Beyond 5G Multi-Tenant Private Networks Integrating Cellular, Wi-Fi, and LiFi, Powered by Artificial Intelligence and Intent Based Policy

Deliverable 5.1

Specification of Use Cases and Demonstration Plan

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Table of Contents

List of Figures

List of Tables

List of Acronyms

3GPP	3rd Generation Partnership Project
5GC	5G Core
5GNR	5G New Radio
ACL	Access Control Lists
AGV	Automatic Guided Vehicle
AI	Artificial Intelligence
AoA	Angle-of-Arrival
API	Application Programming Interface
AT3S	Access Traffic Steering, Switching and Splitting
B5G	Beyond 5G
CBRS	Citizen Broadband Radio Service
COTS	Commercial Off-The-Shelf
CP	Control Plane
CPE	Customer-premises Equipment
CU	Central Unit
DoW	Description of Work
DU	Distributed Unit
E2E	End-to-End
eAT3S	Enhanced AT3S
GDPR	General Data Protection Regulations
HoL	Head-of-Line
IP	Internet Protocol
ISM	Industrial Scientific and Medical
KPI	Key Performance Indicator
L2	Layer 2
LED	Light Emitting Diode
LiFi	Light Fidelity
LoS	Line-of-Sight
LTE	Long Term Evolution
MAC	Medium Access layer
MES	Manufacturing Execution System
ML	Machine Learning
mmWave	Millimetre Wave
MP3S	Multi-Path Steering, Switching and Splitting
MPTCP	Multi-Path TCP
near-RT	near Real-Time
NFV	Network Function Virtualisation
NLoS	Non-Line-of-Sight
non-RT	non Real-Time
NPN	Non-Public Network
NSSAI	Network Slice Selection Assistant Information
O-RAN	Open RAN
OT	Operation Technology
PHY	Physical layer
RAN	Radio Access Network
OCC	Optical Camera Communications

PC	Personal Computer
PLC	Programmable Logic Controller
PLMNID	Public Land Mobile Network Identifier
PNF	Physical Networking Function
PNI-NPN	Public Network Integrated NPN
PoC	Proof-of-Concept
QCA	Qualcomm Atheros
RAN	Radio Access Network
RBEF	Robert Bosch España Fábrica
RIC	Radio Interface Controller
RRM	Radio Resource Management
RSS	Received Signal Strength
RU	Radio Unit
SAS	Spectrum Access System
SBC	Single Board Computer
SDK	Software Development Kit
SDR	Software Defined Radio
SLA	Service Level Assurance
SLAM	Simultaneous Localization and Mapping
SNPN	Standalone NPN
S-NSSAI	Single NSSAI
SSID	Service Set Identifier
SSS	Switching, Steering and Splitting
TCP	Transmission Control Protocol
TDoA	Time-Difference-of-Arrival
ToF	Time-of-Flight
TWR	Two-Way Ranging
UC	Use Case
UE	User Equipment
UL	Uplink
UP	User Plane
UPF	User Plane Function
VLAN	Virtual Local Area Network
VM	Virtual Machine
VRAN	Virtual RAN
VNF	Virtual Networking Function
WAT	Wireless Access Technology
WP	Work Package

Executive Summary

The primary aim of 5G-CLARITY deliverable D5.1 is to provide the guideline for the project use cases implementations and demonstrations. 5G-CLARITY Smart Tourism and Industry 4.0 (Smart Factory) pilots are formulated in three use cases as:

- UC1: 'Enabling enhanced human-robot interaction' (Smart Tourism)
- UC2.1: 'Alternative network for production-data exchange' (Industry 4.0)
- UC2.2: 'Enhanced automated guided-vehicle (AGV) positioning in intralogistics' (Industry 4.0)

These use cases are expected to demonstrate the benefits of 5G-CLARITY innovations that are worked out to address the private network challenges, beyond 3GPP Release 16, on coexistence, integration, and interoperation of private and public networks. Among the outstanding challenges in this regard, one could name spectrum management, multiple wireless access technologies (multi-WAT) and multi-tenancy support, software defined networking (SDN) and network function virtualisation (NFV) powered infrastructure slicing, and data-driven network management. Aiming at addressing these challenges, 5G-CLARITY solutions will be implemented and their performances will be evaluated based on the architecture and definitions that are outlined in 5G-CLARITY D2.2, and the corresponding KPIs defined in 5G-CLARITY D2.1.

For the implementation of multi-WAT scenarios, project partners contribute their specific technologies on 5G new radio access, Wi-Fi and LiFi solutions. A customer-premises equipment (CPE) with multi-WAT functionalities is being put up for the 5G-CLARITY technologies proof-of-concept (PoC) purposes. Furthermore, the scope, objectives, elements, narratives and potential benefits, demonstration scenario and 5G-CLARITY enablers for each use case are discussed, and the preliminary test-plan, implementation plan and tentative timeline are provided as well.

5G-CLARITY UC1 aims to design, deploy, validate, and demonstrate a private network in the M-Shed museum of Bristol city council, with the capability to enable intelligent, pervasive, and robust interactions between a robot –as a tour guide– and humans. The infrastructure will also enable on-demand services such as public safety systems and third-party special events. In this sense, 5G-CLARITY UC1 is used to attest the 5G-CLARITY framework and infrastructure benefits to enhance tourism and entertaining sectors in public spaces while supporting the emergency/surveillance services for public safety and third-party special event services, e.g., conferences, seminars, etc.

5G-CLARITY UC2.1 and UC2.2 will showcase private network benefits and capabilities for Industry 4.0 scenarios in a Bosch factory in Aranjuez, Spain. UC2.1 is aimed at demonstrating 5G-CLARITY key innovations for improving the in-factory connectivity toward future Industry 4.0 scenario networks. The main objective is to validate the feasibility of replacing current Ethernet wired cabling used to connect Manufacturing Execution System (MES)-enabled production lines in the factory floor by the combination of wireless technologies proposed in 5G-CLARITY. By deploying 5G-CLARITY infrastructure and solutions in UC2.1, an improvement in data transmission speed is expected while reliability, latency, data security and response-time are maintained. The benchmark will be the currently in-place wired network performance. If the 5G-CLARITY solution can meet the performance benchmark, the demonstrated wireless solutions can replace current wired connections.

5G-CLARITY UC2.2 aims at enhancing the positioning of an automated guided vehicle (AGV) in the shop floor of the factory. UC2.2 involves an AGV operating on a shuttle service between a warehouse and a production shop floor in the Bosch factory. More concretely, UC2.2 is expected to collect of AGV positioning data in real time with enhanced accuracy using 5G-CLARITY multi-WATs. Accurate positioning information allows recording, evaluating and management of incidents on the factory shop floor along the AGV path. The details of these incidents, e.g., precise location, exact time, etc., will be recorded and the corresponding data base can be used to improve the productivity.

5G-CLARITY recognises two non-public network (NPN) scenarios. First is the standalone NPN (SNPN) defined as an NPN that do not rely on network functions provided by a public land mobile network (PLMN). The second scenario is the public network integrated NPN (PNI-NPN) defined as NPN deployment supported by a PLMN. 5G-CLARITY UC1, and UC2.1 will demonstrate both of these scenarios, where UC1 will showcase the SNPN in the M-Shed museum (as the public space using 5G-CLARITY NPN) for a guide robot management service and content delivery application. The PNI-NPN scenario in UC1 is demonstrated in two narratives, one for an on-demand surveillance application in the museum, and the other for third-party content delivery for special events. UC2.1, which showcases an alternative wireless network for factory production-data exchange, emulates the SNPN scenario by replacing the cable connections of production machines to the MES server. The PNI-NPN scenario is demonstrated based on having a PLMN provided 5G core (5GC), and therefore public SIMs are used in the employed 5G-CLARITY CPEs.

1 Introduction

The emergence of private networks guarantees the delivery of voice, text, data and video, and connection to machines, sensors, devices, and computing systems, as well as people in the privately owned venues and enterprises. So much as popular the private networks are within the industry and research communities, their widespread adoption will only become a reality if their operational costs are small, and a seamless interworking between 5G access and other industry technologies (e.g. wired Ethernet, Wi-Fi and emerging technologies such as LiFi) is made possible. Among the technical challenges, spectrum management, multiple wireless access technologies (multi-WAT) and multi-tenancy support, software defined networking (SDN) and network function virtualisation (NFV) powered infrastructure slicing, and data-driven network management could be named as outstanding. 5G-CLARITY aims at the design and integration of innovative solutions, beyond 3GPP Release 16, in regard to these challenges in a structured format.

5G-CLARITY proposed architecture, worked out in 5G-CLARITY WP2, is structured in four strata to allow a rich set of capabilities in private networks. These capabilities can be flexibly adapted, combined and extended to support a wide variety of services for both public and non-public use, including infrastructural services and communication/digital services. The 5G-CLARITY system architecture, including details of its strata, and the corresponding business ecosystem, its actor role-model and the offered services are documented in 5G-CLARITY D2.2 [1]. The project insight into the integration of private and public networks can be found in this document as well.

Further project innovative elements to address the above-mentioned challenges are worked out in WP3 and WP4. 5G-CLARITY WP3 aims on the development of the user and control plane framework that enables coexistence of the heterogeneous 5G new radio (5GNR)/Wi-Fi/LiFi network, while 5G-CLARITY WP4 works on the development of management systems for private networks. 5G-CLARITY innovations in WP3 focuses on the design and development of a multi-connectivity framework, including interfaces, signalling, scheduling and radio resource management (RRM) that integrates 5GNR, Wi-Fi and LiFi, and indoor positioning solutions with high accuracy. On the other hand, the efforts in 5G-CLARITY WP4 are on the development of enablers of automatic management of heterogeneous multi-connectivity network elements developed in WP3. These include the design of a multitenant SDN/NFV platform to configure the private multi-connectivity network infrastructure and to provision the third-party connectivity services; design of the connectivity services provisioned over multi-WAT infrastructure with an end-to-end (E2E) 5G slice; and finally design of an AI-enabled engine, and associated AI algorithms, which allows autonomic management of the multi-connectivity private network (stand-alone or integrated to the public network). The innovations in these two WPs, which grouped in the four strata of the 5G-CLARITY system described in Section 2.2.

The 5G-CLARITY system, built upon a number of technical innovations, provides a rich business environment, with multiple stakeholders taking part in the entire value chain, interacting with each other following horizontal and vertical customer-provider relationships. These relationships unveil innovative service delivery models, with services spanning public and private administrative domains while using resources from different access technologies.

5G-CLARITY WP5 aims to validate the feasibility of the functionalities and the architectural solutions and innovative elements developed in the project, and to demonstrate them in Smart Tourism and Industry 4.0 scenarios, to be introduced in detail shortly. The first phase of WP5 includes detailed planning by precise definition of the use cases, as well as identifying the parameters/features of interest that need to be monitored, measured and evaluated against the required key performance indicators (KPI). In addition, WP5 aims at defining and experimentation methodology suitable for the use cases under consideration and the project architectural and technology choices.

5G-CLARITY structure and WP inter-relations are described in Figure 1-1.

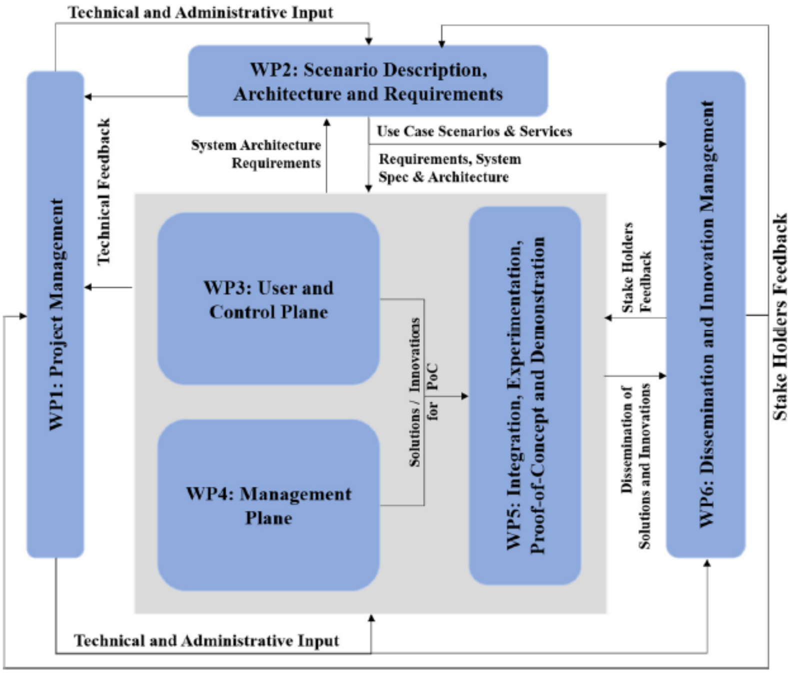

Figure 1-1 5G-CLARITY work package structure

1.1 Scope of the document

As the main objective of 5G-CLARITY WP5, the implementation and demonstration in real operational environments will offer proof-of-concept (PoC) validation of the project proposed architecture and technology innovations as well as detailed KPI evaluation. The first task of WP5, T5.1, sketched the overall 5G-CLARITY demonstrations plans, focusing on detailed specification of the scenarios, technical specifications, and implementation plans for 5G-CLARITY Smart Tourism and Industry 4.0 (Smart Factory) pilots. These pilots are expected to demonstrate the benefits of 5G-CLARITY technologies and their performance based on predefined KPI. The project pilots are organised in three use cases (UC1, UC2.1 and UC2.2) as described in 5G-CLARITY D2.1 [2], and is listed below:

- UC1: 'Enabling enhanced human-robot interaction' (Smart Tourism)
- UC2.1: 'Alternative network for production-data exchange' (Industry 4.0)
- UC2.2: 'Enhanced automated guided-vehicle (AGV) positioning in intralogistics' (Industry 4.0)

T5.2 will follow T5.1 and is responsible for the integration of individual solutions on control and user plane, and management plane, developed in WP3 and WP4, and validation of the integrated platform according to the architecture and plan formulated in T5.1. The output of T5.2 will be used as the basis for final demonstrations of UC1, UC2.1 and UC2.2 in T5.3 and T5.4.

1.2 Document structure

Section 2 introduces the project objectives and 5G-CLARITY architecture, which is worked out in 5G-CLARITY WP2, and reported in 5G-CLARITY D2.2. The elements of the proposed architecture which are the innovations aiming at coexistence, integration and interoperation of private and public networks are introduced in this section as well. These are worked out in 5G-CLARITY WP3 and WP4, and organised based on the stratum-based architecture proposed in 5G-CLARITY WP2.

For the purpose of demonstrating 5G-CLARITY system features supporting multi-WAT and multi-connectivity support, project partners bring-in their technological developments into the use case demonstrations. These technologies include 5G radio access – 5G new radio (5GNR), and central-unit control- and user-plane functions (CU-CP, CU-UP) – Wi-Fi AP and LiFi AP designed and implemented by project partners and will be used in the demonstrations. In addition, we introduce the 5G-CLARITY customer-premises equipment (CPE), which is designed to interface the multi-WAT data traffic to the network. These technologies are described in Section 3.

In the sequel, Sections 4, 5 and 6, are dedicated to the technical description of use cases, UC1, UC2.1 and UC2.2 respectively. 5G-CLARITY use cases are formulated to validate the architectural solutions and technological innovations developed in the project, so each section goes a deep dive into the use case scope and objectives which are defined based on this high-level target. Moreover, the existing infrastructure and the employed components, developed within the project, are detailed for each use case. The demonstration venues, i.e. Bristol's M-Shed museum for the Smart Tourism pilot and the Bosch factory at Aranjuez for the Industry 4.0 pilot are introduced in each corresponding section. The demonstration scenario, expected results, a tentative implementation plan and timeline will follow for each use case, and in the end the demonstration risks and corresponding mitigation plans are identified.

Section 7 presents the conclusions of 5G-CLARITY D5.1 and the next steps.

2 5G-CLARITY Architecture and Innovative Elements

The ambition of 5G-CLARITY is to scope a framework for 5G private networks coexistence and integration to the public networks. This is pursued via a number of objectives and innovative components, which are being designed within the project. Before we proceed to the description of the project use cases, the project objectives, proposed architecture and innovative elements are reviewed in the following subsections.

2.1 Project objectives

To address private network challenges beyond 3GPP Release 16, on coexistence and integration of private and public networks, 5G-CLARITY is focusing on a multi-connectivity framework including 5GNR, Wi-Fi, and LiFi technologies, cm-level positioning and synchronization capabilities, and AI-driven and intent-based network management. These ambitious targets are formulated in the 5G-CLARITY description of work (DoW) in the format of a number of specific objectives as listed here:

- OBJ-TECH-1: Design and validation of a multi-tenant private wireless access network architecture, integrating 5G/Wi-Fi/LiFi, compute resources and machine learning (ML) based network management.
- OBJ-TECH-2: Design and validation of a multi-technology coexistence framework for private 5G/Wi-Fi/LiFi networks that enables efficient spectrum sharing between private and public networks operating in the same band.
- OBJ-TECH-3: Design and development of a multi-connectivity framework integrating 5G/Wi-Fi/LiFi evolving 3GPP Release 16 capabilities.
- OBJ-TECH-4: Demonstrate aggregate system area capacity in relevant indoor scenarios > 500 Mbps/m^2 through smart RRM algorithms and SDN control frameworks that fully exploit the capacity of the combined 5G/Wi-Fi/LiFi access.
- OBJ-TECH-5: Simultaneous support of synchronization and positioning services over the proposed 5G/Wi-Fi/LiFi infrastructure.
- OBJ-TECH-6: Development and demonstration of a 5G/Wi-Fi/LiFi management platform and an intent-based policy language for venue operators, which allows to provision third-party 5G connectivity services in less than 5 minutes, while providing security and isolation to infrastructure and service slices.
- OBJ-TECH-7: Development of management enablers to deploy an E2E 5G slice integrating compute and transport resources of a mobile network operator (MNO), with a 5G/Wi-Fi/LiFi slice deployed inside the venue. The target deployment time of a minimal E2E 5G slice containing compute and network resources is 10 minutes
- OBJ-TECH-8: Development and demonstration of an AI-enabled engine translating high-level intent/policy into continuous network configuration. Demonstrate how AI can reduce both manual and semi-automated intervention in at least two relevant use cases.

As introduced in Section 1, the 5G-CLARITY framework will be validated in two relevant pilots that will benefit from the developed connectivity services. The first pilot aims at showcasing a smart tourism use case in Bristol. The corresponding UC1 will demonstrate how the proposed infrastructure can be used to deliver novel experiences in museum environments, including robot-human interactions.

The second pilot aims at showcasing Industry 4.0 capabilities in a real factory of Bosch in Spain. This pilot consists of two different use cases. UC2.1 works out an ‘alternative wireless network to exchange production data', while UC2.1 is on 'enhanced positioning for AGV in intralogistics'. UC2.1 will demonstrate the use of network slicing technology, together with advanced mechanisms for bandwidth aggregation and increased reliability, to guarantee the performance of production data transmission and Industry 4.0 telemetry services in the factory. UC2.2, on the other hand, will demonstrate how 5G-CLARITY infrastructure fabric and positioning solutions can enable real-time tracking of AGV trajectories.

Table 2-1 presents the list of technical objectives each use case is associated with.

Table 2-1 Project Use Cases and Associated Technical Objectives

Pilot	Use Case	Associated Technical Objectives
Smart Tourism	UC1: Enabling enhanced human-robot interaction	OBJ-TECH-1; OBJ-TECH-2; OBJ-TECH-3; OBJ-TECH-7
Industry 4.0	UC2.1: Alternative network for production-data exchange	OBJ-TECH-1; OBJ-TECH-2; OBJ-TECH-3; OBJ-TECH-4; OBJ-TECH-6; OBJ-TECH-7; OBJ-TECH-8
	UC2.2: Enhanced AGV positioning in intralogistics	OBJ-TECH-2; OBJ-TECH-5; OBJ-TECH-8

2.2 5G-CLARITY proposed architecture

5G-CLARITY brings forward the design of a system that addresses the wide variety of challenges identified today in private network environments, including spectrum flexibility, delivery of critical services, integration with public network infrastructures, and automated (AI-driven) and simplified (intent-based) network management with built-in slicing. The creation of simplicity out of this complex capability set requires applying the principles of abstraction and separation of concerns into the 5G-CLARITY system architecture design, as explained in 5G-CLARITY D2.2, Section 4 [1]. The result is an architecture structured into different strata that can evolve independently from each other.

The initial design of 5G-CLARITY system, captured and detailed in 5G-CLARITY D2.2, is architected into four strata with segregated scope and different technology pace each:

- **Infrastructure stratum** – it is formed by all the on-premise hardware and software resources building up the 5G-CLARITY substrate, including user equipment and a wide variety of compute, storage and networking fabric.
- **Network and application function stratum** – it conveys the 5G-CLARITY user, control and application plane functionality. This stratum includes all virtualized network and application functions that can be executed atop the 5G-CLARITY cloud infrastructure.
- **Management and Orchestration stratum** – it encompasses all the necessary functionality to deploy and operate the different 5G-CLARITY services (and associated resources) throughout their lifetime, from their commissioning to their de-commissioning. This includes provisioning functions (for lifecycle management), monitoring functions (for data collection and processing) and other supporting functions.
- **Intelligence stratum** – it hosts the ML models and related policies which provide AI-driven and intent- based operation capabilities to the overall 5G-CLARITY strata. This stratum allows providing usage simplicity and zero-touch experience for 5G-CLARITY system consumers, especially Operation Technology (OT) actors (e.g. industry verticals), facilitating their access to the system behaviour for Service Level Agreement (SLA) assurance purposes.

Figure 2-1 illustrates the logical arrangement of the four strata into the 5G-CLARITY system architecture, including details on their individual design principles.

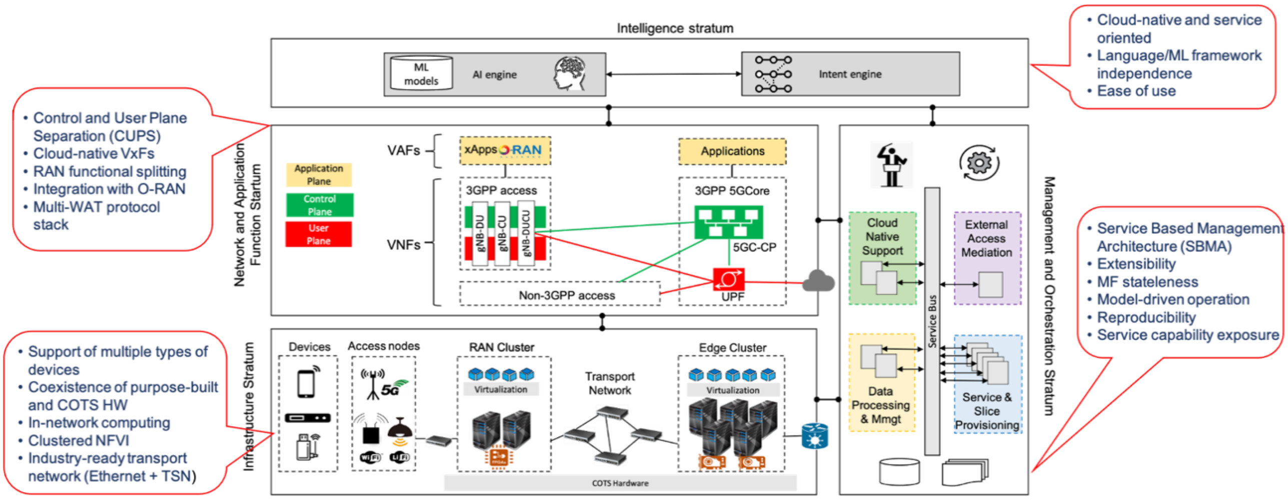

Figure 2-1 5G-CLARITY system architecture

2.3 5G-CLARITY innovative elements

5G-CLARITY architecture allows to provide a rich set of capabilities in private networks. These capabilities can be flexibly adapted, combined and extended to support a wide variety of services for both public and non-public use, including infrastructural services and communication/digital services. The 5G-CLARITY service portfolio brings forward a business ecosystem where multiple actors are allowed to coexist and interact, with vertical (intra-domain) and horizontal (inter-domain) customer-provider relationships among them, empowering innovative service delivery models that go well beyond those defined in the 5G-PPP community so far.

The innovations introduced in the 5G-CLARITY architecture design, as well the innovations used in the structure of each stratum of this architecture are discussed in the following subsections.

2.3.1 Innovative elements in the proposed architecture

5G-CLARITY innovations in the proposed architecture are briefly introduced in Section 2.2, and the logical structure of the proposed strata into the 5G-CLARITY system architecture is captured in Figure 2-1. This architecture is designed to support multiple combinations of stakeholders over a heterogeneous infrastructure with advanced capabilities, e.g., multi-WAT support, network slicing and high-precision positioning, to provide a myriad of B5G services for non-public use. Keeping the proposed architecture simple in such complex environment requires applying the principles of abstraction and separation of functionalities into the design. Further details on 5G-CLARITY proposed architecture and the innovations introduced in its framework are discussed in 5G-CLARITY D2.2 [1].

2.3.2 Innovative elements on the Infrastructure Stratum, and Network and Application Function Stratum

2.3.2.1 Integration of Wi-Fi and LiFi access using a SDN enabled L2 network

The main motivation for using a customized layer 2 (L2) SDN function, as compared to a standard IEEE 802.1 Ethernet segment, is to provide the 5G-CLARITY control plane with the ability to control, with fine granularity, the path followed by packets belonging to different 5G-CLARITY slices within the L2 segment. Notice that a standard 802.1 Ethernet segment implements per-VLAN data plane learning, which does not allow for this fine level of control. Another key requirement for the L2 SDN control plane is to support seamless mobility, meaning that when user devices roam through the various Wi-Fi and LiFi APs connected to the L2 SDN network forwarding paths should be automatically updated. Moreover, the proposed Wi-Fi-LiFi integrated L2 function should ensure that the IP address of the user equipment (UE) remains the same while user devices roam among Wi-Fi and LiFi APs. The 5G-CLARITY Wi-Fi-LiFi integrated L2 SDN network that provides access to Wi-Fi and LiFi UEs and connects to a standard 802.1 Ethernet segment is described in 5G-CLARITY D2.2 and D3.1 [1], [3].

2.3.2.2 RAN-based 5GNR spectrum-access system client

5G-CLARITY will enable a dynamic spectrum access paradigm based on the use of Citizen Radio Broadband Service (CBRS) spectrum access system (SAS) architecture. In the 5G-CLARITY SAS architecture an external SAS acts as an automated and intelligent dynamic spectrum management coordination entity, which will be simulated/emulated in order to provide the RF spectrum parameters that the 5G-CLARITY 5GNR SAS client requires for operation. The current integrated LTE SAS client used in CBRS small cell context will be implemented in Accelleran Open RAN (O-RAN) dRAX™ context as an xApp for 5G-CLARITY (refer to 5G-CLARITY D3.1 [3]) with the following enhanced functionalities:

i. Support grouping information and coexistence grouping so that the cluster of 5GNR distributed unit (DU) and radio units (RU) can operate in co-channel deployment with minimal spectrum within cluster wide Interference Coordination Group;

ii. ii) Align to upcoming CBRS Alliance Release 4 specifications to support 5GNR operation in SA mode and SA NPN/PLMN-integrated NPN.

2.3.2.3 Multi-access based multi-connectivity

5G-CLARITY architecture supports the deployment of multi-WATs. The integration of a non-3GPP network such as Wi-Fi or LiFi requires inter-networking elements within the 5G core (5GC) network. The 5G-CLARITY solution for non-3GPP access integration uses multi-path steering, switching and splitting (MP3S) function, which similar to the 3GPP access traffic steering, switching and splitting (AT3S), can be operate on multi-path TCP (MPTCP) implementation and the switching, steering and splitting (SSS) operations are similar to 3GPP AT3S. The MP3S framework splits the SSS functionality between the network and the UE, where the MP3S in the UE is controlled by the UE policy controller which is operating on access network CP. A real-time telemetry function is collecting real-time measurements from each access technology. This telemetry is carried over to the intelligent telemetry application function which analyses the telemetry and proposes a policy change to the real-time policy-controller. The real-time policy-controller coordinates the dynamic policy changes that impact the MP3S function and eventually schedules of the access network traffic.

In case of 3GPP integrated multi-access, within the scope of 5G-CLARITY no RAN integration approaches will be used in the demonstration pilots, since 5GNR and Wi-Fi will come from different partners. This would be also the normal case in private networks when cellular LTE/5GNR technology is brought into an already established Wi-Fi infrastructure. Instead, the 5G-CLARITY solution will use and demonstrate a core-based enhanced AT3S (eAT3S) integration. This solution will effectively be a hybrid of both core and RAN approaches in the sense that the AT3S will be enhanced to incorporate near real-time (near-RT) RAN controlling of the AT3S policies behind the user plane function (UPF). To this end, it will use multi-WAT telemetry at RAN level (not only UPF level) via near-RT radio interface controller (RIC) and O-RAN xApp framework. The O-RAN based reference architecture will be provided by Accelleran dRAX™ as discussed in 5G-CLARITY D3.1 [3], where the 5G-CLARITY eAT3S CP and UP are discussed as well.

2.3.2.4 Resource management via eAT3S-level traffic routing and resource scheduling

Since in 5G-CLARITY non-3GPP access network is considered as an integrated Wi-Fi/LiFi SDN L2 network, and because non-3GPP access will be integrated with 3GPP access network using AT3S, routing the traffic flows to 3GPP and non-3GPP access networks can be considered as a resource management problem. Moreover, as a 5G-CLARITY CPE/UE will be capable of using 5G, Wi-Fi and LiFi technologies, multiuser access to physical resources of those technologies can also be considered as a resource management problem. Therefore, resource management in 5G-CLARITY will be considered as a two-stage process namely 'traffic routing' and 'gNB/AP-level resource scheduling'.

In the 5G-CLARITY real-time eAT3S, traffic routing is based on, i) comparing the predefined threshold values of network service related KPIs and the real-time performance measurements/telemetry data; and ii) ML-based traffic routing onto different WATs by using the telemetry data and performance measurements. Having a WAT-specific telemetry data and using it within AT3S routing leveraging O-RAN reference architecture is not considered/defined in the current 3GPP AT3S framework. Therefore, both of the noted routing methods are 5G-CLARITY novel solutions.

On the resource scheduling for gNB/AP, the 5G-CLARITY architecture assumes either gNB, Wi-Fi AP or LiFi AP will take care of scheduling its physical resources for the intended user access, once a traffic flow is routed to 5G, Wi-Fi or LiFi network respectively. Therefore, each technology can use its preferred packet scheduler such as round-robin or proportional fair to deliver the routed packets. The off-the-shelf products that are used as 5GNR gNB, Wi-Fi AP and LiFi AP in 5G-CLARITY implementations are described in Section 3. Details of the scheduler for each of these technologies are reported in 5G-CLARITY D3.1, Section 6.2.4.2 [3].

2.3.2.5 Enhanced indoor positioning by integration of multi-technology positioning information

Several technologies that may offer positioning estimates with different precision, based on the environment or the estimation approach, are considered in 5G-CLARITY. If the UE is in the line-of-sight (LoS) of the corresponding AP or not, this is of significance for selecting the position estimation mechanism, and thus the accuracy and reliability of the position estimation. Depending on the possibility that one technology faces a LoS scenario and the other in the non-line-of-sight (NLoS) scenario, the positioning information is used with different confidence. The confidence of the position obtained from the 5G-CLARITY WATs can be used based on the probability of the LoS occurrence at a given moment. The localization server envisaged in 5G-CLARITY, which was introduced in 5G-CLARITY D3.1 Section 6.2.5 [3], is part of the tenant infrastructure and is in charge of managing the position estimates retrieved from the multi-WAT. Each candidate technology contributing to the 5G-CLARITY positioning framework will have an interface towards the localization server. The localization server will encompass a set of methods that will allow the retrieval of requests, the control and intelligent combination of the position estimates, and will push the resulting position estimate to the network. Moreover, this innovative framework based on the localization server will be able to provide enhanced position estimates.

2.3.3 Innovative elements on the Management and Orchestration Stratum, and Intelligence Stratum

2.3.3.1 Multi-domain network slicing for private networks providing multi-WAT, transport and compute services

A novel slicing concept geared towards the notion of multi-tenancy was proposed in 5G-CLARITY D2.2 [1]. 5G-CLARITY slices allow a private network operator to open its physical infrastructure to connectivity (or digital service) providers, where such physical infrastructure comprises multiple domains, including:

- RAN physical infrastructure: 5GNR RUs, Wi-Fi APs and LiFi APs
- RAN cluster: a set of compute nodes supporting virtualised RAN functions such as CUs, DUs and RIC
- Edge cluster: set of compute nodes supporting virtualised 5GC components, as well as other

application and network functions

- Transport nodes: composed of Ethernet compliant devices that connect the RAN physical infrastructure to the RAN and Edge clusters

5G-CLARITY slices can therefore be provisioned across the private network infrastructure by configuring public land mobile identifiers (PLMNID) and single-network slice assistant information (S-NSSAI) in the 5GNR cells, configuring service set identifiers (SSID) in the Wi-Fi and LiFi devices, configuring VLANs in the Ethernet transport devices, and allocating chunks of compute, storage and memory resources in the compute nodes. Isolation mechanisms across the various technologies are used to provide performance guarantees to the various slices.

5G-CLARITY slices are enabled by the service and slice management subsystem described in 5G-CLARITY D2.2 [1]. Within this subsystem, the multi-WAT non real-time (non-RT) controller and the slice manager components described in 5G-CLARITY D4.1 [4] represent the 5G-CLARITY innovations that will be demonstrated in the use cases.

2.3.3.2 Integrated multi-WAT real-time telemetry system

In addition to supporting the management of the lifecycle 5G-CLARITY slices and their associated services, a critical component to enable autonomous network control is the visibility of the state of the network. For this purpose, 5G-CLARITY develops an integrated telemetry subsystem which can aggregate telemetry sources from RAN, compute and transport domains as introduced in 5G-CLARITY D4.1 [4].

Within the 5G-CLARITY telemetry subsystem, the emphasis is on the aggregation of telemetry generated by the 5GNR, Wi-Fi and LiFi networks that can enable real-time network control. This is achieved by means of a real-time RAN RIC that exposes 5GNR, Wi-Fi, and LiFi telemetry to applications through a common data bus. This telemetry is critical to demonstrate the eAT3S concept that is a key innovation in 5G-CLARITY.

2.3.3.3 AI-engine and ML models

ML models controlling aspects of future 5G networks will not be a static network component but will rather be dynamic. Dedicated subsystems in the network stack are required to manage the complexity of such a system. For this purpose, 5G-CLARITY envisions an *AI-engine* that acts as the execution environment for the ML models operating on top of the 5G infrastructure. The 5G-CLARITY AI-engine allows to onboard ML models and manage their execution lifecycle, and provides a unified application programming interface (API) to these models to ingest network telemetry and execute network commands.

The 5G-CLARITY AI-engine along with a selected subset of the ML models, reported in 5G-CLARITY D4.1, will be an instrumental part of the 5G-CLARITY demonstrations.

2.3.3.4 Intent-based networking interface

Operational complexity is an important barrier to the adoption of private 5G networks by vertical users that are used to operate simpler enterprise grade networking technologies. For this purpose, 5G-CLARITY develops a high-level intent interface that will allow a private network operator to manage its network in a declarative manner.

The functionality of the intent based interfaces, and how they are used to simplify the operation of a complex infrastructure supporting slicing and AI-driven operation, will be demonstrated in the 5G-CLARITY use cases.

2.3.4 Summary of 5G-CLARITY innovations

Table 2-2 presents a summary of the 5G-CLARITY innovations mapped to the different 5G-CLARITY strata.

Table 2-2 5G-CLARITY Innovative Elements

Innovation ID	Description	Corresponding Stratum	Evaluation Method
INNO_01	Integration of Wi-Fi and LiFi access using a SDN enabled L2 network	Infrastructure Stratum, Network and Application Function Stratum	UC1, UC2.1
INNO_02	RAN based 5GNR SAS client	Infrastructure Stratum	Simulation
INNO_03	Multi-access based multi-connectivity	Infrastructure Stratum, Network and Application Function Stratum	UC1
INNO_04	Traffic routing to 3GPP and non-3GPP networks	Infrastructure Stratum	Simulation
INNO_05	gNB/AP-level resource scheduling	Infrastructure Stratum	Simulation
INNO_06	Integration of multi-technology positioning information	Infrastructure Stratum	UC2.2
INNO_07	Multi-domain network slicing for private networks	Management and Orchestration Stratum	UC1, UC2.1
INNO_08	Integrated multi-WAT real-time telemetry system	Intelligence Stratum	UC2.1
INNO_09	AI-engine and ML models	Intelligence Stratum	UC2.1
INNO_10	Intent-based networking interface	Intelligence Stratum	UC2.1

3 5G-CLARITY CPE, 5G access, Wi-Fi and LiFi access points

This section provides a description of the 5G-CLARITY radio access nodes contributed by project partners, i.e. Wi-Fi and LiFi APs, and the 5G radio access components to be used for 5G-CLARITY demonstrations. In addition to these devices, a CPE is being designed to be used for interfacing the multi-WAT data traffic to the 5G-CLARITY network.

3.1 RAN cluster and radio setup

The block diagram of the 5G RAN access, Accelleran dRAX™ shown in Figure 3-1, is a cloud native and O-RAN aligned 5G standalone virtual RAN (VRAN) solution. This solution, which is used in 5G-CLARITY use cases, is consisting of a near-RT RIC, CU-CP, CU-UP and xAPP framework components integrated E2E with third party DU and RU components from the disaggregated RAN ecosystem.

The components which will be deployed in the 5G-CLARITY pilots are:

- 1x dRAX™ component with near-RT RIC, CU and xApp framework delivered as a software component (VNF)
- 1x DU component delivered as a software component (VNF)
- 1x RU delivered as a hardware component (physical network function (PNF))

Accelleran dRAX™ is engineered to provide an open and extensible software framework for the CP functions of 4G and 5G RAN and aligns with O-RAN architecture principles defined by both 3GPP and the O-RAN Alliance. dRAX™ is a genuinely cloud-native architecture based on containerised microservices communicating with each other via an asynchronous messaging framework. Each of the major components of the RAN (CU-CP, CU-UP, near-RT RIC) are themselves disaggregated into a fine-grained set of service entities. dRAX™ is delivered as a containerised software-only component that will run on Bristol RAN cluster Commercial Off-The-Shelf (COTS) server.

Accelleran dRAX™ CU software components communicate with the DU software components via standard 3GPP F1 interface over any IP transport. dRAX™ and the DU can be collocated in the same or different RAN cluster COTS server.

The DU software communicates with the RU using O-RAN fronthaul 7.2 split (refer to 5G-CLARITY D3.1 [3]) interface over optical fibre. The RU provides a 10 Gbps SFP+ port for this purpose.

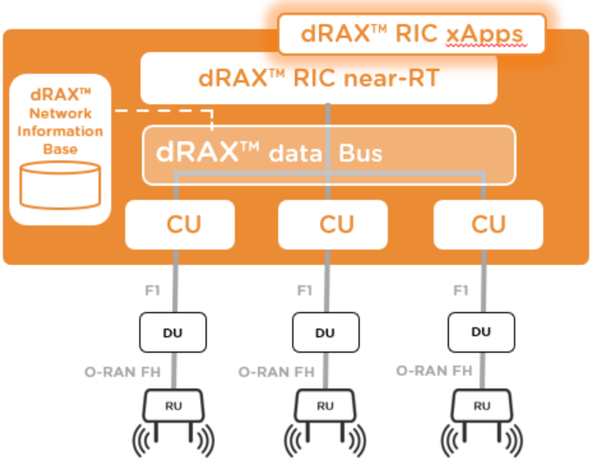

Figure 3-1 Accelleran 5G RAN access

3.2 LiFi access point

Within the context of 5G-CLARITY a LiFi node is a set of devices that could convert and deliver data packets in the form of light. These devices are:

- LiFi AP, which includes:
  - A physical layer (PHY) based on 802.11 OFDM PHY as detailed in 5G-CLARITY D3.1 [3],
  - Digital-to-analogue and analogue-to-digital converters, which convert the digital signal to analogue signal for downlink transmission, and covert the received analogue signal to digital signal for the uplink decoding,
  - A medium access (MAC) layer interface between the PHY and the upper layers, with functions defined in IEEE 802.11. The implemented MAC could be modified to provide full-duplex operation, high protocol efficiency and multiuser support,
- Transmitter driver, for driving the light luminaire,
- LiFi transmitter, which acts as both luminaire for illumination and emitter for optical wireless signals. It is usually an LED lamp for general use cases, and it can be within either visible light spectrum or infrared spectrum,
- LiFi receiver, which converts the uplink infrared signal into electrical signal. It is implemented as a photodiode array with infrared filter and stages of amplification.

A NETCONF server has been implemented in the LiFi AP, as well as a Prometheus agent which retrieves telemetry from the AP. The system shown in Figure 3-2(a) and (b) is the LiFi-XC AP product. Figure 3-2(c) presents the logical block diagram of the LiFi AP connected to a 5G-CLARITY Wi-Fi node.

3.3 Wi-Fi access point

5G-CLARITY features custom Wi-Fi APs developed by i2CAT to support some of the project innovations such as airtime-based slicing or an embedded SDN agent. In addition, to support all slicing features defined in 5G-CLARITY D4.1 [4], these Wi-Fi nodes will also include a set of SDN agents that are used to mark the access traffic coming from different slices, and so they will be used as access switch for the 5G-CLARITY LiFi APs.

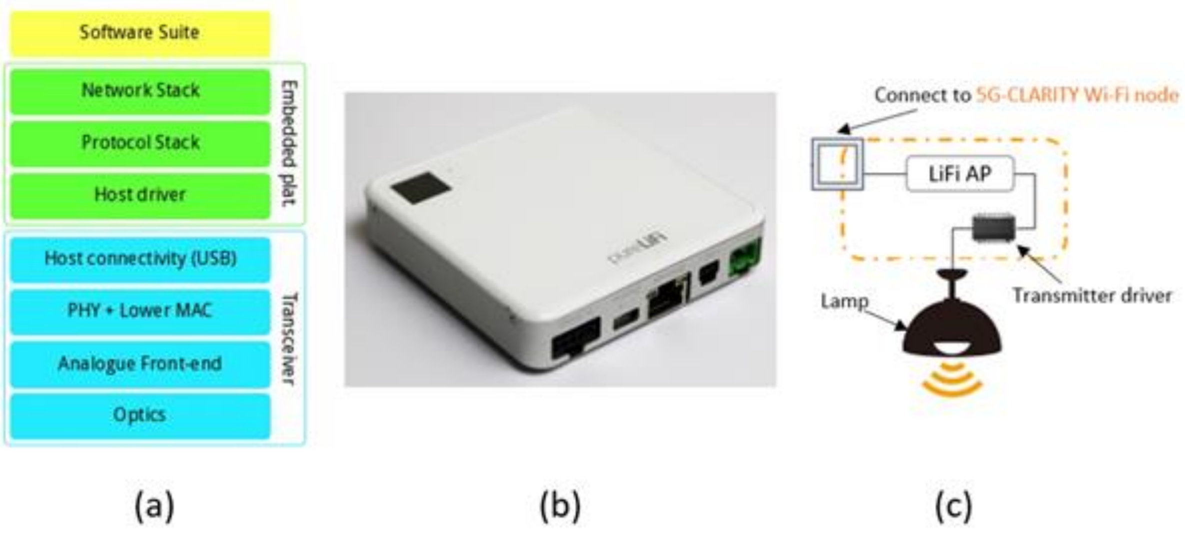

Figure 3-2 (a) LiFi node stack structure; (b) LiFi-XC AP; (c) LiFi AP logical block diagram.

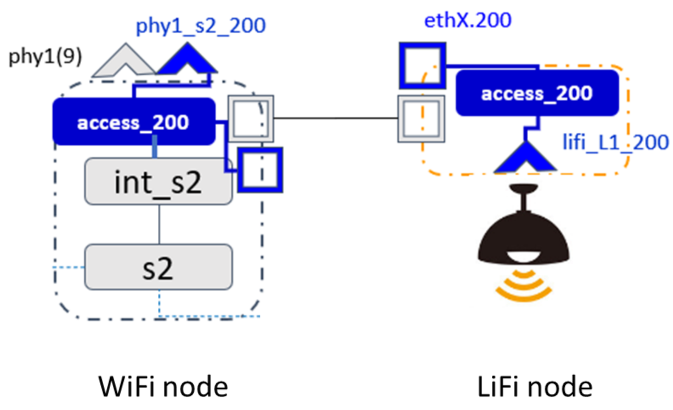

Figure 3-3 Wi-Fi node serving as access SDN switch for LiFi node

Figure 3-3 depicts an example of such Wi-Fi nodes, its internal switches and a connected LiFi. More details on this architecture can be found in 5G-CLARITY D3.1 [3].

In terms of physical design, the 5G-CLARITY Wi-Fi node is composed of a single-board computer (SBC) running Linux Ubuntu 18.04 (or above) and one or more Qualcomm Atheros (QCA) Wi-Fi modems. The current modems are based on the WLE650V5 module from COMPEX that features an IEEE 802.11ac modem from Qualcomm. Throughout the course of the project, the availability of a Wi-Fi 6 modem that could fit the requirements on the integration with the SBC used in the 5G-CLARITY Wi-Fi node will be considered.

3.4 5G-CLARITY CPE

The 5G-CLARITY CPE allows to connect any device with an Ethernet interface to the 5G-CLARITY network by multiplexing the Ethernet traffic over the three WATs considered in the project, namely 5GNR, Wi-Fi and LiFi.

Figure 3-4 depicts a preliminary design for the 5G-CLARITY CPE, where the following components are observed:

- An SBC with a Linux based operating system. In Figure 3-4 a PC Engines APU2 board is depicted running an Ubuntu 18.04 image. A custom kernel image will be deployed in the SBC to accommodate the MPTCP capabilities required to implement the AT3S user plane functionality. This board will have the following interfaces as well:
  - 2x Gigabit ethernet ports,
  - 2x (at least) USB 3 ports,
  - 1x mini PCIe/M.2 interface.
- A USB based LiFi dongle provided by pureLiFi.
- A mini PCIe Wi-Fi module. In Figure 3-4 we can see a WLE650V5 module from COMPEX featuring an IEEE 802.11ac modem from Qualcomm. This modem is currently considered because it offers good compatibility with the Linux operating system running in the SBC. It will be considered if this module can be replaced by any other module featuring a Wi-Fi 6 modem.
- An M.2 based 5GNR modem supporting standalone mode. In Figure 3-4 it can be observed that a Quectel RM500Q module mounted on an evaluation board that connects through USB to the SBC. At the moment of writing this deliverable we are benchmarking the performance of this modem. Alternative modems may be used in different instantiations of the 5G-CLARITY CPE.

A proper encapsulation will have to be designed in order to deploy the 5G-CLARITY CPE in the various project use cases.

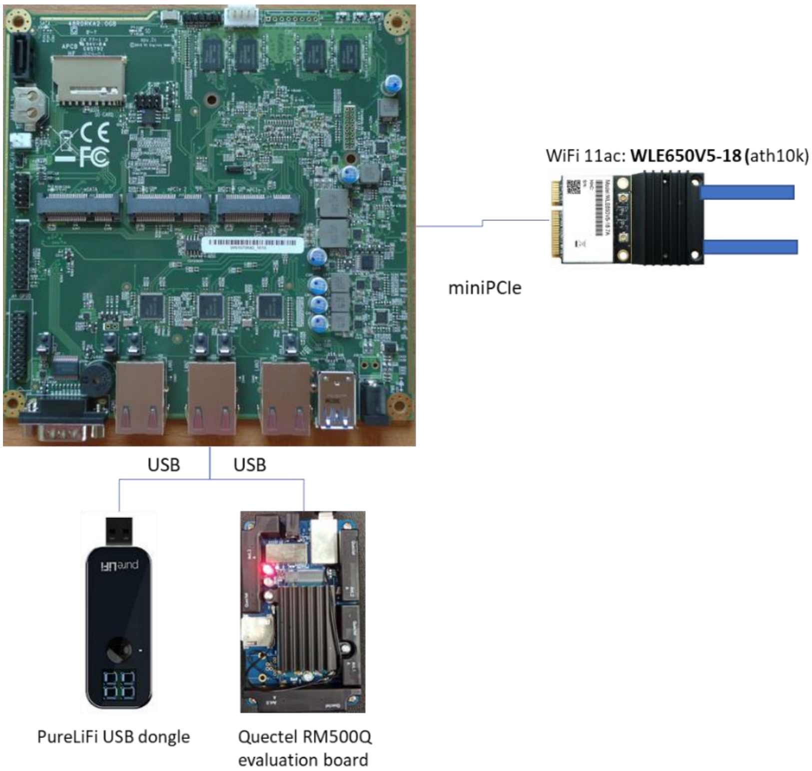

Figure 3-4 5G-CLARITY CPE preliminary design

4 UC1: Enabling Enhanced Human-Robot Interaction (Smart Tourism)

The 5G and beyond 5G (B5G) infrastructure promises to enhance tourism and entertainment sectors in safe public domains by providing smart, pervasive, flexible, sliceable, and robust 5G multi-WAT infrastructure for public and non-public services. 5G-CLARITY UC1 aims to design, deploy, validate, and demonstrate a B5G non-public network (NPN) in public venues (such as museums) with capability to enable intelligent, pervasive, and robust interactions between a robot --as a tour guide-- and humans. The infrastructure will also enable on-demand services such as public safety systems and third-party special events. In this sense, 5G-CLARITY UC1 is used to attest the 5G-CLARITY framework and infrastructure benefits to enhance tourism and entertaining sectors in public spaces while supporting the emergency/surveillance services for public safety and third-party special event services, e.g., conferences, seminars, etc.

In the following, in Section 4.1, the 5G-CLARITY UC1 scope, objectives, elements, narratives and potential benefits are introduced. Then the demonstration scenario and 5G-CLARITY enablers are discussed in Section 4.2, following by the preliminary test-plan, implementation plan and tentative timeline in Sections 4.3 and 4.4. The 5G-CLARITY UC1 descriptions in this section is resumed by the discussion on demonstration risks in Section 4.5.

4.1 UC1 scope and objectives

The main goal of 5G-CLARITY UC1 is to validate and demonstrate the benefits of the 5G-CLARITY multi-WAT and NPN enabled framework and infrastructure in a public museum environment to enhance the interactions between a guide robot and visitors. This can be formulated in the following objectives:

- To integrate, validate, and demonstrate a smart tourism application in a museum supported by the 5G-CLARITY architecture for intelligent, flexible, and robust interactions between visitors and a robot as tour guide (Standalone NPN (SNPN) scenario described in 5G-CLARITY D2.2 [1]).
- To validate and demonstrate the 5G-CLARITY framework to support elastic and robust NPN extensions through E2E slicing for on-demand services such as secure connectivity for emergency and public safety surveillance systems and third-party special events (Public Network Integrated NPN (PNI-NPN) scenario described in 5G-CLARITY D2.2 [1]).

4.1.1 UC1 elements

The 5G-CLARITY UC1 will be demonstrated in three main narratives. This section introduces the components, actors, and applications and services to be deployed and emulated in this use case. Figure 4-1 introduces the overview of UC1 main components and frameworks, where Figure 4-2 provides more details on the connectivity setup. These components are:

- 5G-CLARITY testbed at the University of Bristol: the deployment and integration of 5G-CLARITY network functions and multi-WAT infrastructure to host, connect, and support 5G-CLARITY UC1. To this end, the testbed emulates the scenario of an NPN integrated with a public network (5GUK) and extends external third-party services (i.e., surveillance and special events services) via network slicing. The testbed will connect the 5G-CLARITY edge cluster, hosted in the server room of the smart-internet laboratory of the University of Bristol, to the 5G-CLARITY RAN cluster and 5G-CLARITY multi-WAT access nodes (5GNR RU, Wi-Fi Aps and LiFi APs) in the M-Shed museum of the Bristol city council. The 5G-CLARITY network functions such, as the private gateway, will be hosted in the edge cluster, while RAN functions and applications, e.g., dRAX™ introduced in Section 3.1, will be hosted in the RAN cluster. The deployment and integration of the 5G-CLARITY management, control, and orchestration functions, e.g., slice provisioning and management, will provide the capability to activate and deactivate slices and to connect to the third-party services through the public network.

Network functions and virtual machines (VM) of the 5G-CLARITY framework will be hosted on the edge and RAN clusters of 5G-CLARITY testbed (Figure 4-1 (a)).

- Smart Tourism framework: is the set of applications and components for management, control, programmability, and contents for the guide robot services. The applications will be deployed on VNFs/PNFs and VMs hosted in the 5G-CLARITY edge cluster (Figure 4-1 (b)). These main applications and components are:
  - Guide robot management application: the set of functions for management, control, and orchestration of the guide-robot connectivity, movement, sensors (e.g., physical proximity, voice recognition), actuators (e.g., speeches), data analytics, and built-in devices (e.g., LCD screen).
  - Guide robot positioning application and components: is a set of functions and devices supporting the physical positioning and moving of the guide robot in coordination with the management application. The guide robot positioning devices are a set of infrastructure video cameras (i.e., infrastructure cameras) connected to the guide robot positioning application to collect video streaming. The positioning application architecture is based on the basic idea of the intelligent space model proposed in [5], which uses AI tools to process the stream of images and data collected from infrastructure cameras to enhance the guide robot positioning and movements. Given its processing intensive nature, the AI tools of the guide robot positioning application will be hosted in a compute node equipped with hardware accelerators (e.g., GPU) at the 5G-CLARITY edge cluster.
  - Museum service application: is a set of programmed functions and developed contents defining the guide-robot services for the museum. The museum services include personalized schedules, directives, and tasks to support visitors of the museum, e.g., provides requested information, shows requested expositions, answers visitors frequently asked questions, etc.
  - Private network functions: is a set of network functions (VNF/PNF) instantiated to form the NPN slice, e.g., NPN VNFs.

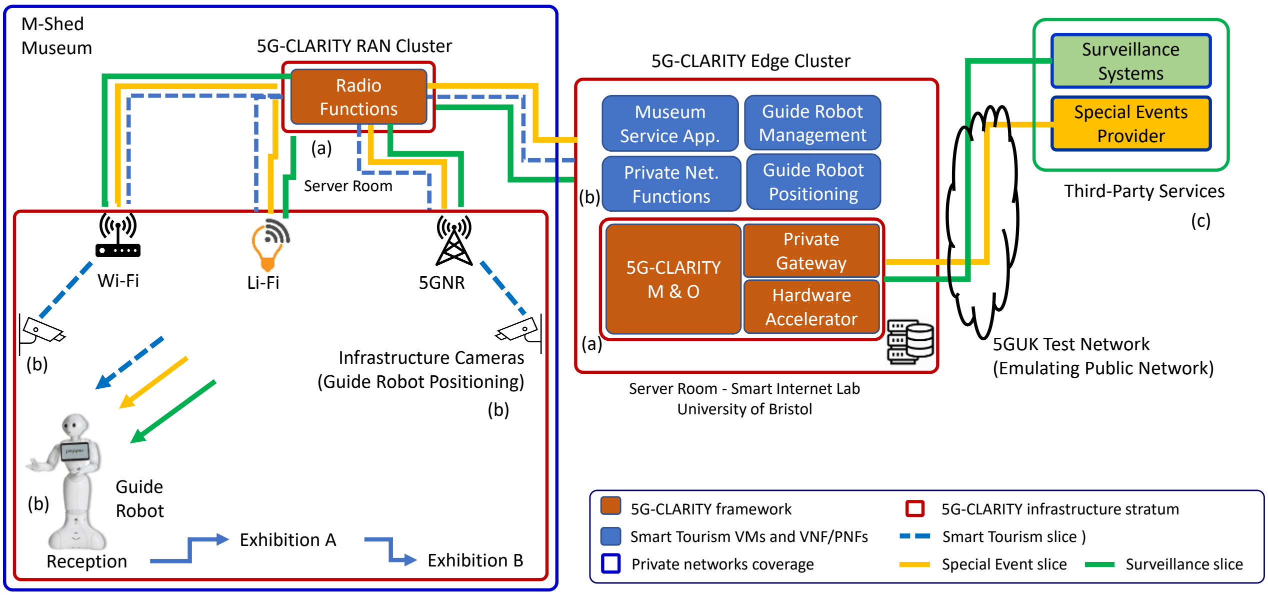

Figure 4-1 UC1 framework, components and service slices overview

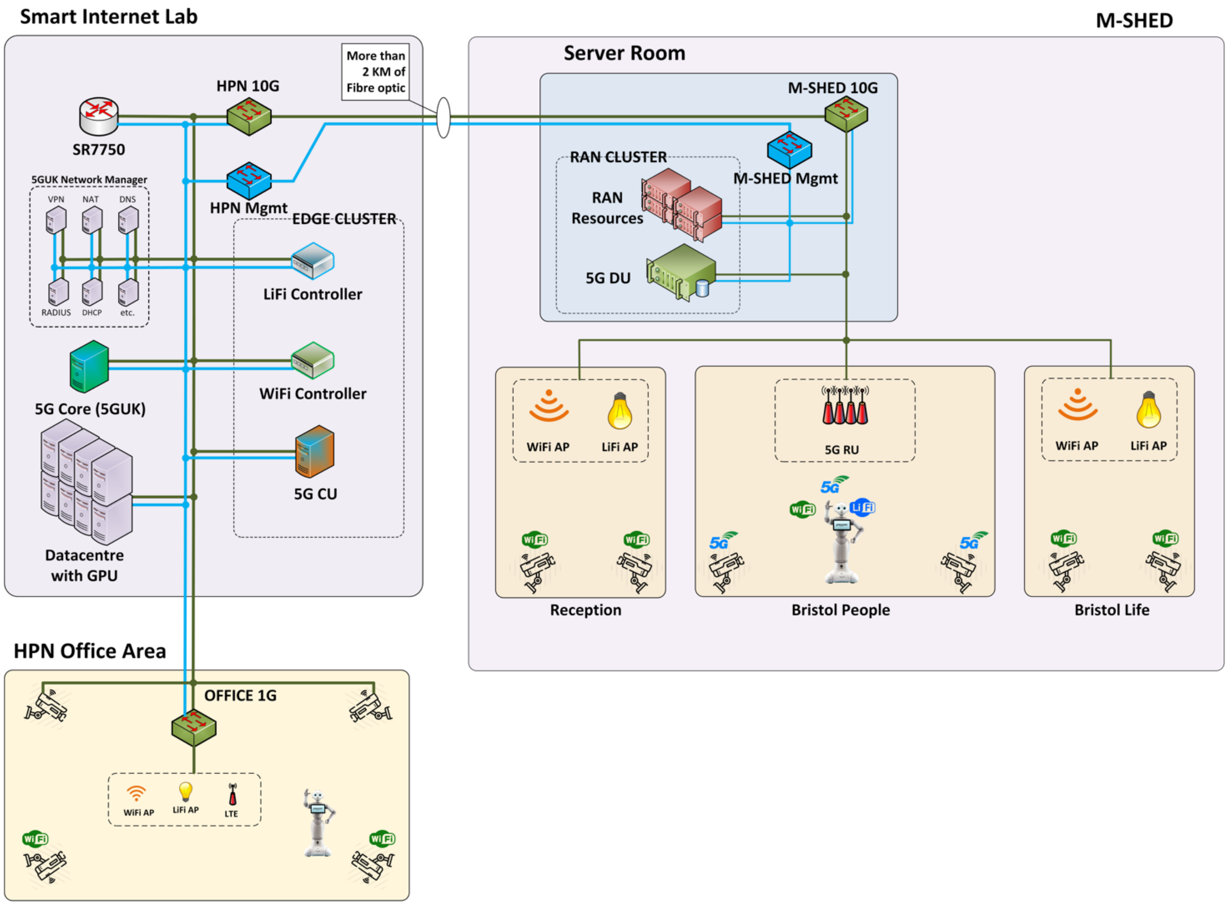

Figure 4-2 Overview of the infrastructure used for UC1 testbed at the University of Bristol

- Guide robot: a mobile robotic device [6] programmed as the tour guide to assist and interact to visitors with the capability to host and showcase multiple interactive contents. The guide robot, shown in Figure 4-3, will be equipped with an onboard video camera (360 degrees) to offer video streaming. The guide robot will be equipped with an onboard 360-degree surveillance camera mounted on its head for the public surveillance demonstration. The 5G-CLARITY CPE requires two Gigabit Ethernet ports, one to connect the guide robot and accommodate the multi-WAT aggregated traffic and the second port for the 360-degree surveillance camera. Since the guide robot moves around in M-Shed to interact with people, it demands high throughput and low latency connectivity to remain operational. When the guide robot moves, the CPE switches to a specific WAT or multi-WAT, based on the availability and based on predefined scenarios.

- Infrastructure cameras: six infrastructure cameras are deployed in the reception and exhibition halls of the M-Shed museum, connected to the network by wire or wirelessly to provide image streams of the environment used for the guide robot management and positioning applications. For positioning, images from multiple cameras will be processed jointly to locate the robot and monitor its movement. At least two cameras are simultaneously used per selected locations within the predefined space for positioning and detection requiring at least 100 Mbps for 5 fps with a resolution of 1280 x 728 pixels. To reduce the overall computational demand from the VMs the target detection will use low frame-rate images (e.g., quick response codes (QR-code)).

- 5G-CLARITY RAN cluster: is deployed in the server room of the M-Shed museum to host VMs and VNFs/PNFs deploying RAN resources and functions (e.g., 5G DU) of the dRAX™ framework as described in Section 3. A fibre connection will connect the RAN cluster and the multi-WAT access node deployed in the M-Shed museum.

- 5G-CLARITY edge cluster: is formed by a group of OpenStack compute nodes to be deployed in servers equipped with GPUs housed in the datacentre, located in the server room of the smart internet laboratory. It hosts VMs and VNFs/PNFs deploying the Smart Tourism framework and 5G-CLARITY infrastructure (e.g., slice manager, NFVO, dashboards, and monitoring tools).
- 5G-CLARITY multi-WAT infrastructure: 5G-CLARITY 5GNR RU, Wi-Fi AP and LiFi AP, introduced in Section 3, will be installed in several locations at the M-Shed reception and halls.
- The transport network: will interconnect all UC1 elements and additional testing locations by using the 5GUK test network infrastructure.
- Measurement and monitoring tool: a set of applications deployed and integrated in the testbed for performance validation. These tools use radio and data analytics collected from the devices to measure the performance in terms of latency, jitter, and uplink/downlink throughput.

The main actors:

- Visitor: people visiting the museum requesting services while walking around in the museum with the guide robot.
- Public safety institution: team of public safety officers monitoring suspicious activities.
- Special visitors: delegates invited to visit the museum for a special event.
- Special event producer: organisations providing remote and ad-hoc special events such as conferences, workshops, product expositions, museum exhibition, social events, etc.

Service slices to be provisioned:

- Smart Tourism slice: interconnecting frameworks and components of the guide-robot service.
- Surveillance slice: interconnecting fixed, and on-demand public surveillance system managed by a public safety institution (e.g., police department).
- Special event slice: providing required interconnections between the special event and content produced (e.g., conferences or workshops).

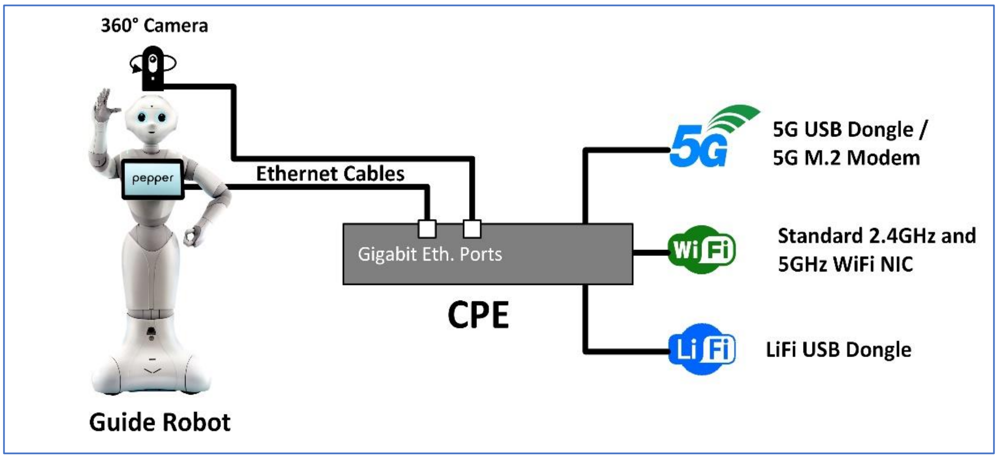

Figure 4-3 The guide robot, and mounted 5G-CLARITY CPE

4.1.2 UC1 narratives

Three main narratives for the UC1 demonstrations are as follows:

Narrative 1: The guide robot guidance to visitors in the museum

- Main technological enabler: multi-connectivity framework, supporting mobility across different wireless access technologies
- Preconditions
    - 5G-CLARITY testbed and smart-tourism framework are operational.
    - The visitor approaches the reception and requests guidance to reach a museum exposition.
    - The guide robot detects the visitor's presence.
- Main flow
    - Guide robot invites the visitor to a guided walk toward the requested museum exposition.
    - The visitor and the guide robot walk to the requested exposition passing through different wireless access nodes (i.e., multi-WAT handover).
    - While passing through other expositions the guide robot delivers summary of historical contents associated to each museum exposition.
    - The visitor and the guide robot arrive at the requested exposition, the guide robot delivers the full historical content associated to the requested exposition.
- Post-conditions
    - The guide robot finishes the presentation, says goodbye and stays in the location waiting for the next visitor's request.

Narrative 2: On-demand surveillance of suspicious activities in the museum

- Main technological enabler: 5G-CLARITY service slices deployed over the NPN integrated with the public network (PNI-NPN scenario) to enable third-party services (Figure 4-1 (c))
- Preconditions
    - 5G-CLARITY testbed and smart tourism framework are operational.
    - Request from a public safety institution is received by the 5G-CLARITY framework.
    - The guide robot onboard camera installed and operational.
- Main Flow
    - 5G-CLARITY framework sets up a secure connection and offers a slice over the NPN to the surveillance system. The provisioned slice is formed by dedicated VNFs to connect the guide robot onboard camera with the surveillance system without disrupting the museum service application.
    - While moving and delivering normal services to visitors, the guide robot activates the onboard camera, streams live video signal through the dedicated slice for surveillance over the NPN.
    - After the surveillance is completed, the public safety institution informs 5G-CLARITY framework.
- Post-conditions
    - 5G-CLARITY framework deactivates the dedicated slice without interrupting other services.
    - The guide robot turns off the onboard camera.

Narrative 3: On-demand third-party content delivery for special events

- Main technological enabler: 5G-CLARITY service slices deployed over a private network integrated with a public network (PNI-NPN scenario) to deliver third-party contents (Figure 4-1 (c)).

- Preconditions
  - 5G-CLARITY testbed and smart tourism framework are operational.
  - A request from the special event organizer for scheduling the special event is received by the 5G-CLARITY framework.
- Main Flow
  - 5G-CLARITY framework activates the scheduled slice.
  - Once the slice is active, third-party instantiates their services on the slice.
  - As visitors arrive, the guide robot welcomes and begins to support the special event.
- Post-conditions
  - 5G-CLARITY framework removes the third-party slice without interrupting other services.

4.1.3 UC1 potential benefits and applications beyond 5G-CLARITY

The 5G-CLARITY UC1 has the potential to benefit the telecommunication business, a number of envisioned benefits are categorised and highlighted in this subsection.

Benefits for MNOs:

- To extend the coverage and capacity offered to their own subscribers for indoor venues where their coverage is none or limited.
- To provide the advantages of aggregating and selecting different access technologies, e.g., Wi-Fi and LiFi.
- To extend their network infrastructure with the RAN clusters provided by the neutral host at a fraction of the cost compared to when these RAN clusters are deployed by themselves (if that was possible at all).
- To provide their subscribers with high throughput, ultra-reliable and low latency services in coverage limited environments, thanks to the edge clusters.

Benefits for neutral host providers:

- To offer coverage and capacity to their customers or tenants (e.g., MNOs) in indoor venues where MNO's coverage is insufficient or absent.
- To provide their own customers or tenants the advantages of aggregating and selecting different access technologies, some of which are based on technologies not requiring licensed spectrum, e.g., Wi-Fi or LiFi, or others requiring inexpensive local/shared access licenses like the ones offered by Ofcom in UK in indoor spaces or outdoor spaces deployed below 10 m height.
- To provide high throughput, ultra-reliable and low latency services to their customers or tenants thanks where MPN's coverage is limited, to the edge clusters.

Potential applications:

- For social distancing and health monitoring, UC1 scenario could allow interaction with autonomous or remotely controlled robots to provide information, while keeping distance between the tour guide and users. These robots could help to enforce venue capacity limits, by counting people and their interpersonal distance at public transportation stations. Furthermore, these robots could incorporate additional sensors, e.g., thermal cameras [7], to detect prespecified symptoms, or AI-based mask detectors notify people who are not wearing one to do so.

- For surveillance applications, with strict privacy protection in compliance to the general data protection regulations (GDPR), robots with cameras could reach additional zones and provide different points of view. Computer vision applications installed at the edge could automatically identify safety threats [8], filed criminals, or lost people. Under emergency scenarios, a fleet of interconnected robots could coordinate the emergency scenarios (e.g., the airport emergency evacuation use case of 5G-TOURS [9], by knowing which exit paths are more suitable, and which ways are less congested.
- Owning an NPN infrastructure could benefit temporary or nomadic venues, such as international airports or cruise ships. In these places, users could enjoy multi-WAT connectivity without depending on local providers. Trade fair venues could provide it as a service, including the self-driven guide robot.

4.2 UC1 demonstration scenario and 5G-CLARITY enablers

The 5G-CLARITY UC1 scenario will be demonstrated in the M-Shed museum, following to its tests in a laboratory environment at the University of Bristol. The 5G-CLARITY testbed for UC1 will be realized by the 5GUK test network connecting the smart internet laboratory of the University of Bristol for the in-lab tests and then the connectivity will be expanded to the M-Shed museum of the Bristol city council for the final demonstrations. The testbed will integrate the 5G-CLARITY infrastructure and components introduced in Section 4.1.1 to support the smart tourism framework. Figure 4-2 presents the overview of the 5G-CLARITY testbed infrastructure, designed based on the high-level architecture introduced in Figure 4-1 and the 5GUK test network infrastructure.

The smart-tourism framework and component will be deployed in the 5G-CLARITY edge cluster and in M-Shed museum. The guide robot management application and the guide robot positioning application will run in several VMs at the edge cluster. Both applications will perform management, control, target detection, positioning, and programmed directives of the guide robot. One of the VMs will host the museum service management application to provide contents and programmed or scheduled directives for the guide robot. The development of the content for the UC1 demonstrations will be based on the narratives defined in Section 4.1.2.

Six infrastructure cameras in total will be deployed in the reception and the exhibition halls of M-Shed museum. These are connected to the transport network by wire and/or wireless technologies to provide continuous image streaming to the VMs hosting the guide robot management and positioning applications. To interconnect the smart tourism framework and components, the 5G-CLARITY framework will deploy an ultra-low latency service slice to connect the six infrastructure cameras deployed in M-Shed with the VMs hosted in the 5G-CLARITY edge cluster.

4.2.1 In-lab test at smart internet lab

The high-performance networks group (HPN) office area and the smart Internet laboratory at the University of Bristol are chosen for UC1 in-lab test location. The in-lab test network setup is presented at the left-hand side of the Figure 4-2. A dedicated out-of-band management network will be setup to be used for control plane signalling of the SDN enabled network devices. Several Dell PowerEdge servers, running the OpenStack cloud, provide the compute as shown in Figure 4-4.

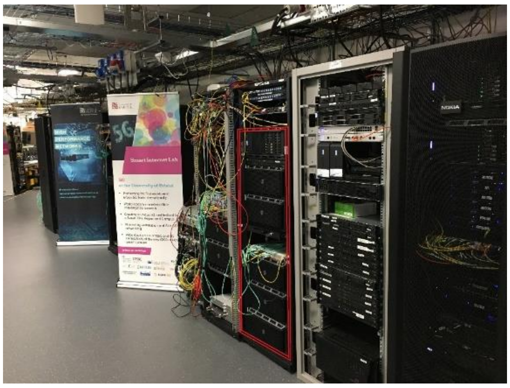

Figure 4-4 OpenStack deployment on Dell servers (red box), smart internet lab

Software services such as DHCP, DNS, internet access, and RADIUS are available as fundamental network services and VPN remote access will be provided to other partners to access their equipment and applications.

The space around HPN office area provides an ideal location for UC1 initial tests. 4G LTE by Nokia picocell are available while 5GNR by Accelleran, Wi-Fi connectivity via a Ruckus AP and LiFi via pureLiFi APs for the initial test will be installed. It is noted that only single cell coverage area will be provided in this test environment. Several cameras will cover the office area to track the robot which will be used for robot positioning purposes. These cameras will be connected to the core using Wi-Fi to test the guide robot positioning and management applications hosted in the 5G-CLARITY edge cluster.

4.2.2 Demonstrations at M-Shed museum

The 5GUK testbed in and around the M-Shed museum offers the suitable venue to support UC1 through a mixture of network entities and various access technologies. The right-hand side of Figure 4-2 shows three spaces in M-Shed that will be used in the 5G-CLARITY UC1 demonstrations and trials: the reception, the Bristol People exhibition hall, and the Bristol Life exhibition hall. These are located in the first floor of M-Shed whose floor plan is presented in Figure 4-5, and Figure 4-6 shows an image of each of these spaces.

The APs provisioned at the M-Shed reception and exhibition halls, and the edge nodes at the server room are configured and used to accommodate various 5G-CLARITY network entities along with supporting 5GUK test network components which are presented in Figure 4-2. To achieve the high-speed radio access connectivity required by UC1, a multi-Gbps backhaul is provided to the rest of the 5GUK testbed. The M-Shed server room, shown in Figure 4-7 hosts 5G-CLARITY RAN cluster. Dedicated fibre connectivity is available to the smart internet lab, which facilitates extension of the 10 Gbps SDN controlled IP data and management networks.

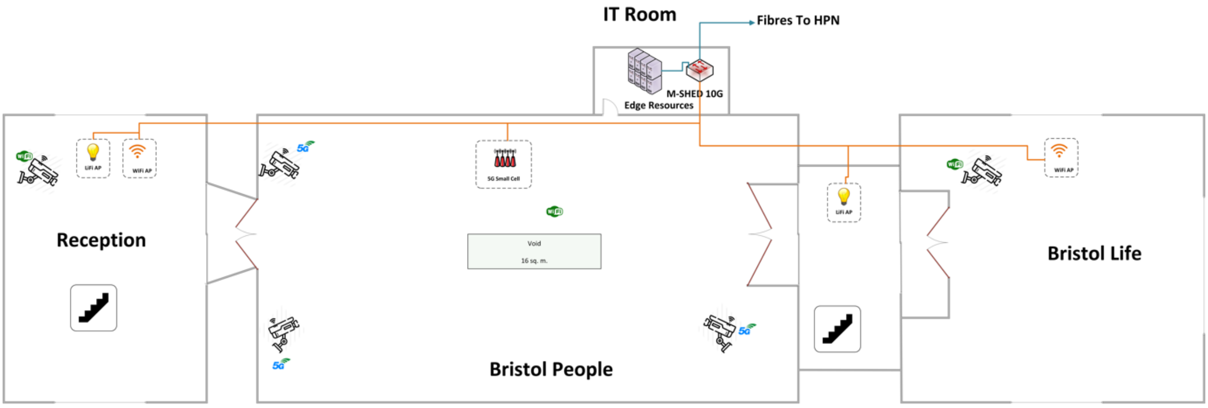

Figure 4-5 M-Shed floor plan (first floor)

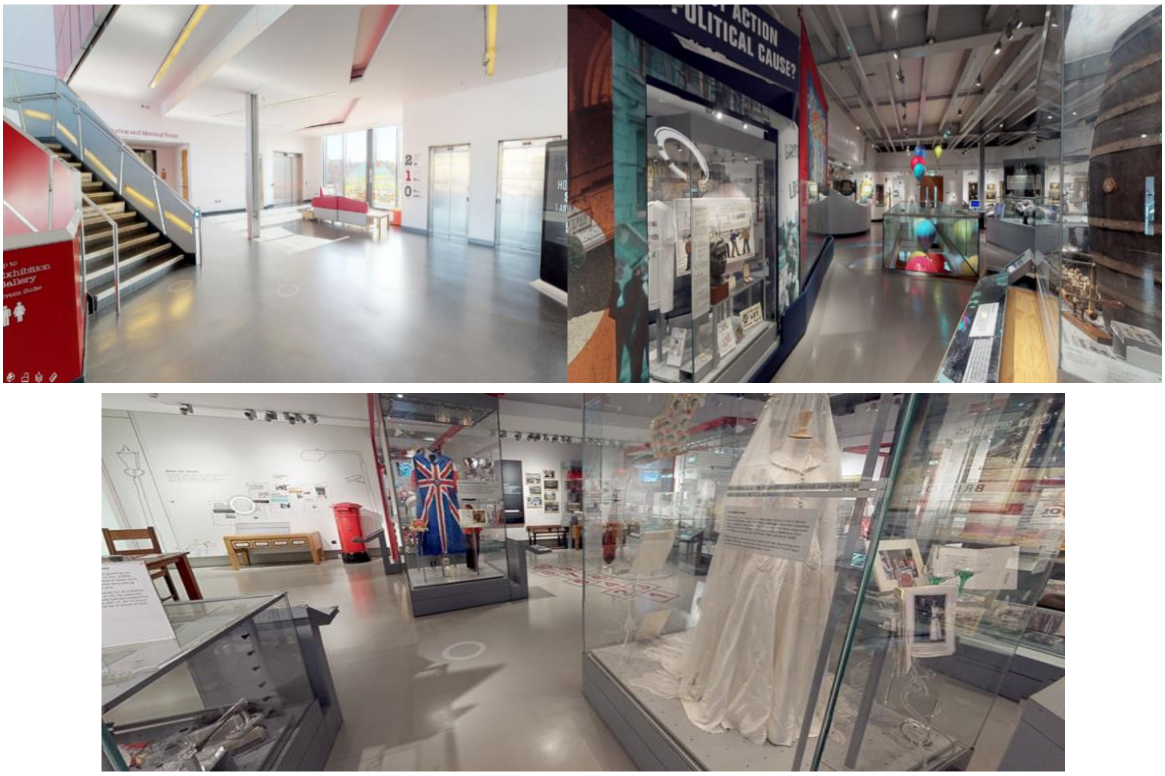

Figure 4-6 M-Shed reception (top left), Bristol people hall (top right), Bristol life hall (bottom)

Figure 4-7 M-Shed server room

4.2.3 5G-CLARITY enablers used in UC1 demonstrations

Table 4-1 describes 5G-CLARITY innovations that will be used in UC1, indicating the demonstration scenario where they will be applied.

Table 4-1 5G-CLARITY Components Contributed to UC1

Name	Description	Demo Environment	Partners
Multi-domain network slicing for private networks	Includes VNFs and multi-WAT, used to deploy eMBB slices for surveillance and special events and also used to deploy a URLLC slice for controlling the guide robot.	Smart Internet Lab, M-Shed	UNIVBRIS
Multi-access based multi-connectivity	MPTCP virtual functions with custom schedulers for 5G-CLARITY CPE.	Smart Internet Lab, M-Shed	UGR
5G-CLARITY CPE	According to the descriptions in Section 3.4	Smart Internet Lab, M-Shed	UNIVBRIS, I2CAT, PLF, ACC, UGR, USTRATH
Edge Cluster	OpenStack deployment which hosts the VNFs for the guide robot management (target detection based on QR codes, robot positioning based on cameras feed, image processing and the programming directive of the guide robot).	Smart Internet Lab, M-Shed	UNIVBRIS, I2CAT, PLF, USTRATH

4.3 UC1 preliminary test-plan and timeline

4.3.1 Preliminary test-plan

Details of the UC1 initial in-lab tests and the preliminary plan for the final demonstration in M-Shed are presented in the Table 4-2.

Table 4-2 UC1 Test-Plan

Test ID	Notes	
UC1-Lab-T1	Description	5G-CLARITY infrastructure elements preliminary in-lab test
	Environment	Smart internet lab
	Precondition	• The guide robot 5G-CLARITY CPE deployed and integrated with the testbed • Infrastructure cameras operational and connected to the 5GC
	Procedure	• 5G-CLARITY slice manager sets up an E2E slice formed by an IP network, vLAN, SSID, and PLMNID emulating a public network. • NFV orchestrator instantiates the VNFs of an application, as well as other essential network functions such as 5GC. • 5G-CLARITY WAT/RAN controllers assign the SSID to LiFi AP, Wi-Fi AP, and PLMNID1 to 5G RU/CU. • The guide robot management and positioning applications use the E2E slice to set up wireless connectivity to the cameras in the lab. • Test all the WAT individually with a custom client device • Test the latency and maximum throughput for each individual interface. Tools: 5GUK measurement and monitoring tools + iperf + ping • Test the latency and maximum throughput for aggregated traffic. Tools: 5GUK

Test ID	Notes	
		measurement and monitoring tools + iperf + ping • Test maximum switching time between interfaces in redundant operation mode. Tools: Measurement and monitoring tools + iperf + ping • Test reliability. Tool: ping
UC1-Lab-T2	Description	UC1 Narrative 1 in-lab test: throughput and multi-WAT functionality
	Environment	Smart internet lab
	Precondition	• The guide robot 5G-CLARITY CPE deployed and integrated with the testbed • Infrastructure cameras operational and connected to the 5GC • The guide robot applications are up and running
	Procedure	• The guide robot moves toward lab by updating its position periodically • The guide robot 5G-CLARITY CPE performs handover between multi-WAT • Test connectivity between the guide robot and the edge server using 5G-CLARITY CPE • Measure latency, throughput and reliability. Tools: Measurement and monitoring tools, iperf + ping
UC1-Lab-T3	Description	UC1 Narrative 2 in-lab test: throughput and multi-WAT functionality
	Environment	Smart internet lab
	Precondition	• The guide robot 5G-CLARITY CPE deployed and integrated with the testbed • The infrastructure cameras are operational and connected to the 5GC • The robot applications are up and running • Museum service applications installed on edge server
	Procedure	• Test the functionality of the guide robot and its interactions with a visitor using connectivity via 5G-CLARITY CPE
UC1-M-Shed-T1	Description	M-Shed 5G-CLARITY infrastructure and UC1 components setup test
	Environment	M-Shed
	Precondition	• 5G-CLARITY multi-WAT infrastructure (5GNR RUs, Wi-Fi APs and LiFi APs) installed • The guide robot 5G-CLARITY CPE deployed and integrated with the testbed • The guide robot management applications up and running
	Procedure	• Test 5G-CLARITY CPE and the multi-WAT functionality and connectivity • Test the latency and maximum throughput for each individual interface. Tools: Measurement and monitoring tools + iperf + ping • Test the latency (average) and maximum throughput for aggregated traffic. Tools: Measurement and monitoring tools + iperf + ping • Test maximum switching time between interfaces in redundant operation mode. Tools: Measurement and monitoring tools + iperf + ping • Test reliability. Tool: ping
UC1-M-Shed-T2	Description	Benchmark the guide-robot integration
	Environment	M-Shed
	Precondition	• 5G-CLARITY multi-WAT infrastructure (5GNR RUs, Wi-Fi APs and LiFi APs) installed • The guide robot 5G-CLARITY CPE deployed and integrated with the testbed • 5G-CLARITY RAN and edge clusters are set up and operational • Infrastructure cameras operational and connected to the 5GC

Test ID		Notes
		• The guide robot applications are up and running
	Procedure	• Test connectivity between the guide robot and edge servers via 5G-CLARITY CPE • Measure latency, throughput and reliability
UC1-M-Shed-T3	Description	The guide robot interaction with visitors
	Environment	M-Shed
	Precondition	• 5G-CLARITY multi-WAT infrastructure (5GNR RUs, Wi-Fi APs and LiFi APs) installed • The guide robot 5G-CLARITY CPE deployed and integrated with the testbed • 5G-CLARITY RAN and edge clusters are set up and operational • Infrastructure cameras are operational and connected to the network • The guide robot management applications are up and running
	Procedure	• Test the functionality of the guide robot and its interaction with the visitor, while connected via 5G-CLARITY CPE

4.4 UC1 implementation plan and timeline

The preliminary implementation plan for UC1, the project Gantt chart, is detailed in Figure 4-8 identifying several tasks and milestones and the involved partners. The UC1 demonstration activities are organized in the following phases:

- M16-M19 (February 2021 – May 2021) Definition and setup of the test environment UC1
    - Partners will define the test environment
    - The requirements for the 5G-CLARITY network setup on UNIVBRIS testbed is derived
    - UNIVBRIS will set up the testbed to host the 5G-CLARITY network, instantiate the required network functions, and integrate other partners' technologies and equipment, such as 5GNR, Wi-Fi 6 and LiFi APs with the testbed.
    - UNIVBRIS will provide remote access solution for the partners to access their equipment for configuration and management purposes.
- M20-M22 (June 2021- August 2021) Preparation and integration of partners' equipment on UNIVBRIS testbed
    - Engaged partners produce the list of contributed equipment UC1and ship them to UNIVBRIS to integrate them with the 5GUK testbed
    - As the end result, multi-WAT setup, i.e. 5GNR RU and Wi-Fi, LiFi APs, and 5G-CLARITY CPE, is ready
- M22-M24 (August 2021-October 2021) Initial test in the lab UC1
    - The integration of the partner technologies for in-lab test
    - The robot can be used to demonstrate its UC1activities in the lab environment, such as the intelligent interaction with visitors while connected to the 5G-CLARITY network using the 5G-CLARITY CPE
- M22-M28 (August 2021- February 2022) Equip the M-Shed demonstration space
    - Equipment is moved to M-Shed for final demo preparations

  - Administrational and technical preparations performed

- M28-M33 (February 2022-July 2022) Setting up the guide robot and its functionalities in M-Shed
  - Guide robot functions are implemented and setup
  - Integration of the guide robot and the cameras with the 5G-CLARITY network using 5G-CLARITY CPE is achieved
  - Guide robot intelligent interaction with visitors is up and running
- M32-M33 (June 2022- July 2022) Final demonstration and KPI evaluation in M-Shed and composing 5G-CLARITY D5.3

4.5 UC1 demonstration risks and mitigation plan

Organising the use case demonstration requires planning and management of a set of coordinated activities. An event manager is required to deliver the demonstration with the maximum output. Hence an administrative risk is identified as the availability of the public space to conduct the demonstrations. As a mitigation plan, it requires a dedicated event manager, responsible for communication and booking of the public spaces in good time ahead of the scheduled events. This also requires careful coordination between the project partners and the event manager to ensure adequate laboratory and field testing of the technologies and their integration before their installation in the public spaces for the final demonstration. Further administration risk may be that of inadequate planning for decommissioning of the technologies under test at the location of the demonstration. This needs to be considered by the event manager.

Milestones and Tasks	**Lead**, Partner	**Jan-21**	**Feb-21**	**Mar-21**	**Apr-21**	**May-21**	**Jun-21**	**Jul-21**	**Aug-21**	**Sep-21**	**Oct-21**	**Nov-21**	**Dec-21**	**Jan-22**	**Feb-22**	**Mar-22**	**Apr-22**	**May-22**	**Jun-22**	**Jul-22**
Month (M)		**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**
T5.2																				
T5.3																				
Define the test environment	**I2CAT**, UNIVBRIS																			
Setup Lab Test Environment	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Setting up 5GC network slices and remote access	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Setting up edge cluster	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Setting up 5GC NFVI/VIM	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Setting up measurement and monitoring	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Spectrum license availability confirmation(n78,B7,B38,n77)	**UNIVBRIS**																			
Network functions implimentation (e. g. dRAX)	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Open 5GS setup	**TID**, ACC, I2CAT, UNIVBRIS																			
5G-CLARITY CPE setup	**UNIVBRIS**, I2CAT, ACC, PLF, UGR, USTRATH																			
Partners' equipment integration plan	**UNIVBRIS**, I2CAT, ACC, PLF																			
Partner lending BOM and agreements	**UNIVBRIS**, I2CAT, ACC, PLF																			
Partner equipment shipment	**UNIVBRIS**, I2CAT, ACC, PLF																			
Integrating partners equipment in 5GUK testbed	**UNIVBRIS**, I2CAT, ACC, PLF, USTRATH																			
Initial test of the UC1 network	**UNIVBRIS**, I2CAT, ACC, PLF																			
Validating lab test setup (functional testing)	**UNIVBRIS**, I2CAT, ACC, PLF																			
Network integration of 5GC, RAN and CPE	**UNIVBRIS**, I2CAT, ACC, PLF																			
5GC network KPI validations	**UNIVBRIS**, I2CAT, ACC, PLF																			
Guide robot application development and integration	**UNIVBRIS**																			
Network integration of the guide robot, 5GC and CPE	**UNIVBRIS**																			
The guide robot applications setup	**UNIVBRIS**																			
Application-related KPI measurements	**UNIVBRIS**																			
5GC setup in 5GUK (5GC management plane)	**TID, I2CAT,** UNIVBRIS, ACC																			
Site survey (M-Shed) to identify multi-WAT nodes locations	**UNIVBRIS**, I2CAT, ACC, PLF																			
Equipment commissioning and installation in M-Shed	**UNIVBRIS**, I2CAT, ACC, PLF																			
Space and event management plus hiring the venue	**UNIVBRIS**																			
Hire contractor for the first fix of wiring	**UNIVBRIS**, I2CAT, ACC, PLF																			
Partners equipment installation	**UNIVBRIS**, I2CAT, ACC, PLF																			
Infrastructure camera installation in M-Shed	**UNIVBRIS**																			
Final network integration and validation	**UNIVBRIS**, I2CAT, ACC, PLF																			
Setting up the guide robot in M-Shed	**UNIVBRIS**																			
Network integration	**UNIVBRIS**																			
Test setup validation	**UNIVBRIS**																			
Setup the guide robot Interaction with visitors	**UNIVBRIS**																			
Prepration and execution of demonstration	**UNIVBRIS**, I2CAT, ACC, TID, PLF, USTRATH																			
Final Demonstration and KPI evaluation	**All**																			
Prepration and delivery of final report	**All**																			
Milestones		M5.1														M5.2				M5.3
Deliverables		D5.1														D5.2				D5.3

Figure 4-8 UC1 tentative implementation plan

The operation and demonstration of the UC1 functionalities necessitates 5G licensed spectrum, which requires careful planning between Accelleran and University of Bristol to acquire the appropriate spectrum license from the UK regulator. At the time of preparing this deliverable, November 2020, the available spectrum suitable for 5G-CLARITY demonstrations 100 MHz in band n78 (3695 MHz – 3800 MHz) which is at risk of not being available for UC1 demonstrations or even beyond July 2021.

As a mitigation plan, University of Bristol has obtained 100 MHz of alternative spectrum in band n77 (3800 MHz – 3900 MHz). A 5GNR microcell for outdoor operation in this band. It is also recognised that the UE devices operating in this band are few in the market and the project currently only has access to prototype devices that may work in band n77 and require band B3 as LTE anchor for NSA operation, while University of Bristol has license to operate anchor LTE in band B7 for the 5G cell coverage.

Table 4-3 UC1 Implementation Risks and Mitigation Plan

Risk ID	Description	Impact	Mitigation Plan
UC1-R1	Lack of 5GNR spectrum license for the band	High	Reorganise demos into a lab PoC using unlicensed radio spectrum, e.g. Wi-Fi/LiFi. Further mitigation is to perform the demo in the shared spectrum at upper n77 band between 3.8GHz-4.1GHz operation of the 5GNR. This implies limited modem devices and 5GNR RU available to use for the demonstration.
UC1-R2	Unavailability of 5GNR RU in time	Medium	Use 4G RU instead
UC1-R3	Lack of support of SA mode in 5G UEs (M.2 cards)	Medium	Share experience between consortium partners on deployment of the 5G UE modem to find a practical solution as UEs during pre-integration activities.
UC1-R4	Interoperability problem with open source free5gc	Low	• Validate interoperability as early as possible to have time to fix the problem • Candidate another open source 5GC for backup plan • If N3IWF is not available on backup 5GC, mitigate as per "problems with the use of the free5gc N3IWF"
UC1-R5	Problems in the integration of Wi-Fi and LiFi at L2	Low	Reduce scope of the setup to integrated Wi-Fi and LiFi at L3
UC1-R6	Lack of computing/memory resources in RAN or edge servers	Low	• Validate computing/memory requirements for all VNF components in advance • Establish backup plan for fast-track increase of computing/memory capacity
UC1-R7	Problems with the connectivity between edge servers, RAN servers and APs	Low	• Validate connectivity requirements in advance, e.g. ports, cables, etc. • Establish backup plan for fast-track support of connectivity required (adding ad-hoc specific ports to servers, switches/gateways/media adapters, installing ad-hoc Ethernet or Fibre cables)
UC1-R8	Problems with the use of the free5gc N3IWF to integrate Wi-Fi and LiFi into the UPF	Low	• Pre-integrate as early as possible to detect any problem • Default to Wi-Fi and LiFi flow integration without UPF at IP level

Risk ID	Description	Impact	Mitigation Plan
UC1-R9	Problems with the capabilities and/or suitability of the MPTCP components	Low	• Pre-integrate as early as possible to detect any problem • Default to MP-IP approach
UC1-R10	Problems in having multi-WAT spots in pilot area	Low	• RF plan coverage footprint for 5GNR, Wi-Fi and LiFi so that parts of some areas have coverage from 2 or 3 such access technologies while others only have coverage from a single access technology

5 UC2.1: Alternative Network to Exchange Production Data (Industry 4.0)

5.1 UC2.1 scope and objectives

As the number of connected devices and the volume of data exchange within factories increases, stringent requirements in terms of communications reliability and latency are imposed on the in-factory network. Current setups rely on the wired connectivity which lack required flexibility for Industry 4.0 applications. Meanwhile Wi-Fi technologies are already in place in many industrial environments, they fall short of meeting requirements on latency, reliability and security for the related applications.

5G-CLARITY UC2.1, 'Alternative Network to Exchange Production Data', is aimed to demonstrate 5G-CLARITY key innovations in improving the in-factory connectivity toward future Industry 4.0 scenario networks. UC2.1 will be implemented in RBEF (Robert Bosch España Fábrica Aranjuez), a Bosch factory located in Aranjuez near Madrid, Spain. The main objective is to validate the feasibility of replacing current Ethernet wired connections used to connect Manufacturing Execution System (MES) enabled production lines in the factory floor by the combination of wireless technologies proposed in 5G-CLARITY.

By deploying the 5G-CLARITY infrastructure and solutions in the UC2.1 scenario, an improvement in data transmission speed is expected while reliability, latency, data security and response time are maintained. The benchmark will be the currently in-place wired network performance. If the 5G-CLARITY solution based on the considered WATs can meet the performance benchmark, it will prove that wireless solutions can replace current wired connections.

Figure 5-1 depicts the current setup used to connect a production line to a MES server, where only two production lines are shown, out of many, for the sake of clarity. Every production line is equipped with several Programmable Logic Controller (PLC) to control different processing units along the production line. Each PLC is connected to a head-of-line (HoL) Ethernet switch via an Ethernet cable. Each MES server controls several production lines, while several MES are located in a technical room.

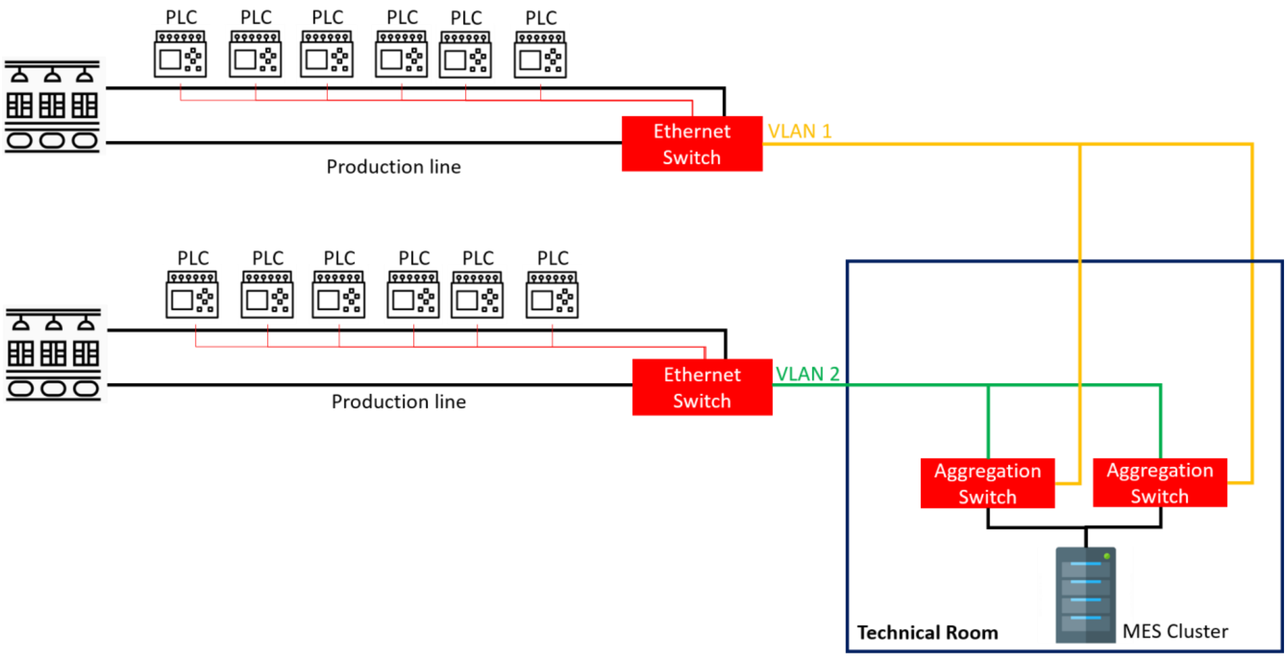

Figure 5-1 Current setup to connect production lines to MES server in the technical room

The Ethernet aggregation switches enable MES interconnection with the production lines as well as providing firewall and access control lists (ACL) functionalities. Essential in the design of the network setup for the factory floor is redundancy and isolation to avoid any malfunction happening in a production line. For this purpose, separate VLANs are used to connect individual production lines to the MES servers. While the current setup fulfils the networking requirements of a MES-enabled production line, it comes with certain disadvantages in terms of deployment burden associated with cabling in the factory floor. This is especially a problem in agile manufacturing environments where production lines may need to be reconfigured often to adapt to the new production requirements.

5G-CLARITY attempts to address this problem by replacing the current connectivity setup with a wireless solution that could be implemented in multiple steps. The factory data-exchange network upgrade is considered in two steps, a short-term solution, and a long-term solution as described below. This two-step approach is taken to avoid any interruption of the production and delivery in the factory.

Short-term solution. Figure 5-2 depicts a short-term vision where the wired network between the HoL switch in each production line and the technical room is replaced by an in-factory 5G-CLARITY network. In this setup 5GNR RU, Wi-Fi APs and LiFi APs are deployed in the factory, covering the area where the production lines are located. The HoL switch is connected to a 5G-CLARITY CPE providing multi-connectivity as detailed in Section 3.4. By using the 5G-CLARITY CPE, the Ethernet traffic generated by PLCs transmitted over various multi-WAT is multiplexed, while application of traffic policies is enabled. The envisaged policies could be capacity aggregation, or latency and reliability adjustment. In this setup each production line includes a 5G-CLARITY CPE that replaces the VLANs in the legacy setup. 5G-CLARITY slicing can be used to enable this per-VLAN separation as it is explained later.

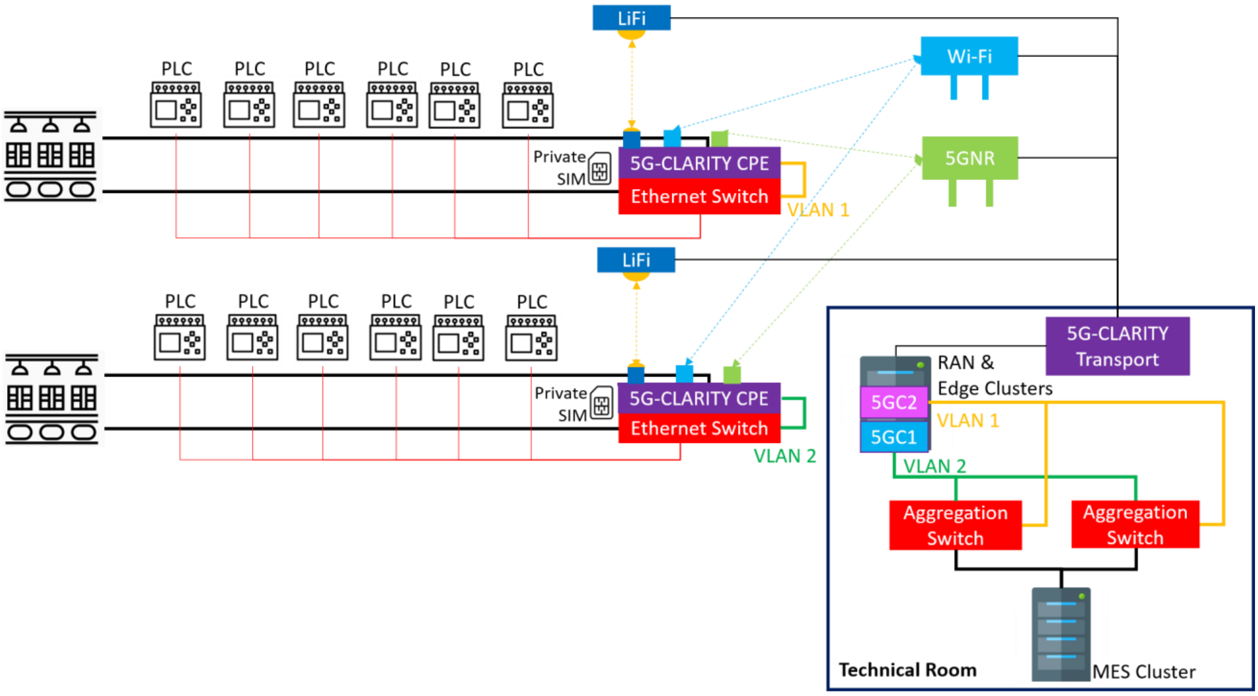

Figure 5-2 5G-CLARITY vision in SNPN setup: short-term vision

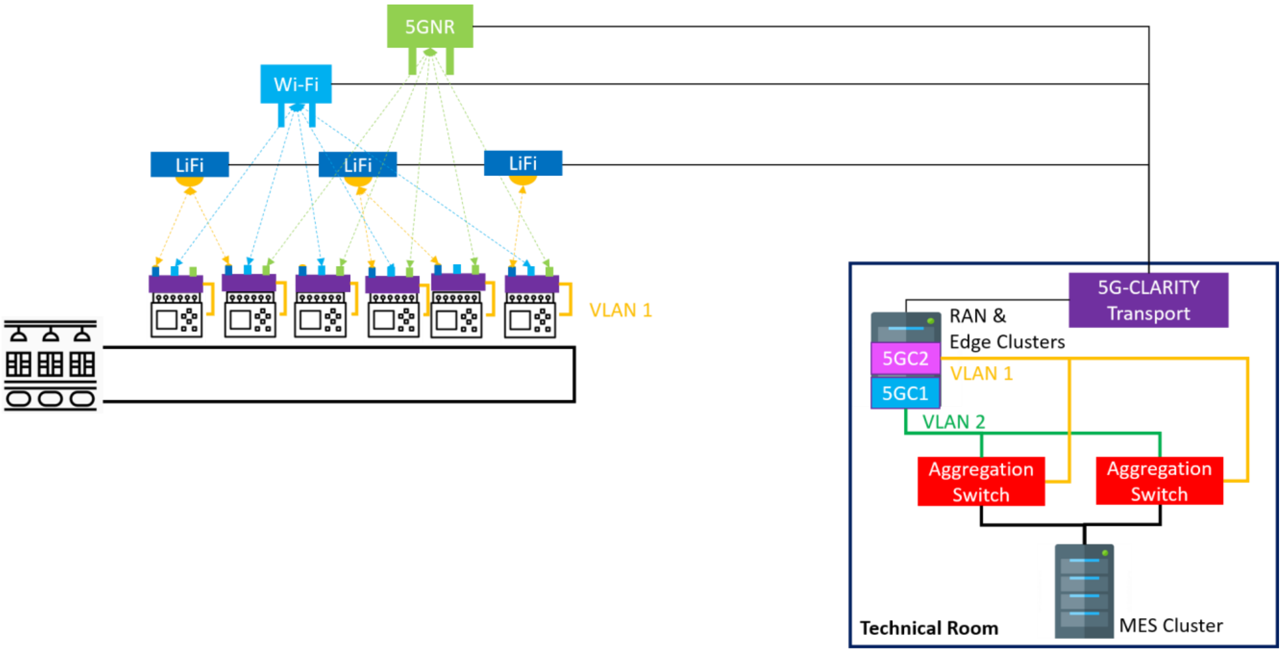

Figure 5-3 5G-CLARITY vision in SNPN setup: long-term vision

Long-term solution. The 5G-CLARITY short-term vision depicted in Figure 5-2 is complemented by a long-term vision in Figure 5-3. Here, the HoL switch is removed and the production line PLCs incorporate a 5G-CLARITY CPE that allows them to connect directly to the 5G-CLARITY network. This setup eliminates all cabling on the factory floor providing the maximum flexibility but requires a denser deployment of LiFi access points to cover PLCs.

The slicing functionality realized by 5G-CLARITY system is the key feature to provide required isolation between different VLANs. Figure 5-4 depicts how 5G-CLARITY slices can be used in UC2.1 for the short-term vision setup, but the same concept applies to the long-term vision setup. A 5G-CLARITY slice is set up to connect each production line to the technical room. Each 5G-CLARITY slice is composed of:

- Logical network identifiers in the wireless AP, i.e. different PLMNID plus S-NSSAI and SSIDs, making it impossible for a PLC or HoL switch to connect to the wrong slice.
- 5G-CLARITY wireless quotas are used to segregate the aggregated wireless capacity among the different slices.
- A core network function, e.g. UPF, in the edge cluster located in the technical room that is in charge of processing the traffic coming from each production line.
- 5G-CLARITY compute quotas which can be used to limit the resources available to each UPF instance, and to provide the necessary isolation so that any malfunction on the UPF instance of one production line does not affect any of the other production lines.

The 5G-CLARITY vision accepts two different implementations, both leveraging the use of NPNs: stand-alone NPN (SNPN) and public network integrated NPN (PNI-NPN). The SNPN implementation, as presented in the scenario of Figure 5-4, is based on having a non-PLMN provided 5GC, so private SIMs are used in the 5G-CLARITY CPEs. In this setup 5GC is entirely deployed within the factory, i.e. on-premise 5GC, which is fully virtualized with constituent UPF and 5GC CP collocated and running on the 5G-CLARITY edge cluster which is located in the technical room.

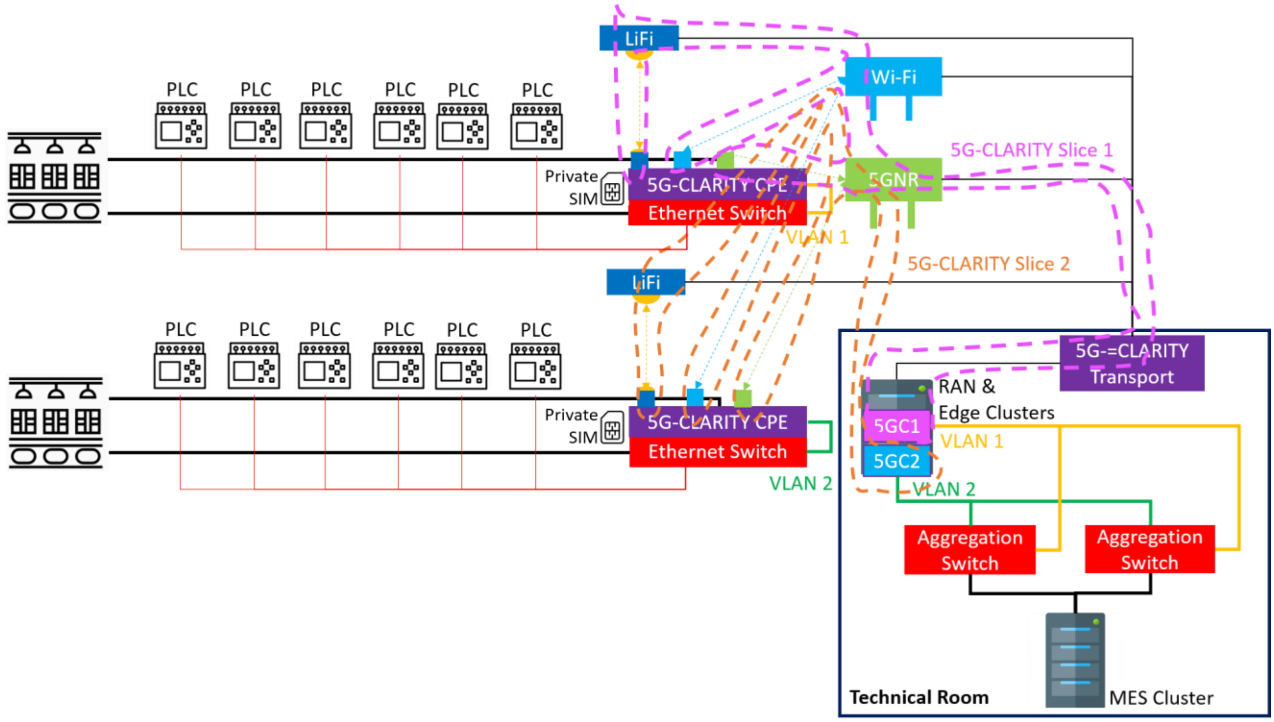

Figure 5-4 5G-CLARITY slices for UC2.1

Alternatively, the PNI-NPN implementation, as shown in the scenario of Figure 5-5, is based on having a PLMN provided 5GC, so public SIMs are used in the 5G-CLARITY CPEs. In this scenario, the UPF is kept separated from the 5GC CP. In particular, UPF is deployed on the 5G-CLARITY edge cluster, while 5GC CP resides in the MNO infrastructure footprint. This setup guarantees that the traffic between production lines and the MES servers never leaves the factory, keeping all user plane flows within Bosch's administrative domain. The role of the MNO is to instantiate the UPFs on the edge cluster and configure the radio devices to support various slices. The communication interfaces between the PLMN and the factory need to be secured according to OT security standards.

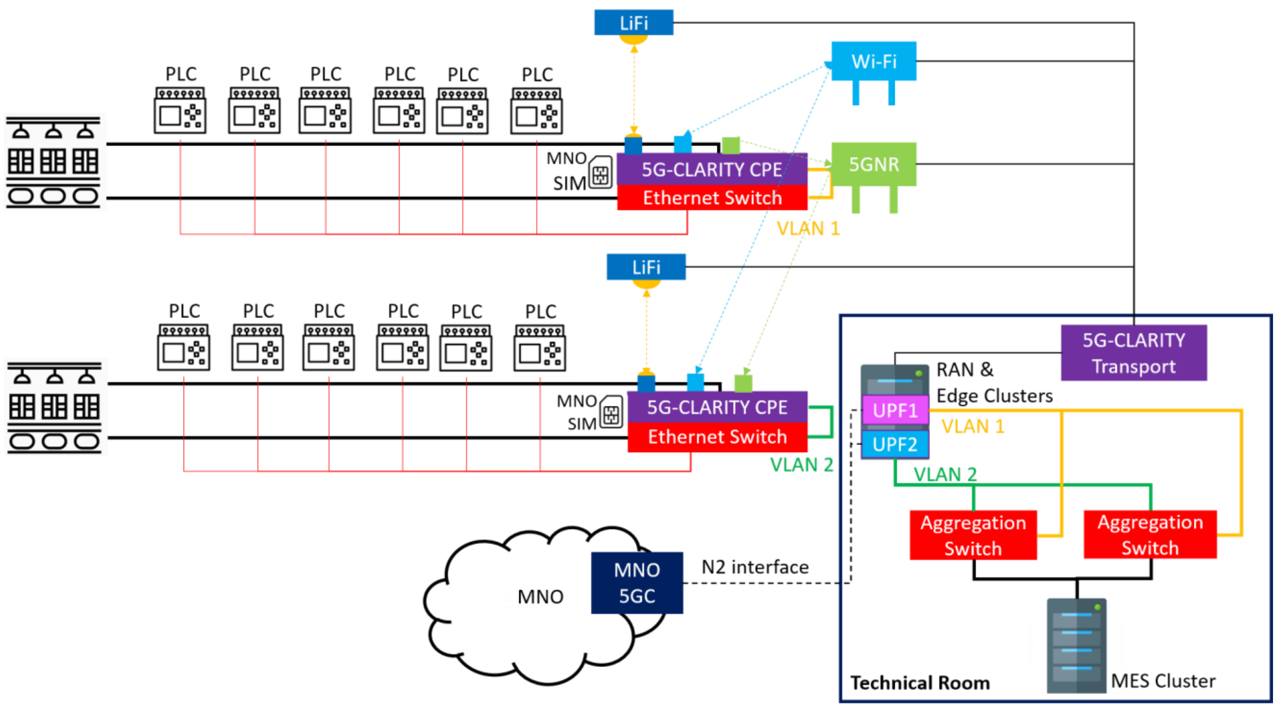

Figure 5-5 5G-CLARITY vision in PNI-NPN for factory data-exchange

5.2 UC2.1 demonstration scenario and 5G-CLARITY enablers

While the previous section has conveyed the vision of the 5G-CLARITY technology adoption in UC2.1, in practice the actual demonstration is constrained by the limitations of interacting with the real production environment such as the Bosch factory in Aranjuez. Hence a three-step implementation/validation setup is proposed as follows:

- Portable production-line testbed. This testbed is used to do preliminary demonstration and to disseminate the 5G-CLARITY innovations in fares, conferences or audit reviews. It will also support the validation of the "adaptive defect-detection in a smart factory" ML algorithm developed in 5G-CLARITY and described in 5G-CLARITY D4.1 [4].
- In-factory setup. It is used to validate the 5G-CLARITY network KPIs within the factory environment, without interacting with real OT infrastructure.
- In-factory emulated production line. It is used to validate the 5G-CLARITY system in the factory environment including the OT infrastructure.

Each of these environments are introduced in the next sub-sections.

5.2.1 Portable production line testbed

The portable production line testbed is a small-scale production line that is used to mimic a realistic factory production line. The idea is to have such a small-scale, portable testbed to do preliminary integration of different 5G-CLARITY components and demonstrate them without any interruption to actual production line. In addition, the portable testbed will be used to disseminate 5G-CLARITY innovations outside a factory environment like fares, congresses as well as project review demonstrations.

The portable testbed will be composed of a conveyor belt, robotic arm and a camera as depicted in Figure 5-6. The camera has wireless connectivity via a 5G-CLARITY CPE while another 5G-CLARITY CPE is used to provide wireless connectivity for the robotic arm and the conveyor belt. With such setup, the portable production line components are connected to 5G-CLARITY integrated 5G/Wi-Fi/LiFi network. The robotic arm is used to pick up the objects/products and place them on the conveyor belt. While the conveyor belt is carrying the objects/products along the production line, the camera monitors the products in real-time by recording and streaming a video. The video will be streamed to an edge device that will process the video, analyse the objects/products and control the camera, e.g., zoom-in to improve object detection performance. In case a defective object/product is detected the robotic arm will remove it from the production line.

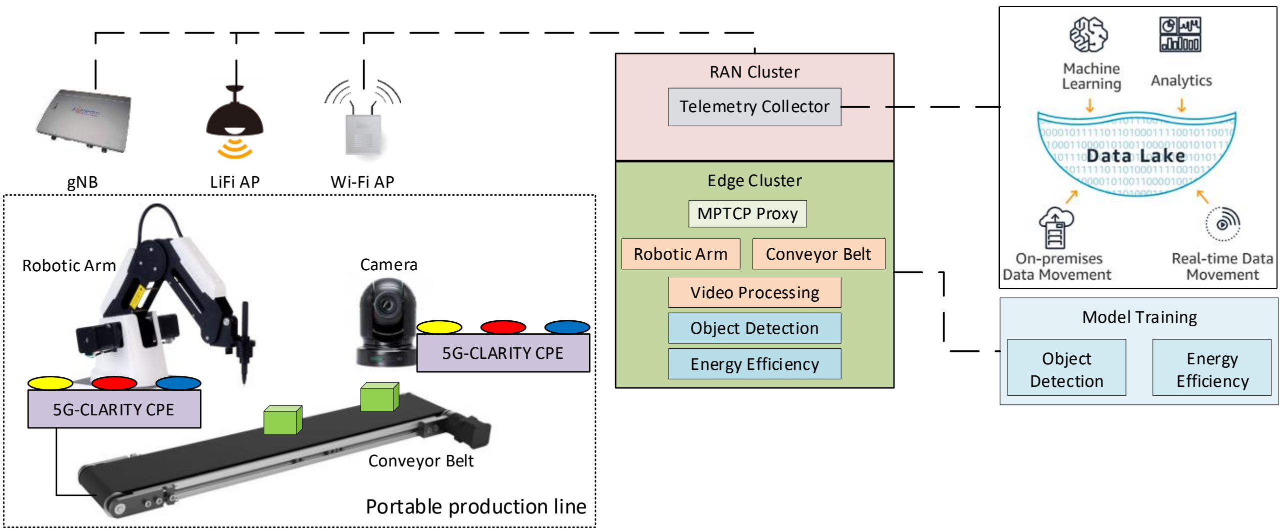

Figure 5-6 5G-CLARITY portable production line testbed and its integration to 5G-CLARITY system architecture

In this setup cardboard cubes will be used as objects/products where some of them will have stickers on it to mimic a deficit on the product. It is worth noting that the CPEs of the camera and robotic arm are not required to have all the interfaces, e.g., camera can utilize Wi-Fi and LiFi interfaces to stream video while the robotic arm can use 5GNR for control signals that require low latency.

The portable production line testbed will be used to validate the 5G-CLARITY network KPIs on multi-connectivity such as throughput (to stream high-definition video from camera to the edge component) and latency (to control the robotic arm, conveyor belt and camera). Moreover, the portable production line testbed will be used to validate some of the ML use cases that are proposed within 5G-CLARITY WP4 such as adaptive AI-based defect detection and access traffic steering ML models [4].

5.2.2 In-factory setup

Figure 5-7 depicts a tentative design for the in factory 5G-CLARITY setup. The goal of this environment is to validate the deployment of the 5G-CLARITY infrastructure within the factory environment, but without connecting OT infrastructure to the network. In this scenario, to model the traffic generated by a production line, a traffic analysis on a real operational production line is performed which includes traffic exchanges between PLCs and the MES. This synthetic traffic will be used in the setup. Additionally, this environment will be used to stress the 5G-CLARITY network to obtain network-level KPIs, e.g., throughput, delay, reliability, in a relevant production environment. The exact number of required 5GNR, Wi-Fi and LiFi devices will be determined after a site survey.

The in-factory setup will be used to support validation of 5G-CLARITY architecture and solutions both in the SNPN and the PNI-NPN setups. For the PNI-NPN setup the MNO network will be emulated using the 5TONIC[1] infrastructure provided by Telefonica, which will feature an Ericsson 5GC. In this case an important aspect to be resolved is how to enable the interconnection between the MNO core and the Bosch plant in Aranjuez, given that Bosch applies strict security rules to any interconnection between the plant and external networks. A potential mitigation could be to use an out-of-band management/control channel using a device connected through LTE instead of the Bosch internal network. This risk has been captured in Section 5.5.

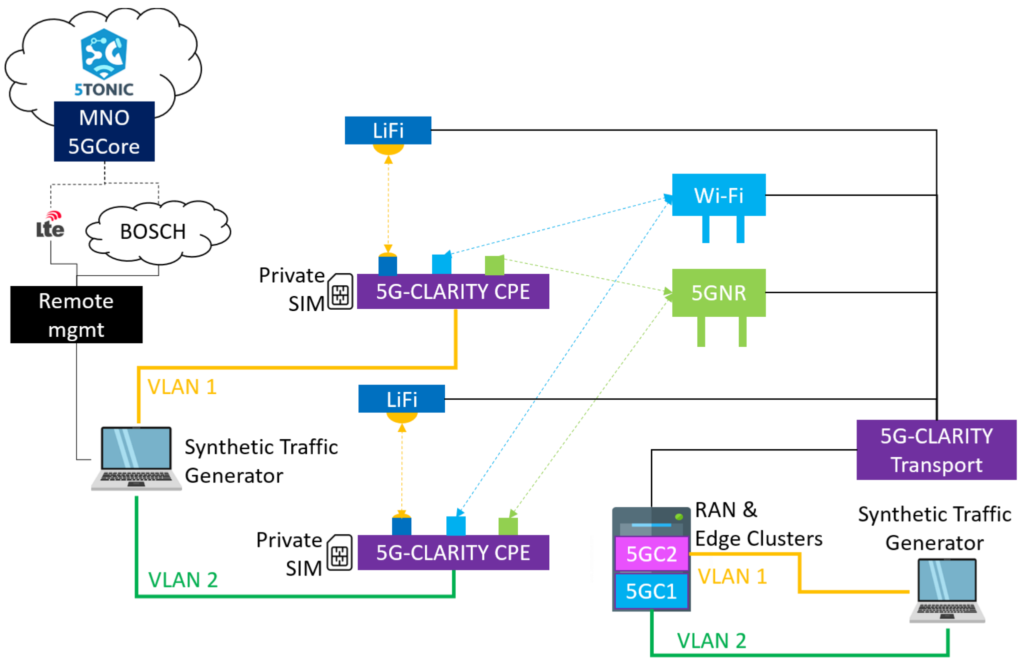

Figure 5-7 5G-CLARITY in-factory setup

[1] https://www.5tonic.org/

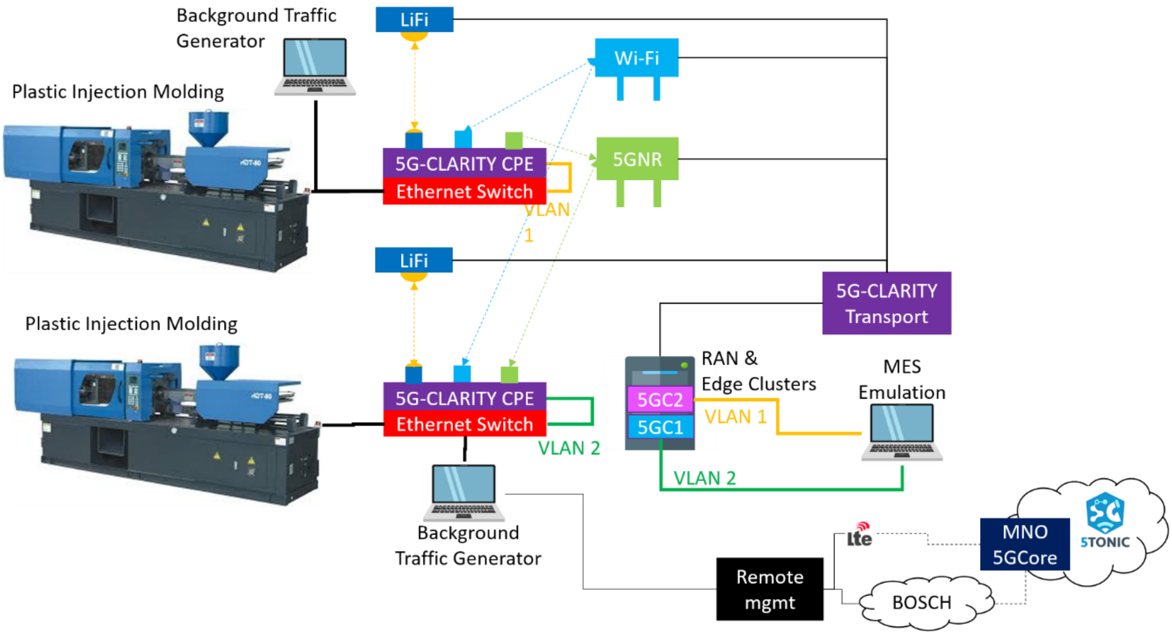

Figure 5-8 5G-CLARITY in-factory emulated production line

5.2.3 In-factory emulated production line

Figure 5-8 represents the in-factory emulated production line scenario, which is built on the previous "5G-CLARITY in-factory setup". The main difference between the two is the real plastic injection moulding machine and/or fuel filter production line(s) which will be connected to the 5G-CLARITY CPE and a MES server deployed at the edge cluster. At least two existing machines working in their corresponding production lines will be included in this scenario. One of these will run on the existing wired technology, while at least one machine will run using 5G-CLARITY network. These machines will be very similar (or the same machine is used in different trials) to guarantee a fair performance comparison of different technologies.

In any case, the in-factory emulated production line is isolated from the MES production server running inside the factory which for obvious reasons cannot be used for the demonstration purpose. This environment will emulate two different production lines controlled by a single MES server and will be used to demonstrate how the 5G-CLARITY network can fulfil the OT related KPIs required in a production environment. Since the traffic generated between a single moulding machine and the MES server is not expected to be significant, background traffic generators will be used to stress the network conditions using the same synthetic traffic used in the "5G-CLARITY in-factory setup".

These setups allow to validate both the SNPN and PNI-NPN configurations using the 5TONIC infrastructure in a factory environment.

5.2.4 5G-CLARITY enablers for UC2.1 demonstrations

Table 5-1 describes the 5G-CLARITY components and innovations that will be used in UC2.1, indicating the demonstration scenario where each will be applied.

Table 5-1 UC2.1 Technology Components

Name	Description	Demo Environment	Partners
Multi-connectivity framework	MPTCP virtual functions with custom schedulers for 5G-CLARITY CPE and Proxy for edge cluster	PORT, INF5GC, INFEMU	UGR

5G-CLARITY CPE	Integrated computer + radio interfaces and multi-connectivity framework	PORT, INF5GC, INFEMU	I2CAT
eAT3S	xApp in dRAX that processes telemetry and adjusts scheduling weights in multi-connectivity framework	PORT, INF5GC, INFEMU	ACC, IDCC
SNPN 5GC	Open5gs for SNPN use case	PORT, INF5GC-SNPN, INFEMU-SNPN	I2CAT
PNI-NPN 5GC	5GC running in 5TONIC premises required to support PNI-NPN setup	INF5GC-PNI, INFEMU-PNI	TID
RAN Cluster	Includes dRAX and Prometheus server to obtain 5GNR, Wi-Fi and LiFi telemetry	PORT, INF5GC, INFEMU	ACC, I2CAT, PLF
Edge Cluster	OpenStack based. Hosts virtual and application network functions	PORT, INF5GC, INFEMU	I2CAT
Service and slice management subsystem	Includes NFVO and multi-WAT non rt-RIC. Used to deploy slices over the infrastructure	INF5GC, INFEMU	I2CAT
AI-vision ML algorithm	YOLOv3 algorithm running on an edge device to analyse the streamed video and recognize potential defects in the production line efficiently and quickly.	PORT	IDCC
Data lake	Cloud or edge based. Stores and pre-processes telemetry data from the applications, network functions and entities	PORT, INF5GC, INFEMU	IDCC

* Legend: PORT: Portable setup, INF5GC: In-factory 5G-CLARITY (SNPN or PNI), INFEMU: In-factory emulated production line (-SNPN or -PNI)

5.3 UC2.1 preliminary test-plan and timeline

This section introduces 5G-CLARITY the preliminary test-plan for the UC2.1 demonstrations, following by a tentative timeline.

5.3.1 Preliminary test-plan

Table 5-2 provides an initial test plan to be executed in UC2.1, indicating the intended demonstration environment for each test.

Table 5-2 UC2.1 Test-Plan

Test ID	Notes	
UC2.1-Lab-T1	Description	Initial lab benchmark with the portable testbed
	Environment	Portable setup
	Precondition	• Factory setup available at I2CAT lab • One 5G-CLARITY CPE deployed along the portable production line • Camera connected to 5G-CLARITY CPE • Video processing function installed in edge device
	Procedure	• Test the platform with 5G-CLARITY CPE that supports multi-connectivity • Test maximum achievable capacity through each interface, as well as aggregating interfaces. Tool: iperf or equivalent. Consider different 5G-CLARITY schedulers • Test latencies through each individual interface. Tool: ping or equivalent • Test latencies in redundant mode (all interfaces in parallel) • Test reliability. Tool: ping or equivalent (measure lost packets)

Test ID	Notes	
UC2.1-Lab-T2	Description	Benchmark with synthetic traffic traces
	Environment	Portable setup
	Precondition	• Factory setup available at I2CAT lab • Two 5G-CLARITY CPEs representing two production lines
	Procedure	• Test 5G-CLARITY scheduling modes: i) default aggregation, ii) redundant, iii) telemetry based weighted round-robin • Measure: latency and reliability
UC2.1-Lab-T3	Description	Slice isolation in front of interferer
	Environment	Portable setup
	Precondition	• Factory setup available at I2CAT lab • Two 5G-CLARITY CPEs representing two production lines
	Procedure	• Scenario 1: 5G-CLARITY CPE transmitting bulk data in uplink and downlink. Measure impact of interfered in throughput, latency, reliability • Scenario 2: 5G-CLARITY CPE replying synthetic data. Measure impact of interfered in throughput, latency, reliability
UC2.1-Lab-T4	Description	AI-based object detection algorithm
	Environment	Portable setup
	Precondition	• Factory setup available at I2CAT lab • Two 5G-CLARITY CPEs are deployed (i) along the portable production line; and (ii) edge • Camera is connected to 5G-CLARITY CPE • Edge device is connected to another 5G-CLARITY CPE • Video processing function installed in edge device • AI algorithm is trained offline and running on the edge device
	Procedure	• Test object detection at, i) edge; and ii) cloud. • Measure, i) detection accuracy; ii) energy consumption; and iii) latency
UC2.1-Lab-T5	Description	Data lake solution
	Environment	Portable setup
	Precondition	• Factory setup available at I2CAT lab • One 5G-CLARITY CPEs deployed along one production line • Custom client device connected to 5G-CLARITY CPE • Custom processing function installed in edge node
	Procedure	• Test 5G-CLARITY components to, i) push; and ii) pull data to/from the 5G-CLARITY telemetry subsystem • Test 5G-CLARITY telemetry subsystem, i) data ingestion; ii) data aggregation; iii) data storage; (iv) data exposure. • Measure: delay
UC2.1-Factory-T1	Description	Initial in-factory benchmark
	Environment	• SNPN • PNI-NPN: measure impact of UPF on telco edge
	Precondition	• 5GNR RU, Wi-Fi and LiFi APs installed in the factory floor.

Test ID		Notes
		• 5G-CLARITY RAN and edge clusters installed on technical room • One 5G-CLARITY CPE deployed along one production line • Custom client device connected to 5G-CLARITY CPE • Custom processing function installed in edge node
	Procedure	• Test maximum achievable capacity through each interface, as well as aggregating interfaces. Tool: iperf or equivalent. Consider different 5G-CLARITY schedulers • Test latencies through each individual interface. Tool: ping or equivalent • Test latencies in redundant mode (all interfaces in parallel) • Test reliability. Tool: ping or equivalent (measure lost packets) • Test telemetry subsystem (pushing and pulling data)
UC2.1-Factory-T2	Description	In-factory benchmark with synthetic traffic traces
	Environment	• SNPN • PNI-NPN: measure impact of UPF on telco edge
	Precondition	• 5GNR RU, Wi-Fi and LiFi APs installed on the factory floor • 5G-CLARITY RAN and edge clusters installed on technical room • One 5G-CLARITY CPE deployed along one production line • Custom client device connected to 5G-CLARITY CPE injecting synthetic traffic traces. Tool: TCP reply or equivalent • Custom processing function installed in edge node
	Procedure	• Test 5G-CLARITY scheduling modes: i) default aggregation, ii) redundant, iii) telemetry based weighted round-robin • Test 5G-CLARITY eAT3S xAPP: i) use telemetry data; ii) modify scheduling mode; iii) update scheduling weights. • Measure: latency and reliability
UC2.1-Factory-T3	Description	Slice isolation in front of interferer
	Environment	• SNPN • PNI-NPN: Measure impact of UPF on telco edge
	Precondition	• 5GNR RU, Wi-Fi and LiFi APs installed in the factory floor • 5G-CLARITY RAN and Edge clusters installed on technical room • One 5G-CLARITY CPEs deployed along one production line • Custom client device connected to 5G-CLARITY CPE • One interfering device in the 5GNR, Wi-Fi, and LiFi. Interfering device is transmitting bulk data using iperf
	Procedure	• Scenario 1: 5G-CLARITY CPE transmitting bulk data in uplink and downlink. Measure impact of interfered in throughput, latency, reliability • Scenario 2: 5G-CLARITY CPE replying synthetic data. Measure impact of interfered in throughput, latency, reliability
UC2.1-Factory-T4	Description	Production line emulation
	Environment	• SNPN • PNI-NPN: measure impact of UPF on telco edge
	Precondition	• 5GNR, Wi-Fi and LiFi installed in the factory floor • 5G-CLARITY RAN and edge clusters installed on technical room

Test ID	Notes	
		• Two moulding machines each connected to a 5G-CLARITY CPE • Emulated MES server available
	Procedure	Validate MES operation while the two HoL switches working
UC2.1-Factory-T5	Description	Production line emulation with background traffic
	Environment	• SNPN • PNI-NPN: measure impact of UPF on telco edge
	Precondition	• 5GNR RU, Wi-Fi and LiFi APs installed in the factory floor • 5G-CLARITY RAN and Edge clusters installed on technical room • Two moulding machines each connected to a 5G-CLARITY CPE • Emulated MES server available • Device generating background traffic
	Procedure	Validate MES operation with the two HoL switches working despite background traffic

5.4 UC2.1 implementation plan and timeline

Figure 5-9 depicts a preliminary implementation plan for UC2.1 identifying the individual milestones and the involved partners. The plan is organized in the following phases:

- ~M16 (~February 2021) Initial technical deployment architecture
  - A technical deployment document is drafted (the project plan)
  - The project plan is submitted to Bosch internal network architecture board for their approval
  - The security requirements related to the PNI-NPN integration are clarified
- M16-M24 (February 2021 – October 2021) Portable production-line testbed setup
  - The portable testbed is set up at i2CAT premises, with the involvement of all contributing partners, integrating the various technological components that will later be deployed in the Bosch factory
  - The portable testbed is used to generate KPIs and to support the technology integrations carried out in WP3 and WP4
  - The portable testbed is used to validate the PNI-NPN setup with 5TONIC
- M25-M28 (September 2021 – February 2022) UC2.1 in-factory setup
  - The in-lab setup is moved to the Bosch factory in Aranjuez and to validate the interconnection to the 5TONIC from the Aranjuez factory
  - Bosch will lead this with the support of technology providers
- M29-M32 (March 2022 – June 2022) UC2.1 demonstration and validation
  - The "5G-CLARITY in-factory setup" and "5G-CLARITY in-factory emulated production line" demo setups for the SNPN and PNI-NPN scenarios are validated against KPIs

This plan will be updated throughout the execution of T5.2 and T5.3.

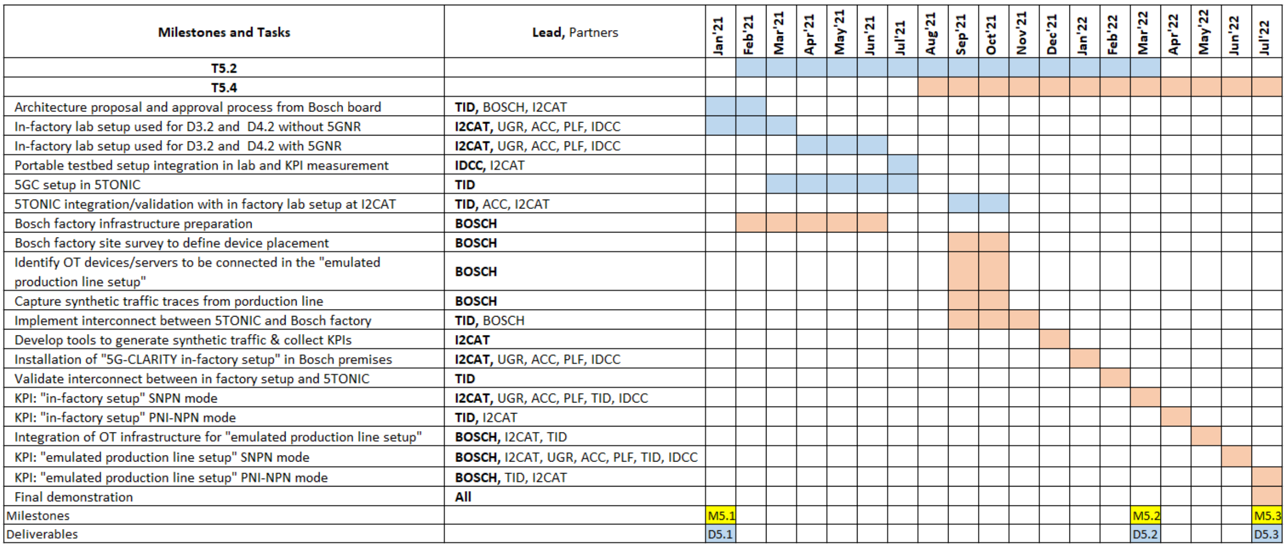

Figure 5-9 UC2.1 tentative implementation plan

5.5 UC2.1 demonstration risks and mitigation plan

Table 5-3 lists the risks identified for this pilot. The two main risks are the moment of writing this deliverable is to secure the 5G spectrum required for the demo, which Telefonica is currently pursuing. Another major risk are the security requirements related to the interconnection of the 5GC from 5TONIC with the Bosch factory. This item is currently being investigated. The risks listed in Table 5-3 will be updated in D5.2.

Table 5-3 UC2.1 Implementation Risks and Mitigation Plan

Risk ID	Description	Impact	Mitigation Plan
UC2.1-R1	Lack of spectrum license for 5G	High	• Telefonica is currently assessing spectrum availability in n78 band with the network operations business unit. Telefonica team has confirmed that the public network has 5G coverage in the Aranjuez factory premises, so there is an ongoing technical analysis about the feasibility of introducing a small cell inside the factory radiating in the same frequency. • Should the n78 spectrum not be available, the n77 band spectrum will be pursued with the Spanish regulator, which is contingent to the availability of an n77 capable radio unit provided by Accelleran. • If n77 is not an option, additional interference-free Wi-Fi channels will be provisioned to try to emulate the 5G performance.
UC2.1-R2	Radio units are not available on time for testing	Low	This risk is low given that Accelleran has delivered a clear roadmap. However, if these nodes are not available other commercially available options will be studied.
UC2.1-R3	MES cannot be emulated in the emulation production line setup	Medium	• As a contingency a connection with the production MES will be studied, which will introduce higher security requirements. • If these requirements cannot be met, we will study if a simplified MES function can be built using custom software.
UC2.1-R4	Interconnect with MNO network cannot be delivered due to stringent interconnectivity security requirements	High	• An out-of-band connectivity channel will be investigated where an LTE router will be used to interconnect with the MNO network. • Alternatively, only the PNI-NPN validation can be considered using the in-factory setup where no real production traffic is used.

	in Bosch factory		
UC2.1-R5	Traffic cannot be sniffed from active production line	Low	This risk is low given that Bosch has many production lines in multiple sites available to execute this action. If this is not possible, synthetic traffic will be generated using a custom traffic generator.
UC2.1-R6	Only one moulding machine available	Medium	If only one moulding machine can be made available for the emulated production line setup, the other one will be emulated using synthetic traffic from a laptop, or any available HoL switch from a production line.
UC2.1-R7	Distributed UPF provisioning not possible with the Ericsson core in 5TONIC	Medium	This would require data plane traffic to leave the Bosch factory. If this is not possible in the emulated production line setup, then we will focus the PNI-NPN evaluation in the 5G-CLARITY in-factory setup where only synthetic traffic is generated.
UC2.1-R8	Internet connection from the factory floor may not be allowed.	Medium	The data lake solution which is cloud-based and eAT3S xAPP which uses telemetry from the data lake are intended to be tested in both portable and in-factory setups. If an internet connection from the factory floor to the cloud is not available, the planned testing on the data lake and eAT3S xAPP will not be possible for the in-factory setups. In this case, the multi-connectivity framework will be tested with static scheduling modes and weights.

6 UC2.2: Enhanced AGV Positioning for Intralogistics (Industry 4.0)

6.1 UC2.2 scope and objectives

6.1.1 Motivation and objective

The use of AGVs in factories and warehouses can mitigate the impact of human errors which then leads to improvements in safety, efficiency, quality and productivity of the intralogistics processes. In Bosch factories and warehouses AGVs are used to transport goods. The AGV has a predefined route for its movements throughout the warehouse but only the origin and destination are known, i.e. the status of the route is ignored. The AGV speed, acceleration and deceleration, as well as the specified stop points where goods are picked up or dropped are predefined. It is however necessary to assess, in near real-time, whether any incident (also known as disturbance) occur along the route, and if so, to identify its exact whereabout. A disturbance is defined as any deviation from the planned route, be it inaccurate speed, sudden acceleration/braking, unplanned stops, or planned stops being either too short or too long. Nominal values and tolerances for all course parameters will be set by Bosch. This way the productivity, safety and efficiency of this process could be enhanced.

5G-CLARITY UC2.2 aims at enhancing the positioning of an AGV in the shop floor of a Bosch factory described in 5G-CLARITY D2.1 [2]. UC2.2 will include an AGV operating on a shuttle service between a warehouse and a production shop floor, in RBEF, Bosch factory located in Aranjuez near Madrid, Spain. Since the two ends of the AGV route are located in different buildings, part of the route will be outdoors. However, only the indoor part of the AGV travelling route is within the scope of the 5G-CLARITY UC2.2.

To obtain the accurate position of an AGV in real time, a multi-technology positioning system will be implemented that is able to retrieve real time information about the position of the AGV within the premises. The main aim of UC2.2 is to achieve real time positioning of the AGV with cm precision and retrieval of the disturbances on the AGV route.

More concretely, UC2.2 expected output is the collection of AGV positioning data in real time with enhanced accuracy using 5G-CLARITY multi-WATs. Accurate positioning information allows recording, evaluating and management of incidents on the factory shop floor along the AGV routes. The details of these incidents, e.g., precise location, exact time, etc., will be recorded and the corresponding data base can be used to improve the productivity.

Moreover, according to the 5G-CLARITY D2.1 [2], UC2.2 will provide the following functionalities:

- Allow real time access to the positioning data generated by the AGV sensors, e.g. speed, acceleration, deceleration, track, and detected incidents (TECH-UC2.2-06).
- Enable a real time data exchange, using 5G technologies with a database located in Germany to generate SAP orders to the warehouse (TECH-UC2.2-07).

6.1.2 Main benefits and potential application

UC2.2 will benefit Bosch production in different aspects as listed below:

- Positioning of the AGV along the route. This is an improvement as currently only the route origin, few intermediate points and the destination can be identified.
- Recording sudden stops on the track and disturbances in the AGV route. Currently no record of any such incident is collected.
- Identifying potential improvements of the AGV operation based on detected disturbances. The

improvement can be pursued in the following aspects:

1) Increasing the AGV speed (now it is limited to 1.25 m/s, but it can be faster). This can result in a reduced AGV cycle time and/or more payload delivered within the same cycle time.

2) Reducing disturbances in the AGV route. This will result in reduced cycle time and less risks to workers and other vehicles, machines and facilities. Identification of disturbances will also help as know-how if the AGV fleet is to be expanded, e.g. to ensure optimal operation and also as a basis for future automation projects that are also related to 5G technologies.

3) Increasing the accuracy of AGV positioning, even further than the sub-meter precision promised in 3GPP Release 16. This will result in increased operator safety and will help to evaluate whether the aisles along which the AGV moves can be narrowed, and if so, how much. The space gained from narrower aisles can be devoted to production operations, thus increasing the overall factory productivity.

5G-CLARITY solutions will enhance the existing positioning and synchronization schemes to provide the position estimates with better precisions. The flexibility of the introduced localization server to incorporate 5G-CLARITY WATs and any other WATs inputs can bring along potential applications in other contexts in private venues.

6.2 UC2.2 demonstration scenario

UC2.2 demonstration scenario involves the normal operation of the AGV along the route of raw material delivery from the warehouse to the production shop floor, picking up of the finished products from the shop floor, and return it to the warehouse. The route along the shop floor (indoor) track is already established, and it is shared with workers and human-operated vehicles. The AGV enters to the factory shop floor already carrying components for unloading at different stations. The outdoor AGV route is out of scope because it requires developing equipment resistant to adverse climatic conditions such as extreme temperatures, rain, moisture and wind.

Figure 6-1 Aerial view of UC2.2, Aranjuez factory, and the AGV route (in red)

Figure 6-1 shows the aerial view of the Aranjuez factory on which the AGV route is highlighted. The AGV moves along a same predetermined path (in red), which is approximately 275 m long on a flat and clean floor. The path and the stations at which the AGV stops are programmed in advanced by the AGV control system. The AGV route is completely defined by the path plus the stops in which goods are left or picked up. Each route involves one of the three different loops, each having different stops:

- Loop 1 is always performed with the purpose of component unloading. The AGV stops at the predefined stations and, at every station, the components are manually unloaded by an operator. When the unloading finishes, the operator pushes a button on the AGV and it resumes its course towards the next station. If the button is not pressed after a predefined time, the AGV will resume the course on its own. Once loop 1 is finished, the AGV stops in a fixed point "P", depicted in Figure 6-1 and Figure 6-2, and checks with the factory computer system (the one that is controlling the manufacturing process) if loop 2 is to be performed. If not, it checks whether loop 3 is to be performed and, if it is not the case, the AGV navigates back to the warehouse.
- Loop 2 is a shuttle transfer of semi-finished goods within the production shop floor. It consists of just two stations, one for loading (see yellow point 1 shown in Figure 6-1 and Figure 6-2), and the other for unloading (see yellow point 2 shown in Figure 6-1 and Figure 6-2). This loop is seldom performed, in fact it is estimated to be performed once in an 8-hour shift. The AGV stop process in loop 2 is identical to those for loop 1. When loop 2 is completed, the AGV navigates to point "P" and checks with the factory computer system if loop 3 is to be performed. If not, the AGV navigates back to the warehouse.
- Loop 3 is for picking up the finished products and transferring them to warehouse. The factory computer system programs the AGV with the list of stations where products can be picked up (station location is predefined) and orders it to start the loop 3. Most of the stations of loop 1 are also included in loop 3. The AGV stop process in loop 3 is the same as those for loop 1. Once loop 3 is completed, the AGV navigates to the exit and leaves the factory shop floor.

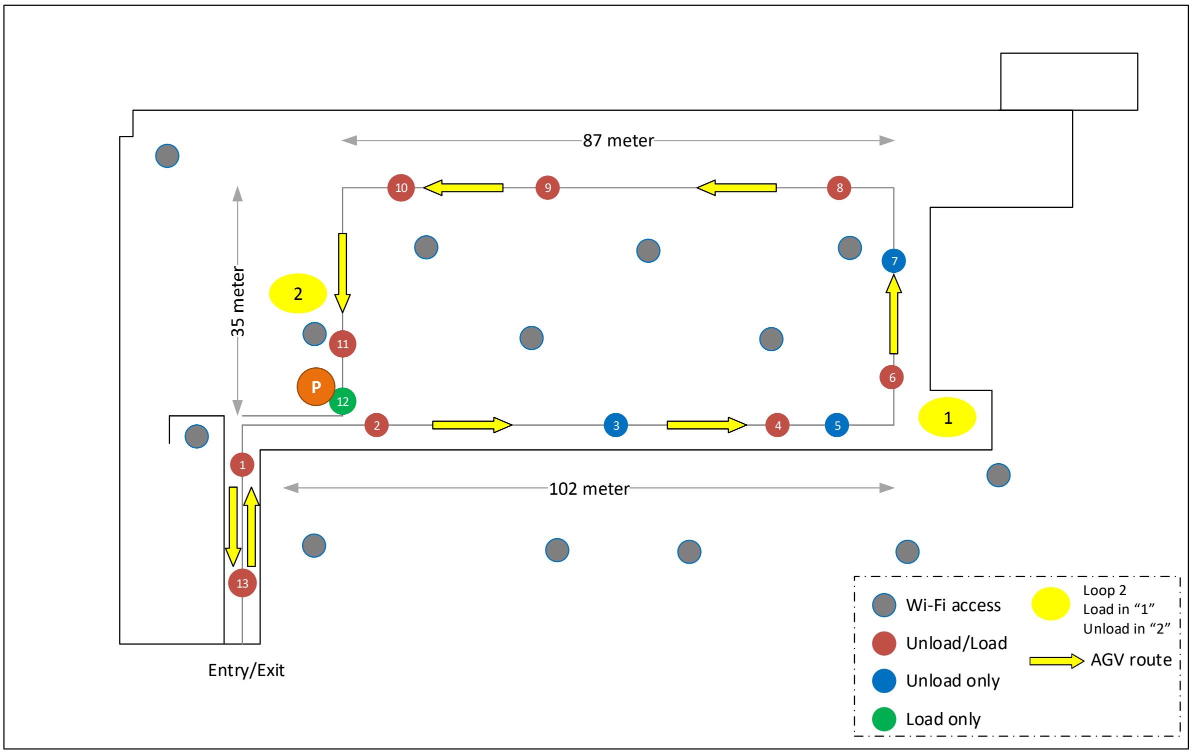

Figure 6-2 AGV route in the production shop and Wi-Fi APs

The expected output of UC2.2 is to determine an optimal route for the AGV with an optimal sequence of stops, which will be calculated based on information from a log on AGV travel as follows:

- Position is to be monitored continuously and in real time. For every position check, a log record will be generated.
- Speed and acceleration are also to be monitored, either directly or as the result of calculation from the AGV position data. If speed falls to zero (the speed is considered to fall to zero if it is below a certain threshold set by Bosch technical specifications) the AGV is considered to have stopped. For each change in speed or acceleration higher than a set amount, a log record will be generated.
- Cruise and maximum speed are to be monitored and checked against minimum and maximum values. A log record will be issued if any of these speeds is outside tolerances or change from last check is bigger than a set amount. Acceleration will also be checked against minimum and maximum values, and a log record will be issued if it exceeds tolerance limits.
- Stopping time at the stations is also to be monitored and checked against minimum and maximum allowable stopping time. A log record is to be issued if time is outside tolerances.
- Non-planned stops are to be monitored. A log record will be issued indicating the stop position and stop time.
- Emergency braking will also be monitored. An emergency braking is considered to occur whenever the AGV decelerates too fast (faster than maximum allowed deceleration) or decelerates in a position where it is not planned to do.
- Dark spots on the route will be identified based on severity and frequency of detected disturbances.

Log records include the occurrence time, the duration and the out-of-tolerance parameters and their values. For ‘severe’ labelled warnings, in addition to the log record an alarm, e.g., an e-mail/SMS/etc. message, will be issued. The ‘severe’ state for each parameter is defined by the ‘production and logistics’ unit.

The AGV is connected to Wi-Fi via a number of Wi-Fi APs existing on the shop floor, as shown in Figure 6-2. The AGV model is the TRIBOT ASTI 3 TN featuring simultaneous localization and mapping (SLAM) guidance [10].

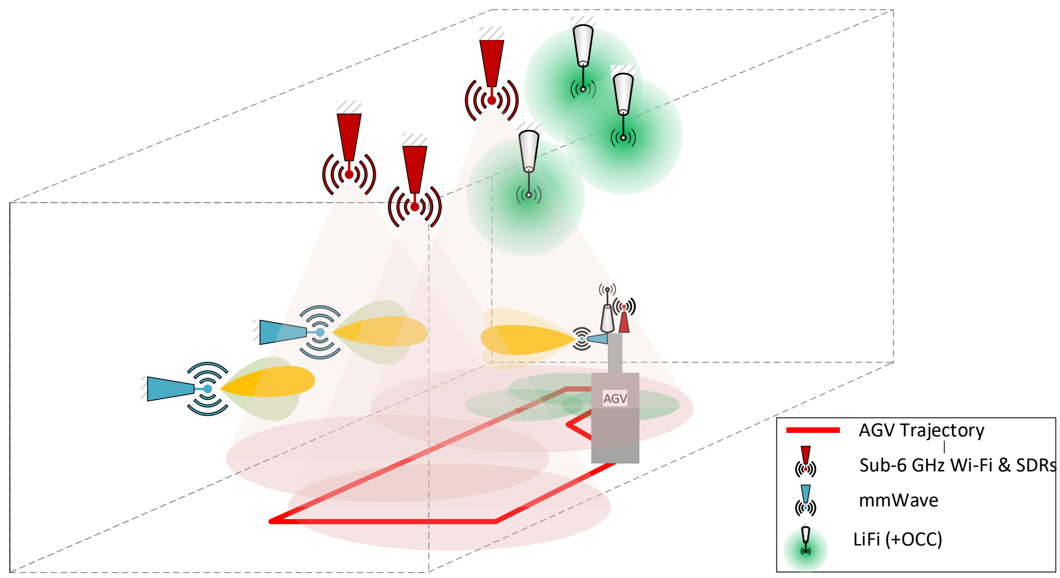

Figure 6-3 3D representation of the demonstration scenario and 5G-CLARITY APs

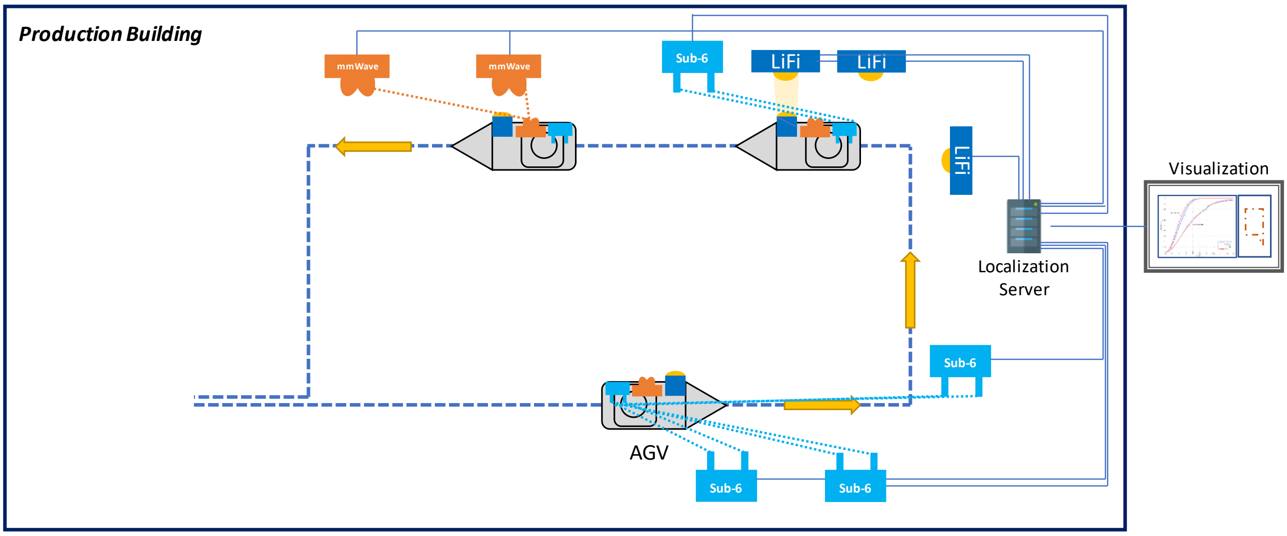

Figure 6-4 5G-CLARITY AGV positioning scenario, sing multi-WAT

Once inside the production shop, the AGV connects to a Wi-Fi AP and gets the information on the stations it needs to stop for delivering raw material. The AGV will start the pre-defined route and will stop in some of the stations depending on the assigned loop.

For the UC2.2 purpose, the 5G-CLARITY WATs, namely Wi-Fi, LiFi, optical camera communications (OCC), mmWave and Sub-6 GHz software defined radio (SDR) systems, will be installed along the route at the ceiling and walls of the production shop to ensure line-of-sight (LoS) connectivity to the AGV. In addition to the communication equipment installed by the AGV manufacturer (sensors, Wi-Fi modems), the AGV will be further equipped with 5G-CLARITY WATs. This will enable data connectivity and positioning of the AGV while moving along the route. The availability of different technologies will allow to improve the position estimates. The WATs installed at the AGV will use supplementary batteries as its power supply or will use the AGV power.

Figure 6-3 shows a 3D-sketch of the scenario including the AGV route and mmWave, LiFi and Sub-6 GHz Wi-Fi and SDR APs. Figure 6-4 provides a more detailed view on how the positioning information data from various technologies are fed to the localization server, which runs on a general compute server within the premises. The trajectory of the AGV will be monitored in real time and a visualization tool will be used to display the route, route parameters and incidents on screen. As well the achieved positioning error by each of the technologies can be displayed.

6.3 5G-CLARITY enablers

A multi-WAT positioning system leveraging Sub-6 GHz Wi-Fi and SDRs, mmWave, LiFi, and OCC connectivity will be implemented to precisely estimate the position of an AGV in real time as it moves along the predefined routes in the factory. The position information stemming from different technologies will be fused in the so-called localization server, which is a software entity that implements several methods for the control of the positioning framework, interfaces with the involved WATs, and hosts algorithms that intelligently combine the position estimates extracted from the considered technologies [1], [3]. All the incoming information will be processed by the server in order to provide a beyond state-of-the-art performance in positioning and tracking of the AGV inside the plant. Currently the AGV specification defines a minimum safety area of 20 cm without human presence and 1 meter if humans (workers) are sharing the path with the AGV only considering Wi-Fi technologies at the production shop. 5G-CLARITY attempts reducing the safety area and optimizing the space use within the building.

The positioning methods will be benefiting from the following:

- ML-based non-line-of-sight (NLoS) identification algorithm, which is developed in 5G-CLARITY and is reported in 5G-CLARITY D4.1 [4],
- Sub-6 GHz ISM band channel availability, i.e. not already used by current Bosch deployments, to determine angle-of-arrival (AoA), aiding directional link setup for both mmWave and LiFi links,
- Time-of-flight (ToF) estimation for the wideband mmWave signal to provide the range (relative to the access point) with high accuracy,
- Use of LiFi to locate the mobile within its confined coverage area,
- Use of OCC and image processing algorithms to enhance the precision of the estimates, detection of NLoS, and to track the movements of the AGV,
- Fusion algorithms using the data from the various positioning sensors thus gaining positioning and accuracy, e.g. Kalman filter, Particle filter,
- Information from AGV sensors, such as accelerometers, that may help detecting incidents occurring along the route.

Table 6-1 shows the 5G-CLARITY components and innovations that UC2.2 will make use of for the demonstrations.

Table 6-1 UC2.2 Technology Components

Name	Description	Setup	Partner(s)
Sub-6	Wi-Fi or SDR Sub-6 GHz signals are used for position estimation	Bosch production building and AGV	IHP
mmWave	A 60 GHz mmWave device with a phased array antenna supporting beam steering	Bosch production building and AGV	IHP
LiFi	LiFi APs (luminaires) that consists of an LED array are deployed at the ceiling as TX units, where off-the-shelf non-imaging photodiodes are utilized for signal detection	Bosch production building and AGV	PLF / USTRATH
OCC positioning system	An OCC device being in LoS with a set of LED luminaires will take an image where the various LEDs are visible	Bosch Production building and AGV	I2CAT
Localization server	The entity in charge of managing the position estimates retrieved in such multi-WAT environment, which fuses different algorithms targeting an enhanced position estimation	Portable	IHP
ML-assisted NLoS detection algorithm	Function(s) that will implement the NLoS identification framework for Sub-6 and mmWave localization	Portable	IHP

6.3.1 Sub-6

The AGV features a Wi-Fi UE that regularly sends Wi-Fi frames to the Wi-Fi APs deployed in the factory. 5G-CLARITY will install additional Sub-6 nodes –SDR nodes (Ettus N321 [11] and/or Ettus N310 [12]) – with a minimum channel bandwidth of 40 MHz that will be able to receive the Wi-Fi frames and perform uplink time-difference-of-arrival (UL-TDoA). An alternative solution to be tested is the use of the SDR UE at the AGV connecting to the different SDR APs deployed at the ceiling of the production building. These SDR nodes offer the flexibility of tuning several parameters, e.g., channel bandwidth and transmit power. Different sets of antennas will be used depending on the agreed deployment, i.e., omni-antennas, or directive antennas.

A minimum number of four Sub-6 GHz SDR APs will be deployed to perform positioning and to achieve a precision of up to 1 m [3]. Regarding synchronization of the SDR APs we contemplate different possibilities, either to perform wireless/wired synchronization using COTS equipment (White Rabbit/cables) or to implement techniques like two-way-ranging (TWR) [13]. This would be at the cost of increased wireless medium usage, because it does not require equipment to support synchronization and reduces the number of required Sub-6 Wi-Fi and SDR nodes.

6.3.2 mmWave

The mmWave equipment will be the one developed in the framework of the 5G-PICTURE and 5GENESIS projects, which involves an IHP proprietary high performance SDR solution (baseband and MAC) including a commercial 60 GHz front-end that supports beam steering [14] and uses a bandwidth of 2.16 GHz. Two mmWave nodes will be considered for the purpose of estimating the position of the AGV, as depicted in Figure 6-5. The target precision is in the cm/sub-cm range [3]. Two solutions are being considered that involve distinct techniques for the accurate estimation of the position:

- The use of a wide radiation pattern antennas (green beams in Figure 6-5) and no beam steering. In this case we will adopt a multilateration scheme, which requires a minimum number of three Aps and that requires the use of the TWR technique. Two APs can be used if additional constraints are added, such as the presence of a wall (see Figure 6-5) at the environment.
- The use of phased antenna arrays (yellow beam in Figure 6-5), where beam steering allows estimating the angle in addition to the distance to the AGV, which will help estimating the position of the AGV.

6.3.3 LiFi

The LiFi localization system will be based on received signal strength (RSS) techniques, introduced in 5G-CLARITY D3.1 [3], which rely on the signal power measured at the receiver to estimate the receiver position. This value is extracted from the photodiode employed by the LiFi terminals and is a simple implementation that doesn't require additional components. Specifically, the LiFi based indoor positioning could be realized by three main techniques: proximity, triangulation, and fingerprinting [15]. Accordingly, in proximity method, the mobile terminal can simply be collocated by detecting the ID of the LiFi AP(s) that the terminal is connected.

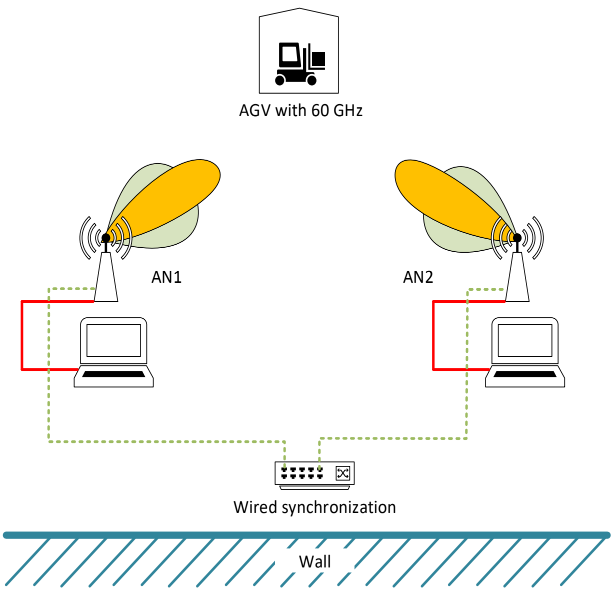

Figure 6-5 AGV mmWave connectivity scenario for positioning purposes

Since the location information of the LiFi APs in 3D-space is known and the signal radiation patterns are conic, the relative location of the terminal could be obtained within a certain range. Although, the application simplicity of the proximity-based positioning method is very high, the accuracy of the result might not always be satisfactory due to the high variance of the estimation. Triangulation method is a well-known positioning technique which is also applicable with LiFi APs. In triangulation, AoA, TDoA and RSS metrics could be used to triangulate the location of the mobile terminal with very high accuracy (order of centimetres) compared to proximity method. The downside of this method is the increased computational complexity burden in the system, especially under high user density and/or mobility conditions. Lastly, the fingerprint is another method for position estimation by the utilization of location dependent features of light. The idea behind the fingerprinting scheme is to achieve localization either active or passively by extracting the information from LoS-plus-NLoS channel impulse response. Unlike, RSS dependent localization techniques, a strong LoS component is not required for fingerprinting based localization. The accuracy and complexity of the fingerprinting method falls between the proximity and triangulation techniques [15]. However, the low-pass characteristics of the front-end optoelectronics, eye safety concerns as well as accurate and almost real-time multipath channel estimation constitutes the challenges for fingerprinting based LiFi localization [16].

The system will be based on pureLiFi LiFi-XC [17], and the number of deployed APs depend on the environment and the required positioning accuracy of the LiFi subsystem. The type of deployed LED luminaires also depends on the demonstration space to guarantee sufficient area is covered by each LiFi AP.

6.3.4 Optimal camera communications

OCC is a set of techniques that allow communicating an LED blinking at frequencies non perceptible to the human eye with a CMOS based camera. A representative example is presented in [18] in which an OCC communication system is described achieving 700 bps between the LED and the CMOS camera while making use of the rolling-shutter effect commonly present in the CMOS sensors used in commercial smartphones.

Positioning is an application that can be built on top of OCC using the steps described in Figure 6-6:

- The CMOS camera takes a photo of the ceiling where LED panels are operating.
- The location of each LED panel is obtained through image processing, and the "bar-code" appearing on the panel surface is decoded using OCC techniques to a unique identifier for that LED panel.
- Each LED identifier is linked to a location of the LED panel in the 3D environment, which is available in the device on a database. Armed with this information and using geometrical methods a device can find the position of the focal point of its camera in the 3D environment.

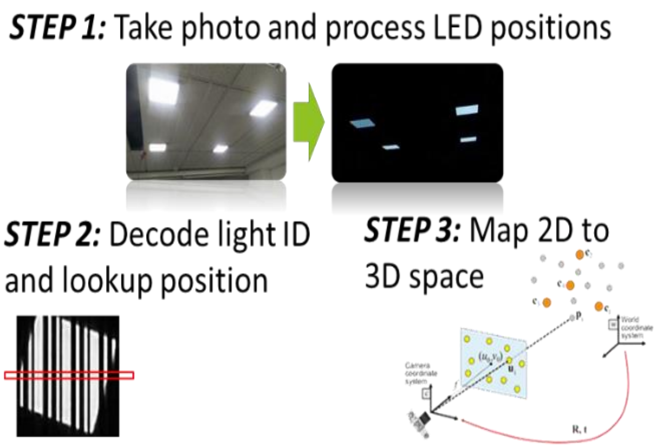

Figure 6-6 Steps involved in the 5G-CLARITY OCC positioning system

There are some aspects that are critical to the operation of this system and that will be carefully considered for the integration of this technology in the AGV pilot:

- Size of the LED panels. Notice that the amount of information that can be decoded from the surface of the LED panel depends on the size of the panel. Using panels that are too small, or even point lights, would make it very challenging to decode the LED identifier. The current solution operates with LED panels of size 20 cm x 20 cm. Other solutions reducing the LED panel size will also be investigated in WP3.
- Number of available LEDs. The precision of the system critically depends on the number of LEDs that are visible by the camera at any time. With 4 LEDs the system can provide cm-level positioning and even orientation. However, the performance degrades when the number of visible LEDs reduces, up to the point where when only one LED is visible the system can only provide a sense of proximity to that visible LED. For the demonstration it will be critical to understand how many LEDs can be deployed and where.
- The user device that obtains the positions. Two alternatives are considered. First, a smartphone running a customized software development kit (SDK) that implements the required image processing functions, where the challenge is to maintain the corresponding app operating even if no user interacts with the smartphone. The second alternative is a Raspberry Pi device connected to a CMOS camera sensor. In both cases the obtained positions will be periodically transmitted to the localization server using Wi-Fi.

6.3.5 Localization server

The localization server is introduced in 5G-CLARITY D2.2 [1] and 5G-CLARITY D3.1 [3]. The localization server will be implemented in Python running on a general-purpose PC using either wired or wireless connection as the communication channel to the WATs.

The localization server will be first tested in simulation using models of the different WATs (Python modules) while it hosts functions to implement known methods for fusing/combining the position estimates stemming from the different WATs as described in Figure 6-7. The localization server will define additional interfaces that will convey the positioning data to a client (e.g. visualization software) for further processing or presenting the results.

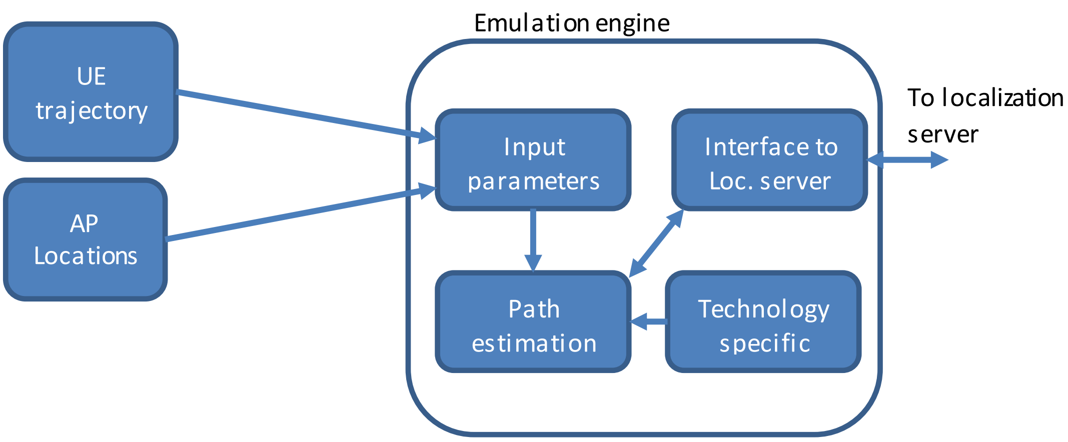

Figure 6-7 Block diagram of the emulation engine

6.4 Preliminary test-plan and timeline

This section introduces 5G-CLARITY the preliminary test-plan for the UC2.2 demonstrations, following by a tentative timeline.

Table 6-2 provides an initial test-plan to be performed in preparation of the final UC2.2 demonstrations.

Table 6-2 UC2.2 Test-Plan

Test ID	Notes	
UC2.2-Lab-T1	Description	Localization server API
	Environment	N/A
	Precondition	• Previous discussion with each of the technology partners to align on the interface • Interfaces with all of the technologies implemented
	Procedure	• Testing of the localization server APIs using each WAT or WAT emulator
UC2.2-Lab-T2	Description	Sub-6 Wi-Fi/SDR localization system initial test
	Environment	Lab
	Precondition	• Availability of the system specifications required (single node) - Sub-6 GHz Wi-Fi/SDR network dimensioning and requirements • SDR procurement, synchronization equipment procurement and front-end availability • Wi-Fi installed in the environment
	Procedure	• Sub-6 GHz SDR basic functionality testing • Sub-6 GHz SDR localization software testing (UL-TDOA, DL-TDOA, TWR) • Wired SDR synchronization tests (Octoclock, White Rabbit@N321) • Sub-6 GHz Wi-Fi/SDR coverage testing (i.e. received power estimation for the area) • Sub-6 GHz SDR based synchronization evaluation and validation • Sub-6 SDR/Wi-Fi localization evaluation
UC2.2-Lab-T3	Description	mmWave localization system initial test
	Environment	Lab
	Precondition	• System specification – mmWave SDR mode (single node) – wide beam solution • mmWave installed in the environment • mmWave network dimensioning and requirements completed
	Procedure	• mmWave coverage tests in separate environments - received power estimation in the area of interest • mmWave connectivity tests • mmWave localization evaluation - synchronization fed from Sub-6 SDRs
UC2.2-Lab-T4	Description	LiFi localization system initial test
	Environment	Lab
	Precondition	• LiFi network dimensioning and requirements finished • LiFi installed in the environment
	Procedure	• Data acquisition and system validation in mock-up environment • LiFi coverage tests in separate environments • Localization tests • LiFi localization evaluation
UC2.2-Lab-T5	Description	OCC localization system test

Test ID	Notes	
	Environment	Lab
	Precondition	• Deployment requirements and estimate accuracy available • OCC installed in the environment
	Procedure	• Data acquisition and system validation in mock-up environment • Coverage tests in separate environments • Localization tests • OCC localization evaluation
UC2.2-Lab-T6	Description	Localization server system initial test
	Environment	Lab
	Precondition	• Localization server requirements finished • Localization server implemented • Localization server installed on a host computer
	Procedure	• Connectivity tests • Initial tests with in-house available WATs
UC2.2-Lab-T7	Description	Positioning system installation, bring-up and testing
	Environment	Lab
	Precondition	• Installation in a lab finished (ideally all systems working simultaneously, fall-back individual testing) • All WAT systems connected
	Procedure	• Standalone tests in a mock-up environment • Power/connectivity requirements testing • Localization server connection tests • Test positioning for each technology (baseline positioning) • Multi-technology testing and improvement evaluation
UC2.2-Factory-T1	Description	AGV unit equipment functionality
	Environment	Bosch production shop
	Precondition	• System installed on the AGV • Connections between the units installed • Power supply for the individual units available
	Procedure	• Testing of proper functionality of the connections between the units on the AGV • Power requirements testing • Connectivity testing • Initial positioning functions testing • Synchronization testing (needed for mmWave)
UC2.2-Factory-T2	Description	APs deployment test
	Environment	Bosch production shop
	Precondition	• Obtained permission from Bosch and devices installed by Bosch
	Procedure	• Connections to APs and devices mounted • Coverage of the deployed WATs testing • Synchronization between APs testing
UC2.2-Factory-T3	Description	Localization server factory tests
	Environment	Bosch production shop

Test ID	Notes	
	Precondition	• WATs installed • Connections between localization server, APs and AGV available • Localization server installed on a host computer
	Procedure	• Testing of connections between the localization server, APs and AGV • Testing of positioning functions of the localization server
UC2.2-Factory-T4	Description	Target client for visualization tests
	Environment	Bosch production shop
	Precondition	• Visualization system installed on a host computer
	Procedure	• Testing of the visualization client using emulated data • Testing of the visualization client using real data
UC2.2-Factory-T5	Description	System precision and accuracy tests
	Environment	Bosch production shop
	Precondition	• Localization system up and running • Previous calibration of the system performed • Defined points (coordinates) at which the precision and accuracy will be evaluated
	Procedure	• Testing of the position precision and accuracy for multiple point previously defined
UC2.2-Factory-T6	Description	System validation tests
	Environment	Bosch production shop
	Precondition	• System up and running • System calibrated
	Procedure	• Initial AGV run to validate the data obtained by the system
UC2.2-Factory-T7	Description	Tests for final demonstrations
	Environment	Bosch production shop
	Precondition	• System calibrated and fully running
	Procedure	• Data acquisition campaign of incidents and route parameters

UC2.2 implementation plan and timeline 5G-CLARITY UC2.2 developments and integration activities will adhere to the subsequent rough schedule:

- Component development
  - Components development and test in separate environments.
  - Simulation models aiming at initial evaluation of the localization algorithms and localization server.
- Integration setup
  - Integration and testing the full setup at IHP laboratories.
- Final demonstration
  - Final demonstration and validation against KPIs at the Bosch factory.

Figure 6-8 shows a preliminary implementation plan for UC2.2, which identifies the individual milestones and the involved partners. This plan will be updated throughout the execution of T5.2 and T5.4.

Milestones and Tasks	Lead, Partners	Jan'21	Feb'21	Mar'21	Apr'21	May'21	Jun'21	Jul'21	Aug'21	Sep'21	Oct'21	Nov'21	Dec'21	Jan'22	Feb'22	Mar'22	Apr'22	May'22	Jun'22	Jul'22
		15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
T5.2																				
T5.4																				
Architectural proposal and approval process from Bosch board	**IHP**, BOSCH, I2CAT, USTRATH/PLF																			
Lab setup at different sites with initial evaluation for D3.2 and D4.2	**IHP**, I2CAT, USTRATH/PLF																			
Set up of a demonstrator at IHP and evaluation of KPIs	**IHP**, I2CAT, USTRATH/PLF																			
Automatization of tests involving the localization server, mockup environment	**IHP**, I2CAT, USTRATH/PLF																			
Positioning system installation involving all WATs, visualization	**IHP**, I2CAT, USTRATH/PLF																			
Bosch factory infrastructure readiness to support the UC	**BOSCH**																			
AGV unit equipment functionality definition in preparation for the tests	**BOSCH**, IHP, I2CAT, USTRATH/PLF																			
Bosch factory site survey	**BOSCH**, IHP, I2CAT, USTRATH/PLF																			
Installation of the different APs at Bosch factory	**BOSCH**, IHP, I2CAT, USTRATH/PLF																			
Connectivity validation between WATs	**IHP**, I2CAT,USTRATH/PLF																			
Validate proper connectivity between the WATs at the AGV and at the infrastructure	**IHP**, I2CAT, USTRATH/PLF																			
Localization server tests and decision on a suitable visualization client	**IHP**																			
System calibration and test of the position estimation in predefined points	**BOSCH**, **IHP**, I2CAT, USTRATH/PLF																			
Validation of tests and KPI assessment	**BOSCH**, **IHP**, I2CAT, USTRATH/PLF																			
Final demonstration activities and final KPI evaluation	**IHP**, I2CAT, USTRATH/PLF, BOSCH																			
Milestones		M5.1														M5.2				M5.3
Deliverables		D5.1														D5.2				D5.3

Figure 6-8 UC2.2 Tentative implementation plan

6.5 UC2.2 demonstration risks and mitigation plan

The AGV used in UC2.2 is one of the standard models approved by Bosch. It is well equipped with a full set of safety equipment. Operating conditions will be according to the specifications and recommendations by the manufacturer, while the safety equipment will be operating at all times during the UC2.2 tests and demonstrations. Thus, no additional risk is expected in this regard.

Modifications to the AGV or to the software that controls it are not allowed without the written permission from the supplier. At this stage of the project no modifications are planned. If such modifications become necessary at a later stage, the supplier has to be partially involved to fulfil the requirements.

The use case needs to detect and monitor incidents –also called disturbances- in the AGV course (see definition of disturbance in Section 6.1). The testing plan is prepared to record such incidents under real normal conditions and validated under lab conditions using simulated incidents. Due to the fact that safety instructions are defined and deployed in Bosch to avoid incidents, it is possible that during the Living Lab demo no real disturbances happen. To mitigate this risk, disturbances may have to be planned and caused intentionally (for instance, by placing obstacles or even humans in the AGV's path) in a controlled and safety environment to verify their detection as a part of the testing plan.

Table 6-3 UC2.2 Implementation Risks and Mitigation Plan

Risk ID	Description	Impact	Mitigation Plan
UC2.2-R1	Delays in the integration of the 5G-CLARITY technologies in use case site	Low	A progressive roll-out of technologies will be considered that can be used to validate the intended KPIs. KPI validation will be performed as soon as the required technology is deployed.
UC2.2-R2	AGV power limitations to supply 5G-CLARITY modems	Low	Use batteries to power 5G-CLARITY modems

UC2.2-R3	Problems with the attachment of units to the ceiling/wall of the production building	Low	Replication of the scenario in a mock-up environment
UC2.2-R4	Additional wireless equipment for 5G-CLARITY mounted on AGV will be exposed to outdoors environment conditions and vibration.	Medium	This must be considered in the design of such components to avoid damage and/or degraded operation
UC2.2-R5	Problems with the connectivity between server and WATs due to lack of ports, cabling, etc.	Medium	Validate connectivity requirements in advance (ports, cables, etc.) Establish back up plan for fast rack support of the required connectivity required, e.g. adding ad-hoc ports to the servers, switches, gateways, etc., and installing ad-hc fibre and Ethernet cables.
UC2.2-R6	5G-CLARITY network makes interference for the existing wireless network and equipment	Low	RF planning for Wi-Fi, mmWave and LiFi, e.g. to have coverage overlapping for more than one technology in some areas
UC2.2-R7	Positioning is not as precise as required due to non-optimal placement or insufficient number of APs, i.e. wireless nodes, etc.	Medium	Thorough analysis of the deployment for the optimization of the placement of additional (mmWave) nodes
UC2.2-R8	If proprietary frames are used, CSMA/CA would be challenging to implement with SDRs	Low	To avoid collisions with existing Wi-Fi and other systems in the factory Bosch must specify which channels should be used in the ISM band

7 Conclusions and Next Steps

5G-CLARITY aims at providing innovative solutions on the coexistence, integration and interoperation of non-public networks with the public mobile networks. 5G-CLARITY pilots for Smart Tourism and Industry 4.0 scenarios will demonstrate the project technical innovations in three use cases. This deliverable serves as the guideline for the project's use case implementation and demonstrations. The descriptions of these use cases are presented in detail along with the objectives, expected results and technological enablers for each. A preliminary project/test plan for each use case accompanied with a tentative timeline is also given.

5G-CLARITY recognises two NPN scenarios, the SNPN, and the PNI-NPN, which will be demonstrated by 5G-CLARITY UC1 and UC2.1. UC1 will showcase the SNPN scenario in the M-Shed museum (as the public space using 5G-CLARITY NPN) for a guide robot management service and content delivery application. The PNI-NPN scenario in UC1 is demonstrated in two narratives, one for an on-demand surveillance application in the museum, and the other for third-party content delivery for special events. UC2.1 showcases an alternative wireless network for factory production-data exchange, emulating the SNPN scenario by replacing the cable connections of production machines (e.g. PLCs) to the manufacturing execution system server. The PNI-NPN scenario is demonstrated based on having a PLMN provided 5GC, which involves using public SIMs in the 5G-CLARITY CPEs.

The contents of this deliverable report the first phase of 5G-CLARITY WP5 that includes, other than the definition and detailed planning of the use cases, the identification of the features and parameters that need to be monitored, measured and evaluated against the KPIs. These are refined for each use case, and described in the frame of preliminary test-plans presented in the corresponding sections.

The task in 5G-CLARITY WP5, T5.2, will entail a closer interaction with WP3 and WP4 in the framework outlined in WP2, to integrate the project's innovations into the use case technological elements, and to validate the individual and integrated solutions in lab environments before being delivered to the final use case venues. These elements will be put together to make the 5G-CLARITY demonstrations in the final months of the project lifetime.

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