EFS Application	Object localization	Localizes an IoT object, using data gathered at anchors.
OCS	Instantiation and deployment	Enables all EFS components above. The communication stack is instantiated and deployed once for each RAT.
Non-EFS	Multi-RAT IoT radio head	The technology-agnostic IoT radio head (software-defined radio + Edge connectivity)

3.4.7 Interim Results

Figure 3-16 shows the photo of the edge side of the testbed. As described in section 3.4.5, it comprises of a radio head (USRP B210 + an Intel NUC PC), a Gigabit switch and an edge PC (Intel NUC). On the edge PC, two RATs of 15.4 and NB-IoT are being implemented. This setup is used for performance evaluation. In this section, we provide some early measurement results to report first year progresses.

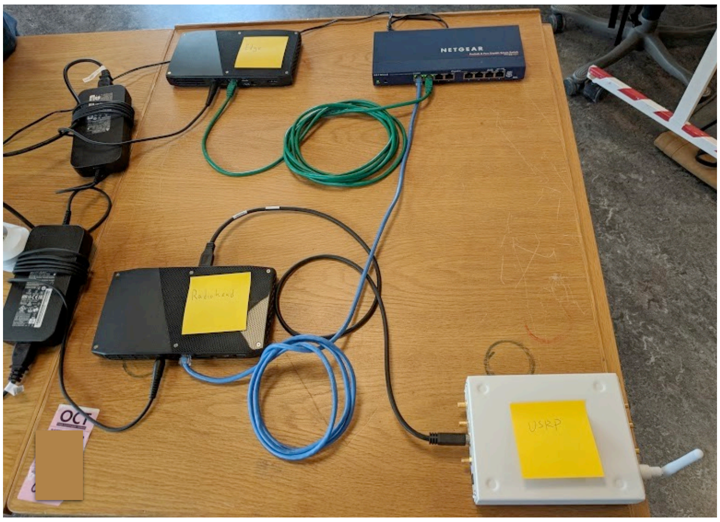

FIGURE 3-16: PHOTO OF CURRENT TESTBED SETUP (RADIO HEAD, ETHERNET SWITCH AND EDGE PC)

3.4.7.1 IEEE 802.15.4 Results

We conduct a performance characterization of the LimeSDR platform for the IEEE 802.15.4 stack. We use the Wime project implementation, and instrument the system to timestamp packet transmission and reception events at different levels in the system: the GNURadio software stack, the LimeSDR driver, the USB controller, and the LimeSDR hardware. The different measurement points are shown and labelled in Figure 3-17.

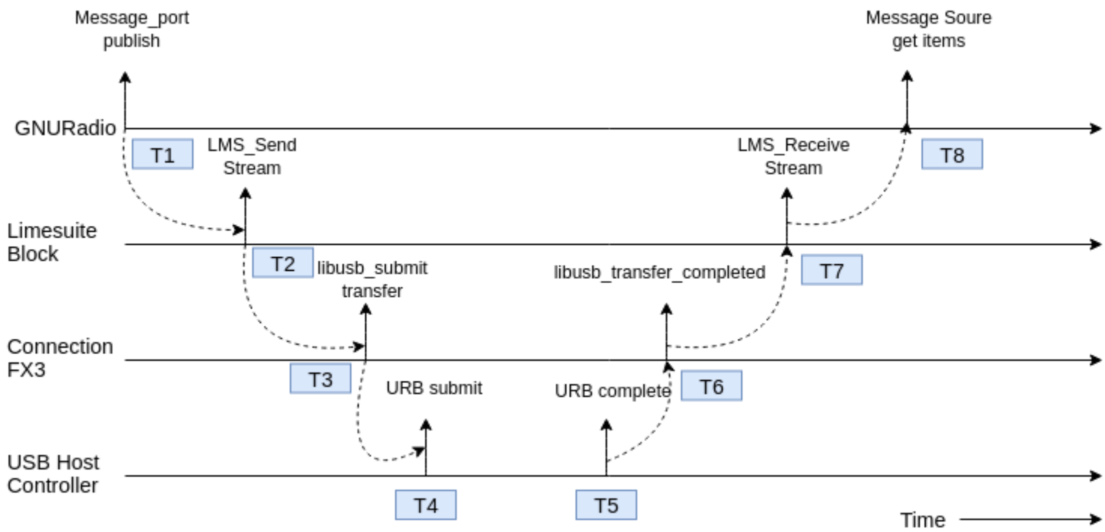

FIGURE 3-17: MEASUREMENT POINTS FOR THE LIMESDR PERFORMANCE CHARACTERIZATION

We designed an experiment to measure the time spent in each component of the chain. A message source generates periodically a 10-byte message every 500 ms. The message is fed to the measurement setup mentioned above, with the TX and RX of the RF Integrated Circuit shorted, so the messages loops back from the TX to the RX.

The result is presented in Figure 3-18. It shows that the GNU Radio component (in charge of modulation/demodulation in software) takes the most time, both in the TX and RX chains. It also contributes the maximum number of jitter to the Round Trip Times. In the TX case, the GNU Radio takes roughly around 250-375 microseconds, whereas on the RX side, it increases to 850-1176 microseconds, so there is a definite need to minimize the processing times.

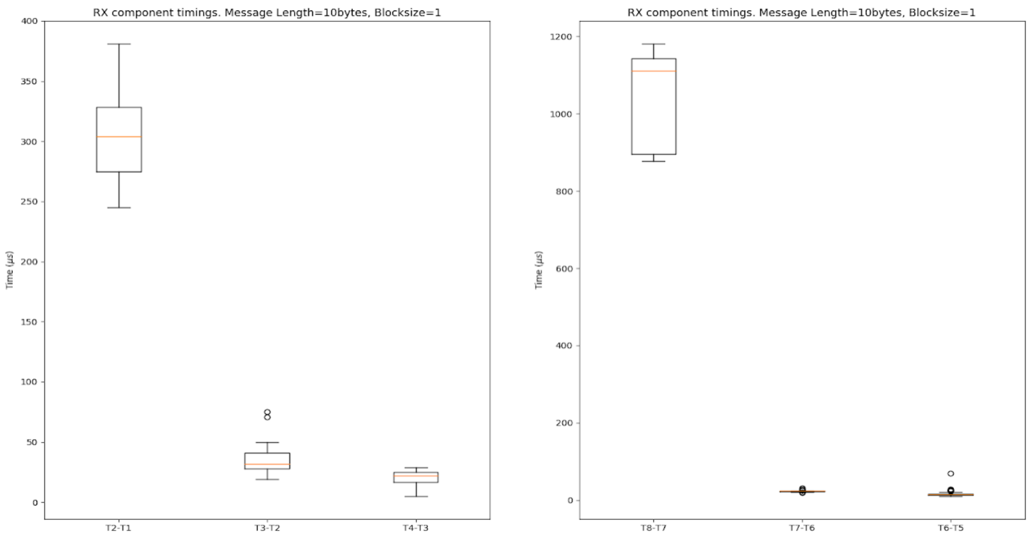

FIGURE 3-18: LIMESDR PERFORMANCE CHARACTERIZATION

In another experiment, we investigate the CPU usage and context switches with GNURadio. A message source generates a packet every 500 ms over 100 seconds. The USB transfer size was set to 2 kB and the number of elements for each block in GNU Radio to 2000. The red dots represent the outliers for the round-trip measurement done on the received packets. In this experiment, the average CPU usage is of 358% (4 core processor). The experiment also shows that neither of these two parameters (%CPU and context switches) can be attributed to the outliers in the round-trip times.

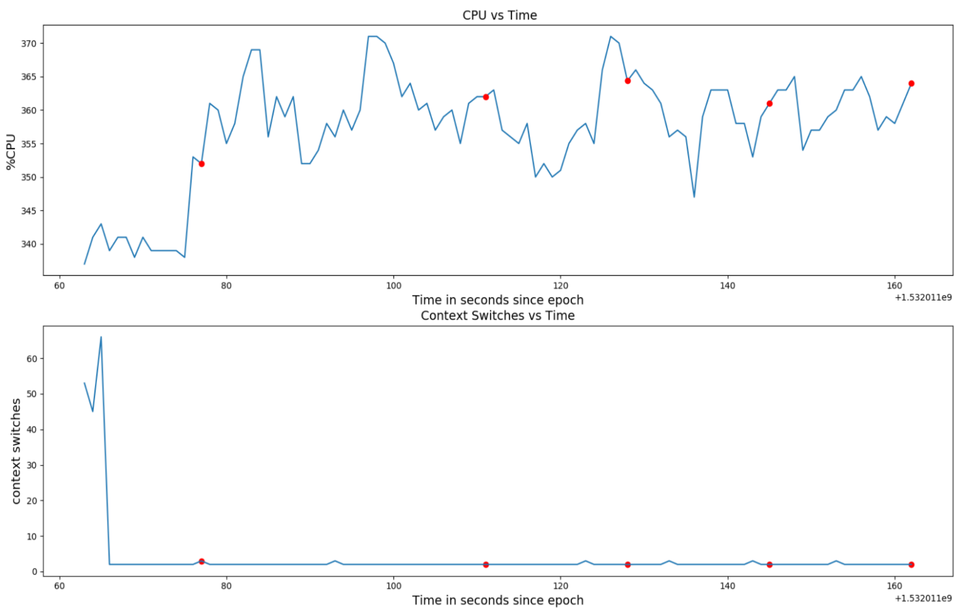

FIGURE 3-19: GNURADIO CPU USAGE CHARACTERIZATION

3.4.7.2 NB-IoT Results

Currently, some key component of NB-IoT PHY have been implemented, OFDM transmitter and receiver following the NB-IoT numerology with NPSS, NSSS and NRS implemented. A convolutional code of coding rate ½ is used for the time being. The PHY layer performance for the current implementation has been measured in our office environment, as shown in Figure 3-20. We placed the NB-IoT transmitter at an office lab room at the up-left corner on the floor plan. The transmit power is configured to 15 dBm, maximum Tx power of USRP B210. To stress the measurement, 4 locations are selected for this measurement, as shown in Figure 3-20.

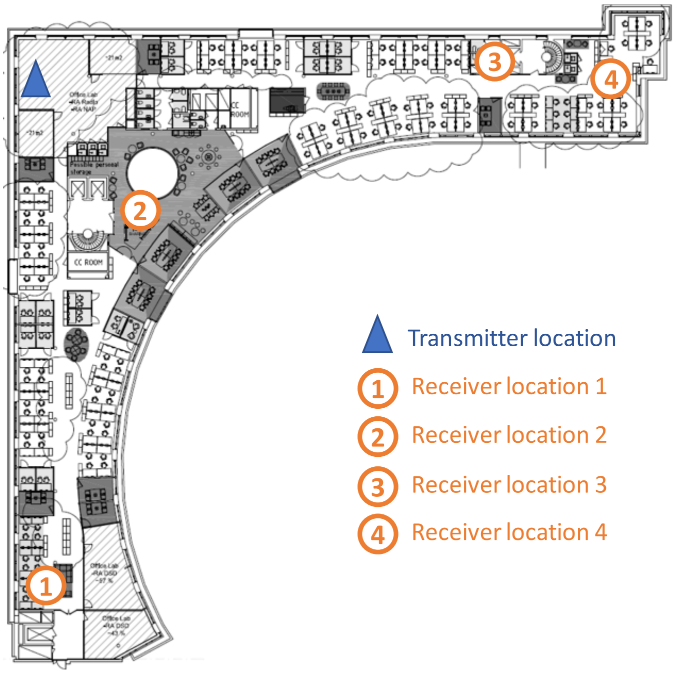

FIGURE 3-20: FLOOR PLAN OF NB-IOT MEASUREMENT

Location 1 is about 60 meters away and has non-line-of-sight (NLOS) at the lower corridor (connected to the office lab room with a glass door) in the floor plan, Location 2 is about 20 meters away at the hallway connected to the office lab room through a glass door. However, it is still NLOS but the signal blocking situation is somewhat better than location 1. Location 3 and 4 are in the upper corridor (connected to the office lab room with a glass door). In this case, a line-of-sight (LOS) signal is available through the door. However, location 3 is beside the corridor and thus has NLOS, while location 4 is in the corridor and thus has LOS.

Table 3-18 shows the measurement results of BER, PER and SNR. The results look reasonable. With LOS for location 1, it can reach quite long more than 60 meters with low PER. With NLOS, the reach is much shorter. Location 2 achieve a similar performance to location 4 at only 20 meters. For longer distance of location 1 and 3 (60 meters and 50 meters), the PER is high due to the low SNR achieved because of longer distances and NLOS.

TABLE 3-18: NB-IOT MEASUREMENT RESULTS OF BER, PER AND SNR

Location	Distance	Description	BER	PER	SNR
1	60 m	End of the corridor, metal-framed glass door in between, NLOS.	1.89%	57.12%	8.4 dB
2	20 m	Metal-framed glass door in between, Metal handrail in between, NLOS.	0.0003%	2%	16.2 dB
3	50 m	Transmitter behind metal-framed glass door, receiver at the side of the corridor, NLOS.	6.43%	66.37%	5.8 dB
4	65 m	End of the corridor. Metal-framed glass door in between, LOS.	0.03%	0.5%	15.9 dB

3.4.8 Integration and Validation Timeline

Table 3-19 shows the integration and validation timeline of the IoT Multi-RAT PoC

Table 3-19: POC#4 Timeline

Description	Multi-RAT IoT Gateway Demo
Q1 - 2018	• Implementation started • Explored LimeSDR platform for the AP • Explored GNURadio
Q2 - 2018	• First working demo with IEEE 802.15.4 as RAT • Contiki-NG used for IEEE 802.15.4 MAC and layers above • Started to implement NB-IoT PHY components
Q3 - 2018	• Further maturation of the demo • Stability enhancement for Radio head-Edge connectivity • Added support for NB-IoT as RAT (DL)
Q4 – 2018	• Performance investigation of NB-IoT DL • Performance characterization of virtualized IEEE 802.15.4 stack
Q1 - 2019	• Performance enhancement of the IEEE 802.15.4 stack (latency, jitter, bandwidth) • NB-IoT: TBD
Q2 - 2019	• Final integration
Q3 - 2019	• Final experimentation and testing

3.5 PoC #5: High-Speed Train

3.5.1 Description

Many mobility challenges are involved in the operation of high-speed trains. In particular, handover and service migration for a group of users can create network congestion and service interruption. Signalling storms can be the result of malfunctioning apps that repeatedly establish and tear-down data connections with a serious effect on the QoS of the network control plane. Adopting the 5G-Coral architecture for 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 for moving network. This is especially true when users are switching from on-board the high-speed train into the train station. Also, this will allow service continuity while transiting from the train into the train station.

The main focus of the high-speed train PoC is when passengers get off the train to the station which may be integrated/co-located with another environment, such as the shopping mall testbed in Taiwan. This demo covers handover and service migration for a group of users. Initially, many passengers/users are connected to high-speed train network via WiFi access point or Small cell access point on board the train. Different users use different applications such as video streaming, voice call, web-browsing, AR with different QoS requirements. Fog nodes will classify users based on Multi-RAT context information from WiFi and LTE into groups. Also, when the train approaches the train station, Fog nodes will trigger handover and service migration for the classified group of users. EFS entities deployed on top of Fog CD are shown in Figure 3-21.

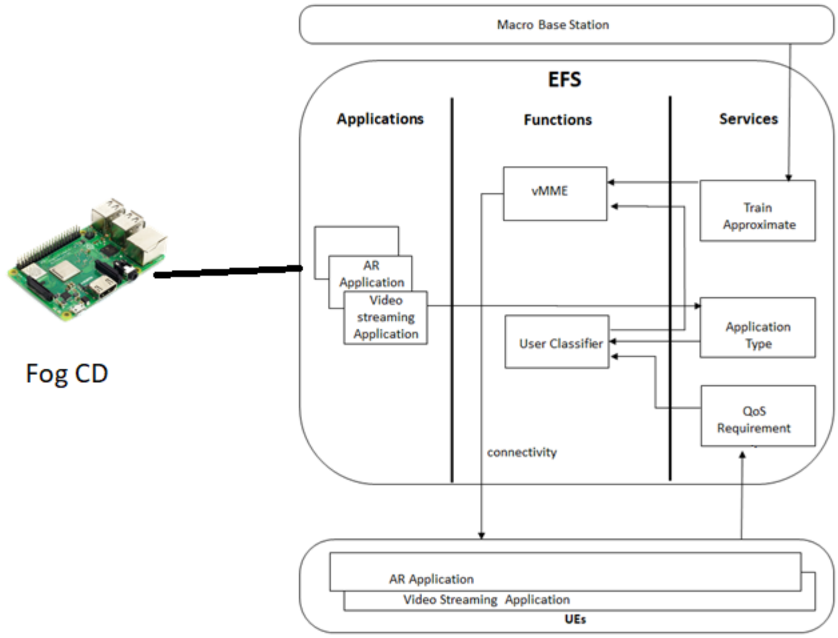

FIGURE 3-21: EFS ENTITIES DEPLOYED ON FOG CD FOR HIGH-SPEED TRAIN USE CASE

3.5.2 Relation with Project Objectives

Table 3-20 shows the relations of the High-Speed Train PoC with the 5G-CORAL project objectives.

TABLE 3-20: HIGH SPEED TRAIN RELATION WITH THE PROJECT OBJECTIVES

Project Objectives	How this demo will tackle the project objectives
Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	
R&D Topic 1: Multi-RAT convergence function to optimise the traffic delivery across the multiple RATs (e.g., selection, aggregation, offloading).	Context information will be extracted from WiFi and Small Cells and will take part in classification users into groups which contribute into offloading and traffic loads.
R & D Topic 2: Develop EFS applications using EFS services from multiple RATs and the transport and core networks to improve network KPIs and user QoE	Using EFS services and functions related to multi-RATs will improve network KPI especially in term of QoE.
Objective 3: Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources	
R & D Topic 5: Develop orchestration and control algorithms for elastic placement and migration of EFS functions and optimised allocation of EFS resources	This demo will optimize resources especially when service migration is needed
Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
R & D Topic 2: Integrate and validate EFS and OCS in large-scale testbeds,	High-speed train demo focusing on validation of EFS and OCS.

such as shopping mall, high-speed train, and connected cars	
R & D Topic 3: 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.	High-speed train demo demonstrate multi-RAT access convergence.

3.5.3 Initial Performance Objectives

Table 3-21 provides an initial list of performance metrics which will be measured through the experiments using high-speed train PoC. Additional metrics are being considered and interim results are being obtained from the ongoing experiments. These will be reported in the next deliverable (D4.2).

TABLE 3-21: POC#5 PERFORMANCE MEASURES/METRICS

Performance metrics	Description	Way of measurement
Migration time	The time requires to migrate an application from on board Fog CD to on land Fog CD due to the mobility of the user.	Starting and Ending time can be time-stamped to obtain the samples
Handover Latency	Round trip time between issuing handover command from eNB and Complete of handover	Time difference between execution of an issue command and receiving the acknowledgment of completion of handover.

3.5.4 Relation with Use Case

The High-speed train PoC is mainly related to the High-speed train use case [D1.1], implementing a group of user handover and a group of user service migration.

3.5.5 Software/Hardware Configuration

This PoC uses several software/hardware components as listed below:

- **Fog Node** - Fog node will be used to host several functions and services of EFS. As EFS functions, vMME and user classifier function will be hosted in the Fog node. As EFS services, QoS, application type and train approximate, which is defined based on PCID of near Macro Base Station, will be hosted on the Fog node. Where, train approximate service will help to determine the macro base station which is connected currently to train, and since the route of the train is known, the approximate location of the train can be determined. Also, the QoS and application services will extract the context information provided by different RATs (WiFi and LTE). Then the user classifier function will classify the user into groups based on obtained information earlier. When the train approaches to the train station, handover of a group of users and service migration for a group of the user will be executed.
- **Access Points (APs)** - One or more hosting devices have 802.11 cards.
- **Small cell** - one small cell will act as eNB on-board the train. Another small cell will act as on land Macro base station, which has the capability to change RSSI and can emulate the high-speed train signal degradation.
- **CPE –** Gateway between on board and on land eNB/small cell. Also it can act as WiFi AP.
- **Smartphones/Wearables** - End devices such as smartphones will be used for different services such as video streaming.

- **Core network** - one computer (e.g. i7, Ubuntu, 12GB) have NExtEPC to act as a core network in high-speed train demo.

3.5.6 Required 5G-CORAL Building Blocks

TABLE 3-22 provides an exhaustive list of 5G-CORAL EFS and OCS building blocks (sub-system) to form a working high-speed train PoC.

Table 3-22: High Speed Train Required 5G-Coral Building Blocks

Sub-system	Component's Name	Description
EFS	vMME	An **EFS Function** responsible to redirect local traffic from onboard and onland Responsible to handover the classified group of users from onboard to on land
EFS	User Classifier	An **EFS Function** to classify users into groups based on the shared application type and QoS requirements
EFS	Train approximate	An **EFS Service** to report the approximate location of the train based on PCI information of Macro base station deployed along the railway.
EFS	QoS and application type service	An **EFS Service** to report users context information related to QoS and application type such as data session, allocated resources, bearer service, network internal routing information.
Non-EFS	LTE Small Cell platform, EPC components	Responsible to provide the connectivity for the end user on the Train and the EFS components
OCS	Service Migration	An **OCS** Component to migrate the end user content from onboard to on land unit once the train approaches the train station.

3.5.7 Interim Results

In ITRI labs, the two-hop architecture adopted by high-speed train testbed was successfully emulated and the reference measurement are shown in Table 3-23. Next step will be focusing on latency measurement and live migration for group of users with different QoS requirements

TABLE 3-23: STATISTICAL RESULTS FOR EMULATED HIGH-SPEED TRAIN USE CASE

Measurement	Minimum	Average	Maximum	Standard deviation
Ping latency from fog CD to core network	38.53ms	49.66 ms	96.78ms	7.46ms
Ping latency from UE to core network	40.63ms	72.30 ms	443.07ms	28.64ms
iperf tcp test from fog CD to core network	34.6 Mbps	35Mbps	37.9Mbps	N/A

iperf tcp test from UE to core network	9.3Mbps	15.3Mbps	24Mbps	N/A

3.5.8 Integration and Validation Timeline

The timeline of high-speed train use case is presented in Table 3-24 as follow:

Table 3-24: PoC#5 Timeline

Description	High-Speed Train Demo
Q1 - 2018	• In lab emulation for high-speed train testbed
Q2 - 2018	• Install vMME using NExtEPC and performance for End-to-End throughput, latency
Q3 - 2018	• Building EFS functions, services
Q4 - 2018	• High-speed train demo for handover for group of users
Q1 - 2019	• High-speed train demo for service migration for group of users
Q2 - 2019	• Optimise system performance
Q3 - 2019	• Final integration of all Demos and components

3.6 PoC#6: Connected Cars

3.6.1 Description

Azcom and Telecom Italia demonstration focuses on "Road Safety" use cases, specifically on a delay sensitive warning service. The PoC aims to show how 5G-CORAL technologies can satisfy the requirements of this scenario. The planned demo consists of the two scenarios depicted in Figure 3-22 (a) and (b).

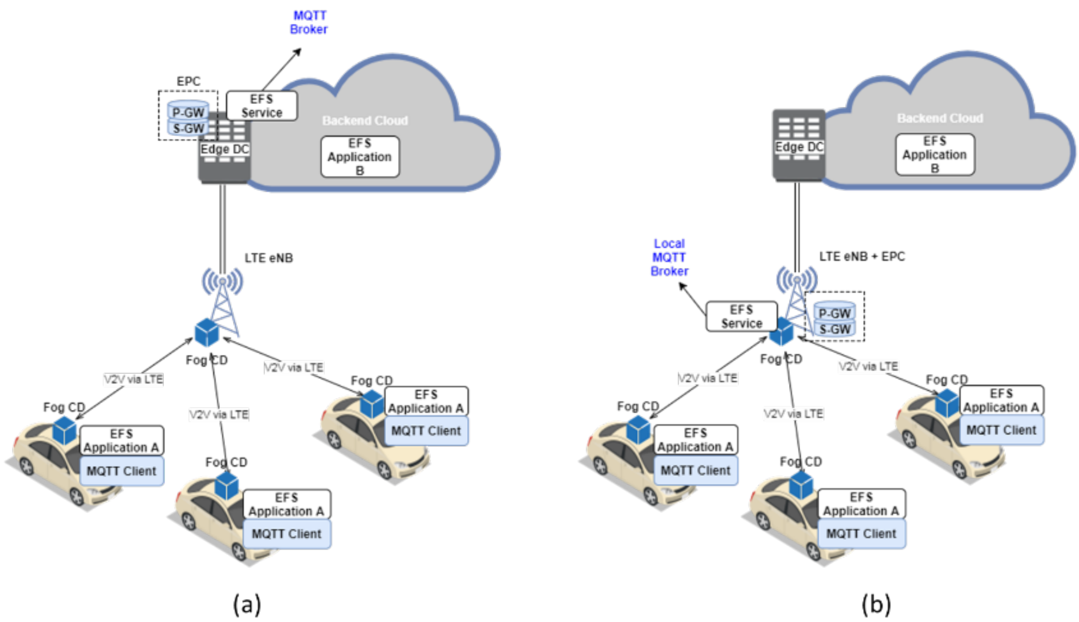

Figure 3-22: Connected Cars PoC Architecture

As depicted in Figure 3-22, 5G-CORAL technologies are configured to run also on the vehicles. For example, an EFS application A implementing the Road Safety mechanisms is deployed on each OBU. Using LTE as RAT and according to [17], the system shall be able to deliver the message within 100 ms with sufficiently low delivery loss. The EFS application, in fact, collects position information provided by nearby vehicles through a message protocol such us MQTT (EFS Service Platform). The EFS Service messages follow the ETSI CAM and ETSI DENM standards [17] to ensure interoperability also toward third party applications.

In a standard configuration the MQTT broker can be instantiated beyond the Core Network, in a distant cloud, as depicted in Figure 3-22(a).. This configuration can't guarantee a low and stable latency in every condition (the average e2e latency can be greater than 100 ms as explained in Section 2.2.1) and the service can be offered only by mandating vehicles speed limitations. Exploiting 5G-CORAL technologies, the MQTT Broker could be instantiated on MEC server near the eNB, where also a local EPC is present (Figure 3-22(b)),), guaranteeing the lowest latency whose lower bound, in this configuration, is represented by 4G LTE RAN air latency (i.e. around 20 ms RTT [18]). In this way, the service can satisfy the 3GPP requirements in [19].

In this PoC the following entities are deployed, as also depicted in Figure 3-23:

- EFS Applications:
    - Collision avoidance: warn in case vehicles can collide;
    - Emergency vehicle approaching: warn if an emergency vehicle is approaching;
    - Vehicle breakdown notification: warn if the vehicle is not working properly.
- EFS Services:
    - Telemetric information as velocity, position, heading, vehicle type…;
    - Warning notification related to a given area and for a certain time.
- EFS Functions:
    - Message Fusion: mandatory for Multi-RAT support, as it selects the freshest messages among duplicates;
    - Message Management: stores received warning messages to show an alert only when relevant;
- Non-EFS Function (TI testbed):
    - Next EPC;
    - Phluido eNB.

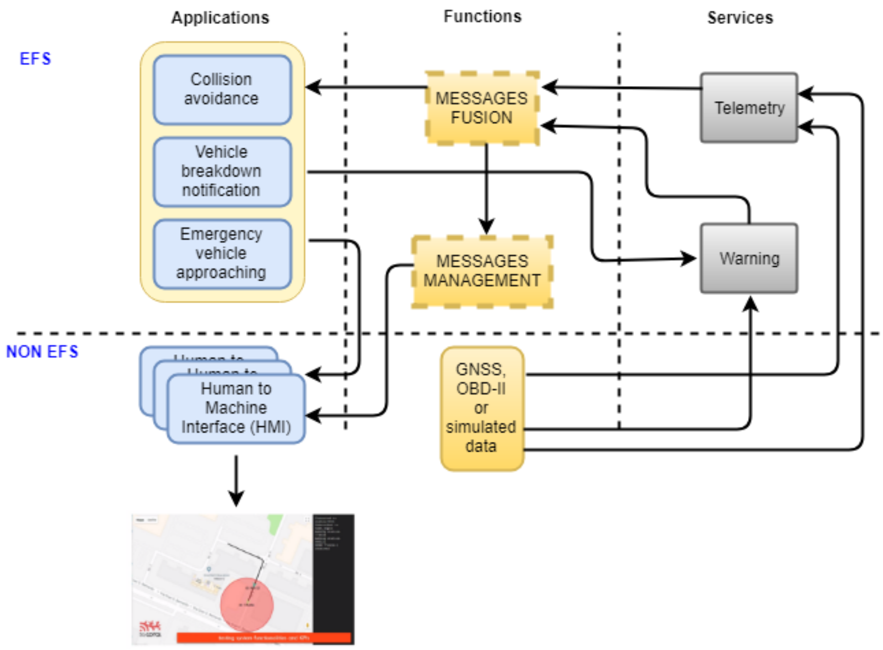

Figure 3-23: EFS entities configuration for connected car use case

The following assumptions are considered for the implementation of this PoC:

- each vehicle is under the coverage of the same LTE cell and so the service interruption due to the handover is not considered;
- the considered maximum car speed will be limited according to the e2e latency performance of the system;
- to address the multi-RAT aspect, the OBU software architecture will be designed to natively support multiple RATs. In the initial developments of this PoC only LTE will be used, depending on the needed effort the addition of a secondary RAT will be evaluated.

The MQTT broker running on a Fog CD (or alternatively on an Edge DC) as well as the software running on the OBUs (EFS applications and functions) are managed by the Eclipse Fog05 OCS. In particular, the Fog05 agent running on the vehicles can be used to deploy, start, stop update and re-configure the functions and applications. As an example, it can instruct a vehicle on how to properly connect to the Service Platform (i.e. provide the MQTT Broker connection details). It can also configure the OBU to make sure it processes the CAM and DENM messages relevant not only for itself, but also for other nearby road users which could have a lower computing power, thus providing a redundant mechanism for alerting.

At the time of the publication of this deliverable, a simulator for the vehicle data generation has been developed. The simulator generates test vectors that will be used for the experimentation activities in TI LTE test-bed. Moreover, a web dashboard for the visualization of CAM and DENM messages has been developed. Two OBUs equipped with the PoC software (initial versions of the EFS Application and Services) have been already integrated in TI LTE test-bed, in Turin (Italy), as depicted in Figure 3-24 and some experimentation activities have been started.

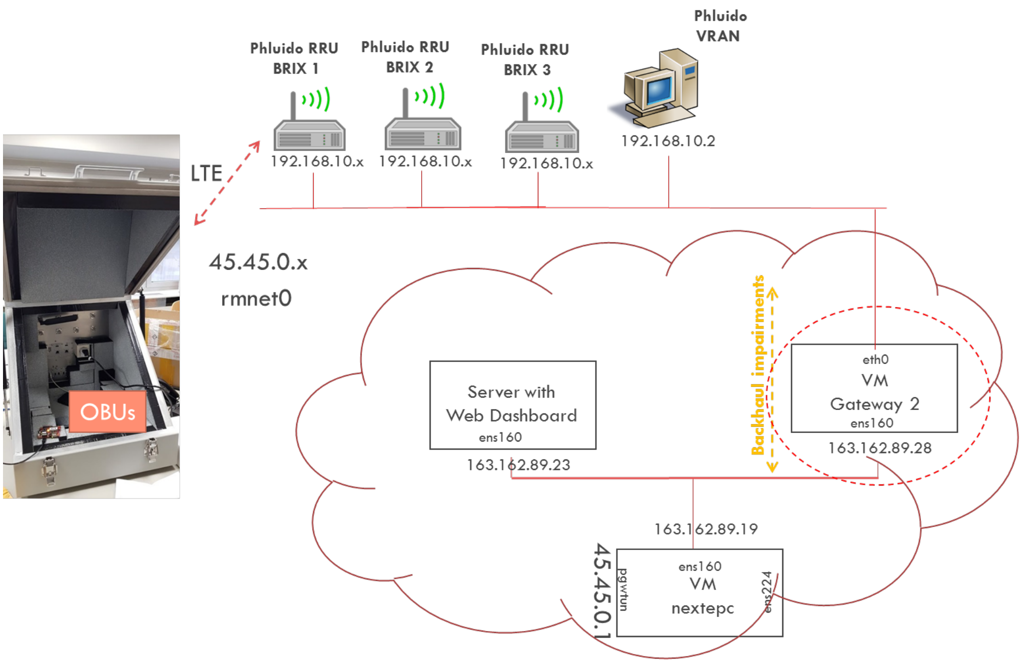

Figure 3-24: PoC integration into the TI connected car testbed

3.6.2 Relation with Project Objectives

Table 3-25 shows the Connected Cars PoC with the project objectives of 5G-CORAL.

TABLE 3-25: POC#6 RELATION WITH PROJECT OBJECTIVES.

Project Objectives	How will this PoC address the project objectives
Objective 2: Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)	
R & D Topic 2: *Network-offloading function* that enables device and core network offloading by running some of its functions in the EFS.	Integration of the computing resources available at cars in the EFS.
Verification: Validate selected EFS components through a system verification in the integration testbeds from WP4.	Integration and verification of components in the Connected Car Testbed
Objective 3: Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources	
R & D Topic 1: Develop interfaces for automated deployment of EFS functions and applications.	The MQTT broker as well as the software running on the OBUs (EFS applications and functions) are managed by the Eclipse Fog05 OCS
Verification: Validate selected OCS components through a system verification in the integration testbeds from WP4.	Integration and verification of components in the Connected Car Testbed
Objective 4: Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs	
R & D Topic 1: Integrate and validate EFS and OCS in large-scale testbeds, such as shopping mall, high-speed train, and connected cars.	Demonstration of Enhanced Safety in connected car scenario in the Connected Car Testbed.
R & D Topic 2: 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.	Demonstration of delay sensitive application "Enhanced Safety in connected car" in a real-world testbed in Turin (Italy) with the support of TI
Verification: 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.	Integration and verification of components in the Connected Car Testbed in Turin (Italy) with the support of TI

3.6.3 Initial Performance Metrics

Table 3-26 provides an initial list of performance metrics that will be considered to be measured through the experiments performed into the TI laboratory testbed. Interim results are being obtained from the ongoing experiments and these will be reported in the next deliverable.

TABLE 3-26: POC#6 PERFORMANCE METRICS

Performance metrics	Description	Way of measurement
Latency	Comparison between having the application running into a distant cloud instead of having the application running on-board the vehicles with a local deployment of the MQTT broker	Timestamp measurements in the experimental laboratory test-bed
Reliability (Tentative)	Comparison of warning missed detection between centralised case and 5G-CORAL one	Warning missed detection (when the message is delivered too late)

3.6.4 Relation with Use Case

This PoC is mainly related to the Safety use case defined in Section 3.2.1 of [9]. The use case included a broader set of requirements and specification since it drives the design of the general 5G-CORAL system. The demonstration, leveraging on some of the 5G-CORAL technologies and concepts, aims to demonstrate a subset of the use case requirements and their feasibility in terms of implementation effort. The covered requirements are limited by the selected RAT. Ideally, using 5G-CORAL technologies (EFS application and service platforms) with a lower latency RAT (e.g., direct communications, NR) also the most stringent latency requirements could be fully satisfied (e.g., self-driving car). This PoC will demonstrate also that some of the 5G-CORAL innovations, as the use of resources of the EFS available not only at the edge but even at the vehicles, could be integrated in a legacy network with a reasonable effort enabling new use cases.

3.6.5 Software/Hardware Configuration

Each car is equipped with a vehicular Fog CD, also known as an on-board unit (OBU) integrating a commercial LTE modem and a limited computation capacity able to run the final application. This device is able to collect position data and data from the vehicle OBD-II/CAN interface from the vehicles, to elaborate and transmit them. Azcom is prototyping a car OBU component based on AirPrime WP7502 solution provided by Sierra Wireless (see Figure 3-25).

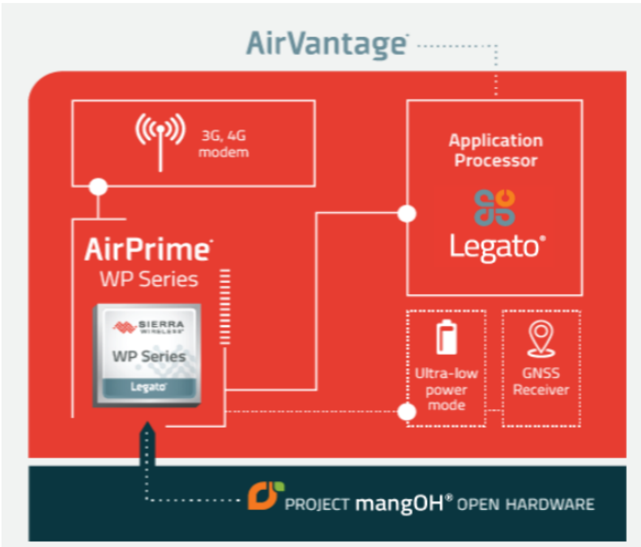

Figure 3-25: On-board unit prototype

TABLE 3-27: CAR MODULE SPECIFICATIONS

Feature	
SoC	ARM Cortex A5 32-bit
Memory	256 MB
Storage	512 MB
Modem	LTE Cat 4, 3GPP Release 9
RF Band	B1, B3, B7, B8, B20
GNSS	GPS L1, Galileo E1, and GLONASS L1 FDMA
Audio	PCM or I²S
Connectivity	USB 2.0, UART serial links
Form Factor	Land Grid Array

The software architecture of the vehicular EFS system is depicted in Figure 3-26.

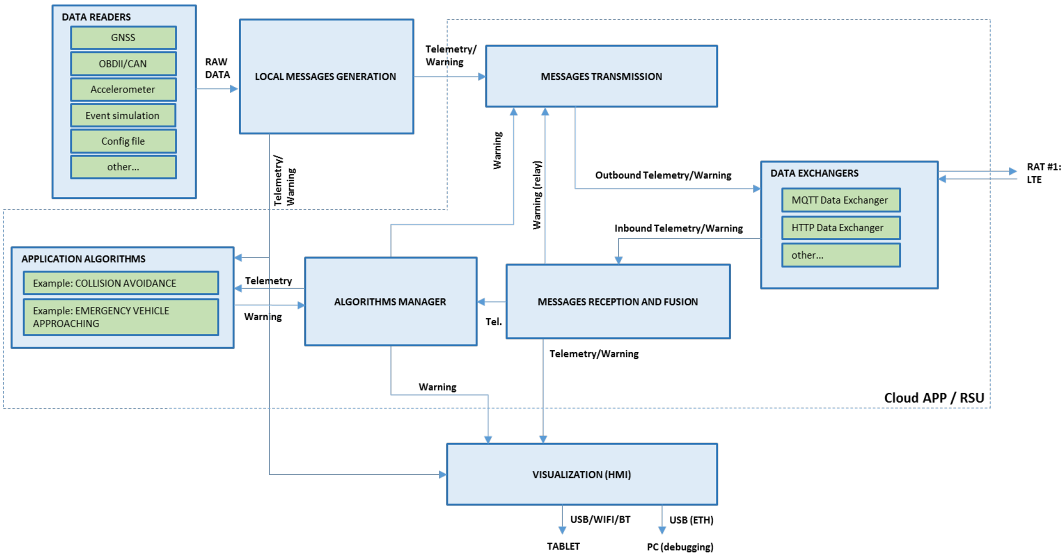

Figure 3-26: Connected Car PoC Software Architecture

The software is made up of several components in order to guarantee the best flexibility. The raw data coming from the sensors (or a test vector) is processed by the local messages generation block which is responsible for data aggregation (e.g. the speed can be read both from the OBD-II/CAN or from the GPS), the generation of the telemetry messages at a given rate and the generation of warning messages if a sensor detects a fault (e.g. "malfunction indication" from the OBD-II/CAN).

The messages are then handled to the messages transmission, which encodes and queues the outbound messages for an asynchronous transmission, discards the expired or empty ones and passes the messages to each of the registered data exchangers. This means that the same messages can be sent with different protocols using different adapters. The data exchangers can also receive data from the nearby vehicles. The messages will be decoded, fused (to avoid duplicate messages coming from different RATs) and then forwarded to the algorithms manager and the visualization blocks. Optionally, the warning messages can be relayed.

The algorithms manager module receives as an input the locally-generated and the received telemetry data which will be fed to multiple applications algorithms, such as collision-avoidance or emergency-vehicle-approaching. These algorithms can produce an output warning message which will be both sent to the visualization block and to the outbound messages queue of the message's transmission.

The Visualization block takes the locally-generated and the received warning messages and stores and maintains them in a local list (e.g. removes the expired ones or those for which termination notification has been sent). As soon as the warnings are received and then every time a new telemetry message is received, every stored warning message is checked to see if it is relevant and therefore whether or not an alert should be given to the driver through an HMI (Human-Machine interface). The HMI is a LED + Buzzer and/or a tablet running and app which can show more details about the warning, such as: type of warning and relevance area.

The software modules can be deployed into the OBU but also at RSU or onto a distant cloud increasing the flexibility and the reliability of the whole system or also providing different use cases with different requirements in term of network and computing resources availability. In fact, the EFS Service is in charge of interfacing all the applications, regardless where they are instantiated, with localisation data and other useful information.

The MQTT Broker, provided on a container image, should be deployed on COTS hardware, such as a Fog CD close to the eNB to reach the lowest latency among the vehicles. For those use cases which are not delay sensitive the MQTT broker can be configured also in a distant cloud.

3.6.6 Required 5G-CORAL Building Blocks

The Connected Cars PoC relays on several 5G-CORAL building blocks: EFS service, EFS application and OCS.

TABLE 3-28: POC#6 REQUIRED 5G-CORAL BUILDING BLOCKS

Sub-system	Component's Name	Description
EFS (Application)	Safety Application	• Collision avoidance: warn in case vehicles can collide; • Emergency vehicle approaching: warn if an emergency vehicle is approaching; • Vehicle breakdown notification: warn if the vehicle is not working properly.
EFS (Service)	Telemetric Service	Telemetric information: • velocity; • position; • heading; • vehicle type.
EFS (Service)	Warning notification	• Warning notification related to a given area and for a certain time.
EFS (Service)	Message Service Platform	• MQTT Broker, provided on a LXD container.
EFS (Functions)	Message Fusion and management	• Message Fusion: mandatory for Multi-RAT support, as it selects the freshest messages among duplicates; • Message Management: stores received warning messages to show an alert only when relevant.
Non-EFS	LTE eNB + EPC components	• provide the connectivity for the EFS components; • deployed at TI test-bed, it consists of a Phluido eNB (running on COTS hardware) and of a Next EPC (running on a VM).
OCS	EFS Application and Service LCM	• The MQTT broker as well as the software running on the OBUs (EFS applications and functions) are managed by the Eclipse Fog05 OCS

3.6.7 Interim Results

Among the experimentation activities described in Section 2.2.2, the initial steps will include an evaluation of the e2e latency of the entire system depicted in Figure 3-27 including the application perspective.

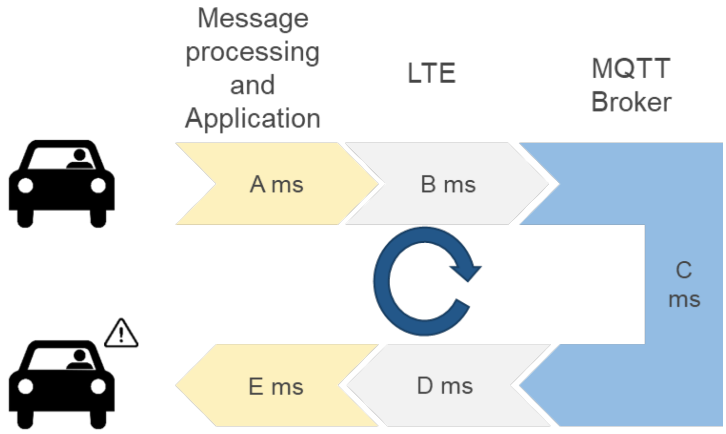

Figure 3-27: Connected car PoC latency budget

The initial measurements performed into the TI Lab testbed have regarded the latency introduced from the LTE network (B and D components in Figure 3-27). The local EPC deployed in the TI Lab testbed has shown poor performances, with RTT latency values around 30-40 ms, also considering that the TI LTE commercial network can reach E2E latency values lower than 20 ms.

In particular conditions, as reported in

Table 2-3, the latency of a commercial LTE network can reach hundreds of milliseconds and unstable jitter values. Then, it is interesting to evaluate how the PoC architecture, integrating the 5G-CORAL concepts and enabling the vehicles as Fog CDs, can cope with these critical situations, in particular compare to the case of a legacy centralized application instantiated in a distant cloud.

Next step will be focusing on identifying also the impact of the service and application layers (A, C and E components in Figure 3-27) to the overall latency metric and potentially the missed warning detection of the safety application related to the overall performance of the system.

3.6.8 Integration and Validation Timeline

Table 3-29 presents the integration and validation timeline throughout the project timeline of 5G-CORAL

TABLE 3-29: POC#6 TIMELINE

Description	Enhanced Safety in connected car
Q1 – 2018	• Refinement of PoC design and software architecture • OBU bring-up • Configuration and installation of NextEPC and LTE eNodeB in TIM Lab
Q2 - 2018	• EFS Service (localisation and warnings) • Integration of OBUs in TI lab • Installation/Configuration of MQTT broker on TI lab cloud • 1st on-field test for CAN OBDII connectivity within the car and network connectivity • OCS support analysis

Q3 - 2018	• EFS Application • Evaluation metrics definition • OCS integration with Fog05 • Conclusion of preliminary Lab Test (in TI Lab) • Discussion for Year 2 Taiwan integration
Q4 – 2018	• First stable release of basic PoC • Conclusion of PoC experimentation (in TI Lab) • Video preparation for Taiwan first year trial • 5G-Coral first review in Taiwan (November, video demo) • 5G-Coral first review in Vienna (December, video demo)
Q1 - 2019	• Evaluation of physical secondary RAT • HMI (tentative, depending on the available effort) • Supporting efforts for MWC 2019 (Barcelona)
Q2 - 2019	• Supporting integration in Taiwan testbed (if feasible)
Q3 - 2019	• Finalizing experimentations and testing • 5G-Coral final review

4 Early Demonstrations

This section describes the early demonstration carried out at different platforms in the first year of the project.

4.1.1 Demo 1: Robotics

This demonstration showed the basic functions of the Cloud Robotics PoC at the European Conference on Networks and Communication (EuCNC) in June 2018 in Ljubljana, Slovenia. The demonstration was shown in the 5TONIC lab as well, in July 2018 [20]. It consisted of two robots placed on a floor inside a marked rectangle (with black ink). The robots form a fleet and move within the rectangle borders in a synchronized manner. If either of the robots reaches the rectangle border, both robots stop and change the direction of the movement (opposite of the border line). The idea is to present the process of deploying the robot resources on edge devices, control the robots remotely by placing the robotic intelligence in the network, assisted by the WiFi infrastructure.

The intelligence of the robots would reside in the network. For that case two additional devices would be needed. The first device would contain the robot intelligence as well as a server application that would allow external users to access and operate with the robots (by giving manual commands). The other device would be used as WiFi Access Point (AP). This device is used for automatically deploying the AP for the robots as well as forwarding the commands received from the first device to the robots. For future, it is planned to have a network-assisted D2D connectivity between the robots.

The hardware used for the demonstration are two robots Lego Mindstorm and two Raspberry Pi devices. Both Raspberry Pi devices are running FogO5 on top of them. The robots don't run FogO5 due to undergoing development of a lightweight implementation. For this reason, legacy code is used for controlling the basic movement functions in the robots.

FIGURE 4-1: 5G-CORAL EUCNC BOOTH

FIGURE 4-2: CLOUD ROBOTICS DEMO AT EUCNC

FIGURE 4-3: THE EUCNC DEMO BEING PRESENTED TO THE EUROPEAN COMMISSION

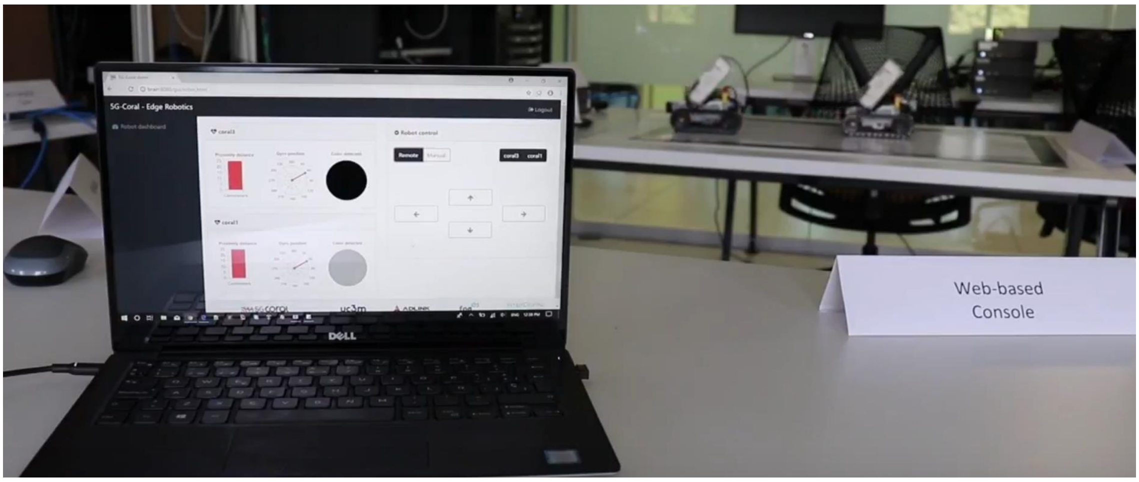

FIGURE 4-4: ROBOTICS DEMO AT 5TONIC

4.1.2 Augmented Reality Live Navigation

The early demonstration of Augmented Reality live navigation was presented in the EuCNC. The Demonstration includes the following components:

- AR Navigation Application – A basic ET side AR navigation application is used to navigate a user to its destination. The user device continuously captures and transmits the image frames to the Fog Node to receive its navigation information. The application utilizes the localization service to obtain current user location and then updates on a mini map in the GUI, which also helps in navigating users.
- Localization Service – Localization service is used to estimate user location. User continuously updates and transmits the collected iBeacon IDID list and g-sensor information to Localization Function hosted inside Fog Node to receive a response with an estimated user location.

- Advertisement – An ET side application is used to allow user to discover possible shop advertisement information. The user device continuously captures and transmits the image frames to the Fog Node to receive its shop recognition result with corresponding advertisement information.

This demonstration aims at providing a continuous indoor AR navigation experience for the clients in the Shopping Mall. The objective is to augment the user recorded video frames with a navigation arrow similar to the popular car navigation application. The user senses a guiding line grounded in the real-world image displayed on his screen so that it reminds a real object, i.e. a pointer, to the desired destination.

The key enabling technology used to bring seamless navigation and shopping experience is Image Recognition. It allows to identify filmed objects and current location of the user and places an arrow for directions in the right spot on the screen. Current solutions deal with this problem by storing images in the data centre. This, however, increases the end-to-end delay between the user and the IR engine. Together with processing delay, it may disrupt the continuous experience of the user. In our demonstration setup we have used Fog nodes placed in the vicinity of the user to decrease the latency which eventually improves the continuous experience of the user.

During the demo, a user walks along a path where shops are located at both sides. While using the AR Navigation app, the location of the user has been identified by Localization function. During the movement, the user keeps discovering the shop information and navigation information by periodically sending snapshot images back to serving Fog Node and receiving the identification result from the Fog Node. In addition, the user gets navigated by periodically sending back the sensed nearby ibeacon list and g-sensor information to Localization function at Fog Node and receiving the most updated local coordinate from Localization function so that the user location is updated and shown on the map.

Video and Poster of this early demonstration in the EuCNC can be found respectively in [21] and [22]. Figure 4-5 presents photos taken in the EuCNC for the AR Live Navigation demonstration

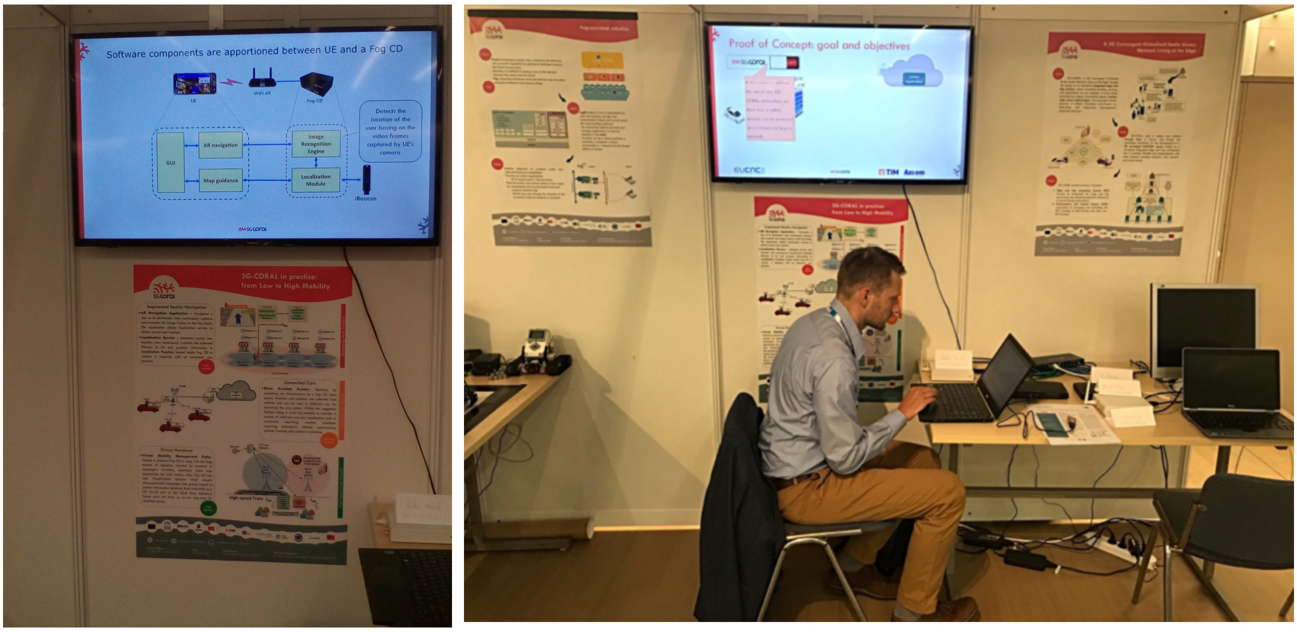

FIGURE 4-5: AR LIVE NAVIGATION IN THE EUCNC

4.1.3 Multi-RAT IoT Gateway

At EuCNC 2018, we demonstrated an initial implementation of the 5G-CORAL Multi-RAT IoT Gateway. The focus was on two RATs: IEEE 802.15.4 and NB-IoT.

The demonstration involved a computer running in the EFS, running virtualized communication stacks as Docker containers. One container was running for each RAT. Another computer was acting as the radio head. It had two Software-Defined-Radios connected to it, so as to handle up to two RATs simultaneously. Baseband signals (IQ samples) were exchanged between the radio head and EFS using Zero-MQ. The setup is illustrated in Figure 4-6.

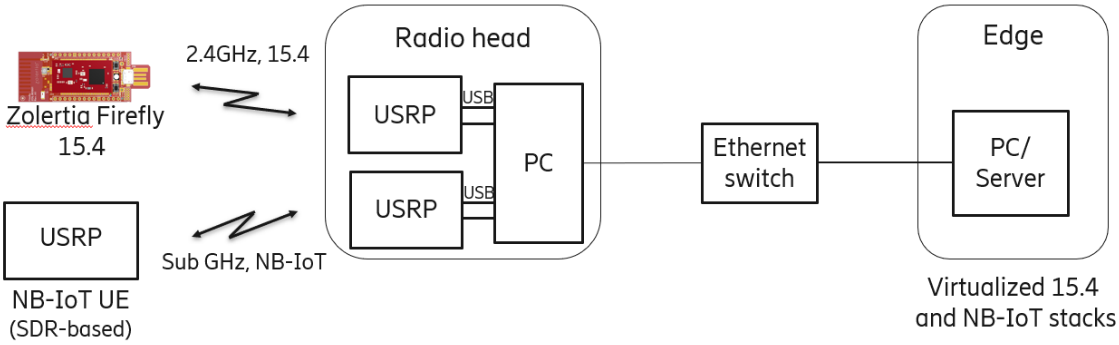

FIGURE 4-6: THE EUCNC 2018 MULTI-RAT GATEWAY DEMO SETUP

To demonstrate IEEE 802.15.4, a native IoT device was in range of the radio head. Specifically, we used a Zolertia Firefly, equipped with a TI CC2538 radio chip, running the Contiki-NG Operating System. Contiki-NG was running a complete 6LoWPAN stack, including RPL, CoAP, and OMA LWM2M [23] (see Figure 4-7). The device was exposing the IPSO profile [24], a standard set of sensor and actuators. The same stack was running in the EFS, to support the virtualized 802.15.4 stack, as well as a LWM2M server (Eclipse IoT Leshan [25]). The demonstration consisted in connecting to the IoT node, and browsing sensors and actuators, from a simple Web browser. One could show how events at the device were reported to the EFS (e.g., press of a button), or how the EFS could control the device (e.g., set LED color).

To demonstrate NB-IoT, a Software-Defined Radio was used as the IoT device. On top of the NB-IoT RAT implementation, the device ran a chat messaging client (Telegram). In the demo, we showed how the IoT device could post chat messaged to the server, located in the EFS.

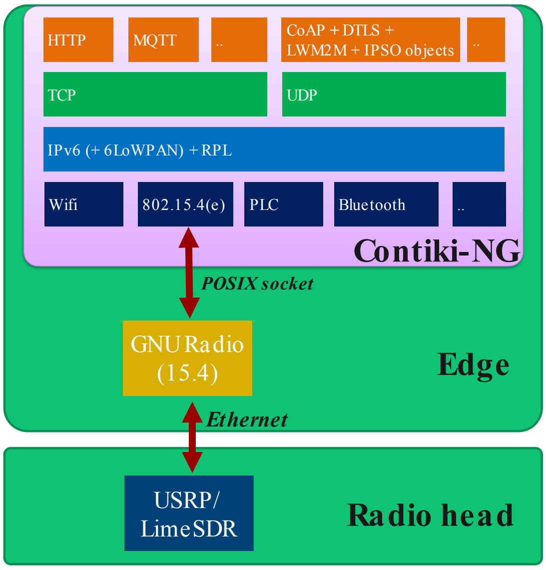

FIGURE 4-7: MULTI-RAT GATEWAY DEMO SETUP -- IEEE 802.15.4 STACK

4.1.4 High-Speed Train

At EuCNC 2018, an initial version of handover for group of user was demonstrated. This demonstration targeted a minimum service interruption for passengers on train especially when transiting from one Macro base station to another one along the railway. In particular, it addressed how fog nodes can handle partially core network functionalities at the edge especially at transit from on board to on land. The demonstration included the following components in an emulation environment of the high speed train:

- Virtual Mobility Management Entity (vMME) – Hosted in on-board Fog node close to the passengers. Consequently, it copes with the huge amount of signalling resulted by hundreds of passengers travelling especially when train approaches the train station. Also, this vMME reduces the service interruption time during handover process by carrying multiple passenger devices into single control message to the core network.
- User Classification Function which classifies aforementioned passengers into groups based on context information obtained from multi-RATs (e.g. LTE, Wi-Fi) such as QCI (QoS Class indicator) which will be used by vMME during the handover process. The QCI divided into several parts as shown in the following Table 4 [26].
- UEs Emulation: it is costly to demonstrate hundreds of UEs handover when switch from high-speed train connection on-board to train station connection on-land. Based on NextEPC [27], we emulate UEs link to core network starting by attachment process and end by handover.

QCI	Resource Type	Priority Level	Packet Delay Budget (NOTE 13)	Packet Error Loss Rate (NOTE 2)	Example Services
1 (NOTE 3)	GBR	2	100 ms (NOTE 1, NOTE 11)	10^{-2}	Conversational Voice
2 (NOTE 3)		4	150 ms (NOTE 1, NOTE 11)	10^{-3}	Conversational Video (Live Streaming)
3 (NOTE 3, NOTE 14)		3	50 ms (NOTE 1, NOTE 11)	10^{-3}	Real Time Gaming, V2X messages Electricity distribution - medium voltage (e.g. TS 22.261 [51] clause 7.2.2) Process automation - monitoring (e.g. TS 22.261 [51] clause 7.2.2)
4 (NOTE 3)		5	300 ms (NOTE 1, NOTE 11)	10^{-6}	Non-Conversational Video (Buffered Streaming)
5 (NOTE 3)	Non-GBR	1	100 ms (NOTE 1, NOTE 10)	10^{-6}	IMS Signalling
6 (NOTE 4)		6	300 ms (NOTE 1, NOTE 10)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file sharing, progressive video, etc.)
7 (NOTE 3)		7	100 ms (NOTE 1, NOTE 10)	10^{-3}	Voice, Video (Live Streaming) Interactive Gaming
8 (NOTE 5)		8	300 ms (NOTE 1)	10^{-6}	Video (Buffered Streaming) TCP-based (e.g., www, e-mail, chat, ftp, p2p file
9 (NOTE 6)		9			sharing, progressive video, etc.)

TABLE 4: 3GPP TS23.304 QCI CLASSIFICATION

Another context information which can be used to classify passenger's devices is ARP (Allocation and Retention Priority). ARP contains information about the priority level, the pre-emption capability and the pre-emption vulnerability as follow:

- Priority level: defines the relative importance of a resource request. This allows deciding whether a bearer establishment or modification request can be accepted or needs to be rejected in case of resource limitations.
- Pre-emption capability and the pre-emption vulnerability can be either set to 'yes' or 'no'

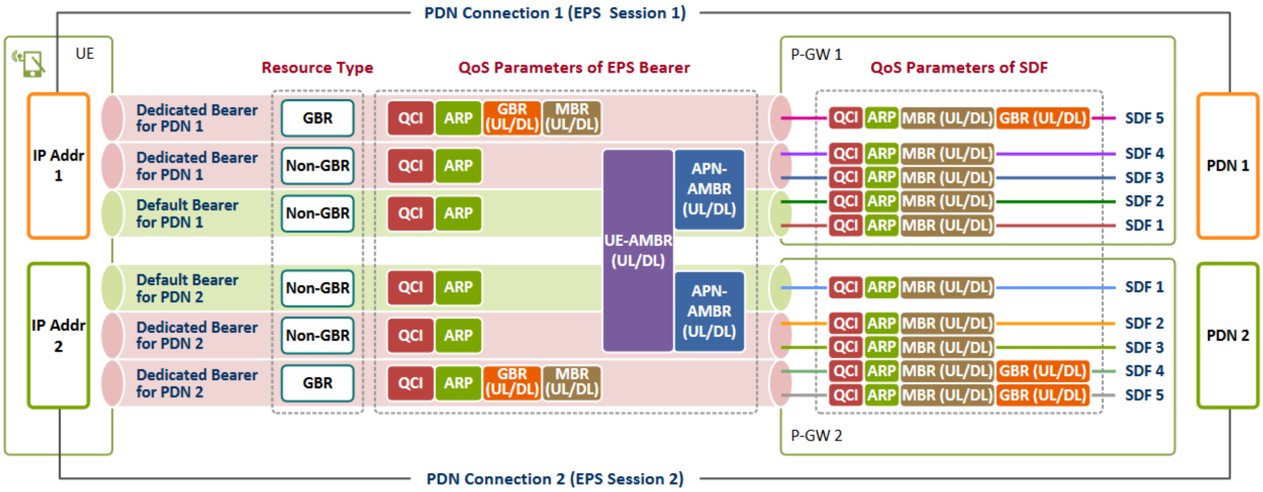

FIGURE 4-8: QOS PARAMETERS FOR SDF AND EPS

Video and Poster of this early demonstration in the EuCNC can be found here in video [28] and a poster [22].

4.1.5 Connected Cars

At EuCNC 2018, an initial overview of the connected car PoC and the developments status was shown through a video [29] and a poster [22]. As described in Section 3.6.1, each vehicle provides alerts regarding the existence of a safety risk, this can be achieved exploiting the 5G-CORAL EFS

Service based on MQTT that collects vehicle status information also through the OBDII interface (see Figure 4-9) and the GNSS receiver and the EFS Application distributed on each vehicle.

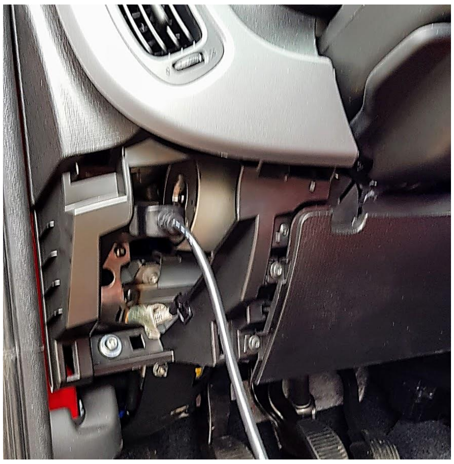

Figure 4-9: OBDII port on a vehicle

At the time of EuCNC 2018 the video showed also the web dashboard which was developed for testing and visualizing the localization information and warning messages, as depicted in Figure 4-10.

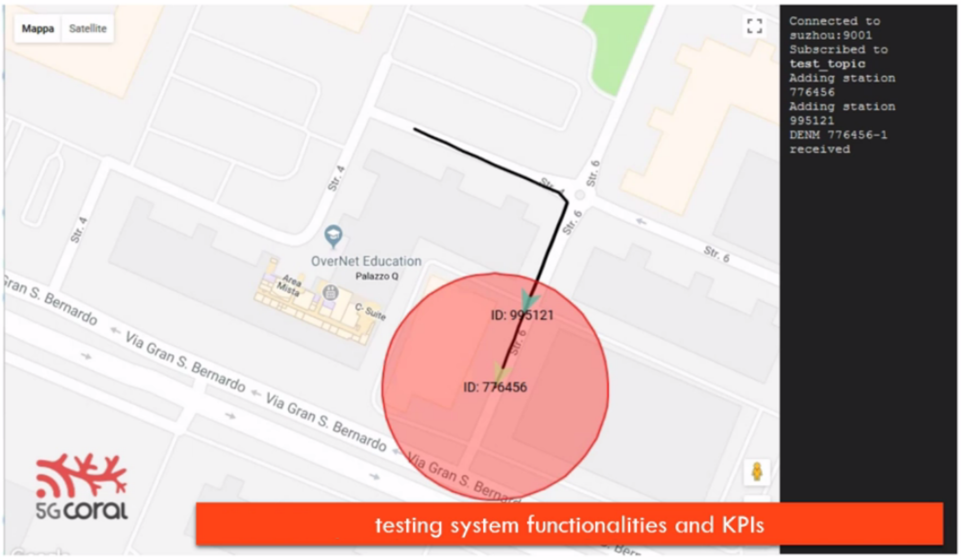

FIGURE 4-10 Web dashboard and a warning generation

5 Conclusion and Next Steps

The work conducted within WP4 during the first year of the 5G-CORAL project has allowed us to select the most promising technologies from 5G-CORAL WP2 and WP3 to develop Proof-of-Concepts supporting the various use cases identified in WP1. In particular, in this deliverable D4.1, 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 (1) Shopping Mall, (2) Connected Cars and, (3) High-Speed Train. The testbeds provide a solid foundation for the assessment and evaluation of the technology solution being developed within 5G-CORAL.

We then presented six PoCs (at the 12-month stage of the project), namely: Augmented Reality Navigation, Virtual Reality, Cloud Robotics, IoT Multi-RAT Gateway, Group Handover in High-Speed Train, and Connected cars. 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 timelines were also presented. This deliverable also provided a glance at the EuCNC'18 demonstrations carried out as the first milestone of actual PoCs under development in the 5G-CORAL project.

In the next year of the project, the six PoCs presented in this deliverable will be further elaborated, tested, evaluated and validated through various performance metrics. Moreover, some use cases may take advantage of sharing common components (like the location service) and data. In particular, PoCs 2, 3 and 6 are anticipated to benefit from such common components, as they need respectively to deploy applications across different operating systems and without packaging them (PoC 2), deploying Robots applications as well as network services that need access to physical wireless interfaces (PoC 3) and deploying of application in the On-board Unit of the cars (PoC 6). These opportunities across PoCs will be explored in the second year of the project.

Work Package 4 has set its eyes in 2018 on the upcoming Taiwan trials scheduled in November 2018 at the Shopping Mall test site (Taiwan) to experiment and validate a subset of components presented in this deliverable. For 2019, two major events have been targeted namely (1) Mobile World Congress in Barcelona and (2) Computex in Taipei, where 5G-CORAL PoCs will be presented in their full scope.

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7 Appendix

7.1 List of components used in the Shopping Mall Site

Following are the list of components used in the Testbed

7.1.1 ITRI

Table 7: ITRI Components in Shopping Mall

Component	Status	Description	Interfaces	Requirements
Wi Fi Access Points	Deployed	IEEE 802.11 ac compliant nodes operating at 5 GHz	Rj-45	N/A
Fog CD	Deployed	RAM (2GB), Storage (EMMC 8GB)	Rj-45	WiFi Access Point
Wireless backhaul	Deployed	Wifi directed backhaul solution	Wifi d2d, 5 ghz	Fog CD
Digital signage	Deployed	A LCD 55-inch screen to play the advertisement	Wifi, 5 ghz	Fog CD
Beacon	Deployed	Determine the location of the user	Wireless Bluetooth	N/A
Small Cell	Ready to be deployed	Provides LTE connectivity for the users in the shopping mall	SMA for antennas RJ-45 for S1 interface	Setup and installation
Remote manager	Deployed	App to remotely manage the Fog CDs including topology	Internet	To be defined
Augmented Reality navigation	Under Development	User application to use the detect the live navigation for any selected destination	WiFi	Fog CD
Image Recognition Server	Under Development	Server hosted in the fog node to assist Augmented reality navigation by recognizing the images	WiFi	Augmented reality navigation application
Distributed Computing	Under Development	Distributes the incoming request	WiFi	Augmented reality navigation application

7.1.2 UC3M

TABLE 7: UC3M COMPONENTS IN SHOPPING MALL

Component	Status	Description	Interfaces	Requirements
Fog CDs with several WiFi interfaces	In progress	Computing devices with limited NFV support and multiple WiFi devices	RJ45/IEEE 802.11n	Wall mounting, grid power
2 Robots	In progress	At least 2 robots to perform the coordination use case	IEEE 802.11n, LTE, BLE	Localization system, wifi coverage, Fog

		and/or the cleaning and security use case		CDs storing the logic nearby
Cloud robotic application	In progress	Application to be deployed and control de robot, potentially 3 different apps	All of above	Fog CDs to run it near the robot location, localization system, KVM/Container support
Orchestration application to federate with Cloud	In progress	App to move control logic of police robot or shopping mall control logic when closed	Internet	Good internet connection

7.1.3 IDCC

TABLE 7: IDCC COMPONENTS IN SHOPPING MALL

Component	Status	Description	Interfaces	Requirements
iMEC	Delivered	Server machine located inside the shopping mall capable of processing some of the VR computing tasks. It will be equipped with a high-end graphic card to support the VR computational requirements.	Ethernet	Connectivity with remote datacentre and inside the shopping mall
Fog nodes	In progress	Nvidia Jetson TX2 boards connected to different points of attachment, such as LTE small cells and Wi-Fi access points. Depending on their capability, more or less complex computation will be hosted on these devices.	Ethernet, Wi-Fi	Wi-Fi connectivity inside the shopping mall
360 cameras	In progress	They capture and records the 360° video and deliver the video live streaming to the real-time acquisition server running on the EFS.	Ethernet, Wi-Fi	Connectivity with remote datacentre and inside the shopping mall

Smartphone	In progress	It will host the media player app as well as the camera selection app, which enable the video streaming consumption and the selection of the point of interest, respectively.	Wi-Fi	Connectivity inside the shopping mall
Laptop + VR heaset	In progress	It operates similarly to the ET with the additional capability of delivering a 360° immersive experience.	Wi-Fi, Ethernet	Connectivity inside the shopping mall
Wi-Fi APs	In progress	To provide Wi-Fi connectivity inside the shopping mall	Ethernet	Internet connectivity

7.1.4 SICS/EAB

TABLE 7-1: SICS COMPONENTS IN SHOPPING MALL

Component	Status	Description	Interfaces	Requirements
IoT Gateway	In progress	AP targeted for multiple different IoT technologies. Transmits raw I/Q signals to central server for processing.	Downwards: IEEE 802.15.4 BLE Upwards: Ethernet	Fast upwards link, high-end central server.
IoT Devices	In progress	e.g. mall customer devices, trash can sensors.	IEEE 802.15.4 BLE	IoT Gateway

7.1.5 NCTU

TABLE 7-2: NCTU COMPONENTS IN SHOPPING MALL

Component	Status	Description	Interfaces	Requirements
Smartphone	In progress	It does observation of iBeacon signals and IMU sensor data for localization.	WiFi, LTE, Bluetooth	N/A
iBeacon	Deployed	It provides location-related information to smartphones.	Bluetooth	Wall mounting, grid power

7.1.6 ADLINK

TABLE 7-3: ADLINK COMPONENTS IN SHOPPING MALL

Component	Status	Description	Interfaces	Requirements
fogØ5	Under Development	It's a fog IaaSIaaS which provides a unified interface for service/function/application deployment, monitoring and management.	IP network	Fog CD
Local Edge Server	Delivered	The Edge Server is a powerful PC which is connected to the fog nodes to offload low latency demanding computing tasks that cannot be handled immediately by the nodes.	Ethernet	Connection to fog nodes and remote datacentre in the field

7.2 List of components used in the High-Speed Train Site

TABLE 7-4: ITRI COMPONENTS IN HIGH SPEED TRAIN

Component	Status	Description	Interfaces	Requirements
Next EPC	In progress	It is used to emulated the core network and as part of modification for S1/S10 interface	Ethernet	LTE compatible- Rel 13
CPE	Deployed	Commercial CPE Installed on train to provide backhaul for car network	RJ-45	LTE compatible
Small Cell	Deployed	Commerical small cell can be installed on train or Train Statiion	Hardware interface: N-type connector, LTE Uu	LTE compatible- Rel 9
raspberry pi 3	Deployed	To install vMME and other EFS functionalities/services		N/A
Multiple Users emulator	In progress	Emulate Multiple UEs LTE functionalites such as Attach, registration, etc.	Ethernet	N/A

7.3 List of components used in the Connected Cars Site

TABLE 7-5: AZCOM/TI COMPONENTS IN CONNECTED CAR

Component	Status	Description	Interfaces	Requirements
OBUs (Fog CDs at the vehicle)	Deployed at TI Lab	a car on-board component based on a solution provided by Sierra Wireless (AirPrime WP7502)	CAN BUS, LTE Uu, Bluetooth, WiFi	LTE Band 3, 7 CAN OBD II
Shielded box	Deployed at TI Lab	for laboratory PoC experimentation		
Phluido eNB	Deployed at TI Lab	for laboratory testing, where experimenting the impact of S1 latency to the system	Ethernet	
Next EPC	Deployed at TI Lab	for laboratory testing, where experimenting the impact of S1 latency to the system	Ethernet	
MQTT Broker	Deployed at TI Lab	EFS Service Platform component	TCP/IP	
OCS	In progress	Fog05 agent integration in OBUs (tentative)		DDS