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

5G-CLARITY Deliverable D2.1

Use Case Specifications and Requirements

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Table of Contents

List of Acronyms ... 6
Executive Summary ... 7
1 Introduction ... 8
1.1 Objectives and scope of this document ... 8
1.2 Document structure ... 9
2 Private Network Use Cases: A Review on the State-of-the-Art ... 10
2.1 Standardization ... 10
2.1.1 3GPP SA1 ... 10
2.1.2 3GPP SA2 ... 10
2.1.3 3GPP SA5 ... 12
2.2 5G Industry Alliances ... 13
2.2.1 5G-ACIA ... 14
2.2.2 Global TD-LTE initiative ... 18
2.2.3 GSMA ... 20
2.2.4 NGMN ... 20
2.3 5G-PPP projects ... 21
2.3.1 Integration of ICT17 and ICT-19 projects ... 23
2.3.2 Analysis of NPN related ICT-17/ICT-19 projects use cases ... 24
2.3.2.1 Group 1: URLLC-type use cases in industrial IoT scenarios ... 24
2.3.2.2 Group 2: mMTC-type use cases in industrial IoT scenarios ... 28
2.3.2.3 Group 3: Use cases in hotspot scenarios ... 31
2.3.2.4 Group 4: Use cases in transportation hub scenarios ... 32
3 Requirements for the 5G-CLARITY Architecture ... 35
3.1 5G-CLARITY project overview ... 35
3.2 5G-CLARITY Architecture: Requirements and KPIs ... 37
4 5G-CLARITY Pilots ... 43
4.1 Smart Tourism Pilot: UC1: Enabling enhanced human-robot interaction ... 43
4.1.1 General description ... 43
4.1.2 Main stakeholders ... 44
4.1.3 Current setup ... 44
4.1.4 Future setup through 5G-CLARITY ... 46
4.1.5 Expected results ... 47
4.2 Industry 4.0 Pilot ... 47
4.2.1 Main Stakeholders ... 48
4.2.2 UC2.1: Wireless multi-service support in Industry 4.0 ... 49
4.2.2.1 General description ... 49
4.2.2.2 Current setup ... 50
4.2.2.3 5G-CLARITY added features ... 51
4.2.2.4 Expected results ... 51
4.2.3 UC2.2: Enhanced positioning for AGV in intralogistics process ... 52
4.2.3.1 General description ... 52
4.2.3.2 Current setup ... 53

4.2.3.3 5G-CLARITY added features 53
4.2.3.4 Expected results 54
5 Use Case Requirements and KPIs 55
5.1 Use case requirements 55
5.1.1 Functional requirements 55
5.1.2 Technical requirements 56
5.2 Key performance indicators 57
6 Conclusions 59
7 Bibliography 60

List of Figures

Figure 2.1. Access to PLMN services via stand-alone non-public networks....................................11
Figure 2.2 Interworking between 3GPP and non-3GPP management systems...............................13
Figure 2.3 ICT-17 projects - Geographic Cartography 22
Figure 2.4. Overview of relevant 5G-PPP Phase III projects, and their relation as “public” (ICT-17) and “private” (ICT-19) 5G networks 23
Figure 2.5 Example of integration 24
Figure 3-1. 5G-CLARITY vision figure extracted from the DoW..37
Figure 4.1 Multi-RAN powered camera-guided root in public area..43
Figure 4.2. Network system architecture of current testbed..45
Figure 4.3. Physical map of the multiple sites involved in UC1..46
Figure 4.4 WSA production line (BOSCH Spain plant) 47
Figure 4.5 Wi-Fi antennas locations in the shop-floor 51
Figure 4.5 Current setup for the forklift pathways..52
Figure 4.7. Example of Forklift pathways and the milk-run 53

List of Tables

Table 2-1. Key issues identified in FS_eNPN and relevance in 5G-CLARITY 11
Table 2-2. 5G-ACIA industrial use case groups [6]..15
Table 2-3 Examples of GTI use cases for private networks 18
Table 2-4 Primary requirements for private networks considered by GTI [10] 19
Table 2-5 ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 1 25
Table 2-6. ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 2 28
Table 2-7. ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 3 31
Table 2-8. ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 4 32
Table 3-1. 5G-CLARITY objectives..35
Table 3-2 5G-CLARITY System Functional Requirements..37
Table 3-3. 5G-CLARITY System KPIs 40
Table 4-1 Partners’ roles for UC1 44
Table 4-2 Main Stakeholders..48
Table 5-1 Functional Requirements UC1..55
Table 5-2. Functional Requirements UC2.1..55
Table 5-3. Functional Requirements UC2.2..55
Table 5-4. Technical Requirements UC1..56
Table 5-5. Technical Requirements UC2.1..56
Table 5-6. Technical Requirements UC2.2..56
Table 5-7. Key Performance Indicators 57

List of Acronyms

3GPP	3rd Generation Partnership Project
5G-ACIA	5G Alliance for Connected Industries and Automation
5GNR	5th Generation New Radio
5GPPP	5th Generation Public Private Partnership
AGV	Automatic Guided Vehicle
AI	Artificial Intelligence
C2C	Control-To-Control
CAG	Closed Access Groups
eMBB	Enhanced Mobile Broadband
GST	General Slice Template
GSMA	Global System for Mobile Communications Association
GTI	Global TD-LTE Initiative
IMF	Internetworking Management Function
KPI	Key Performance Indicator
MNO	Mobile Network Operator
NEST	Network Slice Type
NFV	Network Function Virtualization
NGMN	Next Generation Mobile Networks Alliance
NPN	Non-Public Networks
OCC	Optical Camera Communications
PLMN	Public Land Mobile Network
RAN	Radio Access Network
SDN	Software Defined Networking
SNPN	Stand-alone Non-Public Networks
SotA	State-of-the-art
ToF	Time-of-Flight
TSN	Time-Sensitive Networking
URLLC	Ultra-Reliable Low-Latency Communication

Executive Summary

This document (D2.1), as the first technical deliverable for 5G-CLARITY project, targets to define and detail specifications and requirements for the use cases which will be implemented and demonstrated in the project. To this end, this document first delivers a full study on the existing works across the industrial forums and standardization bodies on the related technologies. 5G-CLARITY technology requirements, specifications, use case definitions, and evaluation KPIs are then derived based on the Description of Work (DoW), and the related technologies state-of-the-art (SotA).

Chapter 2 provides a comprehensive review of the standardisation and industrial alliances related to 5G-CLARITY use cases and technologies. It starts with exploring non-public networks (NPN) use cases and requirements defined within 3GPP working groups, specifically 3GPP SA1, 3GPP SA2, and 3GPP SA5. The architecture envisioned in these working groups are introduced, and the NPN key issues and requirements, studied in these working groups, are specified, and the relevance on each of these items to 5G-CLARITY architecture and requirements are discussed. The most relevant industrial alliances to 5G-CLARITY technologies, in particular on the softwerisation of network, are 5G-PPP, 5G-AICA, GTI, GSMA, and NGMN. Detailed analysis of the studied use cases, including the requirements on 5G capabilities and relevant KPIs, by each of these alliances are analysed and listed to be used as reference. 5G-CLARITY is a 5G-PPP Phase III project, and in this respect the project monitors previous works in the framework of 5G-PPP and always looks for synergies as well as collaborations with other 5GPPP projects. Hence a detailed analysis of ICT-17 and ICT-19 projects, testbeds, integration activities, and related use cases and scenarios are provided in this chapter.

Chapter 3 first introduces 5G-CLARITY scenario overview, and then project objectives are introduced. In light of the studies and reviews on the related works which was detailed in the previous chapter, and considering the project objectives and vision stated in DoW, functional and technical requirements for the projects pilots demonstrations are listed in this chapter, and the applicable use case from SotA for each requirement is introduced.

The innovations developed in the project will be demonstrated in two pilot demonstrators. The Smart Tourism pilot will be demonstrated at the M-Shed museum in Bristol. This pilot intends to showcase how robots help to leverage tourists' satisfactions in public areas, such as museum and exhibitions. The idea is to use 5G-CLARITY innovations to enhance robots' connections to the network, so that the robot can use, in real-time, the intelligence produced somewhere at a processing/command engine in the network. As a result, the interaction between humans and robots will be explored. Moreover, it is expected that 5G-CLARITY innovations provide enabling technologies on new approaches for future exhibitions and demonstrations.

The second pilot demonstrator will be showcased at a BOSCH assembly plant in Barcelona, Spain. The Industry 4.0 pilot is consisted of two use cases; first an alternative network to exchange the plant's production data is designed, implemented and demonstrated. The second use case is to use multiple access technologies, i.e. millimetre-wave (mmWave), Wi-Fi, LiFi and Optical Camera Communications (OCC) to provide an enhanced positioning for Automatic Guided Vehicle (AGV) in the plant. These use cases help the factory to automate assembly and logistic functions, hence the production efficiency (in cost, time, resource use, etc.), productivity, and safety are improved. 5G-CLARITY innovations will enable BOSCH to explore the integration of real-time data (from sensors and machines in the plant) and decision making (can be on-site, remote, AI-assisted) as a step towards the 'connected factory of future.'

By using the insight produced in the previous chapters, Chapter 5 describes detailed description of the functional and technical requirements for each of the introduced use cases. These requirements will be used for the use case planning and implementations. Moreover, a set of KPIs are derived based on these requirements that will be used for the final evaluation of 5G-CLARITY innovations.

1 Introduction

Private 5G networks are arising as a promising way to foster the adoption of 5G technologies by vertical users, which have specific technological and business needs. Following up on this demand, regulatory agencies in Germany and Sweden have allocated 100 MHz for local licenses at 3.7-3.8 GHz. Similarly, the UK is planning to allocate the 3.8-4.2 GHz spectrum for private and shared networks. This trend is also building up in Asia, with Japan planning to allocate private spectrum in the 3.7, 26 and 28 GHz bands, and in the US through the CBRS allocation at 3.5 GHz.

Private networks come with very specific challenges that distinguish them from traditional MNO networks, including:

- Need to coexist and effectively integrate non-3GPP technologies, e.g. IEEE 802.11, which are currently ubiquitous in vertical scenarios such as factories
- Requirement on novel management systems that simplify the operation and maintenance of 5G networks, given that vertical users do not have the operational expertise of MNOs
- Design of mechanisms to combine private and public 5G networks, allowing vertical users to decide the level of 5G functionality that they want to maintain on-premises
- Incorporation of value-added services that have not been traditionally a priority for MNOs, such a cm-level positioning, that may be strategic for vertical users

5G-CLARITY investigates how the concept of private 5G networks should evolve beyond the 3GPP Release 16, by bringing innovation in two main pillars. First, novel user and control plane components will be developed to deliver a private 5G network that integrates 5GNR, Wi-Fi and LiFi, thus enhancing the capabilities of 5GNR in terms of peak data rates, area capacity, low delay, and precise localisation. Second, 5G-CLARITY investigates management enablers that allow to slice the heterogeneous access network, integrate private and MNO networks, operate the network using a high-level intent language, and incorporate network functions implemented using Machine Learning (ML) models.

1.1 Objectives and scope of this document

According to the project description Task 2.1, the objective of this deliverable is to identify the main characteristics and architecture of the use cases to be implemented during the project execution, and to derive requirements that will drive the design of the 5G-CLARITY architecture in Task 2.2 and of the technical innovations developed in WP3 and WP4.

These 5G-CLARITY use cases are grouped in two representative private network pilots:

- Smart Tourism pilot: executed in the WTC museum in Bristol (UK). This pilot will include a use case (UC1) that aims to validate the interaction between human humans and robots for next-generation museum visitor experiences.
- Industry 4.0 pilot: executed in a production BOSCH factory near Barcelona (Spain). This pilot will include two use cases, each corresponding to a different application scenario. UC2.1 is 'wireless multi-service support in industry 4.0', aiming at validating the slicing and critical service capabilities of the wireless connectivity fabric in the factory. And UC2.2 is 'enhanced positioning for AGV in intralogistics process', which pursues validation of high-precision positioning support capabilities and advanced navigation systems to allow AGVs to move goods across the factory without a human operator or driver.

The deliverable 2.1 (D2.1) identifies the overall requirements for the development and assessment of the complete 5G-CLARITY system architecture towards the end product of the project which are UC1, UC2.1 and UC2.2 demo systems, as well as the technical research carried out in WP3 and WP4.

The descriptions provided in this document include:

- In-depth identification of the state-of-the-art on use cases in private networks, including information on relevant KPIs and clarifying their relationship with 5G-CLARITY project.
- Description of the main objectives of the 5G-CLARITY project, including user / control / management plane related objectives.
- High-level view of the 5G-CLARITY architecture, illustrating illustrates the 5G-CLARITY vision of combining 5GNR, Wi-Fi and LiFi technologies in a private 5G network, which is managed by an SDN/NFV management system, and which can interact with public 5G networks.
- Elicitation of the requirements and KPIs the 5G-CLARITY shall support during (and beyond) project's lifetime.
- Detailed specification of the smart tourism pilot, including general description, functional requirements and KPIs of UC1.
- Detailed specification of the industry 4.0 pilot, including general description, functional requirements and KPIs of both UC2.1 and UC2.2

1.2 Document structure

The rest of this document is structured as follows:

- Chapter 2: Private Networks Use Cases: A Review on the State-of-the-Art. This chapter includes a careful review of private network use cases that can be found in the literature, and that are relevant for 5G-CLARITY project. This includes use cases from standards bodies, 5G industry alliances and 5G-PPP Phase III projects.
- Chapter 3: Deriving requirements for the 5G-CLARITY architecture. This chapter clarifies the scope and ambition of the projects in the beyond-5G ecosystem, describing the 5G-CLARITY system objectives, requirements and KPIs.
- Chapter 4: 5G-CLARITY Pilots. This chapter includes general descriptions of 5G-CLARITY pilots, and introduces main stakeholders, current setups, enhancements via 5G-CLARITY and expected results for each use case.
- Chapter 5: Use Cases Requirements and KPIs. This chapter includes functional and technical requirements, as well as KPIs for each 5G-CLARITY use cases.
- Chapter 6: Conclusions. This chapter summarises the discussions presented in this document.

2 Private Network Use Cases: A Review on the State-of-the-Art

The objective of this section is to provide a review and summary on the main works done so far in relation to private networks, with a particular focus on use cases and application scenarios. This includes outcomes from standards bodies organizations (Section 4.1), industry alliances (Section 4.2) and 5G-PPP Phase 3 projects (Section 4.3). This work is relevant to the design of the 5G-CLARITY system, which should be able to address representative private network use cases in the state of the art in addition to the two 5G-CLARITY pilots described in Section 4.

2.1 Standardization

The main body standardizing private 5G networks in the 3GPP. As defined in [1], Non-Public Networks (NPN), or private networks, are 5G systems intended for the sole use of a private entity such as an enterprise, and can be deployed in a variety of settings, utilizing both virtual and physical elements [2]. For instance, NPNs may be deployed on an entity's defined premises, including a campus or a factory to provide coverage in a limited geographic area. The initial NPN classification in 3GPP features two distinct deployment options:

1. A *Stand-alone NPN (SNPN),* which is operated by an NPN operator and not supported by network functions provided by a Public Land Mobile Network (PLMN).
2. A *Public network integrated NPN*, consisting of an NPN deployed with the support of a PLMN.

In the following, we explore NPN use cases and requirements defined within specific 3GPP working groups and highlight their relevance within 5G-CLARITY.

2.1.1 3GPP SA1

The 3GPP System Aspects WG1 (SA1) develops service and feature requirements applicable to mobile and fixed communications technology, including service operation, service interworking and service interoperability among networks. Specifically, in [2] service requirements are defined addressing several aspects, such as high-level requirements, basic capabilities, performance requirements, security and charging. With respect to NPNs, the document specifies the requirements targeting the NPN support:

- Support for both physical and virtual NPNs.
- Different access for NPN subscribers and seamless service continuity.
- Identification and selection of an NPN.
- Access authorization to PLMNs and NPNs.

All these requirements will be relevant to 5G-CLARITY and will be considered throughout the architecture development stage in Task 2.2.

2.1.2 3GPP SA2

The 3GPP System Aspects WG2 (SA2) identifies key functions and entities of the network, how the entities are connected to each other and how the information can be exchanged, based on the service requirements elaborated by the SA1.

As mentioned above, in [1] private networks are classified into SNPN and PNI-NPN. Users in an SNPN may access to PLMN services by reusing the untrusted non-3GPP access architecture, as shown in Figure 2.1, and the UE is configured with subscriber identifiers and credentials for one or multiple SNPNs identified by the combination of PLMN ID and network ID (NID). By contrast, PNI-NPNs are enabled by means of dedicated Data Networks (DNNs) or by Network Slice instance allocated to the NPN. Besides network slicing, access control is ensured by using Closed Access Groups (CAG): a CAG identifies a group of subscribers allowed to access one or more CAG cells associated with the CAG, and block UEs that are not allowed to access the NPN through the associated cells.

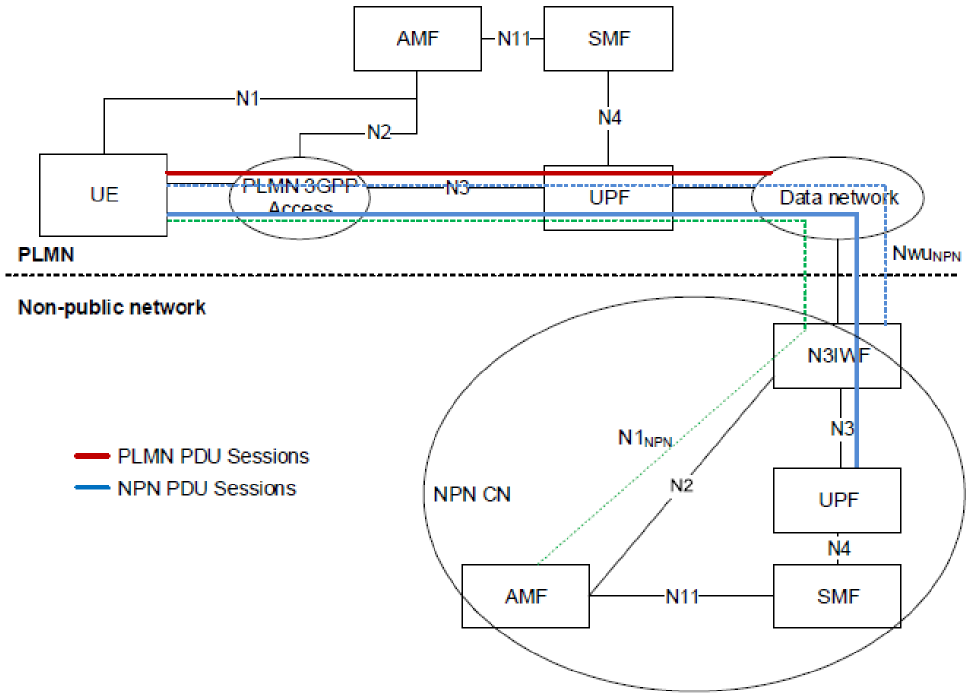

Figure 2.1. Access to PLMN services via stand-alone non-public networks.

In the context of NPNs, SA2 has also recently approved a Rel-17 study item called "Study on enhanced support of Non-Public Networks" (FS_eNPN), which is responsible for developing further enhancements to the 5G System (5GS) support for NPNs, whose Stage 1 service requirements are described in [2]. More specifically, the technical report 23.700 [3] collects the outcomes and findings of this study, which identified six key issues reported in Table 2-1.

Table 2-1. Key issues identified in FS_eNPN and relevance in 5G-CLARITY

Key Issue	Description	Relevance to 5G-CLARITY
Enhancements to support SNPNs along with credentials owned by an entity separate from the standalone NPN.	Subscriptions and credentials are owned by an entity separate from the standalone NPN. This applies to several NPN use cases, such as wireless connectivity for industry, large residential buildings, campuses, malls, and merged standalone NPNs	This is a key use case in the project, as credentials may be managed by an entity external to the SNPN (as envisaged in the smart factory use case introduced in Section 4).
NPN support for Video, Imaging and Audio for Professional Applications (VIAPA)	Use cases driven by service requirements for "Video, Imaging and Audio for Professional Application" (VIAPA), including scenarios where a UE needs to receive data services from one network (e.g., NPN) and paging as well as data services from another network (e.g., PLMN) simultaneously.	Such use cases may be related to the 5G-CLARITY use case enabling human-robot interactions introduced in Section 4.
Support of IMS voice and emergency services for standalone NPNs	Use cases requiring support of IMS voice and emergency services offered by standalone NPNs.	This feature is not considered in the 5G-CLARITY, as voice services will be offered by a public network, or an OTT data application will be used.
UE onboarding and remote provisioning	Support of UE onboarding and provisioning for NPN. It aims at identifying the network entity performing UE subscription provisioning and its location as well	UE onboarding and remote subscription provisioning may be addressed in the smart

	as means to remotely provision new or updated information to the UE for enabling the UE to access the NPN using the 5G system.	factory use case, as the factory operator may not want to be responsible for UE provisioning.
Support for equivalent standalone NPNs	Use cases where a UE needs to access multiple standalone NPNs. More specifically, an authorized UE will be enabled to efficiently access and move between equivalent SNPNs and to efficiently select equivalent SNPNs during the network selection procedure	This is not relevant in 5G-CLARITY, as a single standalone NPN will be initially considered.
Support of non-3GPP access for standalone NPN services	Use case requiring the support for direct connection of non-3GPP access networks to the standalone NPN's 5G core network (CN). In particular, it aims at exploring how to provide direct access to SNPN services via non-3GPP access networks, supporting trusted non-3GPP access network (TNAN) and untrusted non-3GPP access network.	This is a key use case in the project, as 5G-CLARITY intends to enable smart multiple wireless interface access. Specifically, Wi-Fi and LiFi will be the non-3GPP access networks.

2.1.3 3GPP SA5

The 3GPP System Aspects WG5 (SA5) deals with the requirements, architecture and solutions for provisioning and management of the network and its services as well as management of QoE measurement collection and new technologies for RESTful management protocols.

On the topic of NPNs, SA5 is currently addressing a Rel-16 study item called "Study on management aspects of non-public networks" (FS_OAM_NPN), which presents use cases, potential requirements and solutions for the management of NPNs from the service-based management architecture viewpoint. The outcome of such activity is the Technical Report [4], which collects use cases and requirements discussed by operators, vendors and verticals. More specifically, use cases are classified based on the typology of NPN, as follows:

- *SNPNs*. Use cases in this category involve an NPN combining 3GPP and non-3GPP segments and deployed for exclusive use of a private company. As shown in Figure 2.2, the NPN management system features *a)* a 3GPP management system for operating the 3GPP segment of the NPN, *b)* one or more non-3GPP management systems for managing the non-3GPP segments, and *c)* an Internetworking Management Function (IMF), responsible for interconnecting the 3GPP and the non-3GPP management systems without the need for introducing new elements. This class of use cases may fit with 5G-CLARITY vision of enabling multiple wireless access to users by relying on 3GPP 5GNR and non-3GPP interfaces, such as Wi-Fi and LiFi.
- *PNI-NPNs*. Within this category, the study item proposed two different use cases:
    - NPN provisioning using a network slice of a PLMN. Here, an operator needs to deploy a PLMN-integrated NPN in the local data network, for example by deploying a Network Slice Instance (NSI) at the customer's premises, where the NSI can include only Radio Access Network (RAN) element, Core Network (CN) functions or a combination of them. For example, some CN functions may be deployed at customer's premises, while others may be deployed in the PLMN, and this can be supported by two network slice subnet instances, that can be dedicated for a single organisation or shared among multiple entities. On the other hand, some RAN elements may be deployed in the PLMN and supported by one or more network slice subnet instances, dedicated for a single organisation or shared among multiple entities. In 5G-CLARITY, such circumstances may be considered depending on the specific use case. For instance, in the Industry 4.0 pilot introduced in Section 4 a PLMN may offer resources as a network slice for the NPN.
    - Exposure of management capability of NPN. In this scenario, a PLMN operator instantiated an NSI, which includes either only the RAN or only the CN or both for an organisation. The

CN may be supplied by the PLMN operator and the RAN by the PLMN operator or the NPN operator. The NPN customer makes a service request containing requirements of a limited management capability explore, which can allow the NPN customer to dynamically adjust the configuration parameters and policies related to traffic control and performance monitoring, including associated data analytics requirements. This scenario is relevant to 5G-CLARITY and will be considered during the management platform discussion in WP4.

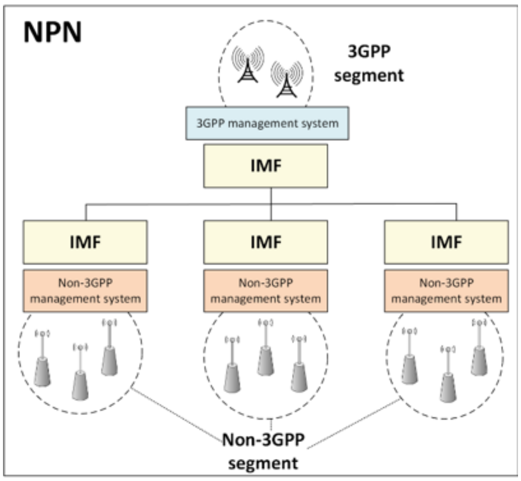

Figure 2.2 Interworking between 3GPP and non-3GPP management systems

2.2 5G Industry Alliances

5G represents a complete revolution of mobile networks for accommodating the over-growing demands of users, services and application. In contrast to previous transitions between mobile networks generations, in 5G there will be a much more complex management requirements based on the softwarisation of network resources. This complexity has resulted in the appearance of several industry alliances and networks. The most relevant alliances to 5G-CLARITY are indicated below:

1. **5G Alliance for Connected Industries and Automation: 5G-ACIA.** (https://www.5g-acia.org/) 5G-ACIA is a global forum for collaboration between automation, engineering, and process industries on the one hand, and telecom operators and suppliers on the other. The paramount objective of 5G-ACIA is to ensure the best possible applicability of 5G technology for connected industries, in particular the manufacturing and process industries. 5G-ACIA will ensure that the interests and particular aspects of the industrial domain are adequately considered in 5G standardisation and regulation.
2. **Global TD-LTE Initiative**: **GTI**. (http://www.gtigroup.org/) GTI was kicked off in February 2011 in Barcelona by Bharti Airtel, China Mobile, Sprint (Clearwire), SoftBank Mobile, and Vodafone. Now GTI consists of 136 operator members and 237 partners. Remarkable achievements of GTI include their role in making TD-LTE a global standard and the convergence of TDD/FDD. GTI 2.0 will continue to help the whole industry benefit from the evolution of TD-LTE, TDD/FDD converged networks and global smartphones, and promote a unified 5G standard and mature end-to-end ecosystem, as well as explore cross-industry markets and opportunities. The GTI 5G Innovation program includes the following subprograms: i) 4G and Evolution, ii) 5G eMBB, iii) 5G Enterprise Network Solutions, iv) Internet of Vehicles (IoV), and v) Cloud Robot.
3. **Global System for Mobile Communications Association: GSMA.** (https://www.gsma.com/) The GSMA represents the interests of mobile operators worldwide, uniting more than 750 operators with over 400 companies in the broader mobile ecosystem, including handset and device makers, software companies, equipment providers and internet companies, as well as organisations in

adjacent industries. The GSMA also produces the industry-led MWC events held in Barcelona, Los Angeles and Shanghai, as well as the Mobile 360 Series of regional conferences.

4. **Next Generation Mobile Networks Alliance**: **NGMN Alliance.** (https://www.ngmn.org/about-us/vision-mission.html/) The main objective of the NGMN Alliance is to expand the communications experience by providing a truly integrated and cohesively managed delivery platform that brings affordable mobile broadband services to the end user with a particular focus on 5G while accelerating the development of LTE-Advanced and its ecosystem.
5. **5G Public Private Partnership: 5G-PPP.** (https://5g-ppp.eu/) 5G-PPP is a joint initiative between the European Commission and European ICT industry (ICT manufacturers, telecommunications operators, service providers, SMEs and research institutions) that aims to empower Europe's leadership in emerging vertical markets such as smart cities, e-health, intelligent transport, education or entertainment and media. 5G-PPP will deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the upcoming decade.

In the next sections, we describe works done by these industry alliances that are relevant to 5G-CLARITY. A separate section (Section 2.3) is devoted to the 5GPPP effort, due to its relevance to 5G-CLARITY.

2.2.1 5G-ACIA

5G-ACIA has published white papers which include industrial use cases and their requirements [5], [6]. In these works, 5G-ACIA heavily relies on the work done in the 3GPP, mostly derived from technical report TR 22.804 [7] and technical specification TS 22.104 [8]. Here we summarise the private network use cases identified by the 5G-ACIA.

The automation in manufacturing encompasses many use cases, which can be categorized into the following areas of application [5]:

1) **Factory automation** refers to those use cases related to the automated control, monitoring, and optimisation of processes and workflows inside a factory.
2) **Process automation** includes those use cases for control of production and handling of substances, thus simplifying and optimizing production processes, and enhancing the energy efficiency and safety.
3) **Human-machine interfaces (HMIs)** and **Production IT**. HMI use cases involve interactions between people and production systems. It is expected that augmented and virtual reality (AR/VR) will play a vital role in the future. On the other hand, Production IT gathers the IT applications of interest in the industry, such as manufacturing execution systems (MES) and enterprise resource planning (ERP) systems, which require to access a large volume of data from the production process in a timely manner.
4) **Logistics and warehousing** group encompass use cases for transporting and storage materials and goods for industrial production.
5) **Monitoring and predictive maintenance** refers to the passive monitoring of specific processes and assets.

5G-ACIA categorizes the industrial use cases into the following ten groups:

1) Motion control
2) Control-to-control (C2C)
3) Mobile control panels

4) Mobile robots
5) Massive wireless sensors
6) Remote access and maintenance
7) Augmented reality (AR)
8) Closed-loop access process control
9) Process monitoring
10) Plant asset management

Table 2-2 includes an explanatory description of the use case groups outlined above, along with their most stringent KPIs and 5G capabilities required to support them.

Table 2-2. 5G-ACIA industrial use case groups [6]

Use Case Group	5G Capabilities	Relevant KPIs
Group 1: Motion control Motion control systems are in charge of controlling the moving and rotating parts of machines precisely. They are typically implemented as closed-loop control systems that cyclically collect data from sensors and send the actions to the actuators. Motion control has the most stringent requirements in terms of latency.	**Type of traffic**: Periodic deterministic and non-deterministic (software updates) communications. **Spectrum**: 5G private. **Deployment scenario**: Standalone NPN. **Network slicing**: one URLLC slice **Data plane features**: in-premises edge computing nodes, Time-Sensitive Networking (TSN).	**Latency**: < 500 µs **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.99999% **Reliability**: up to 10 years **Mobility**: up to 72 km/h **Capacity**: no information **Device density**: 0.1 device / m^2 **Service area**: 50 m x 10 m x 10 m **Positioning accuracy**: no information **Time synchronicity**: < 1 µs (300 UEs, 10000 m^2) **Message size**: 20 – 50 bytes
Group 2: Control-to-control It encompasses those use cases involving communication between multiple industrial controllers. Examples of C2C communications include large items of equipment such as newspaper printing presses and production lines, where machines need to control and coordinate the handover of components. These use cases impose stringent requirements in terms of latency, integrity, and service availability.	**Type of traffic**: Periodic deterministic communication. **Spectrum**: 5G private or public, depending on the use case **Deployment scenario**: Standalone NPN and public network integrated NPN. **Network slicing**: one URLLC slice **Data plane features**: in-premises edge computing nodes, TSN **OAM**: Fault, Configuration, and Performance management.	**Latency**: < 10 ms **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.999999% **Reliability**: up to 10 years **Mobility**: stationary **Capacity**: no information **Device density**: 0.003 device / m^2 **Service area**: 100 m x 30 m x 10 m **Positioning accuracy**: no information **Time synchronicity**: TBD **Message size**: 1000 bytes

Group 3: Mobile control panels This group arranges those use cases that are used for configuring, monitoring, debugging, controlling, and maintaining machines, robots, cranes, or entire production lines. Due to the critical nature of their functions (e.g., emergency stop buttons, dead man's switch), they usually have a wired connection to the equipment. In a 5G network, a signal must be periodically sent and received to verify the control panel is still connected. The verification cycle time depends on the process/equipment. For instance, fast-moving robots will require shorter cycles than slow-moving linear actuators.	**Type of traffic**: Periodic and aperiodic deterministic communications. **Spectrum**: 5G private **Deployment scenario**: Standalone NPN. **Network slicing**: one URLLC slice **Data plane features**: Device-to-Device (D2D) communications support, and TSN	**Latency**: < 4 ms **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.9999% **Reliability**: up to 10 years **Mobility**: stationary **Capacity**: no information **Device density**: 0.04 device / m^2 **Service area**: up to 40 m x 60 m **Positioning accuracy**: up to 1 m horizontally and 3 m vertically **Time synchronicity**: TBD **Message size**: 40-250 bytes
Group 4: Mobile robots Mobile robots group refers to those use cases where moving machines travel along preprogrammed routes or are steered automatically (AGV (Automated Guided Vehicles)) to realize diverse tasks such as transport objects and collect and exchange data for reporting. They typically must interoperate with the elements of their environment (e.g., conveyor assets, and monitoring and control elements). For these use cases, the service areas might be extensive.	**Type of traffic**: (A)periodic deterministic communications, and non-deterministic communication. **Spectrum**: 5G public and private, depending on the use case. **Deployment scenario**: Standalone NPN and public network integrated NPN **Network slicing**: one URLLC slice for control and real-time data exchange and one enhanced Mobile Broadband (eMBB) slice for video streaming. **Data plane features**: in-premises edge computing nodes for deploying the controllers, TSNs.	**Latency**: < 1 ms – 500 ms **Throughput UL**: > 10 Mbps **Throughput DL**: no information **Availability**: up to 99.9999% **Reliability**: ranging from 1 week up to 10 years **Mobility**: up to 50 km/h **Capacity**: no information **Device density**: 100 devices / km^2 **Service area**: up to 1 km^2 **Positioning accuracy**: up to 30 cm horizontally and 3 m vertically **Time synchronicity**: TBD **Message size**: 40-250k bytes
Group 5: Massive wireless networks In the context of manufacturing, wireless sensor networks (WSNs) are destined to monitor processes and equipment, and the respective parameters. Several sensor types are in charge of monitoring the different parameters of the environment, such as sound, CO2 level, pressure, humidity, and temperature. Then, these data are used for various purposes like anomalies detection. WSNs change significantly over time in terms of type, number, and position of sensors deployed. This use case group demands a high density of connections and high	**Type of traffic**: Mixed traffic. **Spectrum**: 5G public and private. **Deployment scenario**: Standalone NPN and hosted NPN. **Network slicing**: one mMTC slice. **Data plane features**: Aggregation gateways, fog computing, multi-access edge computing, and cloud computing. **OAM**: FCAPS management.	**Latency** < 5 ms – 10 ms **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.999999% **Reliability**: no information **Mobility**: no information **Capacity**: no information **Device density**: 1 device / m^2 **Service area**: no information **Positioning accuracy**: no information **Time synchronicity**: no information **Message size**: no information

energy efficiency to enable the operation of the battery-powered sensors for long periods.		
<u>Group 6</u>: **Remote access and maintenance** Remote access is the ability to establish contact and communicate with a device from a distant location for performing remote maintenance. An example use case is the inventorization of devices and periodic extraction of configuration data, event logs, version data, and predictive maintenance information. This use case group demands the network to be accessible from outside.	**Type of traffic**: Non-deterministic communications. **Spectrum**: 5G private. **Deployment scenario**: NPN deployed in conjunction with a PLMN. **Network slicing**: one eMBB slice. **Data plane features**: traffic prioritization to enable the coexistence with critical traffic.	**Latency**: no information **Throughput UL**: 1 Mbps **Throughput DL**: no information **Availability**: no information **Reliability**: ~ 1 month **Mobility**: up to 72 km/h **Capacity**: no information **Device density**: 0.5 devices per m^2 **Service area**: up to 50 m x 10 m x 10 m **Positioning accuracy**: no information **Time synchronicity**: no information **Message size**: no information
<u>Group 7</u>: **Augmented reality** This group brings together use case leveraging Augmented Reality (AR) technology. AR is expected to play a vital role in the industry for monitoring processes and production flows, ad-hoc support from a remote expert, and delivery of step-by-step instructions for specific tasks. The workers will wear head-mounted AR devices for prolonged periods. Then, these devices must be lightweight and energy efficient. These features might be achieved by offloading complex processing tasks to the network (e.g., an edge cloud).	**Type of traffic**: Non-deterministic communications (5QI 80) [9] **Spectrum**: 5G private. **Deployment scenario**: Standalone NPN or public network integrated. **Network slicing**: one eMBB slice (i.e., customized slice, with mobile broadband and low latency capabilities). **Data plane features**: in-premises edge computing node for offloading complex processing tasks.	**Latency**: < 10 ms **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.9% **Reliability**: ~ 1 month **Mobility**: up to 8 km/h **Capacity**: no information **Device density**: no information **Service area**: up to 20 m x 20 m x 4 m **Positioning accuracy**: up to 1 m horizontally and 3 m vertically **Time synchronicity**: no information **Message size**: no information
<u>Group 8</u>: **Closed-loop process control** In closed-loop process control, a controller gathers data from multiple sensors (e.g., pressure, temperature, and pH value) and leverage them to decide how to operate the actuators (e.g., valves, pumps, and heaters/coolers). For these use cases, low latency, determinism, and availability are essential.	**Type of traffic**: Periodic deterministic communications. **Spectrum**: 5G private. **Deployment scenario**: Standalone NPN. **Network slicing**: one URLLC slice. **Data plane features**: in-premises edge computing nodes for running the controllers.	**Latency**: < 10 ms **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.999999% **Reliability**: > 1 year **Mobility**: stationary **Capacity**: no information **Device density**: 0.002 devices / m^2 **Service area**: up to 100 m x 100 m x 50 m **Positioning accuracy**: no information **Time synchronicity**: no information **Message size**: 20 bytes
<u>Group 9</u>: **Process monitoring** Process monitoring applications	**Type of traffic**: periodic deterministic and non-deterministic	**Latency**: < 100 ms **Throughput UL**: up to 2 Mbps

make use of multiple sensors deployed in a production facility to grant visibility into a process or environmental conditions, or into inventories. Data are transmitted to displays for observation and databases for logging and trend monitoring. The performance requirements demanded by this use case are low latency, high availability, and high energy-efficiency.	communications. **Spectrum**: 5G private. **Deployment scenario**: Standalone NPN. **Network slicing**: one mIoT slice. **Data plane features**: Aggregation gateways, fog computing, multi-access edge computing, and cloud computing.	**Throughput DL**: no information **Availability**: up to 99.99% **Reliability**: > 1 week **Mobility**: stationary **Capacity**: 10 Mbps/km^2 **Device density**: 5 devices / km^2 **Service area**: up to 10 km x 10 km x 50 km **Positioning accuracy**: no information **Time synchronicity**: no information **Message size**: 20 bytes
<u>Group 10</u>: Plan asset management The use of sensors for guaranteeing the different assets (e.g., pumps, valves, heaters, instruments, etc.) are well maintained. In this way, timely recognition of any degradation of the assets is possible. For this use case group, positioning is a crucial requirement. Latency and service availability are also relevant, but they are less critical than positioning.	**Type of traffic**: Periodic deterministic and non-deterministic communications. **Spectrum**: 5G private or public, depending on the use case. **Deployment scenario**: Public network integrated NPN **Network slicing**: one mIoT slice. **Data plane features**: Aggregation gateways, fog computing, multi-access edge computing, and cloud computing.	**Latency**: 100 ms to several seconds **Throughput UL**: no information **Throughput DL**: no information **Availability**: up to 99.99% **Reliability**: > 1 week **Mobility**: stationary **Capacity**: no information **Device density**: 1000 devices / km^2 **Service area**: up to 10 km x 10 km x 50 km **Positioning accuracy**: up to 1 m horizontally and 3 m vertically **Time synchronicity**: no information **Message size**: 20 - 255 bytes

2.2.2 Global TD-LTE initiative

GTI provides a technical overview on the LTE and 5GNR private network opportunity in GTI White Paper [10]. The paper looks at gaps in standards that may still hinder the development of private networks, possible deployment issues and ways to enable LTE and 5GNR “private wireless networks”.

The GTI White Paper makes a first analysis and summary of use cases and requirements for Private Networks. For a better understanding of GTI’s scope, the different use cases can be arranged into different groups as shown in Table 2-3.

Table 2-3 Examples of GTI use cases for private networks

Use case group	Description	Applicable vertical markets
Group 1: Automation and Industry 4.0	This group brings together industrial IoT, cloud, big data, and analytics into the industrial floor. It includes the broad scale adoption of robotics for providing the production lines with reconfiguration capabilities. It also involves advancements in logistics and warehousing like pick-and-pack machines and IoT trackers.	Industrial IoT, Industrial Plants, and Oil Exploration and Production
Group 2: Mission-critical services	It includes control and monitoring of the critical infrastructure like in electricity distribution grids and power plants, support for handling situations of emergency, and the network services demanded by Government & military	Industrial IoT, Healthcare, Transportation, Industrial Plants, and Oil Exploration and Production

	agencies.	
Group 3: Traditional Industries	It refers to the improvement of the traditional industries by providing remote connectivity, monitoring capabilities, and fully automated machinery.	Industrial IoT, Industrial Plants, and Oil Exploration and Production
Group 4: Local or Venue Services	It addresses the connectivity provision in Public venues such as airports, stadiums, and hospitals. These venues pose multi ownership issues. These scenarios call for Private networks with the ability of catering the different user groups.	Healthcare

The GTI White Paper use case groups examples for private networks above are all very much in line with the use cases which 5G-CLARITY seeks to target and with the pilots planned within the project. More specifically, the GTI White Paper use case groups 1, 2, and 3 maps well onto the Industry 4.0 Pilot described in Section 4.2, while the GTI White Paper use case group 4 maps well on Smart Tourism Pilot specified in Section 4.1.

In addition to describing use cases, GTI also identified the requirements presented in Table 2-4.

Table 2-4 Primary requirements for private networks considered by GTI [10]

Requirement	Description
Latency	The end-to-end (E2E) delay budget for industrial use cases ranges from 1000 ms to below 5 ms, being the most stringent latency constraint for motion control.
Reliability	Reliability is the capacity of the communication to meet the E2E latency requirement. This requirement can be specified as the required percentage of packets successfully transmitted, i.e., packets delivered within the specified deadline. For instance, the “Factory-Industrial Process automation & Motion Control” group of services demands reliability lower than 99.9999%, which means the probability of unsuccessful transmissions has to be below 10-6. Availability, which is the percentage of time the service is operational, is also crucial for the industry. By way of illustration, emergency communication services (e.g., public safety, hospitals) need 99.999% availability, or equivalently an accumulated outage per annum lower than 300 seconds.
Coverage	The coverage requisite depends on the service. For example, logistics and freight tracking demand wide coverage and reliable location information for inventory and package tracking. Other services such as sensing and actuation in hospitals, refineries, and garages have machines geographically distributed in numerous confined areas. For some scenarios, the service provider might provide coverage on its own to be independent of the operator coverage and rollout strategy.
Private-public network isolation	The assurance of the service reliability and availability, along with the integrity and confidentiality of the data and communications, require isolation between the different industries sharing the network infrastructure. In other words, virtual networks serving distinct vertical customers must be protected; avoiding their resources are accessed from other virtual networks. Then, the use of appropriate data breakout architectures and convenient network slice separation are necessary. Depending on the scenario, network slices might be managed by either the Mobile Network Operator (MNO) or their users. In the latter case, Self-Management of resources/policies, APIs, Service Assurance, and proper interfaces for flexible slice control between a private and a public network are a must. Last, it is worth mentioning there is a model where the vertical owns part of the network resources, and the missing parts are taken from the MNO according to a given SLA through the designated interfaces.
Charging / billing	The interfaces between Public and Private networks must allow flexible billing and charging. Depending on the vertical, aggregated network usage information collection or detailed accounting per subscription may be required. Depending on the deployment option, only the network infrastructure charges, only the use of spectrum charges or both could apply. Furthermore, the information collected should enable the verification of the SLA the vertical has with the MNO fulfilment in terms of services, QoS, and allocated resources. Last, online and offline

	charging should be supported.
Security and identity management	Secure communications involve personal or confidential data will not reach the public domain as well as their integrity. Private networks are expected to support a wide range of verticals, each of which requires different levels of security. For instance, mission-critical applications like the smart operation of industrial automation processes need a high level of communication security that might not fit the massive Internet of Things (mIoT) due to the simplicity and reduced energy budget of the sensors. Besides, the heterogeneity of devices expected in private networks requests new device-user identity management to complement the universal SIM/USIM. Lastly, appropriate trust relations have to be established between the Public and Private networks based on the level of resource sharing. Thus, authentication by the private network only, authentication by the public service/network provider only, or authentication by both of them might be needed. The encryption and integrity protection for the control and user planes at the network and application layers might also be required.

The GTI White Paper “primary” requirements for private networks are in line with the aspects that need to be covered with the NPN networks targeted by 5G-CLARITY and some of them are distilled either directly or indirectly in the initial analysis of 5G-CLARITY functional requirements and KPIs to be discussed in section 3.

2.2.3 GSMA

GSMA’s activities are centred around network slicing, and particularly on translating industrial use cases requirements into network slice specifications. The GSMA’s network slicing vision is presented in [11], highlighting its importance for the operations digitalisation and mobilisation, expansion, and processes improvement of the businesses. Network Slicing Taskforce, which was created after [11], is a project initiated by Future Network Programme in GSMA that addresses the concept, requirements, and monetisation of the network slicing. Outcomes from this project yielded the publication of two GSMA white papers [12], [13]. In the GSMA White Paper [13], two novel concepts are proposed, namely General Slice Template (GST) and Network Slice Type (NEST). GST specifies a set of typical slice attributes the industry can use as a baseline for the definition of a network slice type. On the other side, NEST is a GST filled with values or ranges for all or an attributes subset. These values/ranges depend on the service and technical requirements of the specific industry vertical use case. Last, given that AR is included in some industrial use cases, it is relevant to mention the GSMA white paper [14]. This document covers the Cloud AR/VR reference architecture, and technical requirements from different perspectives (e.g., devices, application, and network), among others.

The GST and NEST concepts introduced by the GSMA will be considered when designing slice definition templates for the 5G-CLARITY private network in WP4.

2.2.4 NGMN

NGMN compiled the initial technical requirements for some selected use cases across the vertical industries (including industrial IoT) in White Paper [15]. This document also highlights the external factors that need to be considered to make those use cases economically viable. In NGMN White Papers [16], [17], under the 5G Extreme Requirements Task Force project, NGMN identifies and analyses realistic end-to-end deployment configurations that can potentially deliver the 5G extreme services. NGMN white paper [18] reviews the URLLC use cases developed in several SDOs and industrial consortia. Finally, in NGMN White Paper [19], NGMN clarifies how 5G can meet vertical requirements and underlines the critical 5G URLLC technology enablers for use cases identified in the report [18]. Specifically, the document addresses the main enablers for achieving the latency, reliability, synchronisation, and positioning constraints imposed by URLLC use cases. Moreover, it describes the 5G URLLC reference architecture, including NPN deployment options, and details reference deployments for different verticals, among them, the Factory of Future.

The mentioned NGMN white papers will be considered when designing the 5G-CLARITY architecture in Task 2.2.

2.3 5G-PPP projects

Created with the purpose of reinforcing the leadership of European industry in 5G technology to successfully compete on global markets and open innovation opportunities, the 5G-PPP is now in its third phase. Unlike 5G-PPP Phase 1, which performed fundamental research for the fifth generation of network communications, and 5G-PPP Phase 2, focused on using 5G technologies for the digitisation of vertical industries, 5G-PPP Phase 3 addresses the development and rollout of pan-European, 5G-ready service platforms for advanced vertical experimentation. Within this phase, two groups of projects are relevant according to 5G-CLARITY project's scope:

- *Infrastructure projects,* developed in the context of the 5G-PPP ICT-17-2018 call (end-to-end 5G facility), and started in July 2018. A total of three projects were granted in this call: 5G-VINNI, 5G-EVE and 5GENESIS. These are the so-called ICT-17 projects.
- *Vertical use cases projects*, developed in the context of the 5G-PPP ICT-19-2019 call (advanced 5G validation trials across multiple vertical industries), and with starting date in June 2019. A total of eight projects were granted in this call: 5GSMART, 5G-TOURS, FULL5G, 5G!DRONES, 5GROWTH, 5G-HEART, 5GSOLUTIONS, 5G-VICTORI. These form the so-called ICT-19 projects.

On the one hand, **ICT-17 projects** provide a pan-European large-scale 5G validation network infrastructure that demonstrate how key 5G KPIs that can be met, and accessed and used by industry verticals to set up research trials of innovative use cases, testing and validating specific applications that are dependent upon those KPIs. The key platforms and cities taking part in the three ICT-17 projects are summarized in the geographic cartography presented in Figure 2.3. The infrastructure resulting from the combination of these projects, which covers about 20 EU sites and nodes on a pan-EU basis, shall provide the adequate level of openness to make it possible for verticals to test their innovative 5G application scenarios using ad-hoc network resource control. To this end, testing and monitoring tools as well as management capabilities are exposed via well-defined APIs that vertical customers can consume to assess the readiness of their use cases under different load conditions.

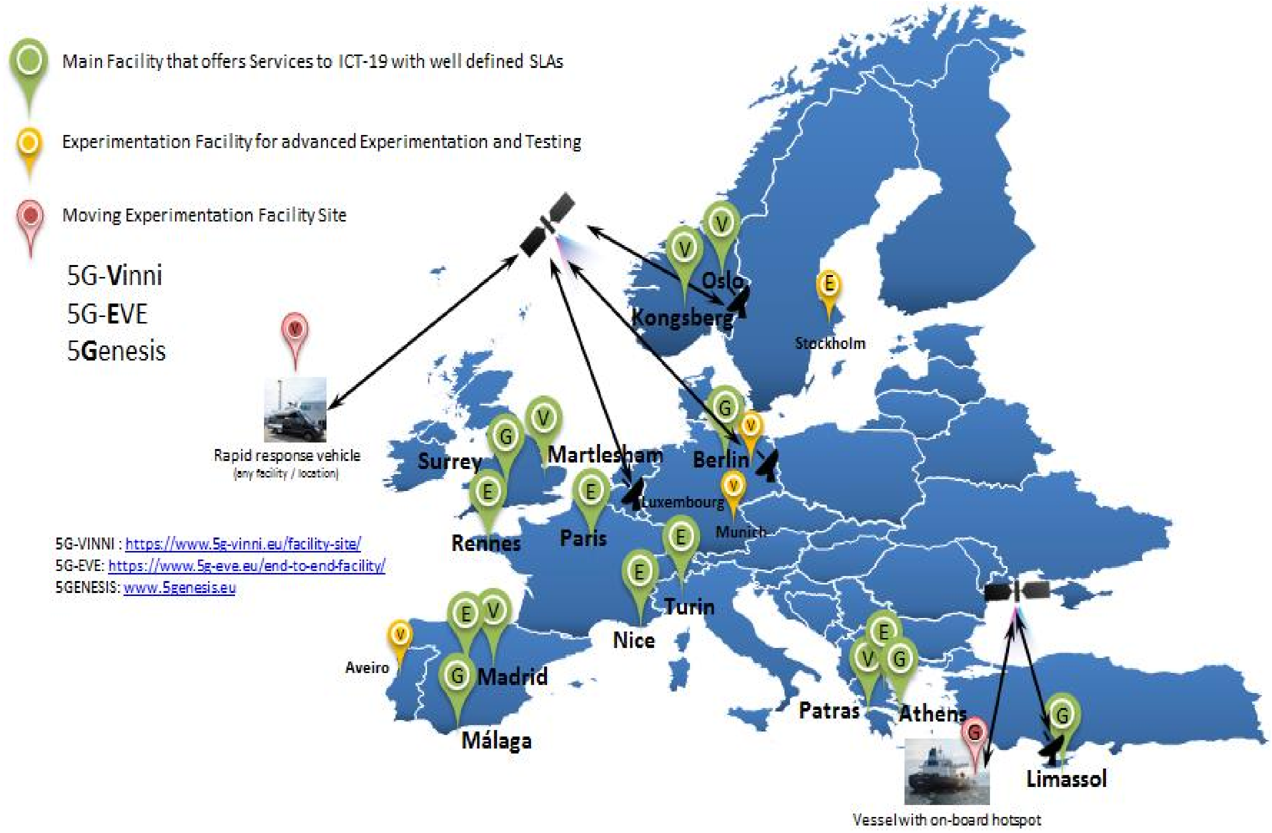

Figure 2.3 ICT-17 projects - Geographic Cartography

On the other hand, the main objective of **ICT-19 projects** is the technical and business validation of 5G technologies from the verticals' point of view, following a field-trial-based approach on vertical-specific private venues, e.g. factories, campus, etc. The network defined within the logical perimeter of a vertical-owned site of that type is rarely end-to-end; indeed, it is usually a subnetwork consisting of one (or more) network segment(s). The rest of the segments thus shall be provided an external network, out of the logical perimeter of the vertical premises. In the context of ICT-19 projects, this external network will be the 5G validation network infrastructure deployed and made available by ICT-17 projects. This means that any trial to demonstrate an ICT-19 vertical use case will be typically executed on top of an E2E network infrastructure consisting of a public segment (i.e. the infrastructure made available by ICT-17 projects) and a non-public segment (i.e. the vertical-owned site).

Figure 2.4 shows the ICT-17 and ICT-19 projects and their intended interactions. The outcomes of these projects are of key relevance for the 5G-CLARITY project, especially in which respects to the interaction between the public and non-public segments mentioned above, which will be addressed by 5G-CLARITY in Task 4.2. In the following subsection, we provide more details on this topic.

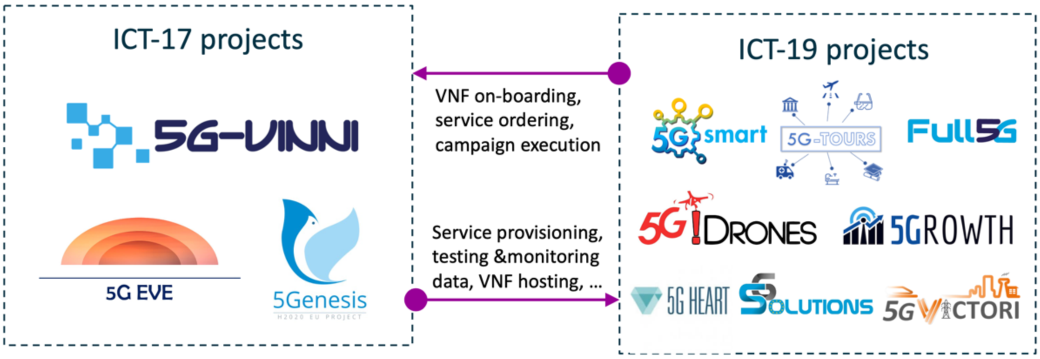

Figure 2.4. Overview of relevant 5G-PPP Phase III projects, and their relation as “public” (ICT-17) and “private” (ICT-19) 5G networks

2.3.1 Integration of ICT17 and ICT-19 projects

The readiness and behaviour of any vertical use case shall be validated using an E2E network. Although some vertical-specific private sites can provide E2E capabilities (in terms of resources as well as management and orchestration) at their own, there exists some others that do not. In such a case, integration with the public network is required to build the E2E network. This integration needs to be understood in terms of *connectivity* (ensuring reachability between private and public network sites) and *interworking* & *exposure* (management systems from private and public networks sites are interoperable, ensuring exchange of management request-responses between them with non-repudiation).

This situation is very common in 5G-PPP Phase 3 projects, by simply considering that *i)* facilities from ICT-17 projects represents public network infrastructure, and *ii)* factories and local venues from ICT-19 projects represent vertical-specific private sites. In these projects, the intended integration is typically done using slicing, with an ICT-17 site providing a given ICT-19 site with missed 5G components (e.g. 5GC control plane, ICT-17 support application) and necessary connectivity (e.g. WAN connectivity) in the form of a dedicated network slice subnet instance (NSSI). By attaching this NSSI to the on-premises deployed components, the ICT-19 site can have an E2E Network Slice Instance (NSI) at his disposal.

Figure 2.5 shows an example of integration expected for ICT-17 and ICT-19 projects. In this scenario, an industry vertical (from ICT-19 project) requests to a public network operator (from ICT-17 project) the provisioning of an NSI. This NSI will be used by the industry vertical to set up a given use case, validating its KPIs under different load conditions through the execution of a set of trials. In this concrete example, note that this use requires the establishment of two sessions within the NSI: one URLLC session (green dotted line) and an eMBB session (red dotted line).

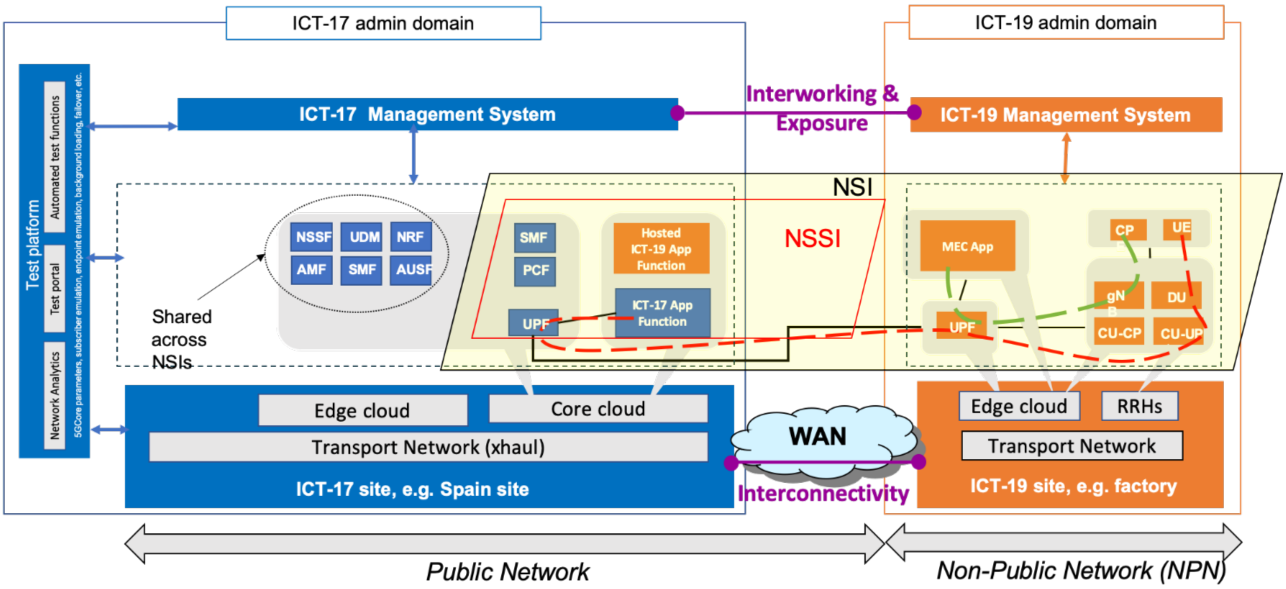

Figure 2.5 Example of integration

2.3.2 Analysis of NPN related ICT-17/ICT-19 projects use cases

In this section, we will provide an overview of the NPN related use cases from ICT-17 and ICT-19 projects that are relevant (and thus on the radar) for 5G-CLARITY. For the specification of each selected use case, we will extract information valuable and useful for the 5G-CLARITY ecosystem, aligned with the project's scope. This includes:

- **Use case description**, which provides a summary of the scope of the use case, highlighting outcomes that can be expected from scenarios deployed based on this use case.
- **5G capabilities**, giving an insight on the main functional aspects of the use case itself. This includes information on:
  - Spectrum type: private or public. There exist different options for private spectrum allocation: *i)* licensed spectrum, obtained from the regulator; *ii)* licensed spectrum, sub-leased from the MNO; and *iii)* unlicensed spectrum, with asynchronous or synchronized sharing. For more information on these options see [20] .
  - Deployment scenario based on 3GPP categorization: stand-alone NPN or public network integrated NPN.
  - Network slicing, offering information on network slices to be deployed for the use case.
  - Remarkable features at the data plane (e.g. edge computing, support with wired technologies, service applications, etc.) and at the management plane (e.g., management stack composition across NPN and the public network, slice provisioning models, etc.).
- **Relevant KPIs**, giving an insight into the main behavioural aspects of the use case itself, allowing their characterisation from a performance point of view. The baseline KPIs selected for use case evaluation are compliant with 5G-PPP TMVWG (Test, Measurement and KPIs Validation Working Group) on-going work in [21]. They include latency, throughput (UL and DL), availability & reliability, mobility, capacity, device density / number of devices, coverage area, and positioning accuracy. For each use case, only the KPIs relevant for 5G-CLARITY will be shown.

For a better comprehensive understanding, the NPN related ICT-17/ICT-19 use cases relevant for 5G-CLARITY ecosystem have been arranged into four different groups, each scoping a different environment for use case execution.

2.3.2.1 Group 1: URLLC-type use cases in industrial IoT scenarios

This group encompasses industrial use cases requiring stringent requirements in terms of latency, reliability and high-accuracy positioning, typically executed in indoor, private environments (i.e., factories of the future) that can be supported with outdoor deployments. Classified under the URLLC service category, these use cases allow Industry 4.0 verticals (i.e., manufacturing and logistics companies) to carry out critical processes within their factory premises.

Table 2-5 ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 1

Use Case (Project)	5G Capabilities	Relevant KPIs
Use case name: 5G-connected AGVs (5G-EVE) **Use case description**: This use case focuses on Mobile Cloud Robotics (MCR) applied to a smart wireless logistic facility. Mobile robots are used to transport goods between various stations in a process or to and from depots. As long as there are no constraints imposed in their movement capabilities caused by unexpected obstacles, robots can carry out any sequence of events to ensure that materials arrive at the right place just in time, thus proving productivity and supporting the implementation of effective lean manufacturing. The new robots adopted in this use case are connected to the cloud using 5G communications. They include only low-level controls, sensors and actuators, while their intelligence is moved to the cloud, with access to almost unlimited computing power.	**Spectrum**: 5G private (unlicensed spectrum) **Deployment scenario**: SNPN **Network Slicing**: one URLLC slice (for control traffic). **Data plane features**: on-premises edge computing node hosting robot's intelligence. **Management plane features:** NPN administrator has the full visibility of the slice and can retail all control over it.	**Latency**: <10 ms **Throughput UL**: 54 Mbps (peak, aggregated) **Throughput DL**: 6480 Mbps (peak, aggregated) **Availability**: >99.9% **Reliability**: > 99.9% **Mobility**: up to 20 km/h **Capacity**: 2.16 Mbps/m^2 **Device density**: up to 40,000 devices / km^2 **Service area**: Not specified **Positioning accuracy**: Not specified
Use case name: Autonomous vehicles in manufacturing environments (5G-EVE) **Use case description**: The aim of this use case is the virtualization of the control algorithms of AGVs. These algorithms, currently executed in the AGV's Programmable Logic Control, are in charge of governing thee internal control loop processes (i.e. collecting the information of the AGV's sensors, taking the appropriate control decisions and generating the necessary signals to regulate the speed of the motors). Thanks to the 5G communication capabilities, these internal control algorithms will be able to be moved out of the AGV and they will be able to be reallocated in a virtual machine. This way, the well-known benefits of the software virtualization	**Spectrum**: 5G private (unlicensed spectrum) **Deployment scenario**: SNPN **Network Slicing**: one URLLC slice (for control traffic) **Data plane features**: on-premises edge computing node executing AGVs control algorithms. **Management plane features**: NPN administrator has the full visibility of the slice, and can retail all control over it.	**Latency**: <10 ms **Throughput UL**: 80 Mbps (peak, aggregated) **Throughput DL**: 400 Mbps (peak, aggregated) **Availability**: >99.99% **Reliability**: >99.99% **Mobility**: No **Capacity**: 3.2 Mbps/m^2 **Device density**: 40,000 devices / km^{-2} **Service area**: Not specified **Positioning accuracy**: Not specified

will be also exploited in this application field.		
Use case name: Edge-enabled robots (5G-VINNI) **Use case description:** This use case demonstrates the remote control of a robot housing a 360-degree camera that may be used in an industrial environment. The camera provides an immersive telepresence capability to the remote controller who is able to view the content on AR/VR headset providing them with real-time information with which to guide the actuation and movement of the robot, ensuring its movement throughout a reliable path.	**Spectrum**: 5G private (licensed spectrum, leased from the MNO). **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for the 360-degree content) and one URLLC slice (to ensure a reliable control path). **Data plane features**: on-premises edge computing node to host AR/VR software, wired-wireless convergence within the factory. **Management plane features**: eMBB and URLLC slices are provisioned on demand. Part of the control of the slices are retained by the MNO. Interworking between MNO's and vertical's management stacks (needed for end-to-end operation), using appropriate capability exposure mechanisms for this end.	The KPIs of this use case are not publicly available at the time of writing this document.
Use case name: Connected Worker - Remote Operation of Quality Equipment (5GROWTH) **Use case description:** In this use case, an operator programs the Coordinate Measuring Machine (CMM) remotely using a virtual joystick in a mobile device, while a live video of the CMM is displayed giving feedback to the operator. This use case will require the establishment of two different sessions running at the same time: one for the video streaming (eMBB), to feed operator with information on anytime device's position; and one for device control (URLLC), to allow an operator to change the device's trajectory according to the video's feedback.	**Spectrum**: 5G private (licensed spectrum, leased from the MNO) **Deployment scenario**: SNPN **Network Slicing**: one eMBB slice (for video streaming) and one URLLC slice (to control the synchronization of the video streaming and the virtual joystick). **Data plane features**: on-premises edge computing node for real-time video streaming, wireline technology for eMBB, delay-sensitive fronthaul data plane technology. **Management plane features**: eMBB and URLLC slices are non-permanent (always running at the same time, i.e. the same life-cycle management will be applied to them). Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms.	**Latency**: <5 ms **Throughput DL – video streams**: 100 Mbps (peak, aggregated) **Throughput DL – control actions**: 128-400 Kbps (peak, per user) **Availability**: >99.99% **Reliability**: >99.99% **Mobility**: up to 3 km/h **Number of devices**: 1 device connected simultaneously **Service area**: Not specified **Positioning accuracy**: Not specified
Use case name: Connected Worker – Augmented Zero Defect Manufacturing Decision Support System (5GROWTH) **Use case description:** This use case leverages 5G edge infrastructure to deploy factory software components together with other machines to	**Spectrum**: 5G private (licensed spectrum, leased from the MNO) **Deployment scenario**: SNPN **Network Slicing**: one eMBB slice (for video streaming) and one URLLC slice (to control the synchronization of the video streaming and the virtual	**Latency**: <5 ms **Throughput DL – video streaming**: 1 Gbps (peak, aggregated) **Throughput UL – control traffic**: 128-400 Kbps (guaranteed, per device)

enable machine-to-machine communication, creating new collaboration capabilities between the CMM and AGVs. This collaboration will improve the performance of the quality control station and will foster automation in the measuring process, by allowing to share one CMM among several production lines making the same product or, if using flexible fixtures, even different products.	joystick). **Data plane features**: on-premises edge computing node hosting software components, definition of multi-cast domains. **Management plane features**: eMBB and URLLC slices are non-permanent. Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms.	**Availability**: >99.99% **Reliability**: >99.99% **Mobility**: 3-50 km/h **Number of terminals**: up to 20 devices simultaneously connected. **Capacity**: Not specified **Service area**: Not specified **Positioning accuracy**: Not specified
Use case name: Time-critical process optimization inside digital factories (5G-SOLUTIONS) **Use case description:** This use case consists of leveraging 5G technology to enable a real time product and process control, thus marking a sensible improvement in the quality control system in industrial production chains. To this end, a digital hyperspectral monitoring system will be integrated into the production chain, making it possible to detect defeats in the production chain. This type of solution requires high data rate and consistent reliability level that will be implemented with a 5G wireless connectivity.	**Spectrum**: 5G private (unlicensed spectrum) **Deployment scenario**: SNPN **Network Slicing**: one URLLC slice. **Data plane features**: on-premises edge computing node to host 5GC software components and backend applications (e.g. algorithms and data storage). Reliability solutions at the data plane (e.g. duplication of sessions across parallel user plane functions). **Management plane features**: NPN administrator has the full visibility of the slice and can retail all control over it.	**Latency**: <2 ms **Throughput UL**: 2 Gbps (peak, aggregated) **Availability**: >99.999% **Reliability**: >99.999% **Mobility**: up to 20 km/h **Capacity**: 2.16 Mbps/m^2 **Number of devices**: up to 10 devices simultaneously connected. **Service area**: Not specified
Use case name: Remote controlling digital factories (5G-SOLUTIONS) **Use case description:** This use case will allow remote workers (i.e. outside the factory) to use the data coming from tablets/smartphones for preventive analytics and easy access to work instructions. In the latter case, this means that remote workers would be able to view the camera or iPad/Google glass of a local worker. To this end, a service application allowing *i)* AR support in production & assembly, and *ii)* AR support in maintenance and repair, will be installed executed within the factory, and be enabled to exchange information with remote worker's tablets/smartphones.	**Spectrum**: 5G private (licensed spectrum, leased from the MNO). **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for AR visualization) and one URLLC slice (to allow remote workers to send instructions/notifications towards local workers). **Data plane features**: on-premise computing node to host 5GC software components and backend applications (e.g. algorithms and data storage). Wireline and wireless convergence. Firewalling/NAT solutions (at the boundaries of the factory) to discriminate public and private sessions coming in/out from/to the public network. **Management plane features**: slice provisioned on demand. Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms.	**Latency**: < 10 ms **Throughput UL - video streams**: 1 Gbps (peak, aggregated) **Throughput UL - sensor data**: tens of Kbps (peak, aggregated) **Throughput DL - video streams:** tens of Mbps (guaranteed, per user) **Throughput DL - remote control:** tens of Kbps (guaranteed) **Availability**: >99.99% **Reliability**: >99.99% **Number of devices**: up to 10 simultaneously connected **Service area**: Not specified **Positioning accuracy**: <0.2 m

Use case name: Rapid deployment, auto-/re-configuration and testing of new robots (5G-SOLUTIONS) **Use case description:** This use cases aims to explore the possibilities of utilizing the core functionalities of 5G to significantly lower expenses and reduced time for commissioning and reconfiguring robotized manufacturing. The goal is to demonstrate how to achieve deployment of new robots into existing plants through automatic on-boarding of industry requirements. This encompasses auto-configuration of (mobile) robots and the corresponding 5G service configuration needed for interconnection / interworking across solutions from different robot manufacturers.	**Spectrum**: 5G private (licensed spectrum, leased from the MNO). **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice. **Data plane features**: Common underlaying technology for multi-provider robot connectivity. **Management plane features**: slice provisioned on demand. Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms. Closed-loop automation enablers for auto-(re)configuration of the robots.	**Latency**: <10 ms **Throughput UL - video streams**: 1 Gbps (peak, per user) **Throughput UL - sensor data**: tens of Kbps (peak, per device) **Throughput DL**: 6480 Mbps (peak, aggregated) **Availability**: Not specified **Reliability**: Not specified **Number of devices**: Not specified **Service area**: Not specified

2.3.2.2 Group 2: mMTC-type use cases in industrial IoT scenarios

This group is similar to Group 1 but focused on Industry 4.0 delay-tolerant use cases belonging to massive Machine-Type Communications (mMTC) service category. These use cases generally require massive device connectivity, and the collection and processing of non-real-time data from multiple sources.

Table 2-6. ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 2

Use Case (Project)	5G Capabilities	Relevant KPIs
Use case name: Local IoT communications (5G-VINNI) **Use case description:** This use case aims to seek support for efficient Machine-to-Machine communication in the backhaul. To this end, different applications will be installed in the edge nodes, so that most traffic is processed locally. This will enable a significant reduction of traffic load towards the central node, and hence a considerable reduced usage of the networking resources that make up the backhaul.	**Spectrum**: 5G private (licensed spectrum, leased from the MNO). **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one mMTC slice **Data plane features**: on-premises edge computing node for local process traffic, MNO central node for backend applications hosting (e.g. database, M2M apps). **Management plane features**: Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms.	The KPIs of this use case are not publicly available as at the time of writing this document.
Use case name: Digital Twin Apps (5GROWTH) **Use Case description:** The objective of this use case is to develop a 5G-enabled Digital Twin for a vast production plant, which involves a huge number of devices as well as different processes. Having a digital twin of the entire plant allows to have	**Spectrum**: 5G private (unlicensed spectrum) **Deployment scenario**: Standalone NPN **Network Slicing**: no slicing. **Data plane features**: on-premises edge node. Massive connectivity support, with multiple sessions conveying asynchronous packets. Link capacity optimization using multiplexing gains.	**Latency**: <15 ms **Throughput UL**: 250 Mbps (peak, aggregated) **Availability**: >99.9999% **Reliability**: >99.9999% **Mobility**: 3-50 km/h **Device density**: up to 5,000 devices / km^2

information of the status of the production lines (in terms of cycle time). This allows creating historic data and calculate some statistics, in order to predict future failures or bottlenecks, giving the opportunity to move up actions and prevent problems when required.	**Management plane features**: Data-driven AI engine to trigger remediation operations (e.g. healing, scaling, re-configuration) according to beforehand-defined policies.	**Service area**: 5 km^2
Use case name: Telemetry /Monitoring Apps (5GROWTH) **Use Case description:** This use case aims at using telemetry to monitor the actual health of the machinery and to collect multi-dimensional data (including vibration, pressure and temperature data) useful to develop predictive maintenance algorithms, e.g. to prevent future failures. Using 5G enables to remove cables and many other network hardware, replacing them with software components to increase resilience and flexibility with a significant reduction of costs as well.	**Spectrum**: 5G private (licensed spectrum, leased from the operator) **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one mMTC slice. **Data plane features**: MNO central node for backend applications hosting (e.g. database, M2M apps). Removal of wireline solutions within the factory. (L3) VPN services for MNO-factory data plane connectivity. Encrypted packets to preserve data privacy. **Management plane features**: basic slice management operations, i.e. commissioning and decommissioning.	**Latency**: 15-100 ms **Throughput UL**: 250 Mbps (peak, aggregated) **Availability**: >99.9999% **Reliability**: >99.9999% **Mobility**: 3-50 km/h **Device density**: up to 5,000 devices / km^2 **Service area**: 5 km^2
Use case name: Digital tutorials and remote support (5GROWTH) **Use Case description:** This use case aims at providing technicians and maintenance staff with digital tutorials and remote support by means of high definition videos and live connections to remote technical offices. The main objective is to reduce the mean time to resolve (MTTR) using streaming with a skilled technician in remote locations to support maintenance and repair operations. Other advantage is the possibility to access to tutorials and instructions for training purposes.	**Spectrum**: 5G private (unlicensed spectrum) **Deployment scenario**: Standalone NPN **Network Slicing**: one mMTC slice. **Data plane features**: MNO central node for backend applications hosting. (L3) VPN services for MNO-factory data plane connectivity. Encrypted packets to preserve data privacy. **Management plane features**: basic slice management operations, i.e. commissioning and decommissioning.	**Latency**: <15 ms **Throughput DL**: 500 Mbps (peak, aggregated) **Availability**: >99.9999% **Reliability**: >99.9999% **Mobility**: up to 3 km/h **Capacity**: 2.16 Mbps/m^2 **Device density**: up to 100 devices / km^2 **Service area**: 5 km^2 **Positioning accuracy**: Not specified
Use case name: Non-time-critical communication inside the factory (5G-SOLUTIONS) **Use Case Description:** This use case is about using 5G technology to set up a mobile environment that can provide a reliable coverage for Industrial IoT-applications inside a real factory. This is of key interest, considering that carrier-grade factories are private venues where mobile technologies have traditionally struggled and where data collection and	**Spectrum**: 5G private (unlicensed spectrum) **Deployment scenario**: Standalone NPN **Network Slicing**: one mMTC slice. **Data plane features**: wireless and wireline convergence within the factory. On-premises edge node hosting data processing software application. **Management plane features**: NPN administrator has the full visibility of the slice and can retail all control over it.	**Latency**: Not specified **Throughput UL**: Not specified **Throughput DL**: Not specified **Availability**: >99.999% **Reliability**: >99.999% **Mobility**: Not specified **Device density**: Not specified **Service area**: Not specified

aggregation from around 20,000 sensors leverage PLC data. Augmenting the existing wired data collection systems with 5G wireless technology will allow the factory to expand its data collection footprint and integrate intelligent instruments to complement wired technologies and drive the digital factory agenda in line with industry 4.0 paradigm.		
Use case name: Factories of the Future – Digital Utilities (5G-VICTORI) **Use case description:** This use case focuses on the development of a fully automated Digital Utility Management system to demonstrate effective handling and decision making based on data, massively generated from sensing devices and transmitted over a 5G network	**Spectrum**: 5G private (licensed spectrum, leased from the MNO), unlicensed spectrum. **Deployment scenario**: Standalone NPN. **Network Slicing**: multiple slices. **Data plane features**: Sensors (5G and non-5G enabled), wireline and wireless convergence. **Management plane features**: Management, automated allocation of resources upon request considering optimisation of resource utilisation and required QoS. Instantiation of VNFs.	**Latency**: 10 ms (Monitoring & Alerting Services) **Throughput UL**: 0.1 Mbps (per device) **Throughput DL**: Not specified **Availability**: > 99.9999999% (SIL 7) **Reliability**: > 99.9999999% (SIL 7) **Mobility**: N/A **Device Density**: Low, not critical 100 Dev over 2000 m2 **Traffic Density**: Low, not critical 1000 Mbps/ 2000 m^2
Use case name: Energy metering for High Voltage -HV- and Low Voltage -LV- (5G-VICTORI) **Use case description:** 5G-VICTORI will demonstrate the operation of a dynamically re-configurable ICT infrastructure to facilitate the smart energy operation at: a) the HV (150kV/20kV) primary substations of ADMIE (fault detection and preventive maintenance), taking advantage of the low latency signal exchange between the substations and the control Center, and, b) LV energy metering application for AIM smart city. The new 5G infrastructure interconnected with dedicated servers will measure the energy efficiency, energy metering will provide real time data on energy consumption and CO2 emissions in public transportation	<u>**HV use case**</u> **Spectrum**: 5G private (licensed spectrum, leased from the MNO), unlicensed. **Deployment scenario**: wireline/wireless convergence. **Data plane features**: Sensors (5G and non-5G enabled), wireline and wireless convergence. **Management plane features**: Management, automated allocation of resources upon request considering optimisation of resource utilisation and required QoS. Instantiation of VNFs. <u>**LV use case**</u> **Spectrum**: 4G/5G private (licensed spectrum, leased from the MNO). **Deployment scenario**: wireline/wireless convergence. **Data plane features**: wireless and wireline convergence. Edge node hosting data collection and processing. **Management plane features**: Management and orchestration capabilities for resources, service and slice orchestration. Infrastructure	<u>**HV use case**</u> **–** <u>**URLLC (rail operations)**</u> **Latency**: <10 ms **Data rate**: 1 Mbps **Availability**: >99.9999% (SIL 4) **Reliability**: >99.9999% (SIL 4) **Mobility**: 50-150 Km/h **Device Density**: Non-critical <u>**LV use case**</u> **Service deployment time**: 90 min **Scaling time**: 5 min **Service Availability**: 99.9% **Service Reliability**: 99.9% **Max simultaneous devices support**: up to 1000

	monitoring tools. Service configuration and execution. Life Cycle Management and slicing life cycle management. Scalability. Closed loop functions. Monitoring.	

2.3.2.3 Group 3: Use cases in hotspot scenarios

This group includes use cases deployed in hotspots of high demand, such as shopping malls, stadiums or hall parks. Although these use cases can be of different types (from short-lived air concerts or football matches to long-lived eMBB services near coast during summer holidays), all of them are focused on testing and showcasing 5G densification, e.g. small cells with enhanced MIMO mechanisms, and core network control plane scalability capabilities.

Table 2-7. ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 3

Use Case (Project)	5G Capabilities	Relevant KPIs
Use case name: On-site Live Event Experience (5G-EVE) **Use case description:** This use case focuses on providing high-fidelity media with highly immersive viewing experience (replay, 360º view, choose a specific camera, etc.) in large scale event sites, including cinemas, stadiums and big urban parks.	**Spectrum**: 5G public **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for highly immersive viewing experience) **Data plane features**: Local CDN. On-premises edge computing node executing the whole NPN user plane (e.g., UPF, video streamer). NPN control plane and entirely hosted by the public network. **Management plane features**: Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms.	**Latency**: <100 ms **Throughput UL**: 2 Mbps (peak, per user) **Throughput DL**: 1500 Mbps (peak, aggregated) **Availability**: >99.9% **Reliability**: >99.9% **Mobility**: up to 100 km/h **Capacity**: Not specified **Device density**: 40,000 devices / km^{-2} **Coverage area**: Not specified **Positioning accuracy**: Not specified.
Use case name: Sport event (5G-EVE) **Use case description:** This use case is aiming at the demonstration of the 5G capabilities to provide edge media services for spectators. To this end, an AR application is going to be developed and installed in the smartphones of the audience. Using the AR application and the camera of the smartphone, the users will be able to focus on any object in the scene (e.g. a particular player in a football match, or a musician on a concert event) and instantly receive information (e.g. live statistics of the player or the biography of the performing musician).	**Spectrum**: 5G public **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for crew entertainment and vessel-to-office communications). **Data plane features**: Local CDN. On-premises edge computing node executing the whole NPN user plane (e.g., UPF, AR application). NPN control plane and entirely hosted by the public network. **Management plane features**: Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms	The KPIs of this use case are not publicly available as at the date of this document.

Use case name: Robot-assisted museum guide and monitoring (5G-TOURS) **Use case description:** The goal of this use case is to leverage robotic technology to provide an enhanced museum visit experience. Visitors interact with the robot, asking information on what they can see and where. In this use case, high bandwidth is required upstream to transmit data acquired by the robot sensory system and make it available to the set of systems that control the robot. These systems, which include map navigation software and robot's languages system, constitute the robot's brain and are hosted in an edge node. The robot's brain analyzes the received data and compute the commands for the robot, including robot speech (audio format) and motor velocity for the wheels.	**Spectrum**: 5G public **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for video streaming) and one URLLC slice (for robot control). **Data plane features**: on-premise computing node to host robot's intelligence. Firewalling/NAT solutions at the boundaries of the museum to discriminate private sessions from public sessions (e.g. visitors browsing Internet). **Management plane features**: Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms	**Latency**: <10 ms **Throughput UL - robot control:** 5-10 Mbps (guaranteed) **Throughput DL – video streams**: 15 Mbps (peak) **Availability**: >99.9999% **Reliability**: >99.9999% **Mobility**: Not specified **Coverage area**: Not specified **Positioning accuracy**: Not specified

2.3.2.4 Group 4: Use cases in transportation hub scenarios

This group encompasses use cases relevant for transportation verticals, executed on public hubs like airports, maritime ports, and railway stations.

Table 2-8. ICT-17/ICT-19 use cases relevant for 5G-CLARITY project - Group 4

Use case (Project)	5G capabilities	Relevant KPIs
Use case name: 5G maritime communications (5GENESIS) **Use case description:** This use case will show how the integration of SATCOM and 5G can help to deploy full-scale 5G communications. In particular, it will involve the deployment of a "5G hotspot" in the sea, either on a cargo ship or an off-shore facility, using satellite as backhaul and 5G RAN and edge services to allow *i)* access by personal 5G terminals of the crew, and *ii)* localized session handling between two or more on-board terminals.	**Spectrum**: 5G public for mobile access, and 5G private (licensed spectrum, from the regulator) for satellite access. **Deployment scenario**: Public network integrated NPN. **Network Slicing**: no slicing **Data plane features**: mobile satellite connectivity and terrestrial connectivity, local device communication, edge node for 3rd party service hosting. **Management plane features**: multi-access 3GPP management system, with a seamless integration of mobile and satellite capabilities.	The KPIs of this use case are not publicly available as at the date of this document.

Use case name: Autonomous assets and logistics for smart port (5G-SOLUTIONS) **Use case description:** this use case aims to provide Yara Birkeland project, i.e. set up a smart port with zero-emission delivery, with 5G technology to *i)* digitize and automate the cargo information flow to simplify the logistic process and generating the information for the cargo, and *ii)* bring automation in container movements of inbounds and outbounds. The smart port will have an automatic crane system, a battery powered container feeder and battery powered straddle carriers than handle the transport at the side.	**Spectrum**: 5G private (public spectrum, leased from the MNO): **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for video streaming) and one URLLC slice (for robot control). **Data plane features**: multi-access cloud functionality. Seamless routing between base stations. Protocols to govern the logistics interface between port infrastructure and new, undefined assets. **Management plane features**: Multi-access management system.	**Latency**: <10 ms **Throughput UL**: 100 Mbps (peak, per device) **Availability**: >99.99% **Reliability**: >99.99% **Mobility**: up to 50 km/h **Number of devices**: 3 straddle carriers, 1 crane and 1 vessel equipped with 5G client UEs. **Coverage area**: 1 km^2 **Positioning accuracy**: <0.5 m
Use case name: Port Safety - monitor and detect irregular sounds (5G-SOLUTIONS) **Use case description:** Irregular noise or sound detection technology, e.g. explosions or gunshot detection, is considered a major safety and security part of a smart port design. The deployment of such detection systems (e.g. sensitive microphones and UHD+ closed-circuit television cameras) through the use of a reliable 5G network, transmitting real-time audio-visual information on events to the ports operations center, is of utmost importance to port authorities by allowing them to act immediately and find out the exact location of the incident. This use case plans to use machine learning to detect irregular sounds coming from any of the microphones.	**Spectrum**: 5G private (licensed spectrum, sub-leased from the MNO). **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one eMBB slice (for video streaming) and one URLLC slice (for robot control). **Data plane features**: edge computing hosting a VNF that executes TensorFlow. Reliable and secure physical ensuring accurate and timely information. **Management plane features**: the whole NPN management relies on the NPN operator.	**Latency**: <10 ms **Throughput UL**: 100 Mbps (peak, per device) **Availability**: >99.99% **Reliability**: >99.99% **Mobility**: up to 50 km/h **Device density**: > 0.1 device / m^2 **Coverage area**: 1 km^2 **Positioning accuracy**: <10 m
Use case name: Smart Airport parking management (5G-TOURS) **Use case description:** this is a solution that relies on 5G provided mMTC functionality. A large number of sensors installed at each individual parking position will help keep track of available and occupied spots in real-time, facilitating the parking process within an airport as well as in any other controlled parking area. As a result, this will also add to the travelling efficiency of tourists	**Spectrum**: 5G public **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one mIoT slice **Data plane features**: nothing relevant to remark. **Management plane features**: the whole NPN management relies on the MNO.	**Latency**: <10 s **Throughput UL**: Not specified **Throughput DL**: Not specified **Availability**: >99.99% **Reliability**: >99.99% **Number of devices**: around 100 **Coverage area**: 5 km^2 **Positioning accuracy** < 1 m

through targeted parking spot suggestions.		
Use case name: Emergency airport evacuation (5G-TOURS) **Use case description:** In this use case, an application will monitor the location of the different users and provide them with instructions for evacuation. It will rely on 5G capabilities so as to instantly notify travelers and identify the exact position of the crowds. Based on this, it will devise an evacuation plan and send individual messages to each user with personalized instructions. Additionally, a detailed 3D digital model of the section to be evacuated along with all objects contained therein, e.g. seats, desks and monitors, will be created into the evacuation support system.	**Spectrum**: 5G public **Deployment scenario**: Public network integrated NPN. **Network Slicing**: one URLLC slice **Data plane features**: on-premises edge compute node to execute 3D evacuation map. Packet duplication and establishment of parallel sessions to increase reliability and availability. **Management plane features**: Interworking between MNO's and vertical's management stacks using appropriate capability exposure mechanisms	**Latency**: <10 ms **Throughput DL:** few Mbps (guaranteed, per user) **Availability**: >99.99% **Reliability**: >99.99% **Mobility**: up to 10 km/h **Capacity**: 2,16 Gbps/km^2 **Device density:** several passengers / m^2, 4 police officers and 6 security officers. **Coverage area**: 5 km^2 **Positioning accuracy** < 1 m

3 Requirements for the 5G-CLARITY Architecture

The aim of this section is to clarify the 5G-CLARITY project's scope in the beyond-5G ecosystem. Taking into account the SotA work carried out in section 2, and considering the overall objectives set up in the 5G-CLARITY DoW, we derive in Section 3.2 a set of functional requirements and KPIs to be fulfilled by the 5G-CLARITY architecture that will be defined in the upcoming deliverable D2.2.

3.1 5G-CLARITY project overview

5G-CLARITY brings forward the design of a system for beyond-5G private networks that addresses key challenges related to spectrum flexibility, delivery of critical services, and autonomic network management. The project is structured in two main pillars:

First pillar: a heterogeneous wireless access network that integrates 5GNR, Wi-Fi, and LiFi, thus delivering:

i) Per-UE and aggregate capacities beyond 3GPP R16, through interface aggregation and intelligent interface selection,
ii) Lower delays and higher reliability than 3GPP R16, through parallel access and selective packet duplication, and
iii) An indoor positioning service with cm-level accuracy, through the combination of RF Time-of-Flight (ToF), and Optical Camera Communications (OCC) for LiFi.

The integration of LiFi in private beyond-5G networks, which will be based on the upcoming IEEE 802.11bb standard, is a key component of the 5G-CLARITY vision, whereby the focalized nature of light propagation offers essential features for private networks such as increased security, as light does not propagate through walls, area capacity, and positioning accuracy.

Second pillar: A novel management plane based on the principles of Software Defined Networking (SDN) and Network Function Virtualisation (NFV), and powered by Artificial Intelligence (AI) algorithms, in order to enable network slicing, and autonomic network management. The envisioned management plane will feature:

i) An SDN/NFV platform exposing an Application Programming Interface (API) to drive the network configuration, to extract network state, and to manage the creation of infrastructure and service slices,
ii) An AI engine that will collect data from the SDN/NFV platform and learn over time how to optimize the configuration of the network, and
iii) A high-level intent-based policy language that will allow an infrastructure operator to interact with the network using business primitives instead of low-level network configuration.

The aforementioned 5G-CLARITY technologies will be demonstrated in two key private network use cases (UC-I and UC-II) that will be further elaborated in Section 4.

Aligned with the previous two pillars, the main objectives of the 5G-CLARITY project are split into *user & control plane objectives* and *management plane objectives*. A summary of these objectives can be found in Table 3-1. 5G-CLARITY objectives

Table 3-1. 5G-CLARITY objectives

User & Control Plane Objectives (Pillar 1 related objectives)	
OBJ-TECH-1	Design and validation of a multi-tenant private wireless access network architecture, integrating 5G/Wi-Fi/LiFi, compute resources and 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 R16 capabilities by: i. Achieving downlink user experienced data rates[1] > 1 Gbps through interface aggregation. ii. Reducing latency in the air interface < 1 ms for uplink and downlink through parallel access across various technologies. iii. Providing reliability[2] of at least six 9s through smart interface selection. iv. Supporting vertical handover between wireless technologies with handover times < 5 ms.
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 synchronisation and positioning services over the proposed 5G/Wi-Fi/LiFi infrastructure: i. Positioning to peak accuracy < 1 cm, and availability of < 1-meter accuracy 99% of the time. ii. Reducing latency in the air interface < 1 ms for uplink and downlink through parallel access across various technologies.
Management Plane Objectives (Pillar 2 related objectives)	
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 3rd-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 an 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 2 relevant use cases.

Figure 3-1, extracted from the 5G-CLARITY DoW, illustrates the 5G-CLARITY vision of combining 5GNR, Wi-Fi and LiFi technologies within the private 5G network, which is managed by an SDN/NFV management system, and which can interact with public 5G networks.

[1] The IMT-2020 objective 4.3 on user experienced data rate is set to 100 Mbps for DL and 50 Mbps for UL. Notice that this is different to the peak data rate, which IMT-2020 sets to 20 Gbps for DL and 10 Gbps for UL. Experienced data rate refers to the data-rate reliably experienced by the user during normal network operation

[2] IMT-2020 sets a reliability KPI of five 9s for a 32B packet in 1ms

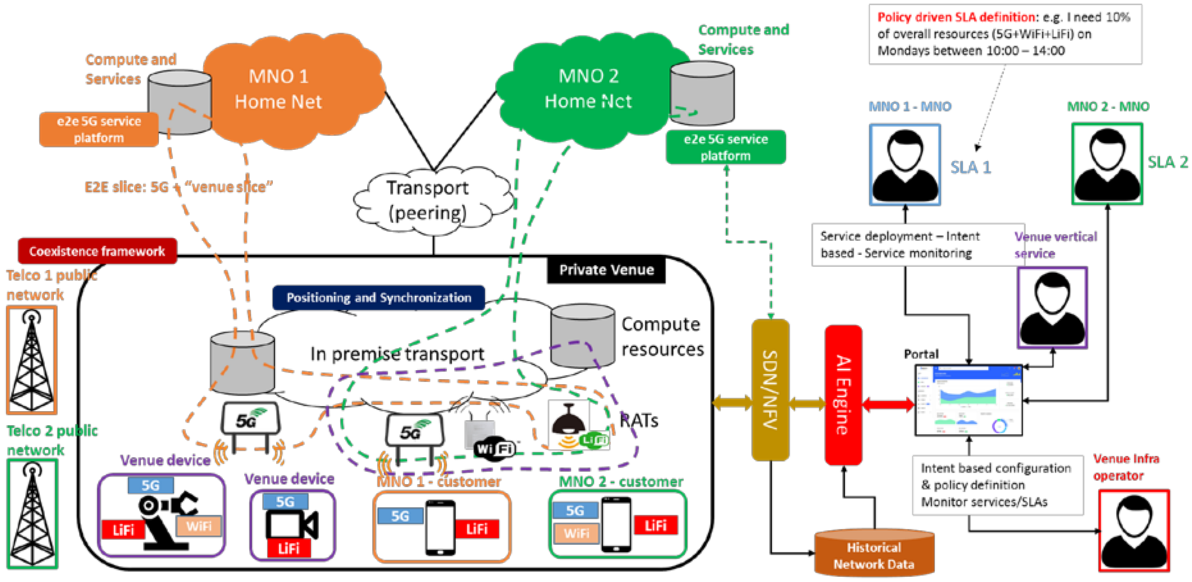

Figure 3-1. 5G-CLARITY vision figure extracted from the DoW.

3.2 5G-CLARITY Architecture: Requirements and KPIs

Based on the 5G-CLARITY objectives and the state-of-the-art use cases surveyed in section 2, we present an initial set of functional requirements and KPIs that shall be fulfilled by the 5G-CLARITY system. The architecture of this system will be developed in D2.2.

The rationale that we have followed in our approach is that the 5G-CLARITY architecture has to be able to address the objectives stated in the DoW and the specific requirements introduced by the two pilots considered in the project (sections 4 and 5), but it should also be able to address the main private network use cases defined in the SotA. For this purpose, we present in Table 3-2 the functional requirements for the 5G-CLARITY architecture, and we relate these requirements to the state-of-the-art use cases reviewed in section 2 that are addressed by each requirement. For better understanding, we have arranged the requirements into general requirements (5GC.FR. GEN-x), resource-related requirements (5GC.FR.REC-x), security-related requirements (5GC.FR.SEC-x) and management-related requirements (5GC.FR.MGT-X).

Table 3-2 5G-CLARITY System Functional Requirements

Functional Requirement	Description	Applicable SotA Use Cases
5GC.FR.GEN-1	5G-CLARITY system shall allow the deployment and operation of NPNs in either of their forms, including SNPNs and public network integrated NPNs.	**3GPP**: SA1, SA2, SA5 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.GEN-2	Any device authorized to be served by 5G-CLARITY system takes the role of NPN subscriber.	**3GPP**: SA1, SA2 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.GEN-3	5G-CLARITY system shall provide device synchronization via wireless transport of clock distribution protocols.	**3GPP**: SA1, SA2 **5G-ACIA**: Groups 1, 2, 3, 4 **GTI**: Groups 1, 2 **5G-PPP**: Group 1

5GC.FR.GEN-4	5G-CLARITY system shall provide optimized traffic steering mechanism when handling packets with low payload size.	**3GPP**: SA1, SA2 **5G-ACIA**: Groups 1, 3, 4, 8, 9, 10 **GTI**: Group 1 **5G-PPP**: Group 2
5GC.FR.RES-1	5G-CLARITY system managed resources are restricted to in-premises resources, i.e. resources that are present/deployed within the logical perimeter of the private venue.	**3GPP**: SA1, SA2 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.RES-2	5G-CLARITY system managed resources include wireless resources, compute resources (i.e. computing and storage nodes) and connectivity resources (i.e. links and forwarding devices).	**3GPP**: SA1, SA2 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.RES-3	5G-CLARITY system managed wireless resources shall include resources from two or more wireless access technologies, including 3GPP (5GNR) and non-3GPP (Wi-Fi, LiFi) technologies.	**3GPP**: SA2 **5G-ACIA:** No information **GTI**: Group 1 **5G-PPP**: Group 4 (5G maritime communications)
5GC.FR.RES-4	5G-CLARITY system managed compute resources shall have in-built virtualization capabilities to allow the execution of VNF instances.	**3GPP:** SA1, SA2 **5G-ACIA**: Groups 1, 2, 4, 5, 7, 8, 9, 10 **GTI**: Groups 1, 4 **5G-PPP**: all groups
5GC.FR.RES-5	5G-CLARITY system managed connectivity resources span across different network segments.	**3GPP:** SA1, SA2 **5G-ACIA**: Groups 4, 5, 7 **GTI**: Groups 2, 3, 4 **5G-PPP**: all groups
5GC.FR.RES-6	5G-CLARITY system managed connectivity resources shall provide QoS-assured data plane connectivity across deployed network functions, including PNFs and VNF instances.	**3GPP**: SA1, SA2 **5G-ACIA**: Groups 4, 5, 7 **GTI**: Groups 2, 3, 4 **5G-PPP**: all groups
5GC.FR.RES-7	5G-CLARITY system managed compute and connectivity resources shall be able to interact with MNO provided PLMN resources for the realization of public network integrated NPNs.	**3GPP**: SA2 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR-SEC-1	NPN subscribers shall only include private subscribers, i.e. no PLMN subscribers, for SNPN scenarios.	**3GPP**: SA2 **5G-ACIA**: Group 6 **GTI:** Groups 2, 3, 4 **5G-PPP**: Group 3
5GC.FR-SEC-2	NPN subscribers shall include both private subscribers and PLMN subscribers for public network integrated NPN scenarios.	**3GPP**: SA2 **5G-ACIA**: Group 6 **GTI:** Groups 2, 3, 4 **5G-PPP**: Group 3

5GC.FR.SEC-3	5G-CLARITY system shall provide second authentication/authorization for NPN subscribers when these subscribers are PLMN subscribers, in order to check their MNO provided credentials.	**3GPP**: SA2 **5G-ACIA**: Group 6 **GTI:** Groups 2, 3, 4 **5G-PPP**: Group 3
5GC.FR.SEC-4	5G-CLARITY system shall allow any authenticated/authorized NPN subscriber to keep sessions using one or more wireless access technologies.	**3GPP**: SA2 **5G-ACIA**: No information **GTI**: Group 1 **5G-PPP**: all groups
5GC.FR.MGT-1	5G-CLARITY management system consists of a set of management functions exchanging management data (i.e. performance measurements, fault alarms) and provisioning operations through well-defined interfaces using a common information model.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.MGT-2	5G-CLARITY management system is deployed within the logical perimeter of the private venue.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.MGT-3	5G-CLARITY management system is in charge of configuring the in-premises resources for the provisioning of one or more NPNs.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: Groups 2, 3, 4 **5G-PPP**: all groups
5GC.FR.MGT-4	5G-CLARITY management system shall include one 3GPP management system, to manage the 5G segments of running NPNs, and one or more non-3GPP management systems, to manage Wi-Fi/LiFi segments of running NPNs.	**3GPP**: SA5 **5G-ACIA**: N/A **GTI**: Group 1 **5G-PPP**: Group 4 (5G maritime communications)
5GC.FR.MGT-5	5G-CLARITY management system shall allow integration between 3GPP and non-3GPP management systems, for the provisioning of NPNs with multi-WAT capabilities.	**3GPP**: SA5 **5G-ACIA**: No information **GTI:** Group 1 **5G-PPP**: Group 4 (5G maritime communications)
5GC.FR.MGT-6	5G-CLARITY management system shall provide means of interworking with an external PLMN management system to allow the provisioning of public network integrated NPNs.	**3GPP**: SA5 **5G-ACIA**: Groups 4, 6, 10 **GTI**: Groups 2, 3, 4 **5G-PPP**: all groups
5GC.FR.MGT-6	To deliver neutral hosting functionality to more than one MNO, the 5G-CLARITY private management system shall support interworking with more than one concurrent PLMN management system.	**3GPP**: SA5 **5G-ACIA**: No information **GTI:** Group 4 **5G-PPP**: all groups
5GC.FR.MGT-7	5G-CLARITY system management shall allow the provisioning of application-tailored NPNs in the form of end-to-end network slices.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: Groups 1, 2, 4 **5G-PPP**: all groups

5GC.FR.MGT-8	5G-CLARITY management system shall have the ability to pop-up a network slice on demand to support a given application.	**3GPP**: SA5 **5G-ACIA**: Groups 4, 6, 7 **GTI:** Groups 1, 2 **5G-PPP**: Groups 1, 3
5GC.FR.MGT-9	5G-CLARITY management system shall support commissioning, modification and de-commissioning of network slices.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: Groups 1, 2 **5G-PPP**: all groups
5GC.FR.MGT-10	5G-CLARITY management system shall provide monitoring mechanisms to continuously check the behaviour and status of running slices.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: Groups 1, 2 **5G-PPP**: all groups
5GC.FR.MGT-11	5G-CLARITY management system shall have the ability to expose telemetry data on a per-slice basis, using live dashboards or user-friendly reports for this end.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: Groups 1, 2 **5G-PPP**: Groups 1, 2, 3
5GC.FR.MGT-12	5G-CLARITY management system shall expose interfaces to enable NPN operator to configure physical elements.	**3GPP**: SA5 **5G-ACIA**: all groups **GTI**: all groups **5G-PPP**: all groups
5GC.FR.MGT-13	5G-CLARITY management system shall expose high level intent interfaces to enable NPN customer to install policies, on the basis of telemetry data.	**3GPP**: SA5 **5G-ACIA**: No information **GTI:** No information **5G-PPP**: No information
5GC.FR.MGT-14	5G-CLARITY management system workflows automation and decisions are supported / driven by an AI engine.	**3GPP**: SA5 **5G-ACIA**: No information **GTI**: No information **5G-PPP**: Group 2 (Digital Twin apps)

After providing the functional requirements for the 5G-CLARITY architecture, we derive now performance KPIs based again on the 5G-CLARITY DoW objectives, and on the KPI identified in the SotA review presented in section 2. Table 3-3 lists the 5G-CLARITY KPIs (5GC.KPI-x), illustrating also their relationship to the above-listed 5G-CLARITY functional requirements. For this table, only use cases from 5G-ACIA and 5G-PPP Phase 3 projects will be considered, as they are the only ones who provide measurable KPI values.

Table 3-3. 5G-CLARITY System KPIs

KPI	Description	Related Functional Requirements	Applicable SotA use cases
5GC.KPI-1	UE downlink experienced data rates **> 1 Gbps** through interface aggregation.	5GC.FR.RES-3,4 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA**: No group **5G-PPP**: Group 1 (5G-connected AGVs; connected worker; time-critical process optimization into digital factories; remote controlling

			digital factories; rapid deployment of new robots) and Group 3 (on-site live experience).
5GC.KPI-2	Air interface latency **< 1 ms** for uplink and downlink through parallel access across various technologies.	5GC.FR.GEN-4 5GC.FR.RES-3 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA**: Groups 1, 3, 4 **5G-PPP**: Group 1 (connected worker; time-critical process optimization into digital factories).
5GC.KPI-3	Air interface reliability of at least six 9s **(> 99.9999%)** through smart interface selection.	5GC.FR.RES-3 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA**: Groups 1, 2, 3, 4, 5,7 **5G-PPP**: Group 2 (digital twins; telemetry / monitoring apps; digital tutorials and remote support) and Group 3 (robot-assisted museum guide and monitoring)
5GC.KPI-4	Vertical handover between different WATs with handover times **< 5 ms**.	5GC.FR.RES-3 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,1]	**5G-ACIA**: No information **5G-PPP**: No information
5GC.KPI-5	Area capacity in dense private venues **> 500 Mbps /m²** through RRM and SDN mechanisms fully exploiting combined multi-WAT capacity.	5GC.FR.RES-3 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA**: Any group **5G-PPP**: Any group
5GC.KPI-6	Reliability of a least four 9s **(> 99.99 %)** between devices in the private venue and an in-premises deployed VNF instance[3].	5GC.FR.RES-3,4 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA**: Groups 1, 2, 3, 4, 5, 7, 8, 9, 10 **5G-PPP**: Group 1 (autonomous vehicles; connected worker; time-critical process optimization inside digital factories; remote controlling digital factories), Group 2 (non-time-critical communications inside the factory), Group 4 (all use cases) and use cases defined in 5GC.KPI-4
5GC.KPI-7	Network latency **< 5 ms** between devices in the private venue and an in-premises deployed VNF instance[3].	5GC.FR.RES-3,4 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA:** Groups 1, 3, 4, 5 **5G-PPP**: Group 1 (connected worker; time-critical process optimization into digital factories).
5GC.KPI-8	Peak positioning accuracy **< 1 cm**, for an availability of sub-meter accuracy > 99% of the time.	5GC.FR.GEN-4 5GC.FR.RES-3 5GC.FR.MGT-10,11	**5G-ACIA**: Any group **5G-PPP**: Any use case
5GC.KPI-9	99% coverage over a service area **> 100 m²**	5GC.FR.RES-3,4,5	**5G-ACIA**: Groups 1, 2, 3, 4 **5G-PPP**: all use cases

[3] A VNF instance running on a local edge compute node, i.e. compute node deployed within the logical perimeter of the private venue.

5GC.KPI-10	Service support with a device density **> 200 devices/km^2**	5GC.FR.GEN-4 5GC.FR.RES-3	**5G-ACIA**: Groups 1, 3, 6, 7, 10 **5G-PPP**: Group 1 (5G-connected AGVs; autonomous vehicles in manufacturing environments), Group 2 (digital twin apps; telemetry/monitoring apps) and Group 3 (on-site live experience)
5GC.KPI-11	Optimized traffic handling for packets with payload size **< 256 bytes.**	5GC.FR.GEN-5	**5G-ACIA**: Groups 1, 3, 8, 9,10 **5G-PPP**: No information
5GC.KPI-12	Service deployment time **< 5 min**, for the provisioning of third-party[4] 5G connectivity services inside the private venue.	5GC.FR.RES-3,4	**5G-ACIA**: No information **5G-PPP**: No information
5GC.KPI-1	UE downlink experienced data rates **> 1 Gbps** through interface aggregation.	5GC.FR.RES-3,4 5GC.FR.SEC-3 5GC.FR.MGT-3,4,10,11	**5G-ACIA**: No group **5G-PPP**: Group 1 (5G-connected AGVs; connected worker; time-critical process optimization into digital factories; remote controlling digital factories; rapid deployment of new robots) and Group 3 (on-site live experience).

[4] Third-party refers to any business entity taking the role of private venue infrastructure tenant, and that deploys one or more services using private venue resources. An example of a tenant here is the MNO.

4 5G-CLARITY Pilots

5G-CLARITY has selected two main pilots to demonstrate the developed innovations in the area of private networks, namely a Smart Tourism pilot in Bristol, and an Industry 4.0 pilot demonstration in a real factory provided by BOSCH in Barcelona. In this chapter, each use case is described in detail, including information regarding: i) expected behaviour, describing the pre-/post-conditions and flow of actions that govern the use case itself; ii) potential, foreseeable ecosystem scenarios arising from this use case; and iii) stakeholders that can be involved in this use case, identifying their roles and highlighting their intended interactions.

4.1 Smart Tourism Pilot: UC1: Enabling enhanced human-robot interaction

4.1.1 General description

The Smart Tourism pilot demonstration intends to showcase how robots help to leverage tourist satisfactions in public areas, such as museums or exhibitions. Robots will play a significant role in our future life. In crowded public areas, robots can perform tasks such as visiting guidance, introductions, and other tasks that are currently performed by humans. In such areas, using only local intelligence robots will have difficulties to observe and be aware of the surrounding situations, thus providing real-time feedback and decisions. It will be of great benefit for the design of robots to use intelligence located in the network, rather than relying only on the robot itself. With these considerations, UC1 is designed to demonstrate applications of robots powered by network intelligence, which will be controlled remotely and guided with assistance from wireless-powered networking cameras. As shown in Figure 4.1, a remote-controlled robot will perform various tasks in a complex environment. Wireless cameras will be connected to a private network and will be used to guide the brainless robot and redesign its route based on real-time information obtained from the cameras.

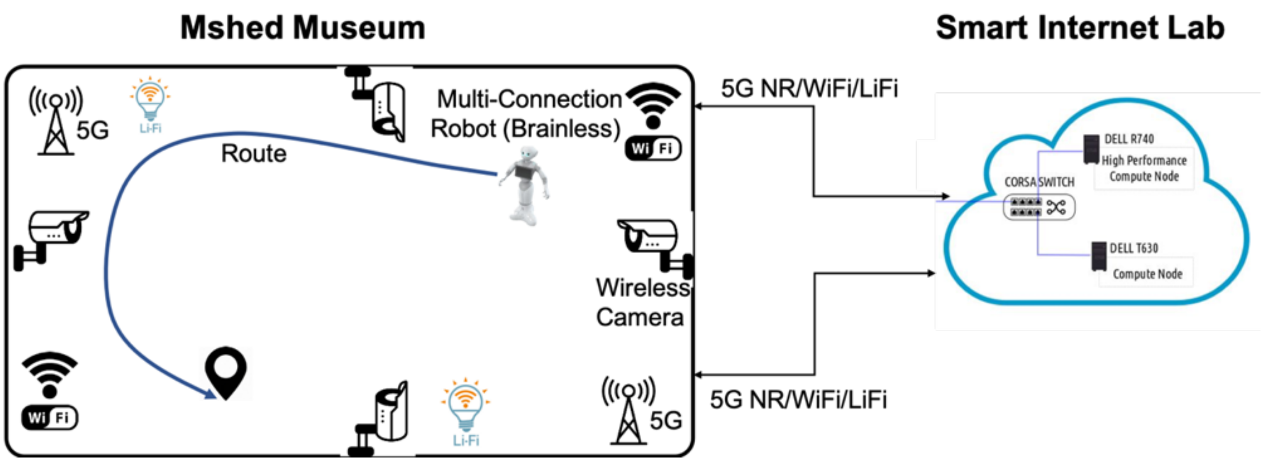

Figure 4.1 Multi-RAN powered camera-guided root in public area

The demonstration is planned at the M-Shed[5] museum venue in Bristol. In this demonstration, the remote-controlled robot will walk to the destination guided by the cameras, which are acting as the eyes of the robot. The robot will be equipped with multiple connections through Wi-Fi, LiFi and 5GNR. Multiple cameras are deployed to monitor and provide precise positioning for the robot. Remotely, the robot will be guided through an optimized path to deliver some tasks. The cameras will be connected to a high-performance server through multiple WATs. The movement of the robot will be in both private and public networks. The demonstration will be designed to validate the following key 5G-CLARITY objectives and KPIs:

- Integration of multiple WATs providing bandwidth aggregation for network applications

[5] https://www.bristolmuseums.org.uk/m-shed/

- End-to-End Network slicing for URLLC services, such as remote robot control
- Operation of 5G based fixed wireless broadband with high-definition cameras
- Smooth handover between private and public networks
- High-performance edge computing for video-based computer vision

4.1.2 Main stakeholders

The main stakeholders for UC1 are primarily identified based on the 'stake holder roles in the 5G ecosystem' specified by 5G PPP Architecture Working Group [22], according to Table 4-1. This list will be updated during the course of project and as use cases are further planned in 5G-CLARITY 'WP5: Integration, Experimentation, Proof-of-Concept and Demonstration.'

Table 4-1 Partners' roles for UC1

Stakeholder Role [22]	Representing Partner
Data Centre Service Provider / Data Centre Aggregator / VISP / Infrastructure aggregator	UNIVBRIS
Network operator / network service aggregator	UNIVBRIS
(Communication/Digital/Network Slice as a) Service Provider	UNIVBRIS
(Communication/Digital/Network Slice as a) Service Customer	UNIVBRIS
Operation Support Provider(s)	IDCC (support for KPI validation) LMI (provides AI for management aspects)
HW/SW suppliers	ACC (5GNR supplier) I2CAT (Wi-Fi supplier) PLF/UEDIN (LiFi supplier)

4.1.3 Current setup

The UC1 demonstration will be implemented based on the existent setup that is available through the 5GUK Test Network[6] in Bristol. The existing system architecture is the result of an iterative design process across various technical use-cases executed in previous projects and is shown in Figure 4.1. There are four distinct areas, such as the HPN, the Pump Rooms, We The Curious and M-Shed. Each area has a direct involvement in the museum pilot that will be described in the following sections. Considering the demonstrated area, brief descriptions are provided for the involved locations.

[6] http://www.bristol.ac.uk/engineering/research/smart/5guk/

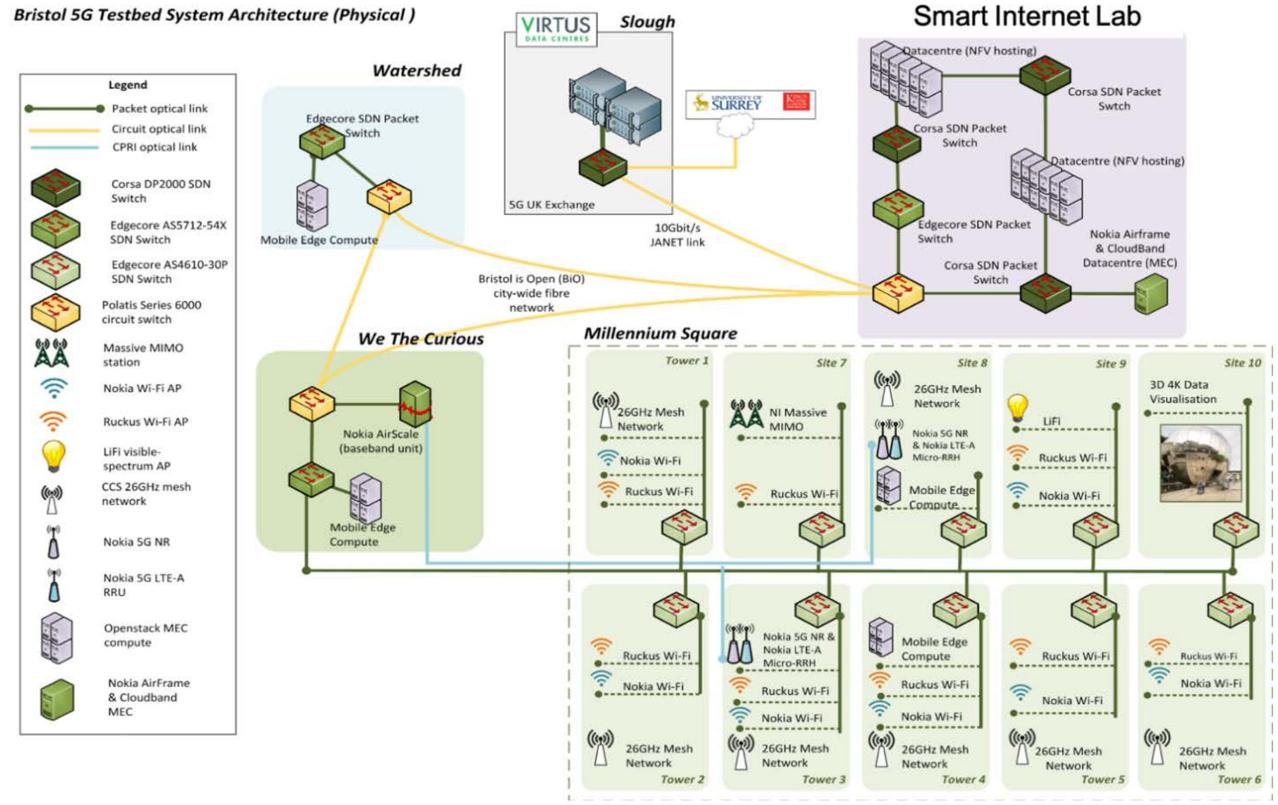

Figure 4.2. Network system architecture of current testbed

The current testbed includes several sites with focus on different applications.

1. **Smart Internet Lab (SLab).**

The HPN group at the University of Bristol is the core of the 5G network testbed due to its physical location and the existence of many 5G components. Fibre connectivity is present between HPN and We The Curious (WTC) that links the 10Gbps Edgecore IP networks in HPN with the existing testbed in Millennium Square. Similarly, a 10Gbps leased line via BT will allow high speed connectivity to the Guildhall in Bath. A dedicated out of band management network will be provided to allow for the separation of the control and data plane of SDN enabled network devices, which is a fundamental 5G network architecture principle.

2. **We The Curious (WTC)**

A significant proportion of We The Curious network was put in place by the DCMS Phase 0 project at the University of Bristol. The 5G testbed in this location includes an extension of the 10Gbps SDN controlled Edgecore IP network to the datacentre in WTC Server Room and seven locations around Millennium Square. To support specific 5G use-cases, compute capacity will be added in WTC server room and the base of each tower. This will provide Mobile Edge Computing (MEC) as close to the edge as possible for 5G research applications. A major addition to the testbed will be the deployment of 5G New Radio in the form of a Nokia 128 antenna element Massive MIMO base station.

3. **M-Shed The Museum**

The 5G network in and around the M-Shed venue will support the 5G-CLARITY Smart Tourism Pilot through a mix of 5G network components and various radio access technologies. The server room in M-Shed is the core of the 5G network at this location. Fibre connectivity will be provided to the HPN lab which will facilitate extension of the 10Gbps SDN controlled IP data and management networks. Additionally, layer 0 optical switching capability will be provided through Polatis switches to allow direct fibre connections to datacentre devices. This location has the capability to house mobile edge compute capability so that use-case owners can deploy their applications as close to the users as possible. A new fibre will be installed inside M-Shed to connect this server room with the East Roof Space (Figure 4.3). Six new Ethernet connections are required to link the Server Room directly with the three Exhibit Rooms where the Smart Tourism use-case will be demoed. These Ethernet links will provide 1Gbps to the device and PoE. Since SDN enabled Edgecore switches are being utilised at each layer, these components of the network can be orchestrated from an SDN controller located in the network core (SLab).

To support the use-cases inside M-Shed, three exhibit rooms must be connected to the network and provide radio access technology for client devices. This access will comprise Wi-Fi (from Ruckus R720s) and LTE provided through Nokia license assisted access (LAA) Picocells. The Towers in Millennium Square are equipped with 26GHz fixed wireless access mesh nodes which will allow gigabit connectivity across the Bristol Harbour to M-Shed. This wireless connection can be used as an alternative to the BNET fibre (via the Server Room) to backhaul use-case data traffic. This is also a compelling use of 5G technology which will maintain the scalability of the network architecture. LiFi Access Point provided by pureLiFi are already available in this location, which represents an excellent starting point to demonstrate the 5G-CLARITY innovations. Figure 4.3 shows the physical location of the multiple sites.

Figure 4.3. Physical map of the multiple sites involved in UC1

4.1.4 Future setup through 5G-CLARITY

With this pilot, UNIVBRIS expects to demonstrate interactions between Private and Public 5G networks, where the M-Shed museum will act as the private network domain, and the rest of the 5GUK Test Network will represent the public network domain. Other key features include the integration of multiple RATs, where the Wi-Fi, LiFi and 5GNR network in the M-Shed museum will be upgraded with the one developed by 5G-CLARITY. In addition, in 5G-CLARITY the network will be managed by an Artificial Intelligence-based management policy. An integrated monitoring platform for multiple WATs and EDGE computing will be developed for the current testbed. The monitoring platform will provide information for AI/ML applications, to achieve physical layer channel abstraction, intelligent network configuration, proactive network handover, and self-organized RANs. 5G-CLARITY will also provide end-to-end network slicing technology supporting eMBB and URLLC services with different QoS. The AI-driven network management and slicing over the integrated monitoring platform will reduce network operation cost and management cost in the visionary network scenarios. 5G-CLARITY will develop novel network framework for private and public 5G networks with integration of multiple WATs. The smooth integration of private and public networks will be one of the key enabling-technologies for this pilot.

To perform the demonstration, an open testing zone will be set up to explore interactions between humans and robots with the developed technologies in 5G-CLARITY. The testing zone will be equipped with wireless high-definition cameras. Novel positioning technologies will be developed to track robots for better human-robot interaction. Pepper Robots from SoftBank will be used for the demonstration.

4.1.5 Expected results

It is expected robots and AI will play a significant role for future tourism industries. In 5G-CLARITY, social interactions between humans and robots will be explored for museum-focused visiting experience. As a local museum, the M-Shed museum will benefit from an improved visitor satisfaction. The developed new technologies in 5G-CLARITY will also provide enabling technologies for new approaches for future exhibitions and demonstrations. The technologies developed in the demonstrations can be even applied in other application scenarios, to make a lasting impact on 5G-powered applications.

4.2 Industry 4.0 Pilot

The Industry 4.0 Pilot which will be implemented and demonstrated in a BOSCH assembly plant in Spain, and consists of two use cases introduced below, which will be used to demonstrate two key functionalities provided by 5G-CLARITY:

i) Guaranteed URLLC services through slicing of the wireless infrastructure,
ii) High precision indoor positioning.

The use cases are denominated as:

- UC2.1: Alternative network to exchange production data
- UC2.2: Enhanced positioning for AGV in intralogistics process

The facility where UC2.1 will be demonstrated is a Wiper Systems Assembly (WSA) production line. Depending on each car design, windshields come in different sizes and require appropriately sized wiper systems to ensure efficient, reliable windshield cleaning. BOSCH manufactures a complete portfolio of effective wiper drives for every windshield size. Consequently, the WSA is produced in about 50 different production lines, which are distributed in 12 different locations all around the world, thereof 12 production lines in BOSCH Spain.

The WSA production line that will be used for 5G-CRARITY demonstrator, the layout of which is shown in Figure 4.4, consists of thirteen working stations whereof seven of them are fully automatic, one is semi-automatic, and the remaining five stations are manual. The production line made by these workstations work in a nonstop sequence for assembling various components. There is a final packaging and labelling station which is handled by a worker. The current line has a cycle time of 14 seconds.

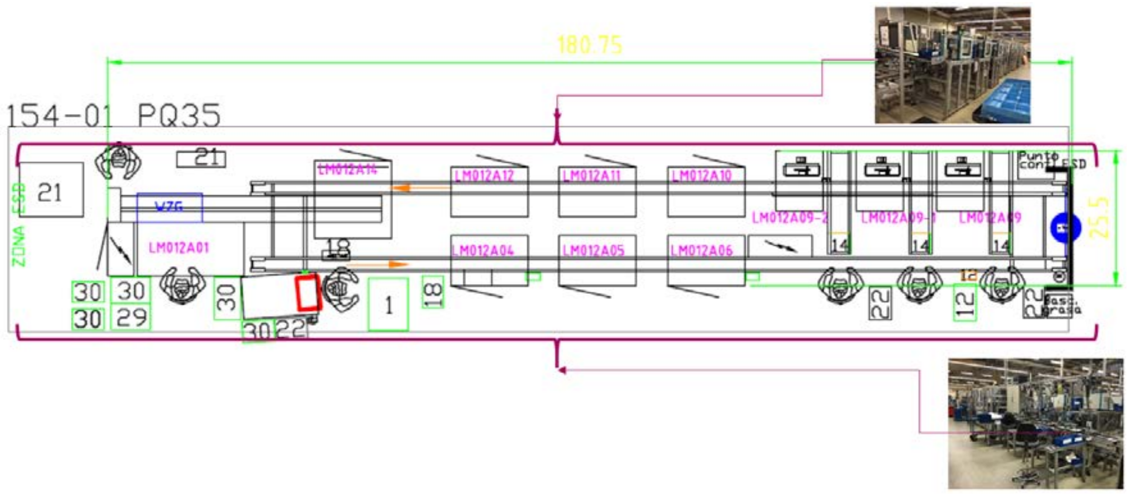

Figure 4.4 WSA production line (BOSCH Spain plant)

Before the production on a WSA is planned, the responsible employee checks that materials, components, tooling, specification, machine-setting plan, quality details, and anything else needed to produce the batch are available. Then the production date is programmed, and the orders released to move everything to the production line.

Following critical manufacturing processes and operations, automotive industry customers, particularly car makers, require their suppliers to record, store and process everything. Automatic reports must reflect machine settings for every WSA workstation, the quality issues, material flows, movement of materials and containers from the warehouse to the shop-floor, i.e. intralogistics, and of course any event or incident that occurs. Therefore, 'all-parameters' data needs to be transmitted from each device, collected, and processed, to be available for further analysis.

At the end of the production line is the wiper system packaging. Once the box is full of wiper systems, a worker packs it, and asks for the label from a server located in Germany. The requested information for the label is generated by the server and is sent back to a printer located at the end of the production line. This process takes up to 32 seconds. The worker attaches the label to the box and requests to move it from the production area to the warehouse.

The BOSCH plant has three different warehouse areas to keep the containers according the category of the goods:

- Main warehouse: which is full of metallic shelving, including the inbound area and the dispatching area,
- Supermarket: which is the area where semi-elaborated products are kept temporarily, to be moved to the production line for the final assembly,
- Production area: where the containers of material and components for the assembly, and boxes to collect final product (or parts) are located.

In the plant, and across the factory, specific containers are used to carry materials and goods. These need to be moved from one area to the other when production workers request parts and goods. Empty containers need to be returned to the warehouse to be available to the next dispatch.

The 5G-CLARITY proposed 5G/Wi-Fi/LiFi infrastructure will be developed and validated in the BOSCH plant in Spain to demonstrate how the proposed infrastructure can enable not only real-time tracking of AGVs but also the use of network slicing, including bandwidth, delay and reliability, to guarantee the performance of the different systems and the Industry 4.0 tools and services in the factory.

4.2.1 Main Stakeholders

The main stakeholders for UC2.1 and UC2.2 are primarily identified based on the 'stake holder roles in the 5G ecosystem' specified by 5G PPP Architecture Working Group [22], according to Table 4-2. This list will be updated during the course of project and as use cases are further planned in 5G-CLARITY 'WP5: Integration, Experimentation, Proof-of-Concept and Demonstration.'

Table 4-2 Main Stakeholders

Stakeholder Role [22]	Representing Partner
Data Centre Service Provider / Data Centre Aggregator / VISP / Infrastructure aggregator	BOSCH
Network operator	BOSCH (for standalone NPN) TID (for public network integrated NPN)
Network service aggregator	BOSCH/TID (to be discussed in WP5)
(Communication/Digital/Network Slice as a) Service Provider	BOSCH
(Communication/Digital/Network Slice as a) Service Customer	To be discussed in WP5
Operation Support Provider(s)	IDCC (support for KPI validation)

	LMI (provides AI for management aspects)
HW/SW suppliers	ACC (5GNR supplier) I2CAT (Wi-Fi supplier) PLF/UEDIN (LiFi supplier) LMI (SW supplier for AI) IHP (HW supplier for mmWave localization)

4.2.2 UC2.1: Wireless multi-service support in Industry 4.0

4.2.2.1 General description

UC2.1 is focused on production-data transmission. Every machine setting and its parameters, the movement of materials and containers, tooling storage, etc., is released only by electronic orders. This information is sourced from production-line personnel, e.g. workers, process engineers and the plant manager.

Keeping the setting parameters, e.g. forces, temperatures, pressures, electrical parameters, etc., at their right values will ensure the quality of every produced part and can help the production to reach the 'Zero Defects' target requested by the automotive customers. Any deviation from the setting parameters can be the root cause of a defect. In case of such a deviation, the production process must react within the cycle-time of the production to minimize the risk of quality deficit, and to trigger alarms for implementing corrective actions. The overall benefit of such an on-time reaction would be minimizing the production line downtime and thus increasing the productivity. Availability of various kinds of related (recorded) data, e.g. setting parameters, can be used in off-line data mining which in turn can play a crucial role in detecting various relevant factors in production quality. There are several systems in BOSCH manufacturing plants to manage data gathered from production and logistics. The most relevant ones to the project are described as:

1. Systems, Applications and Products Enterprise Resource Planning (SAP-ERP): SAP-ERP is the integrated management system of main business processes. It provides an integrated and continuously updated view of core business processes and track business resources—cash, raw materials, production capacity—and the status of business commitments: orders, purchase orders, and payroll.
2. Manufacturing Execution System (MES): MES is used in manufacturing, to track and document the transformation of raw materials to finished WSAs. MES provides information that helps manufacturing decision makers understand how current conditions on the shop floor can be optimized to improve production output.
3. Energy Management System: Used to integrate consumption data of every machine and device, with the objective to learn how to reduce energy cost.
4. Material Orders System: Warehouses are connected to production means to receive orders of goods to cover production needs.
5. Intralogistics System: Control operation System is managing the orders, preparation, movement, delivery and positioning of goods inside the factory.

Current connectivity infrastructure to exchange information in the plant is a mixture of wired and wireless networks. This infrastructure is currently used to guarantee the data exchange across the different systems, supporting main services in the factory, such as those introduced above. Current setup issues can be summarised as:

a. ERP-SAP process cannot share any Wi-Fi network because ERP-SAP has priority on the rest of services and even could stop the production,
b. Currently, each new sensor needs to be connected to the main server by means of wires to transmit parameter data to the head-switch. The data logger has only limited connectors and thus there is a

limit for the number of added parameters. In addition, any layout modification would require a re-wiring which can be costly.

c. The real-time interaction with the MES database (normally based in another location) requires low round-trip latency which currently is not supported by the BOSCH Global Network, and thus some MES features are missed.

d. The latency of the process to generate a label of finished box is so long that the box must be moved without the label to an interim area, pushed by the preparation of a new empty box. The label will be attached later. This may cause an error due to wrong labelling.

4.2.2.2 Current setup

The current setup includes:

1. **Wired connections**: Because Wi-Fi infrastructure cannot support the massive data exchange required for the new industry 4.0 data mining, all data are collected using a wired network. Each device is connected by means of wire, Ethernet and EtherCAT connections with a Head-Switch in every production line, which is then connected to the local main Server by a fibre.
2. **Wi-Fi**: The shop-floor facilities in the production area have four Wi-Fi SSID regulated by the ACL (VLAN). Each one used exclusively for a particular service as:
   - Wi-Fi office (AP-ERP, office automation, etc.)
   - Wireless guns
   - Wi-Fi Smartphones and laptops access to the Mobile Service netWork (MSW)
   - Wi-Fi ITM access to a BCN LAN and production VLAN

   Figure 4.5 shows the Wi-Fi Antennas locations on the demonstration area considered for UC2.1, where each antenna is indicated by AP*x* in the figure. Among these AP10 is located to cover Warehouse and AP7 is above the production line.

3. **The global network of BOSCH**: The BOSCH intranet guarantees a secure connection to exchange relevant information between different factories and locations but with a very high latency.
4. **LEDs suitable for LiFi installation:** There are several LEDs installed in the factory shop-floor ceiling which are currently used for lighting. These could be used to be equipped with the LiFi APs during the course of the project. LiFi can provide an alternative high-capacity localized data transmission capability.

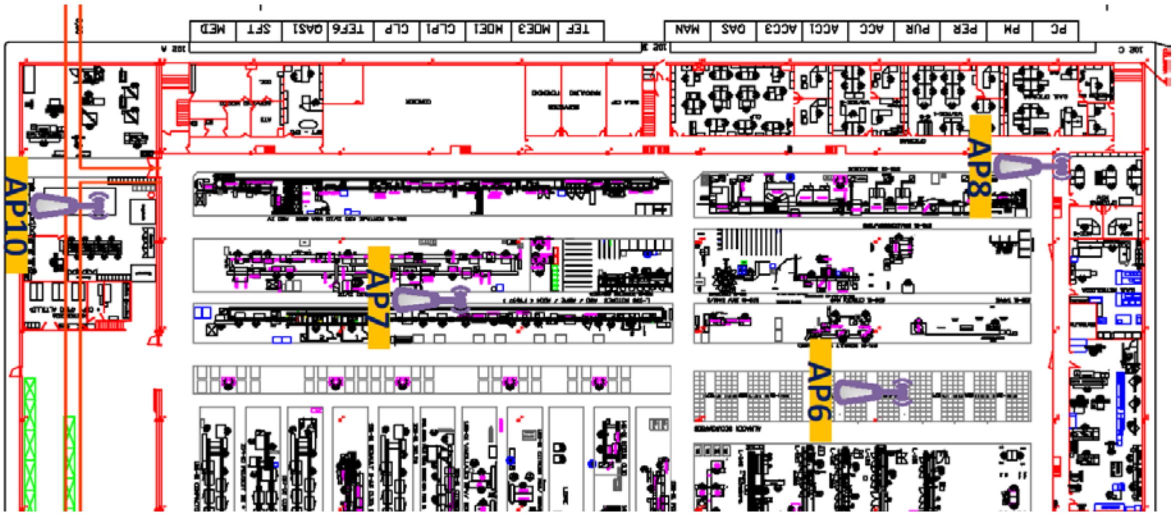

Figure 4.5 Wi-Fi antennas locations in the shop-floor

4.2.2.3 5G-CLARITY added features

During 5G-CLARITY the following features will be added to the setup:

- The integrated multiple-WATs (Wi-Fi, 5GNR and LiFi) will enhance the current data transmission capacity and reduce transmission delays, with the end-goal of replacing the head switch of the production line by a 5G-CLARITY wireless switch.
- The current four SSID Wi-Fi network will be augmented by a 5GNR/Wi-Fi/LiFi network that supports four concurrent slices, consisting of a service identifier (SSID and PLMNID) and a guaranteed wireless resource quota.
- The 5G-CLARITY advanced network management system will allow the factory IT administrator to deploy new wireless services using an intuitive interface.
- A public 5G slice will be setup connecting the private networks within different BOSCH factory plants to allow low delay access to the MES database.

To perform the demonstration, a working station of the WSA production-line will be prepared to explore the following new services:

1. **Wireless service to the production-line.** Configurable multi-WAT 5GNR/Wi-Fi/LiFi connectivity in the demo site to support multiple services and to connect the multiple systems introduced in Section 4.2.2.1. This setup will replace the current wire and Wi-Fi networks with a more reliable data-transmission scheme to achieve the challenging technical requirements.
2. **5G service to follow up critical process.** The end-to-end solution implemented in the project will enable real-time data exchange of the local quality-tests with the MES database located elsewhere using a 5G public network. The end-to-end connectivity via the dedicated network slice can guarantee the required reliable data-exchange. By using this service, some relevant MES features for which documentation and proof of processes, events and actions are required, will become feasible. The use of this service will also improve the quality-control system of the data exchange, without a need to stop the process. Moreover, this service will ensure a low latency, secure and reliable data exchange with SAP-ERP to release boxes in production.

4.2.2.4 Expected results

UC2.1 is expected to provide an alternative flexible and reliable wireless connectivity for IoT sensors and machines to exchange information with the systems used by the manufacturing companies. The plant where UC2.1 is planned to be implemented, will benefit with an improved productivity and lowered general production cost. 5G-CLARITY will provide enabling technologies toward the 'Factory of the Future' where the only fixed elements are the floor, the walls, and the roof, everything else will be portable and can be moved around. UC2.1 will allow to validate the wireless slicing capabilities and to test the performance of multi-WAT solution proposed by 5G-CLARITY. UC2.1 will provide a relevant example of how the designed beyond 5G network infrastructure can increase efficiency and productivity of an Industry 4.0 environment.

Moreover, within the use case the interactions between private and public 5G networks can be examined. This feature has the potential to reduce HW investments and management cost via using HW resources located in other cities/countries within the company.

BOSCH will use the developed solutions for this use case to enhance connectivity solutions in other plants worldwide. The factory in Spain is the lead wiper system production plant, that is its engineering office is responsible for the development, design and maintenance of the manufacturing lines in other worldwide plants. It is expected that the demonstrated solutions will be gradually used to enhance other plants.

4.2.3 UC2.2: Enhanced positioning for AGV in intralogistics process

4.2.3.1 General description

UC2.2 is focused on providing high precision positioning of the movement of goods in the shop-floor. In traditional warehouses, human errors can impact safety, efficiency, quality, and productivity, and hence is costly. Using AGVs instead of human workers in a factory can enhance these production related characteristics. AGVs can also significantly improve the intralogistics, i.e. the organization and execution of the internal movement of goods in a factory.

In the UC2.2 demo area, there are three forklift pathways as illustrated in Figure 4.5. The blue line shows the route for the material carried from the warehouse to the production. The yellow line indicates the return route to the main warehouse of empty boxes, and the route used to move the final product to the warehouse. The magenta line is the route used for the delivery of customer boxes.

The driver delivers the goods to the production area with a train, called milk-run, driven by a tractor head. The driver picks-up the finished product and returns with the empty boxes as shown in Figure 4.7.The trolleys are moved manually from/to the milk-run to/from the reception/delivery area.

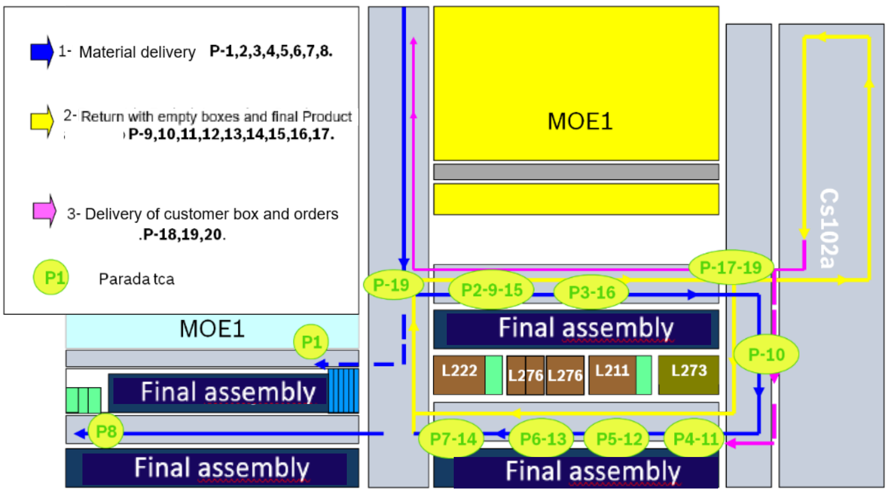

Figure 4.6 Current setup for the forklift pathways

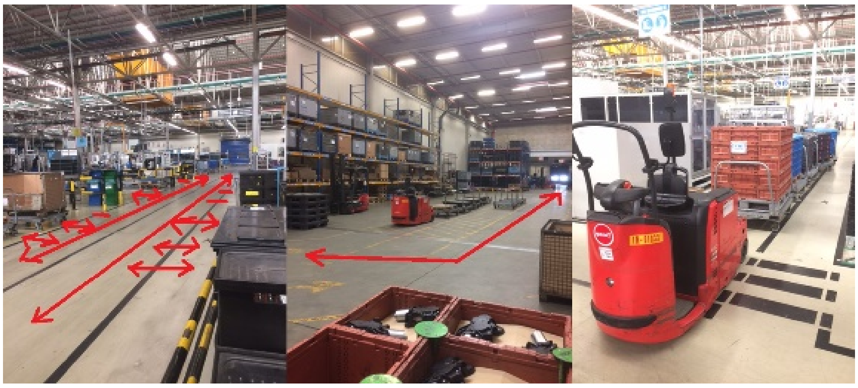

Figure 4.7. Example of Forklift pathways and the milk-run

4.2.3.2 Current setup

Currently every 30 minutes the forklift drives along the shop-floor and stops at points marked by 'P*xx*' in Figure 4.5, to deliver goods or collect boxes. The driver leaves the material and collects empty containers, and then triggers new material orders to the intralogistics system by means of wireless guns using the existing Wi-Fi network.

The SAP server located in Germany, receives the order via the BOSCH Global Network, processes it and sends it back to a local system to be used to control the process. The operator prepares the order to the warehouse worker and sets the stops. The warehouse worker prepares the material and charges the container to be distributed by the forklift in his regular drives.

UC2.2 needs to deal with the following issues:

- Localisation of the forklift (currently only start and end positions are can be identified),
- Collision record on the track (currently no record of any such incidents are collected),
- Missed orders, or those delivered with delay (currently this is known only if orders are sent by the driver or are received by the warehouse).

4.2.3.3 5G-CLARITY added features

This use case will allow to demonstrate that the slicing and critical service capabilities of the 5G/Wi-Fi/LiFi infrastructure proposed in 5G-CLARITY will provide high precision positioning of intralogistics vehicles of the goods and containers distributed by them and relevant tracking information of vehicles on the shop floor.

UC2.2 will develop a joint radio, mmWave, LiFi, and OCC high resolution positioning system to locate the AGV and forklift in real time on the predefined routes in the factory. Multiple sensors on the AGV and forklift will be used to employ the radio (sub-6 GHz), mmWave, LiFi, and OCC positioning algorithm, fuse all information and provide a beyond state-of-the-art performance in positioning and tracking inside the plant. Here are features of the positioning method and elements used therein:

- Multi-sensor approach leveraging sub-6 GHz, mmWave, LiFi and OCC positionings,
- Using sub-6 GHz band as a side channel to determine angle of arrival (AoA), aiding directional link setup for both mmWave and LiFi links,
- Using time-of-flight estimation for the wideband mmWave signal to provide the range (relative to the access point) with high accuracy,
- Using LiFi to locate the mobile within its confined coverage area,
- Using OCC and image processing algorithm used for positioning to enhance the precision of the positioning, detection of the non-line-of-sight, and to track the movements of the AGV and forklift,
- Employing an ML algorithm to fuse the data from the various positioning sensors this gaining accuracy.

Various parameters will be derived from the positions recorded by the sensors mounted on the AGV, e.g. speed, acceleration, deceleration, track identity, incidents detected by the internal or surrounding sensors. Thus, a complementary ML algorithm will process the retrieved positioning data from the forklift and AGV in order to detect anomalies, calculate time and/or speed, trigger alarms, send messages, and create inputs for reports to improve the decisions-making process on the production-line.

4.2.3.4 Expected results

The future manufacturing is expected to significantly relay on AGV and AI-based processes and algorithms. 5G-CLARITY will demonstrate enhanced positioning for AGVs in the plant whereby working interaction between human and AGV can be explored, and the effects on the efficiency and security can be monitored. It is expected that the plant will benefit from an improved productivity and lowered general production costs. 5G-CLARITY technologies will also enable the integration of the data from AGV sensors and those of the AGV control system to enhance the safety in a connected factory of the future. The developments in UC2.2 should improve various production KPI's such as: i) Workforce labour cost, ii) Safety in the production area, and iii) Material traceability.

5 Use Case Requirements and KPIs

Based on the analysis of the use cases introduced in Section 4, a list of service associated requirements is derived per use case. The outcome is an initial list of service requirements aiming at guiding the system architecture design on Task 2.1. This first version of requirements may be refined at later stages of the project, considering the progress done in WP3, WP4, and WP5. This effort will also help to understand the potential impact of the 5G-CLARITY solution, identifying areas that could be improved or require more attention.

5.1 Use case requirements

5.1.1 Functional requirements

Table 5-1 Functional Requirements UC1

Functional Requirement ID	Description
FUNC-UC1-01	Connect the robot with multiple WATs, such as Wi-Fi, LiFi and 5GNR
FUNC-UC1-02	Wireless camera with fixed broadband connections through multiple WAT
FUNC-UC1-03	Precise positioning with computer vision and wireless multi-WAT positioning technologies
FUNC-UC1-04	Target recognition and path planning for specific task. Some images or pictures will be used to indicate targets.
FUNC-UC1-05	Environment awareness and surveillance with cameras. The images captured by cameras will be used to locate possible obstacles and moving objects on the path.
FUNC-UC1-06	Edge-computing based video processing and analysis
FUNC-UC1-07	Handover between private and public 5G networks
FUNC-UC1-08	Multi-WAT interface for user equipment.

Table 5-2. Functional Requirements UC2.1

Functional Requirement ID	Description
FUNC-UC2.1-01	Wireless production line. Using 5G/Wi-Fi/LiFi technologies to provide flexible and reliable connection for IoT sensors, PLCs, laser, to SAP ERP, MES and Energy platform systems, currently connected by wire to a header switch, which connects the production line with the main server
FUNC-UC2.1-02	Enhanced wireless connection (Wi-Fi) for engineers
FUNC-UC2.1-03	Follow up critical process by bidirectional data exchange: using a public 5G network to enable a real time data exchange of online quality tests, with a database located in Germany to generate SAP quality reports
FUNC-UC2.1-04	Product delivery data: using a public 5G network to enable a real time data exchange with a database located in Germany to generate SAP labels
FUNC-UC2.1-05	Production data exchange with factories located in other cities/countries using a public 5G connection, guaranteeing a secure and reliable data exchange, using the “slicing concept” and “public-private network" connectivity

Table 5-3. Functional Requirements UC2.2

Functional	Description

Requirement ID	
FUNC-UC2.2-06	Allow real-time access to the positioning data generated by the AGV sensors, e.g. speed, acceleration, deceleration, track, and detected incidents.
FUNC-UC2.2-07	Warehouse orders: using 5G technology to enable a real time data exchange with a database located in Germany to generate SAP orders to the warehouse

5.1.2 Technical requirements

Table 5-4. Technical Requirements UC1

Technical Requirement ID	Description	Functional Requirement ID
TECH-UC1-01	Bandwidth aggregation over two or more WATs to double the maximum bandwidth.	FUNC-UC1-08 FUNC-UC1-01
TECH-UC1-02	Camera connections with a bandwidth up to 200 Mbit/s per camera to support 4K video at 5fps	FUNC-UC1-02
TECH-UC1-03	Bandwidth per area at 100 Mbit/s/m^2	FUNC-UC1-01 FUNC-UC1-02 FUNC-UC1-08
TECH-UC1-03	Remote controlling the robot with a latency less than 100 ms	FUNC-UC1-03 FUNC-UC1-03 FUNC-UC1-06
TECH-UC1-04	Seamless handover strategies between private and public networks to support the mobility of the robot with a latency of less than 500 ms	FUNC-UC1-07

Table 5-5. Technical Requirements UC2.1

Technical Requirement ID	Description	Functional Requirement ID
TECH-UC2.1-01	SAP ERP service: data rate is low (10 Mbps), with a latency less than 3 ms, at a packet delivery > 99.99999%	FUNC-UC2.1-01 FUNC-UC2.1-02 FUNC-UC2.2-07
TECH-UC2.1-02	MES for production line: data rate > 1000 Mbps (connected to the header switch), at a latency < 3 ms	FUNC-UC2.1-03
TECH-UC2.1-03	For Energy data: data is low (10 Mbps), with a latency < 50ms, packet delivery > 99.99999% (only in few critical machines)	FUNC-UC2.1-01
TECH-UC2.1-04	Public 5G net connection: data rate is low (10 Mbps), with a latency < 3 ms, packet delivery > 99.99999%	FUNC-UC2.1-03 FUNC-UC2.1-04 FUNC-UC2.1-05 FUNC-UC2.2-07
TECH-UC2.1-05	For delivery orders: data rate is low (10 Mbps), with a latency < 3ms, packet delivery > 99.99999%	FUNC - UC2.1-04

Table 5-6. Technical Requirements UC2.2

Technical	Description	Functional

Requirement ID		Requirement ID
TECH-UC2.2-06	For movement monitoring and messaging: data rate is low (54 Mbps), latency < 10ms, packet delivery > 99.9%	FUNC-UC2.2-06
TECH-UC2.2-07	Precision accuracy: 10 cm (tolerance +/- 2 cm)	FUNC-UC2.2-06
TECH-UC2.2-08	For Warehouse orders: data rate is low (10 Mbps), latency < 3ms, packet delivery > 99.99999%	FUNC-UC2.2-07

5.2 Key performance indicators

Based on the functional and technical requirements identified in the previous section we derive now a set of KPIs to be fulfilled by the 5G-CLARITY system.

Table 5-7. Key Performance Indicators

Requirement ID	Functional Requirement: Description	Technical Requirement: KPI's
FUNC-UC1-01 **FUNC-UC1-08**	1. Connect the robot with multiple WATs, such as Wi-Fi, LiFi and 5GNR 2. Multi-WAT interface	**Spectrum**: 5G private and 5G public **Throughput:** >100 Mbps **Switching Time (WAT Interface)**: < 1 s
FUNC-UC1-02	Wireless powered camera with fixed broadband connections through multiple RAT	**Spectrum**: 5G private **Latency**: <3 ms **Throughput per camera:** >100 Mbps **Number of devices**: up to 10 devices simultaneously connected. **Coverage area**: 100 m^2
FUNC-UC1-03	Precise positioning with computer vision and wireless multi-WAT positioning technologies	**Position accuracy:** < 10 cm
FUNC-UC1-04 **FUNC-UC1-05**	1. Target recognition and path planning for specific task. Some images or pictures will be used to indicate targets. 2. Environment awareness and surveillance with cameras. The images captured by cameras will be used to locate possible obstacles and moving objects on the path.	**Route planning time:** <1s **Target recognition time:** <1s
FUNC-UC1-06	Edge-computing based video processing and analysis	**Total processing time:** < 200ms (5 fps)
FUNC-UC1-07	Handover between private and public 5G networks	**Handover time:** < 500ms

FUNC-UC2.1-01 **FUNC-UC2.1-02**	1. To provide flexible and reliable connection for IoT sensors, PLCs, laser, to SAP ERP, MES and Energy platform systems, via multi-WAT (5GNR, Wi-Fi, LiFi), and augment the existing wired data collection systems with new wireless network 2. Programmers and engineers are connected to machines to ensure that changes do not affect the process	**Spectrum**: 5G private **Latency**: <3 ms (50 ms for Energy data) **Throughput:** < 10 Mbps (for each single equipment) **Throughput UL**: 10 Gbps (simultaneous with all services) **Availability**: > 99.999% **Reliability**: > 99.999% **Mobility**: Not specified **Capacity**: Not specified **Number of devices**: up to 60 devices simultaneously connected. **Coverage area**: 2000 m^2
FUNC-UC2.1-03 **FUNC-UC2.1-05**	Enable a real time data exchange of online quality tests with a database located in Germany, using the 5G network, to generate SAP quality reports	**Spectrum**: 5G private and 5G public **Throughput**: 10 Mbps **Availability**: >99.99999% **Reliability**: >99.99999%
FUNC-UC2.1-04 **FUNC-UC2.1-05**	Establish the link from the scanner devices in the plant to the server in Germany, with guaranteed security and reliability of the data exchange (uses private and public 5G networks)	**Spectrum**: 5G private and 5G Public **Throughput**: 10 Mbps **Availability**: >99.99999% **Reliability**: >99.99999% **Printing time** < 2s (since label request)
FUNC-UC2.2-06	1. Establish low latency, reliable link from the AGV to the operators sitting outside the plant. 2. Position of the AGV with a high accuracy is provided at real time	**Spectrum**: 5G private **Latency**: <10 ms **Throughput UL**: 54 Mbps (peak) **Availability**: >99.9% **Reliability**: >99.9% **Mobility**: up to 20 km/h **Capacity**: 2,16 $Mbps/km^2$ **Device density**: Not specified **Coverage area**: 8600 m^2 **Positioning accuracy**: 10cm
FUNC-UC2.2-07 **FUNC-UC2.1-05**	Guaranteed secure and reliable data transmission from the sensors at the plant, to the SAP ERP located outside (Spain or Germany), via private and public 5G, using a dedicated network slice managed by 5G-CLARITY AI-based management engine	**Spectrum**: 5G private and 5G Public **Throughput**: 10 Mbps **Availability**: >99.99999% **Reliability**: >99.99999%

6 Conclusions

This report, 5G-CLARITY D2.1, provides an overall vision on the project's use cases, and related KPIs for 5G-CLARITY technologies and pilot demonstrations. These were derived based on the study of the SotA, envisioned architecture, and project targets. D2.1 is the outcome of Task 2.1 during which we set the guidelines for the development and assessment of the project's use cases, as well sketched and stablished specifications and requirements for each use case.

To derive the most suitable specifications for the use cases, project's partners used their best experience and expertise, and a comprehensive SotA study on the existing sources, especially on the related standardization, projects and forums was performed, and their results were considered. Most importantly, 5G-PPP projects, ICT-17 and ICT-19, were considered and analysed carefully, and relevant use cases, capabilities and KPIs were taken into account. In this respect, it was tried to derive requirements, specifications and technology KPIs which are aligned, and beyond related 5G-PPP projects.

The functional and technical requirements derived in this deliverable sketch a clear guideline for the implementation of 5G-CLARITY technologies in respect to each of the use cases. Hence these were carefully set, and the corresponding KPIs were derived to be both realistic and achievable but beyond SotA. As a result, a clear guideline for the technical works in other WPs of the project is successfully sketched.

The presented use cases require stringent requirements in terms of latency, data rate, reliability and high-accuracy positioning, typically executed in indoor/private environments that can be supported with outdoor deployments. These use cases allow related verticals, e.g. manufacturing, logistics companies, tourism, exhibitions, etc., to carry out critical processes within their premises. The demonstrated 5G-CLARITY technologies will be tested according the defined KPIs, as well as the efficiency of the usage at each of the venues, i.e. the robot-human interaction for the Smart Tourism, and the efficiency of the wireless data network for assembly-line, and AGV usage for the Industry 4.0.

The defined KPIs comply with 5G-PPP works, but additional business KPIs must be taken into account to measure how the proposed technology improves the current scenario of the pilots. Not only that, but ensuring it can offer real benefits to the pilots and to future industry users. These KPIs will be later used for the performance evaluation of the final demonstrators.

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