UNIVERSIDAD POLITECNICA DE VALENCIA

DEPARTAMENTO DE COMUNICACIONES

Máster Universitario en Tecnologías, Sistemas y Redes de Comunicaciones

Distributed 5G system architecture for applications virtualization in Industry 4.0 and Edge Computing

Author: Andrea Fernández Sierra
Director 1: David Gómez Barquero (DCOM)
Cotutor: Nuria Molner Suriana (iTeam)
Director 2: Marc Mollà Roselló (Ericsson)
Start date: 01/03/2021
Workplace: Mobile Communications Group (MCG)

Objectives – The objectives are:

- To contribute the development of the 5G-INDUCE project.
- To design an hybrid edge-cloud 5G (5th Generation) architecture in the Ford site and to identify the VNFs (Virtualized Network Functions) for the three proposed use cases (UCs) of the project: Autonomous indoor fleet management, AGV (Autonomous guided vehicle) operation based on human gesture recognition and VR (Virtual Reality) immersion for AGV control.
- To analyze edge and cloud computing network deployments and their advantages and disadvantages.
- To propose a 5G network deployment in Ford.

Methodology – To carry out this research documentation of the 5G-INDUCE project has been consulted. In addition, academis scientific articles by authors with recognized prestige and company reports have been consulted on the topics to be discussed. Subsequently, this information has been interpreted and reflected in this document. Throughout the development of this project meetings has been taken place every two weeks with the European consortium and every week with the Spanish one.

Results – The results obtained are:

- A common network architecture for the three UCs of the project to meet the objectives of each UC.
- Analysis and definition of the architecture of each UC and its network functions.
- To analyze edge and cloud computing network deployments and their advantages and disadvantages.
- 5G network deployment planning in Ford factory.

Future Guidelines – Throughout the development of this project, ideas of interest have been arisen to progress it. The fist idea could be to virtualize the UCs of the project with Docker, to test each presented network deployment numerically such as latency, throughput, lost packets. Latency measurements could be carried out using a VPN (Virtual Private Network) from the UPV (University Polytechnic of Valencia) to Ericsson's 5G laboratory using the iperf3 tool to later compare results. Moreover, this solution could be scaled up to more than one area of the Ford factory or even to more than one factory, increasing the edge computing capacity, the RAN (Radio Access Network) equipment needed and the network architecture.

Abstract - The main goal of this thesis is to analyze the potential 5G architectures in a real-life Industry 4.0 case in the Ford factory in Valencia. We will work with an architecture in which the user plane (data) and control plane (signaling) are separated. It will allow 5G network functions and applications to run in different locations with compute resources. For example, on-premise, on cloud, or potential half-way architectures (close data center). The outcome of this thesis will be to evaluate the obtained results to understand the main differences by each mentioned architecture.

Subjects: 5G, Industry 4.0, Edge computing, NetApps (Network Applications), 5G Architecture, CUPS (Control and User Plane Separation), Virtualization.

Author: Andrea Fernández Sierra, email: anfersi2@iteam.upv.es
Director 1: David Gómez Barquero, email: dagobar@iteam.upv.es
Cotutor: Nuria Molner Siurana, email: numolsiu@iteam.upv.es
Director 2: Marc Mollà Roselló, email: marc.molla@ericsson.com
Fecha de entrega: 10-03-2021

Contents

1 Introduction

The capabilities of 5G such as: its inherent low latency, high data rates and the ability to connect multiple devices at the same time, allow manufacturers to monitor in real-time the entire manufacturing process of a workpiece. According to Capgemini [1], 60% of early industrial 5G adopters are experiencing improved operational efficiencies and 43% are reporting increased flexibility. Further, 40% of industrial organizations are expected to roll out 5G at scale by 2023.

As population ages, industrial competitiveness will depend more and more on the agility of workers to acquire new skills. The spread of 5G to industries will have as a requirement cybersecurity specialists and system integrators, among others. In addition, employees will need to be trained to cope the changes.

Over the next few years as one of the drivers of Europe's digital transformation, 5G will generate a sharply impact on the employment, the economy, and the environment, as well as other advanced technologies such as cloud computing, artificial intelligence, and robotics. 5G could enhance the jobs of up to a fifth of the workforce according to Omdia. It estimates that there will be 20.3 million people in employment in Spain in 2030, with 322,000 of those jobs created as a result of 5G, 1.6% of the national workforce[2]. The largest volume of 5G generated jobs are in information and communication sector. Figure 1 shows the proportion of new employees by sector.

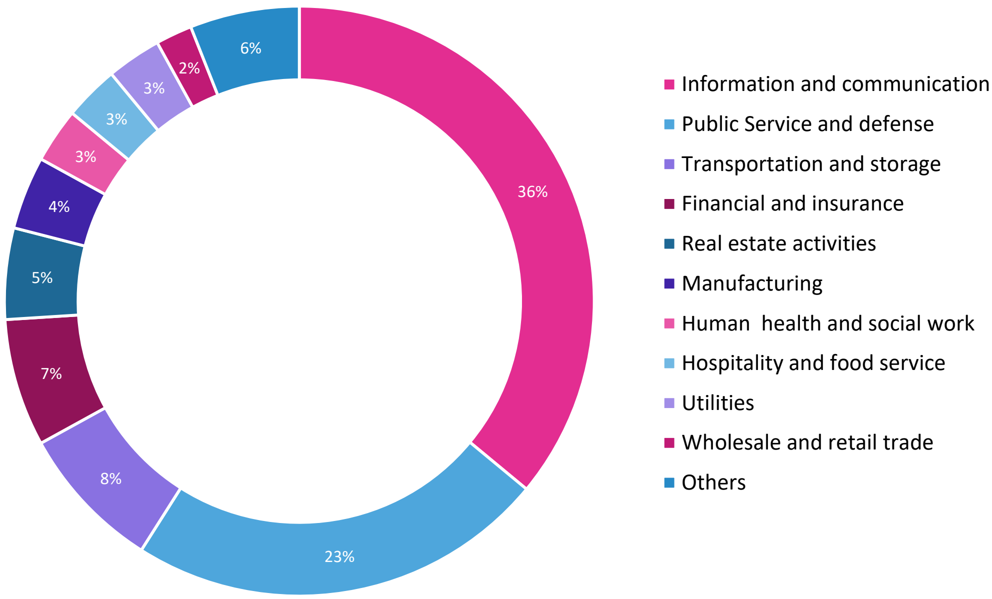


Figure 1: Proportion of new employees by sector in Spain as a consequence of 5G[2].

The fact that the information and communication sector represents most new 5G jobs is partly explained as in Spain this sector employs around 8% of the workforce. Public services and defense represents an important proportion of the jobs generated in Spain, about 13% of the workforce. Several of the sectors mentioned are not traditionally related to technology advancement, such as transportation and storage, human health... However, they are among the top 10 sectors by employment generated, a further reflection of the breadth of impact of 5G. It is expected that 5G will enable $12.3 trillion global economic output and support 22 million jobs by 2035 [2].

Besides, the power of 5G will also bring a positive impact on the environment. It will enhance efficiency and reduce the movement of people and things, thus reducing greenhouse gas (GHG) emissions per unit of production. Omdia forecasts that 5G services will enable a reduction in GHG emissions of million tons of carbon dioxide equivalent (MtCO2e) in Spain in 2030[2].

5G stresses the importance of integrating with the existing industry standards to make the transition faster and more effective. Many processes are already automated but companies are still looking for greater speed, greater performance etcetera through new technologies. The major density of office locations such as, on-premise solutions, data centers and network infrastructure achieves a level of trust with the customer that can reduce the time to market.

The telecommunications network with its distributed architecture, and its move towards the edge of the cloud allows to take advantage of both the strength of the European telecommunications providers, leaders in the provision of cloud native 5G[3]. The market takes advantage of this and develops solutions tailored to the needs of the industry, as well as, a growing ecosystem of small cloud providers.

In Spain, 5G deployments have been carried out recently. In January 2021, Ericsson announced a partnership with Ford Almussafes of Valencia to trial realistic experimentation facilities for the deployment of network functions in the industrial sector. Ford Spain competes with the rest of the factories to be among the most innovative one, Ford factory will manufacture hybrid engines for the entire European market. By 2026, 100 per cent of Fords passenger vehicle range in Europe will have a zero-emission option, as announced by Ford. It will opt for fully electric or plug-in hybrid vehicles, becoming fully electric by 2030. Ford employs approximately 53,000 employees at its facilities, up to 67,000 if we include joint ventures and subsidiaries. Ford Factory will have a work schedule that will involve working 24 hours a day during the 7 days of the week, all contributing to its success[4].

In this project at least three UCs will be tested in Ford premises related to the direct business interests of FORD and include: autonomous guided vehicles fleet management; AGVs based on human gesture recognition; and VR immersion of AGVs control. The AGVs are highly flexible, intelligent, and versatile system that is used to transport materials from different loading points of the facilities of an industrial environment[5]. For the design of an AGVs environment must be considered the design of trajectories, the number of vehicles that comprise the system, the requirements that the vehicles need to easily adapt, what type of materials the AGV will transport and how, when and where the loading and unloading of material will be take place. In the same way, it is necessary to know where the batteries of the vehicles will be charged and what safety systems will be used to avoid possible collisions and damage to the system.

Nowadays, AGVs are already used in Ford premises. There are just eight guided vehicles in the Ford engine plant. It is estimated that in the coming years there will be no guided vehicles in the factory. AGVs work guided through black lines and solely for indoor functions. Ford facilities have charging stations to which AGVs move when their battery level is low. Because of this, some specific needs have been identified for connectivity and modernization of the AGVs fleet that would optimize some of the processes of the distribution chain both in indoors and outdoors warehouses. Figure 2 shows the current situation at Ford factory. In those, AGVs from ASTI (recently adhered to ABBV) are guided through black lines.

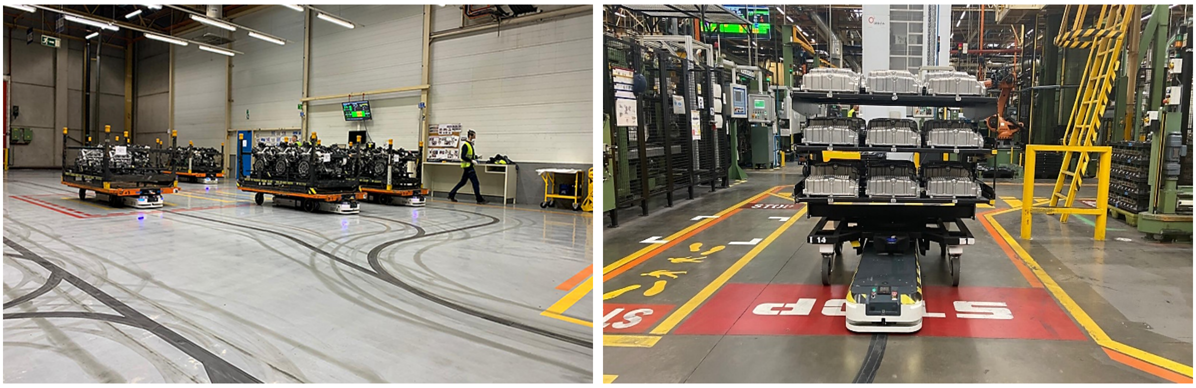


Figure 2: AGVs at Ford premises nowadays.

The way robots collaborate with humans is becoming increasingly important. An AGV in an environment without humans and it does not need the same attention and efficiency as one in which there are humans. One of the key issues for the AGV is the quality of service requirements. In order to the control system to react and make decisions such as stopping a movement, the efficient and reliable communication provided by 5G is very important. To achieve this efficiency a lot of signaling, high bandwidth, low latency and fast decision making is required. It is also necessary to have processing capacity in the edge and on cloud, thus being able to process the data in real time, implement more advanced applications[6].

2 State of Art

The telecommunications industry has been immersed on an incredible transition which will redefine its role in industry and society while it prospers. Although 5G often is represented as a tool for higher speeds or critical to the development of Industry 4.0. It illustrates a foundational shift for wireless communications that it is placed directly at the center of a fully digitized economy. The 5G architecture itself consists of two partsthe new generation Radio Network (NGRAN) who supports the New Radio (NR), and the 5G Core Network (5GC)[7].

3GPP (3rd Generation Partnership Project) is a global system engineering project that defines the specification used by millions of mobile subscribers worldwide. Participants, including suppliers and operators, are involved in the creation of the specification from the initial R&D (Research and Development) to the final standards-complying product. Ideas are taken to the body for approval resulting in the technical specification.

5G is defined by a set of requirements that allow for a set of usage scenarios, 5G services. These 5G services are:

- **URLLC:** Ultra-reliable low latency communications, requires very low latency services and high reliability, critical needs communications (autonomous car, industry automation...) where bandwidth is not quite as important as speed, end to end latency 1 ms or less[7].
- **mMTC:** Massive Machine Type Communications, enables machine to machine (M2M) communications and Internet of things (IoT), connecting thousands of devices in a small area, small amounts of data are sporadically transmitted (smart cities)[7].
- **eMBB:**: Enhanced Mobile Broadband, high speed, and wide coverage area, which does not encompass either of the other two groups. The aim is to serve more densely populated metropolitan centers with downlink speeds approximately 1 Gbps indoors, and 300 Mbps outdoors[7].

Figure 3 compares the 5G KPIs (Key Performance Indicators) for each type of 5G service, each one is different and requires study. Interpolating this to a real UC yields values that are very different from the theoretical ones.

There are a lot of interesting architectural changes in 5G Core when is compared with 4Gs (4th Generation) EPC (Evolved Packet Core). 4G was proprietary hardware (meeting specifications); however, 5G has been implemented with software. 5G provides more scalability and its maintenance is much easier (just have to update software in the cloud)[8]. Some examples are:

1. Control and User Plane Separation, this has been adopted by 3GPP in Release 14 in 2017. It allows use both planes independently, because of this, new network architecture initiatives such as the Software Defined Network (SDN) arise.

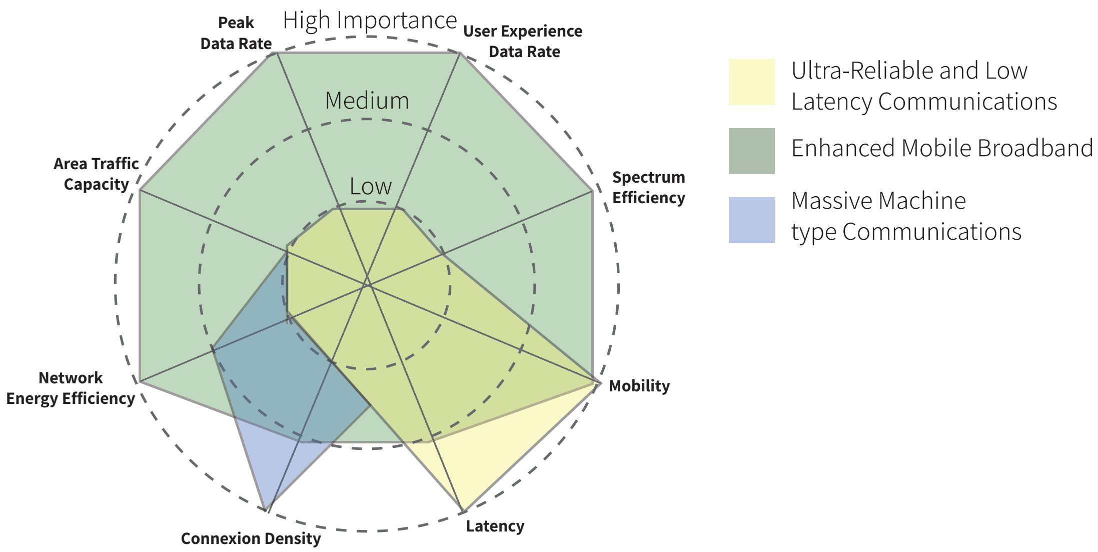


Figure 3: 5G KPIs for each kind of 5G service.

2. Stateless networks functions are enabled in the Control Plane for scalability and resilience. In the control Plane the NFs (Network Functions) as UDM (Unified Data Manager), PCF (Policy Control Function) do not save the data inside their VMs (Virtual Machines) or Containers (Docker, Kubernetes). Instead, the data are stored remotely at UDR (Unified Data Repository) and UDSF (Unstructured Data Storage Function) for structured and unstructured 3GPP NF data storage respectively for stateless NF operations. In other words, if a NF fails, the backup NF could be retrieved the data and the state from the UDR (Unified Data Repository).

3. Service Base Architecture (SBA), it provides a framework in which common applications can be deployed using components from different sources. It relates to the common bus where API (Application Programming Interface) REST are published. The control plane and data repositories are delivered via NF, each authorize to access the others services. There are two types of representations: 5G Core Service based representation and 5G Core reference point representation. The first one is a logical communication bus between NF, they communicate through APIS REST, web servers with the HTTP (Hypertext Transfer) protocol, through which requests are sent. The second one is similar to the first one but the communication between NF is more limited.

4. Network Slicing offers end to end virtual network partitions depending on the needs. It requires an automated configuration and ready QoS (Quality of service) and disassemble it in a few seconds.

3GPP offers a detailed overview of the areas of work that are being developed so that 5G is a tool of facing verticals. The growth rate in 5G deployments is faster than in previous technologies, especially in relation to 4G. The improvements provided by each of the releases are briefly explained below[9].

- **Release 15:** It focus is Enhanced Mobile Broadband. It allows mMTC and IoT, Vehicle-to-Everything Communications (V2x), SBA, WLAN (Wireless Local Area Network) and unlicensed spectrum, SlicingCurrently, there are products from this Release on market[10].

- **Release 16:** It was completed in 2020. Its main focus is to enable ultra-reliable low latency for mission-critical applications. Some of the improvements it includes are slow latency, time synchronization for time-critical applications, resource management, preemption (URLLC data transmission can preempt ongoing non-URLLC transmissions), fast processing, reliability5G URLLC is a good match for standard defined for Time Sensitive Networking (TSN) which is a perfect candidate for industrial automation[11].

- **Release 17:** : It is mostly study items as NR MIMO (Multiple-Input and Multiple-Output), Industrial IoT, low complexity NR devices, power saving, NR coverage, Non-Public networks, RAN Slicing, Edge computing in 5G Core[12]...

A critical factor of 5G is computing capacity. The edge places computing capabilities close to the traffic originates, at the edge of the network. This reduces latency and eliminates the need for all traffic to run across the entire transport network, optimizing the use of network resources. Edge resources will also enable new applications, such as virtual reality, augmented reality, and autonomous driving, that need to be run close to the data sources.[13] A variety of network functions will run at the edge. However, it is not feasible to simply move all workloads to the edge of the network. Instead, a balance of centralized and distributed compute resources in a layered architecture across the network between the core and edge will enable workloads to be placed where they can best support the required service and traffic profiles[14].

Cloud computing consists of offering computing services over the network using cloud storage. Cloud multiplies the resources that the user can access without installing anything on their device. Some of the most known cloud providers are AWS (Amazon Web Services), Google Cloud and Microsoft Azure[15].

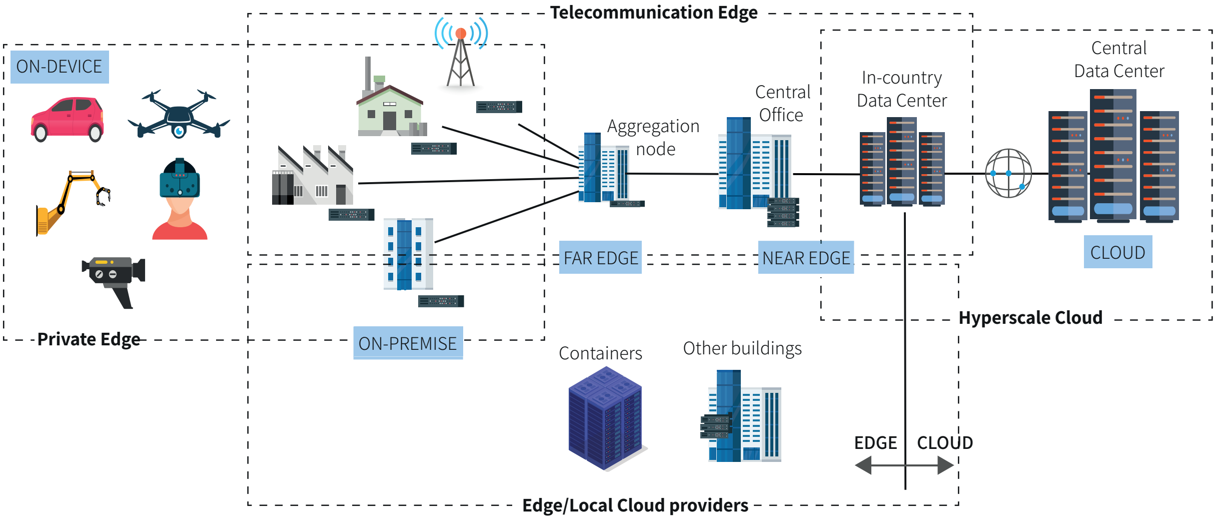
Edge and Cloud services could be built in three type of facilities[16]:

- **Cloud data centers:** It is a data center hosted on cloud. It stores information on cloud in a distributed way and taking advantage of the versatility of virtualization. It allows local devices to take on the heavy workloads and storage. These tasks are carried out by servers, dedicated to attend the request at any time and offering services, resources, hardware, software, and data, only through an Internet connection. It is the cloud provider that is responsible for maintenance and updates.

- **Edge data centers:** It is the combination of ultra-low latency and proximity of the facilities with the flexibility and the scalability of the public cloud. In terms of power and resource consumption provides much higher efficiency. It is due to the hardware utilization could increase with respect to the on-premise solution (in the facilities) where the infrastructure is shared by a bigger number of tenants. On issue that would reduce network power consumption as well as connectivity and operational costs is hosting multiple cloud providers in the same public edge data centre.

- **On-premise data center:**: Based on physical containers or edge hardware designed with less power and in relation to the requirements which could be developed in cases of requiring extreme privacy or latency.

An edge deployment generally will start in the Near Edge (core nodes, bigger facilities) and advance progressively until Far Edge (physical containers, aggregation nodes), Figure 4. Alternatively, other edge providers may cover the demand with an on-premise (private) near premise edge deployment. In order to interconnect the edge nodes to the cloud, may create a specific network or to reuse one of the existing public networks[14].The key parameter that distinguish each of the environments is the distance to the end-user.



Average Latency	1 ms	2.5 ms	5 ms	10 ms	< 20 ms	> 20 ms
Per market	100000 s	10000 s	100 s	10 s	< 10	Units
DC Power	< 20 kW	<50 kW	30-100 kW	0.5-1 MW	5-20 MW	20-100 MW
Distance	0-5 km		100 km	Several hundred km	1000 km	

Figure 4: Characteristics of Edge and Cloud computing locations[14].

A critical factor in any of the three facilities mentioned is the virtualization of applications and NFs. NFs virtualization is used to virtualize network services, such as routers, firewall and load balancers, that traditionally ran on proprietary hardware. These services are packaged as VMs on basic hardware, allowing service providers to run their networks on standard servers (cloud, edge, etcetera), rather than on proprietary systems. In addition, it improves scalability and agility by allowing providers to offer new network services and applications as requested without the need for additional hardware resources. Application virtualizations allows users to access and use an application from a computer other than the one with the application installed. For the user, the virtualized application experience is the same as using the application installed on a physical device. Some examples of virtualization based on containers are Kubernetes and Dockers. Nowadays, the trend marks a progressive fusion between them. The use of containers has grown in popularity and has become a viable strategy for virtualization in recent years[17].

3 5G-INDUCE

The 5G-INDUCE project develops and open and cooperative 5G network platforms that will allow the showcasing and evaluation of advanced network applications, supporting emerging and innovative services related to the industry 4.0.

The goal is to provide an end-to-end orchestration platform over enabling experimentation infrastructures for advanced 5G network applications that can be applied for the realisation of extensive 5G UCs in the broader Industry 4.0 sector, leading to technological and business validation of 5G technologies by multiple collaborating tenants (e.g. manufacturing, logistics, maintenance power management, security/surveillance and more). Focus is given on validation of the 5G-readiness of both telecom operators and applications providers.

The 5G-INDUCE experimentation facilities (ExFas) are deployed with the goal to validate and showcase over a real industrial 5G environment the developed NetApps. Three ExFas are envisioned Spain, Italy, and Greece, all linked with large industrial facilities (Ford, Whirlpool and PPC respectively) while being supported by advance 5G infrastructures, this document will focus on just in the Spain experimentation facility in Ford. The overall purpose of the adopted ExFa sites is to address actual Industry 4.0 needs in a diverse set of industrial environments, showcasing the beneficial use of 5G technology in terms of latency, optimized interoperability and management, security, and safety.

Following the evolution of AGVs use in Ford three UCs will be tested to achieve a higher level of automation and increase human-machine iteration:

- **UC1:** Autonomous AGV fleet management.
- **UC2:** Smart operation of AGVs based on human gesture recognition.
- **UC3:**: VR immersion of AGVs control.

Figure 5 shows the Spanish consortium of the project.

Figure 5: Spanish consortium.

4 Use Cases Overview

This section describes the defined network application related UC scenarios in 5G-INDUCE for the Valencia experimentation facility. The UCs describe advance industrial sector operations that are expected to be benefited by the presence of the 5G network environment. UCs will be explained in detail below.

4.1 Use Case 1: Autonomous indoor fleet management

Currently, AGVs are guided vehicles that move autonomously following a predetermined route. They are usually used to transport products, heavy materials, or any other object. The objective of this UC is to manage a fleet of AGVs with simultaneous localization and mapping (SLAM) navigation. It is expected to integrate 5G connectivity and edge computing capabilities.

This UC will have the ability to control each movement taking into consideration the destination of the AGV. For this, they must be connected with other NetApps to receive information from the vehicles on cameras and sensors, connections with other NetApps to send information to the vehicle on the next position.

The main advantage of this implementation is that this way it would not be necessary to follow black lines, everything would work automatically with a predetermined route avoiding collisions. Besides, outdoor routes could be established.

Below, the AGV path for this UC in Ford premises is shown in Figure 6. The AGV path will start on the red flag (loading point), here the user will load the AGV with heavy materials. The red line corresponds to indoor area, the green one to outdoor area. The change of AGV is produced when the area changes from indoor to outdoor. The AGV path will finish on the green flag (unloading point). Currently, the format of carriage that will transport the materials remains to be determined.

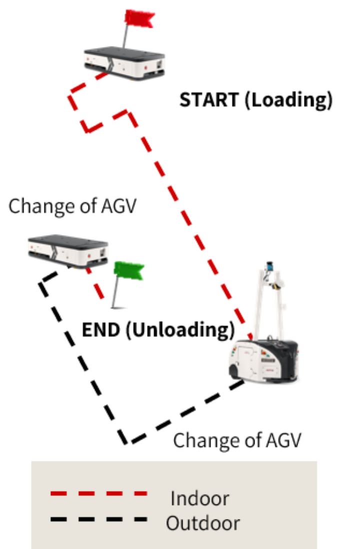


Figure 6: AGV path in Ford factory.

Each phase of this AGV path corresponds to the following areas of Ford premises, Figure 7.

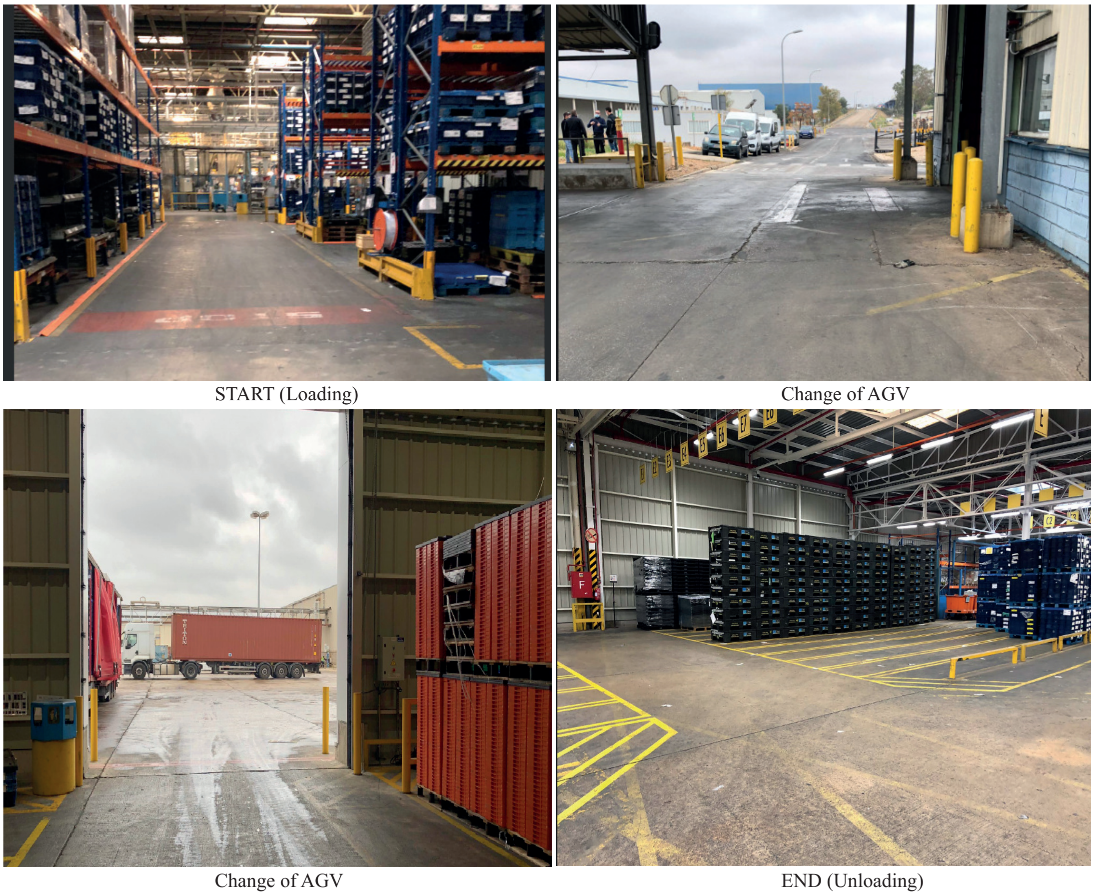


Figure 7: Ford premises areas in a predetermined route.

Regarding to the requirements of this UC, the low latency and low jitter are essential to enable the remote driving of AGVs. The UC1 requires lower latency than the other UCs to avoid collision with each other. Table 1 below shows the provisional requirements established for this UC.

4.2 Use Case 2: Smart AGV operation based on human gesture recognition

This UC is based on the intelligent monitoring and recognition of human gestures by the AGVs. The objective of this UC is to control industrial operations of AGVs through human gestures without using any type of special equipment (haptic gloves, AR glasses) in order to optimize the control process. Besides, an improvement in the human-machine interaction wants to be achieved.

Human-machine interaction has become a perfect support on the production line. In this way, operators are free from repetitive tasks and can take advantage to supervise and

SUBJECT(+ CONDICTION)	COMMITMENT	VALUE
E2E Latency (Control Plane)	SHOULD	10 ms
Response time AGV (Command)	SHALL	20 ms
Video processing in Edge (Bitrate)	SHALL	5-10 Mbps per AGV
vSLAM algorithm runtime in AGV	SHALL	10 ms (5 ms + 10 ms (5G Control Plane Latency))
vSLAM algorithm runtime in Edge	SHALL	5 ms
Internal variables (Bitrate)	SHALL	128000 bps
Downlink data flow (Position, speed, orientation, % error)	SHALL	25600 bps
Uplink Communication Maintenance	SHALL	10 ms
Downlink Communication Maintenance	SHALL	10 ms
Maximum % of packet loss Uplink (vSLAM)	SHALL	1%
Maximum % of packet loss Downlink (vSLAM)	SHALL	1%

Table 1: UC1 Requirements.

maintenance tasks that robots are not able to perform.

This UC will have the ability to guide industrial AGVs by human gestures permitting easy, touch-free interaction with robots. In this UC, a software development kit from Gestoos[18] is used. Some gestures that are recognized by the software are shown in Figure 8.

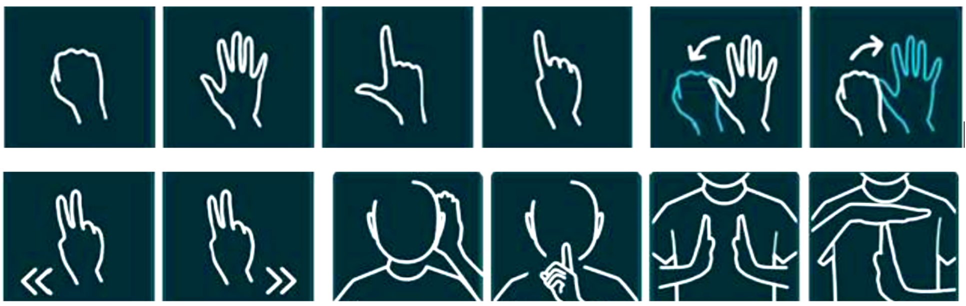


Figure 8: Available gestures.

Figure 9 shows some gestures examples using the gesture recognition software. On pictures a), b) and c) the end user makes a number with a hand pose in front of the camera of the AGV. As a result, the pose generates a command which is received by the robot. Finally, the robot moves to the area of the factory represented. On the other two d) and e) the end user makes a hand pose to stop and to run the robot.

The main advantage of this implementation is that training some gestures with AGVs,

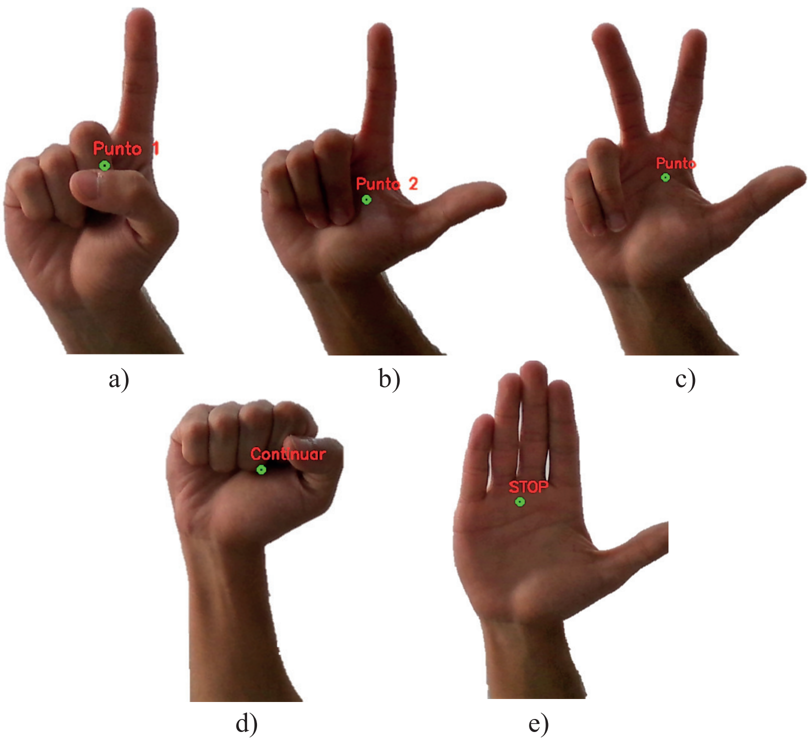


Figure 9: Gestures examples with the gesture recognition software.

for example numbers (in relation to different areas of the factory) or with orders can facilitate the work of the operators and a greater speed in the execution of tasks.

Regarding to the requirements of this UC, the latency is not a critical parameter. For example, in this UC if the AGV takes one second to react to the gesture, the operator would not perceive it slow. End to end latency should be less than human perception to achieve fluid operations. Table 2 contains the provisional requirements established for this UC.

SUBJECT(+ CONDICTION)	COMMITMENT	VALUE
Runtime Cockpit	SHALL	10 ms
Runtime Gestoos	SHALL	70 ms
E2E Latency	SHOULD	10 ms
Maximum % of packet loss Uplink (Gesture recognition)	SHALL	1%
Bitrate Uplink (UL) (Camera)	SHALL	5-10 Mbps
Bitrate Downlink (DL) (Command)	SHALL	TBD
Throughput	SHALL	min 10 Mbps
Bandwidth	SHALL	min 10 Mbps (RTP)
Edge cloud processing (gesture recognition)	SHOULD	be less than 100 ms

Table 2: UC2 Requirements.

4.3 Use Case 3: VR immersion for AGV control

This UC is based on mixed reality. Through the immersed experience, the operator will obtain a high-quality interactive perspective of what is happening where the AGVs are. Besides, it can provide to the industry extra beneficial services such as security or person recognition.

The objective of this UC is to explore VR and 5G capabilities to provide an immersive live 360 view from the AGV to a remote viewer.

If an AGV notify an error, the operator will put on the AR glasses to see what is happening in the AGV. Through the glasses the operator will be able to see the vision of a 360 degree camera installed in the AGV and specific information from the AGV as coordinates, error type The camera chosen is KANDAO QOOCAM 8K Enterprise. Moreover, new tools will be developed to reach low end-to-end latencies. That way, it can provide information on actions taken, to receive information about alerts, to determinate priority data sent, to send data to the vehicle to avoid a collision.

The main advantage of this implementation is that the operator can solve the problems that are happening almost in real time. YBVR [19] building the next generation VR video distribution platform. It is dedicated to making and producing immersive experiences during broadcasts and events. Its technology helps to broadcast, for example, a tennis match from the court to the VR glasses of the spectators, who can choose the point of view they want to see at any time instantly with their controls.

Regarding to the requirements of this UC, the low latency is essential to enable the immersive experience without delays, otherwise, the operator could feel dizzy. UL bitrate is another critical requirement of this UC. The bitrate is the amount of information that is played per second, bitrate is the amount of information which can be played per second, the more information the better the quality of the video. A video recorded in a high-quality format and with a very high resolution can look distorted and jumpy because its bitrate is very low. It is necessary that the UL bitrate be as high as possible, that way the operator will have a good 360 degree perception of the environment. The provisional requirements established for this UC are shown in Table 3.

SUBJECT(+ CONDICTION)	COMMITMENT	VALUE
Runtime NF1 (Video processing)	SHOULD	30 ms
Runtime NF2 (Video delivery)	SHOULD	20 ms
Runtime Cockpit (Optional)	SHOULD	10 ms
Glasses Latency	SHOULD	10 ms
E2E Latency	SHOULD	100 ms
Throughput	SHALL	Upload 80 Mbps
Maximum % of packet loss	SHALL	0.3%

Table 3: UC3 Requirements.

5 Ford Experimentation Facility

In this section the characteristics of the deployment area in Ford experimentation facility will be explained. The 5G-INDUCE experimentation facilities are deployed with the goal to validate and showcase over a real industrial 5G environment the developed network application. The experimentation facility in Valencia (Spain) is linked with a large industrial facility, Ford, located in Almussafes (Valencia).

Figure 10 shows an aerial view of the Ford factory. The black box includes the Ford factory surface, and the green box includes the deployment coverage area. Zooming the deployment coverage area, two areas can be differentiated on it, Figure 11. All the industrial sector operations have the same UC testing scenario. 5G-INDUCE project will explore multi-location scenarios, outdoors and indoors.

Figure 10: Coverage area in Ford factory.

- **Scenario 1:** Outdoor transport operations between different outdoor warehouses of Ford (supplier area to production halls). It will be using a specific outdoor AGV, tractor AGV (Figure 12 - left). Table 4 shows its characteristics.
- **Scenario 2:** Indoor transport in Ford warehouses, coordinated with transportation of pieces from scenario 1. Several indoor AGVs, platform AGVs (Figure 12 - right) to perform the same transport missions using the indoor SLAM location. Table 5 shows its characteristics.

Figure 11: Multi-locations scenarios, outdoor and indoor in coverage area in Ford factory.

Figure 12: Tractor AGV (left) and platform AGV (right)[20][21].

	TRIBOT 5000 (Tractor AGV)
Towing capacity	5000 Kg
Dimensions (LxWxH)(mm)	1221 x 695 x 762
Environment	From 0.035 to 2.5
Navigation	Magnetic / SLAM + Magnetic (Dual navigation)

Table 4: Tractor AGV characteristics[20].

	EBOT 350 (platform AGV)
Payload	350 kg
Dimensions (LxWxH)(mm)	1052 x 660 x 352
Lifting table	120 mm stroke
Movement	Omnidirectional
Speed range	From 0.05 to 1.7
Navigation	QR Codes/SLAM - Natural Navigation with pre-defined virtual path

Table 5: Platform AGV characteristics[21].

Figure 13 shown the AGV path in Ford premises . As explained previously in section 4 the AGV path will start on the red flag. The change of AGV is produced when the area changes from indoor to outdoor. The AGV path will finish on the green flag.

Figure 13: AGV path in Ford factory.

6 Results

This section shows the results obtained in this project. First, a common network architecture is proposed for the three UCs mentioned. It also defines and analyses the architecture of each UC and its network functions. Below, the advantages and disadvantages of each proposed location will be analysed with the aim of achieving an optimal deployment. Finally, 5G network deployment in Ford is explained.

6.1 5G Architecture

In this section the general 5G architecture will be explained in detail. It will allow 5G network functions and applications to run in different locations with compute resources, for example, on-premise, on cloud, or hybrid architectures (close data center, far data center). We will work with a standalone 5G architecture, autonomous 5G, in which the user plane (data) and control plane (signaling) are separated.

The Valencia 5G experimental facility, will be built on top of the 5TONIC co-creation laboratory [22], an open research and innovation lab for 5G technologies. It will use an end-to-end 5G network that allows to experiment under a wide set of technical conditions in order to validate specific vertical UCs.

Ericsson is the partner providing both Radio Access Network (RAN) and 5G Core network in the laboratory. The infrastructure supports two types of common 5G services: eMBB and mMTC.

The network deployment is composed on the one hand by the RAN and the 5G Core user-plane, which are the elements deployed near the users in Valencia and allows to connect through a secure connection with the 5TONIC central core for managing the control plane.

The control plane is composed by the 5G Core and its network functions (AMF (Access and Mobility Management Function), UDM, UDR). 5G provides a distributed network across different sites using remote coverage. This part of the network will be deployed in Ericsson, Madrid. Figure 13 shows the overall architecture of the three UCs.

In the proposed architecture, the main components to the three UCs are shown:

- **5G Modem:** It is provided by Fivecomm. It provides 5G New Radio connection adn uses the 3.5 GHz frequency band.
- **gNB (Next generation Node B):** it is part of the radio access network, the 5G radio base station. It is only used when referring to an NR base station connected to 5G Core Network. It also works at 3.5 GHz frequency band. These antennas can be replaced further with millimetre antennas (mmWave), for applications in the millimetre frequency band.
- **UPF (User Plane Function):** It is one of the NFs of the 5G Core network. It is the responsible of forwarding the traffic, packet routing and applying QoS rules[8].
- **VPN:** Through VPN will be connected to 5G Core.

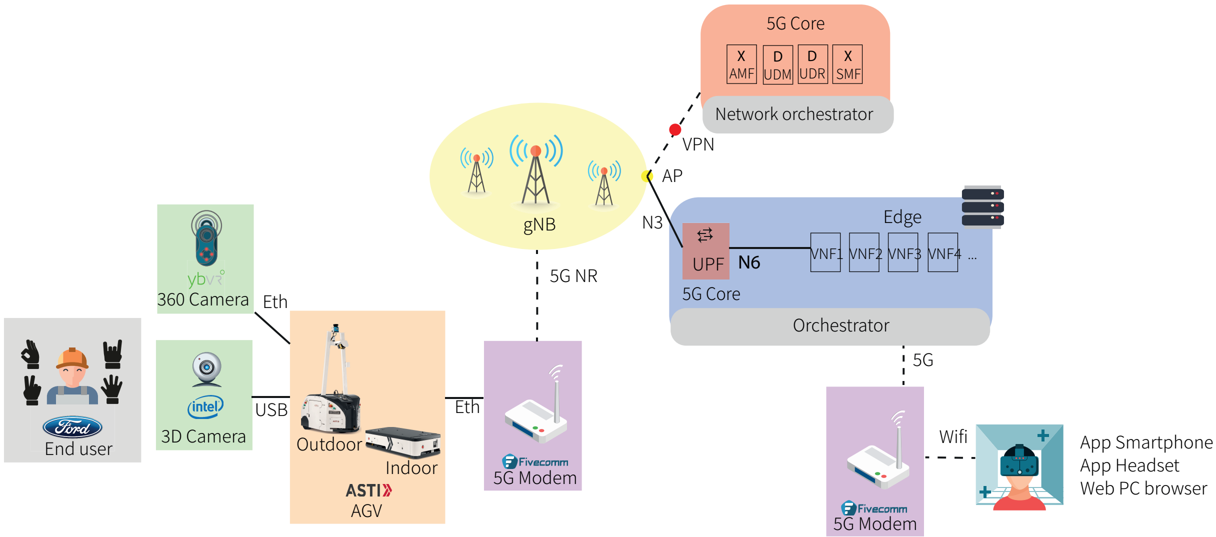


Figure 14: Overall 5G architecture in Ford factory.

- **5G Core:** It is the main element of a 5G mobile network. It establishes reliable and secure connectivity for end users and provides access to its services. It handles many essential functions in the mobile network such as connectivity, mobility management, authentication, policy management[7].
- **Edge:** It is an intermediate node in which data is processed at the edge of the network, as close to it as possible.

The main interfaces are:

- **N3:** It is the interface between the RAN (gNB) and the UPF.
- **N6:** It is the interface between the UPF and the data network.

Two orchestrators of resources are used to manage computing capacity one in 5TONIC and one in the Edge.

The data path and the NFs of each UC will be analysed below:

6.1.1 Use Case 1: Autonomous indoor fleet management

In this UC, the information (position of AGV took by a LiDAR sensor) will go from the AGV, connected to the 5G modem to the edge where commands (UDP (User Datagram Protocol) will be processed, and the response (order) will be sent back to the AGV (NUC PC (Next Unit of Computing Personal Computer)).

The network application is formed by four VNFs (run at the edge):

- **Trolley detector VNF:** To know the exact position of the trolley. The AGV needs to know where the trolley is located.

- **AGV coordinator VNF:** To know the state in which the AGVs are.
- **Logistic Process manager VNF:** Request to de AGV coordinator the AGV states.
- **VSLAM VNF:** To provide vSLAM localization from the AGVs to the AGV coordinator.

Figure 15 shows the application graph of UC1.

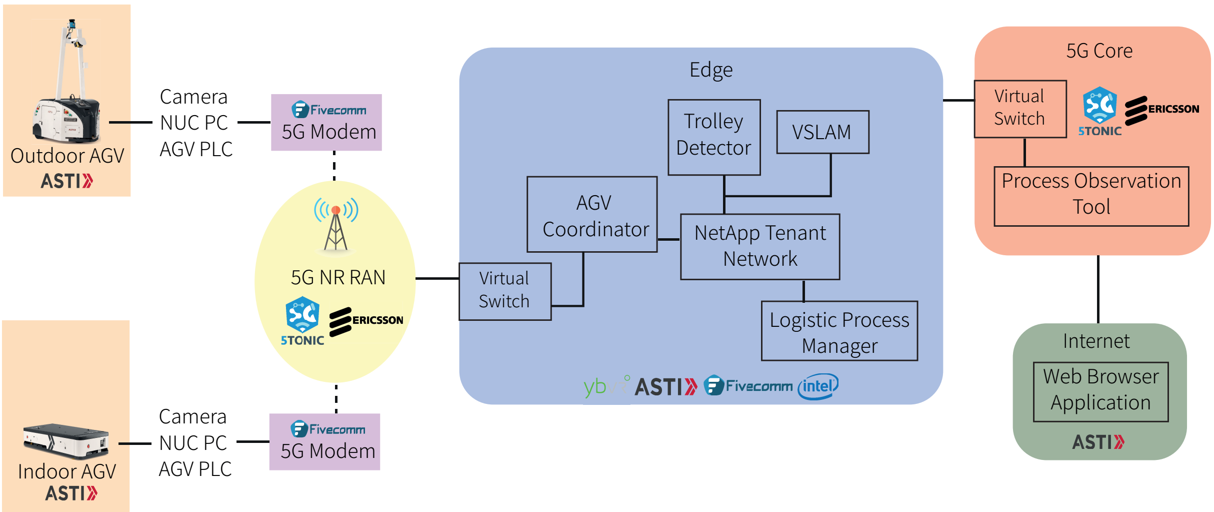


Figure 15: VNFs in UC1.

To carry out the virtualization, in a single Dockerfile the four VNFs will be merged. A potential performance improvement will be experimented, this way, the final integration with the orchestrator of resources will be easier.

The use of a 5G architecture with Edge computing allows low latencies and very short processing times, thus being able to achieve real time control of the AGVs.

6.1.2 Use Case 2: Smart AGV operation based on human gesture recognition

In this UC, the information will go from the industry operator to the Edge where the command will be sent back, Figure 16. The industry operator makes a gesture, this gesture is recognized by the camera. The AGV, located in the experimentation facility of Ford, receives the RGB (Red Green Blue)/depth and gesture info from the 3D (3 dimensional) camera placed in the AGV. The 5G modem, connected to the AGV will send the video stream encoded using H.264 and RTP (Real-time Transport Protocol) protocol to the edge. In the edge, the video will be decoded to process it (frame by frame). The algorithm detects the gesture and selects the different commands to be sent to the AGV. The raw processed video from the 3D camera will be encoded again using H.264 and RTP to be sent back to the AGV (UDP command). The AGV will move, stop, or change its direction depending on the workers order.

The network application is formed by three VNFs (run at the edge):

- **Video encoding/decoding VNF:** To encode and decode the video stream.
- **Gesture recognition VNF:** Detects the gesture and select the different commands to be sent to the AGV.
- **AGV control VNF:** Translate the selected command into a compatible AGV order, using UDP frames with JSON (JavaScript Object Notation) format.

Figure 16 shows the application graph of UC2.

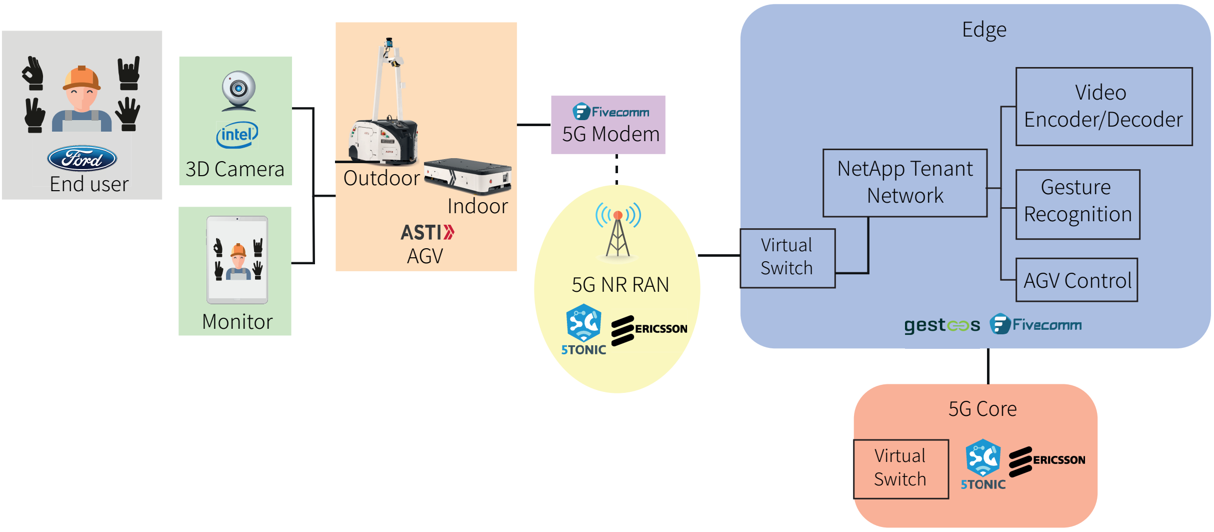


Figure 16: VNFs in UC2.

To carry out the virtualization in a single Dockerfile the three NFs will be merged.

In this UC, the use of a 5G architecture with Edge computing provides real time monitoring of the Ford factory. The SDK (Software Development Kit) could be run in the AGV by itself without edge computing and 5G, but processing times would be much longer (encoding/decoding) and the speed of the network would be lower (no advanced prediction failures).

6.1.3 Use Case 3: VR immersion and AGV control

The 360 camera is mounted on an AGV. It must acquire an IP (Internet Protocol) address from a DHCP (Dynamic Host Configuration Protocol) server in order to work. It outputs RTMP (Real Time Messaging Protocol) video (up to 80 Mbps) over built-in Wi-Fi. The RTMP video reaches a network application capable of processing this video flow and streaming to different devices. The information will go from the 360 degree camera connected to the 5G modem to the Edge, where the video will be processed. The response order will be sent back to the AGV in a different way.

The network application is formed by two VNFs (run at the edge):

- **Equirectangular video processing VNF:** Takes a 360 Video, processes, and overlays relevant information from AGV Telemetry.

- **Video delivery VNF:** Takes prepared video and packages for video streaming over multiple platforms.

Figure 17 shows the application graph of UC3.

In the same way to carry out the virtualization, in a single Dockerfile the two VNFs will be merged.

In this case, the use of a 5G architecture with Edge computing allows to achieve AGV remote control in real time through virtual reality. Moreover, some additional implementations will be tested to analyze the latency in each of them such as: app headset, app smartphone, web PC browser...

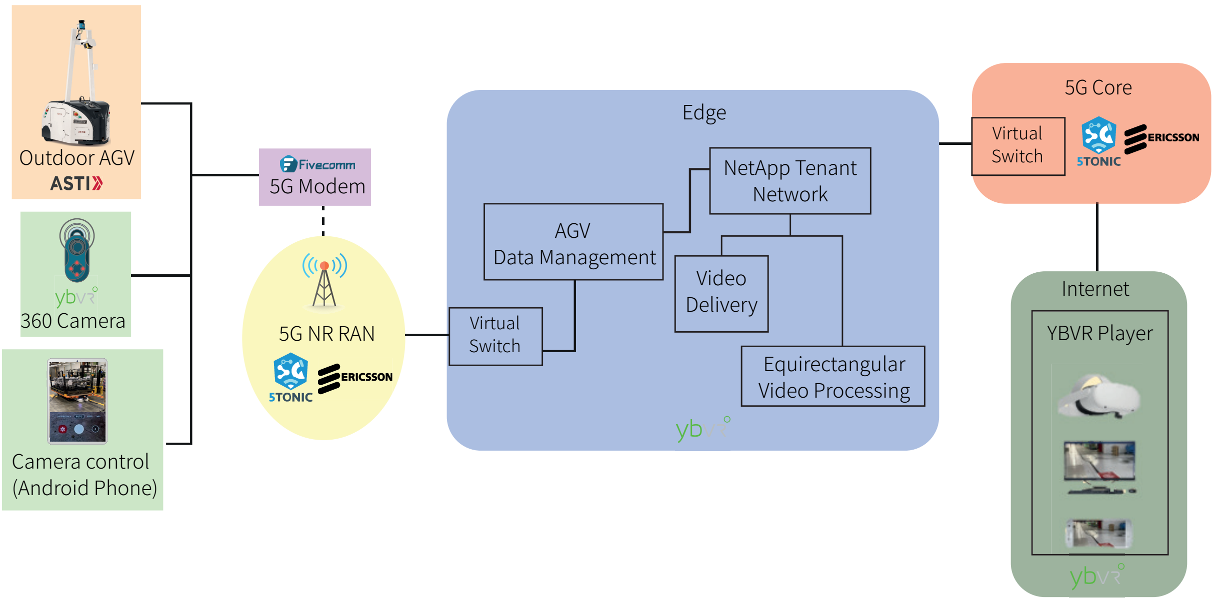


Figure 17: VNFs in UC3.

6.2 Edge and Cloud Computing Network Deployments

In this section, in order to find the deployment that provides the best results, 5G network functions and applications are analyzed in different locations with compute resources: on-premise, on cloud, near-far edge and hybrid edge-cloud solutions. Besides, the advantages and disadvantages of edge computing and cloud computing have been analysed in different location.

The Table 6 below shows the characteristics, the technical and non-technical requirements of each location.

There is also a hybrid edge-cloud solution that combines both technologies. This solution integrates server hosting in a data center (on-premise, near edge or far edge) with the ability to move certain workloads to the cloud.

Edge is used when the latency is a fundamental requirement, while Cloud allows to analyze large amounts of data simultaneously[23]. The advantages and disadvantages of edge and cloud computing are discussed below.

TYPE	CHARACTERISTICS	TECHNICAL REQUIREMENTS	NON TECHNICAL REQUIREMENTS
CLOUD	Less than thousand km away from the device	Wide area access and multi-tenancy	Public and generic hardware and software
NEAR EDGE (In-Country Data Center)	Several hundred km away from the device	Wide area access and multy-tenancy	Public and hardware and software tend to increase multi-tenancy ratio and efficiency
FAR EDGE (Telecommunication towers)	Covering a certain area (100 km) and near premise (50 km)	Wide area access, multy-tenancy and local area	Public and specific hardware and software configuration
ON-PREMISE EDGE	Close to data source 0-5 km (depends on coverage area)	It may require real time connectivity	Private and highly depending on verticals

Table 6: Edge and Cloud computing locations[14].

6.2.1 Edge Computing

Table 7 shows the advantages and disadvantages of Edge Computing.

ADVANTAGES	DISADVANTAGES
Proximity: The devices are located close to the data generating equipment, facilitating their control	More hardware
Location: It works in isolation from the rest of the network	Unrecoverable data
Reduced latency: Network delays are reduced (high speed)	
Bandwidth savings: Only specific data is processed so bandwidth consumption is reduced	
Immediacy: Analyse large volume of data in near real time	
Cybersecurity: It reduces the amount of data hosted in Cloud and decentralizes it. In case of on-premise edge computing everything is centralized, and it does not go outside	

Table 7: Pros and cons Edge computing[24], [25], [26], [27].

6.2.2 Cloud Computing

Table 8 shows the advantages and disadvantages of Cloud Computing.

ADVANTAGES	DISADVANTAGES
Scalability and flexibility	**Loss of control of shared data**
Cost savings: Demand use and less hardware	**Security:** at centralized points
Remote access	**Internet:** depends on internet, require fast and stable connection
Automatic updates	
External computing: less load on equipment	

Table 8: Pros and cons Cloud computing[23], [27].

To sum up both tables, Table 9 shows a comparison between edge and cloud computing from - - (very bad), - (bad), + (good) to + + (very good).

CONCEPT	EDGE COMPUTING	CLOUD COMPUTING
COST	-	++
LATENCY	++	-
FLEXIBILITY	+	++
BANDWIDTH	++	+
EQUIPMENT	-	++
IMMEDIACY	+	-

Table 9: Edge and Cloud computing comparation.

6.3 5G Network Deployments

Modifying the location of the elements of the network allows to obtain different hybrid edge-cloud architectures in 5G networks as mentioned before. Figure 18 shows three different deployments of a 5G architecture. The first one, all in the factory (on-premise). The second one, a hybrid solution in which the control plane is remote and the UPF is decentralized at the edge, and the third with everything outside the factory (outdoor). In the second case, three types of edges are proposed: edge on-premise, far edge, a telecommunications tower such as the solution of Cellnex company or near edge, in an in-country data center as Telefonica company data centers.

This project proposes to modify the location of two of the elements of the network the UPF and the Edge. The proposed locations for the UPF are the UPF on-premise (complete 5G Core in Ericsson, Madrid), the UPF separated for the rest of the 5G Core (decentralized) in Ford Valencia, in UPV Valencia (not yet confirmed) as a near-far edge

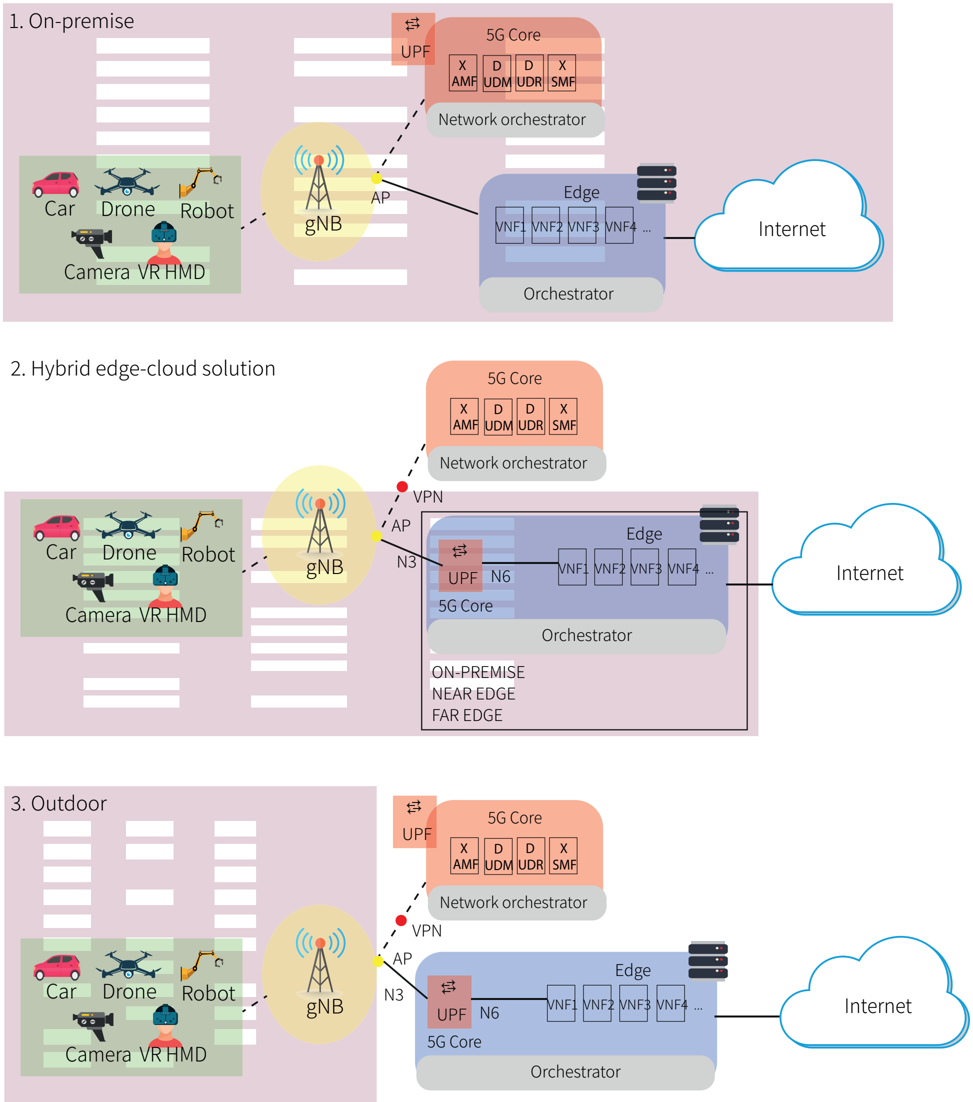


Figure 18: Deployments of a 5G architecture[28].

or in an in-country data center of Telefonica as a near edge, in this case the location is unknown. The proposed locations for the Edge are edge on-premise (Ford Valencia) or in UPV Valencia (decentralized). There are also hybrid locations such as the UPF on-premise and the edge in an In-country data center or in a far edge. Notice that the control plane is not critical so there is a possibility that it could go on cloud with the UPF applications as long as the security requirements are met.

6.3.1 User Plane Function (UPF) Locations

The main goal of modifying the location of the UPF is to adapt to the needs of the client getting the best possible results. At the moment, three locations will be analysed:

- **UPF on-premise:** The UPF is located at the enterprises own facilities. Their core purposes have been kept the complete control within the organization. That way, the data security is very high because the data is stored and managed only within the enterprise. These are designed to be as close to the end-user as possible, where latency is lowest. The control plane traffic is faster, Table 10.

UPF ON-PREMISE	OBSERVATION
Cost	High, it is not always easy for a single company to implement a 5G Core. It is necessary to acquire dedicated hardware
Latency	Very low, as close to the end-user as possible.
Flexibility	Very low, the hardware supports a number of resources, if it is needed to increase it over time, it would be necessary to acquire more.

Table 10: Overall analysis of UPF on-premise.

- **UPF in UPV/Ford/ Telefonica (hybrid architecture):** The UPF is located outside the factory, so the traffic can go to the UPF and then come back inside the enterprise. In this location security mechanisms are necessary. In this architecture, the network latency is higher. The data security is lower, it is lower than the previous one because generated data go outside the enterprise, Table 11.

UPF (HYBRID ARCHITECTURE)	OBSERVATION
Cost	The cost may be shared between more than one company
Latency	High, it can be a significant problem depending on the distance
Flexibility	Low, the chance of resolving a problem is not as easy as in on-premise deployment

Table 11: Overall analysis of UPF in a hybrid architecture.

6.3.2 Edge Locations

The main goal of implementing edge computing is to shorten the path to data processing. Two locations are being considered better:

- **Edge on- premise:** The edge located at the Ford factory, as close as the end-user as possible. In this architecture the speed is an essential requirement. The edge can be deployed in different ways, as one or two servers, as a rack collocated in the existing on-premise data centre, or as a mini-data centre enclosure which could be up to a single rack, Table 12.

EDGE ON-PREMISE	OBSERVATION
Cost	Low, there is few physical equipment
Latency	Low, the location is as close as possible to the place where the data is generated
Flexibility	High, lower than the cloud, able to dispose internally in the company without depending on third parties

Table 12: Overall analysis of Edge on-premise.

- **Edge in UPV (hybrid architecture):** The Edge is located furthermost from the enterprise. That way the traffic must go to the edge and then come back, Table 13.

UPF (HYBRID ARCHITECTURE)	OBSERVATION
Cost	Low, sometimes a close data center cost less than a private data center, due to the expenses involved in developing all the infrastructure
Latency	Low, it is bigger than the previous one because it is further away
Flexibility	High, lower than the cloud, to be able to dispose internally in the company without depending on third parties

Table 13: Overall analysis of Edge in a hybrid architecture.

6.4 5G Network Deployment in Ford Factory

In this section, the 5G Radio Access Network that will be deployed in Ford is described.

At the end of this section, indicative design layouts (produced with AutoCAD) are provided. Layout 01 shows the AGV itinerary in Ford factory. The red point shows the start of the route, load point. The green one shows the end of the route, unload point. The blue line corresponds with the AGV itinerary inside the motor factory.

6.4.1 Radio Solution

This section explains a possible rethinking of the infrastructure. Coverage is needed throughout the deployment area (approximated 23.000 m2). Layout 02 shows the indoor radio solution found. Highlighted with an orange cross is the location of the DOTs and with purple box the position of the Flight Rack. This design will be analyzed with the coverage planner tool that simulates the area and decide the best place to cover the AGV itinerary. Flight Rack must be positioned in a protected place with ventilation and secure from industrial dust.

The elements mentioned for radio solution are explained in Table 14:

5G Radio DOT: is the smallest Ericsson antenna planned for indoor coverage. It offers an innovative and high performing solution that effectively connects indoor users to the whole mobile ecosystem.

5G Flight Rack: 19" rack flight case for professional mixer or other equipment. Manufactured in coated plywood. Hermetically closing lid, carrying handles, rubber feet, and metal protective corner pieces. Robust construction for transporting and protecting the equipment inside the rack.

Table 14: Elements for radio solution.

Flight Rack includes all the 5G RAN equipment, Figure 19. 5G RAN equipment is explained below:

- **Baseband 6630:** It provides switching, traffic management, timing, baseband processing, and radio interfacing. The baseband units in the 19-inch format, with 15 Common Public Radio Interface (CPRI) ports, enable increased connectivity for radio units.
- **Router 6471:** It is a high-capacity access router, designed to provide high density 10 interfaces. It supports VPN services over IP/MPLS (Multiprotocol Label Switching) networks, service provider SDN, extensive quality of service and precise synchronization features. With 100 Gbps of switching capacity, the Router 6471 delivers wire-speed performance to fully support LTE (Long Term Evolution), LTE Advanced, 5G, access sites.
- **5G IRU 8846:** The main purpose of the IRU is the transmission of signals providing an interface to the RDs (Radio Dots) through the Radio Dot Interface (RDI) and

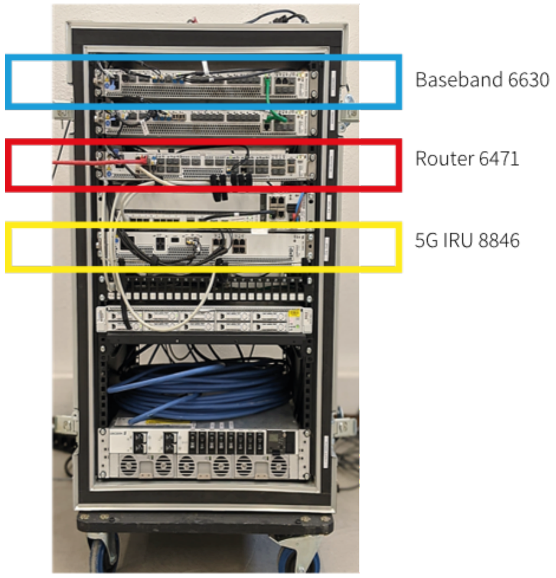


Figure 19: 5G RAN equipment.

supplies power to the RDs through the RDI. It can be mounted in a standard 19 rack, or in a remote location using the included wall mounting brackets. It can utilize either AC (Alternating Current) or DC (Direct current) power supply.

Figure 20 shows the RAN parts that will be installed in Ford Factory. Moreover, a GNSS (Global navigation satellite system) Active Antenna from GPS (Global Positioning System) are used. It is for the TDD (Time Division Duplex) synchronization. In relation to the cables to be used, Ethernet cable must be CAT6ax/FTP where x could be F, S or U, the fiber optic is standard fiber par, Ericsson will provide the 10 Gbps SFTP (Secure File Transfer Protocol) to connect. Finally, GPS cable is a standar RJ45 but with a special PIN definition.

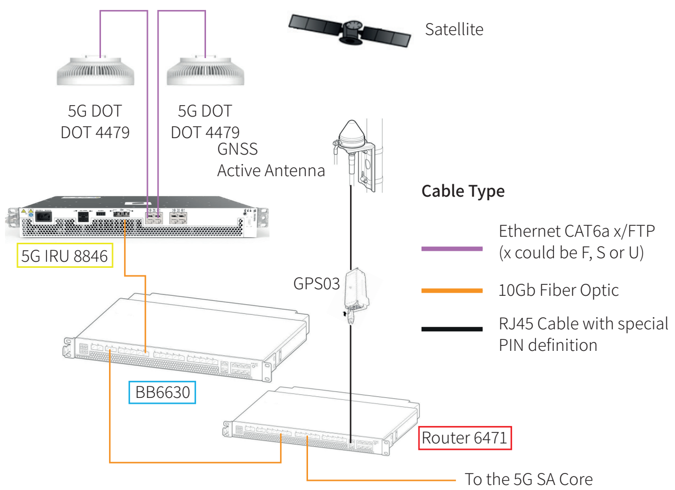


Figure 20: Installation design in FORD Factory.

On the other hand, indoor and outdoor radio solution has been proposed. Its current use will not be confirmed until the coverage tests are carried out. From the outdoor perspective, Layout 02 shows outdoor solution too, the yellow star represents the outdoor antenna. Generally, indoor coverage is covered by DOTs that are also designed with this purpose, and outdoor area will be covered with an outdoor antenna AIR6488, also designed for this purpose. However, the design will be analyzed with the coverage planner tool that simulates the area and decide the best antennas to cover the AGV track.

Finally, if the outdoor antenna, AIR6488 will be placed in the following coordinates (39.322198, -0.420733), Figure 21 and covering south area from the antenna, Figure 22.

Figure 21: AIR6488 coordinates.

The element mentioned for radio solution is explained in Table 15.

AIR6488:: 5G Advanced Antenna System (AAS), with 64 transmitters and 64 receivers. Enhanced bitrate per user achieved through interference suppression by applying beamforming capabilities in the downlink and the uplink.

Table 15: Outdoor element for radio solution.

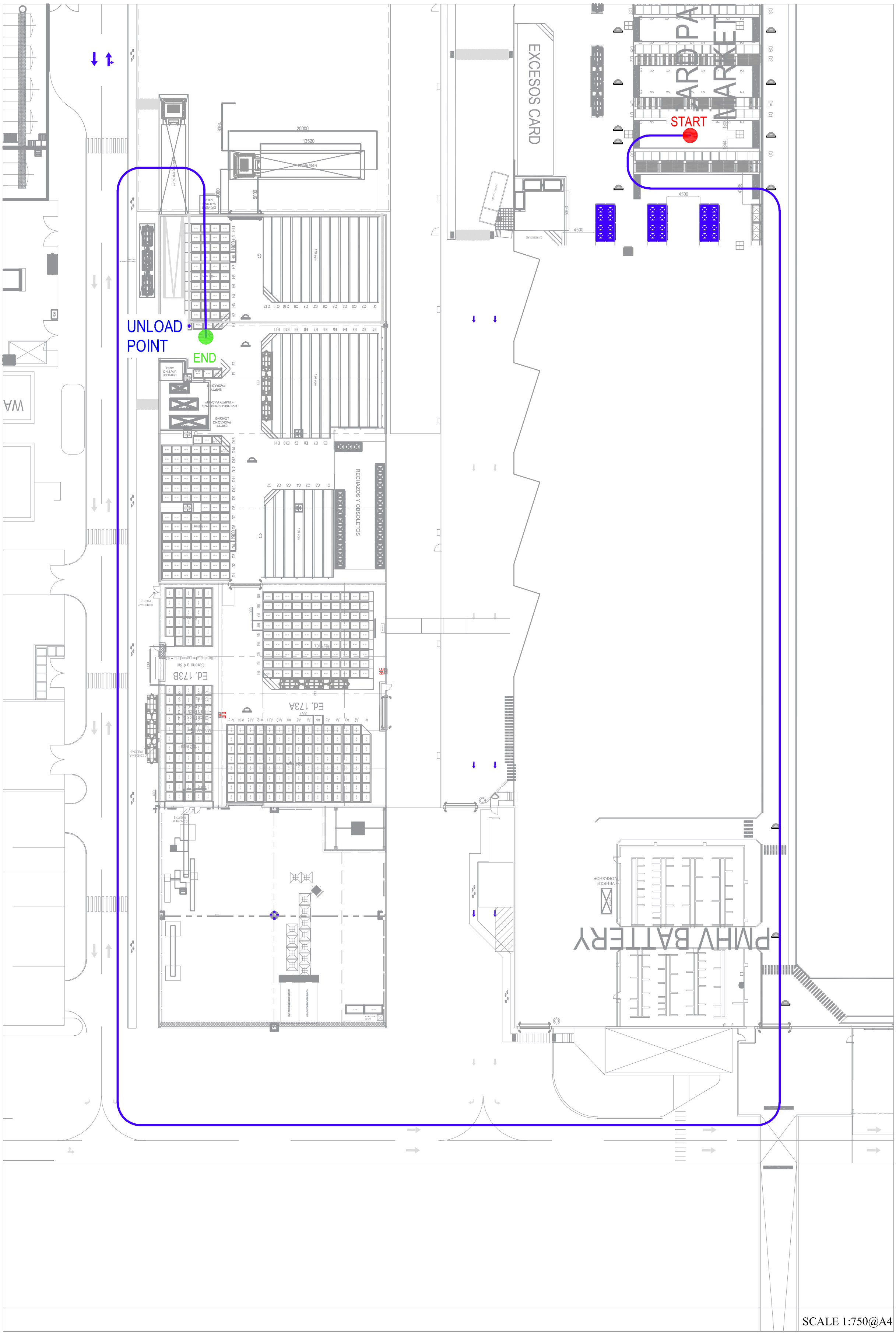
Regarding the radio specifications, Table 16 shows the radio specifications to take into consideration. Both antennas work in the same band and with the same central frequency

Figure 22: Outdoor antenna AIR6488 coverage.

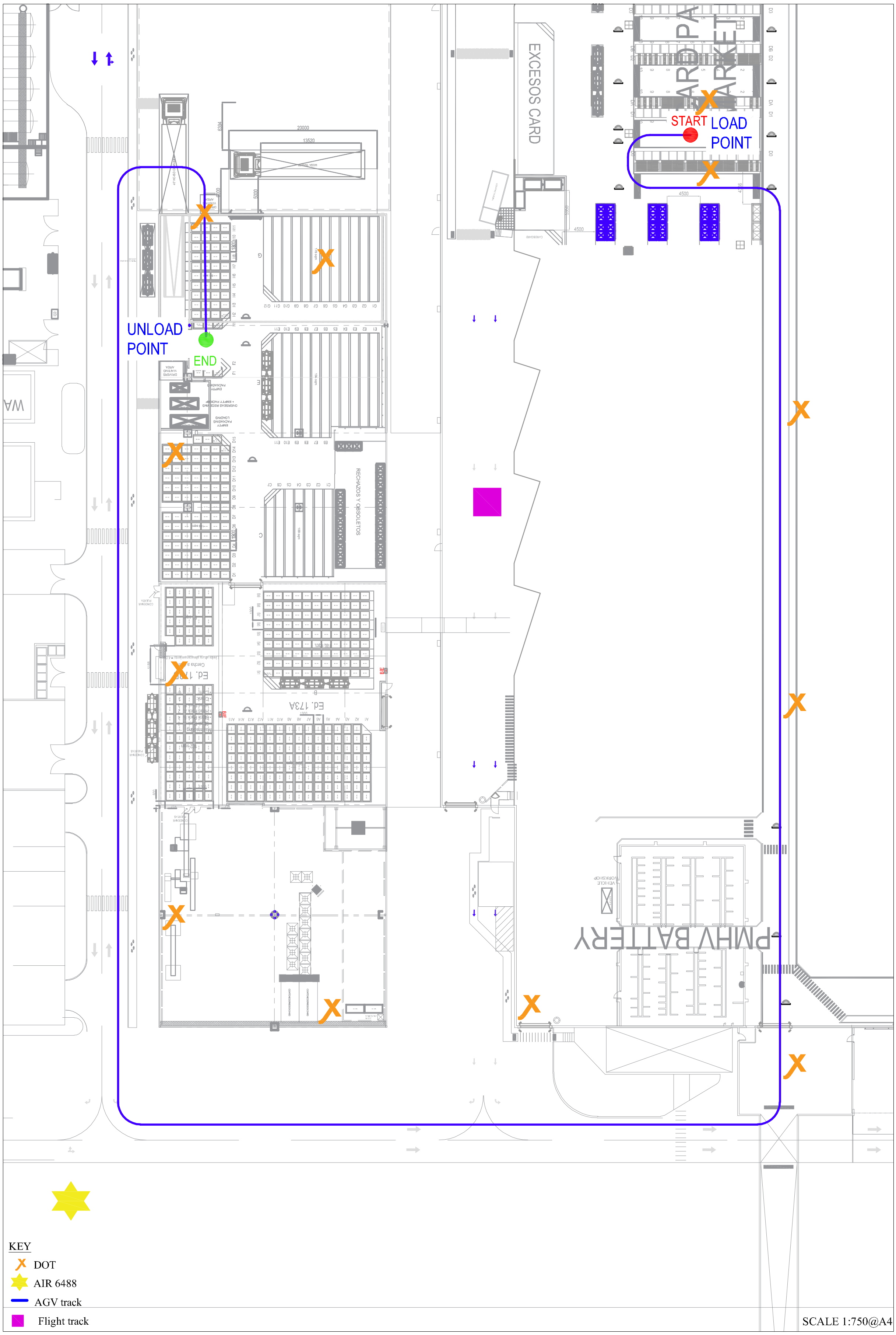
and bandwidth. The output power and beamwidth will be the main difference as they are design for different purposes. Take in consideration that the DOT is similar to an omnidirectional antenna that is the reason the Vertical and Horizontal beamwidth is not considered.

MODEL	ANTENNA	FRECUENCY	MAXIMUM OUTPUT POWER
DOT 4479	Indoor	Band 78: Central frequency 3775 MHz and bandwidth 50 MHz	EIRP:4x24 dBm, 4x250 mW
AIR 6488	Outdoor	Band 78: Central frequency 3775 MHz and bandwidth 50 MHz	Macro = 1x69 dBm,2x200 W Hotspot = 1x64 dBm, 2x200 W Highrise = 1x69 dBm, 2x200 W

Table 16: Radio specifications.



Layout 01: shows the AGV itinerary in the Ford factory



Layout 02: indoor and outdoor solution

7 Conclusions and Lessons Learned

The goal of this document is to analyse the ambition of finding the best deployment of antennas in real industrial scenarios. Such locations have been found withing the context of several UCs that belong to the European project 5G-INDUCE. Additionally, the information used in the project has been collected and exposed in this document with the intention that the reader can draw their own conclusions and evaluate the types of deployments in which are maybe good to use 5G.

The conclusions obtained as part of this project are presented below:

- 5G has driven the industry's global economic growth. This mobile technology increases connection speed, minimizes latency, and multiplies exponentially multiplies the number of connected devices. Combining 5G with other technologies such as Edge and Cloud computing increases its advantages.
- The importance of choosing the right network deployment should be highlighted. It can be seen in section 3 that each application has requirements to achieve. For example, it has been seen how in some of them, the latency is a critical parameter to avoid collisions in comparison to others, in which it is something not relevant. This gives greater priority to the flexibility of the deployment or the transmission of the video.
- It has been verified that the virtualization is a key factor in 5G deployments both NFs and applications. Virtualization allows to reduce costs in practically all fields from the installation and configuration of equipment to the processes of backup, monitoring, management, and administration of the infrastructure. It decreases the number of physical servers needed and the percentage of disuse of the resources they have, increasing their energy efficiency. It also gives the possibility of centralizing and automating processes whose administration consumes a lot of time keeping the quality of the service high.
- In terms of the results obtained out of the three architectures mentioned, the one that involves the lowest cost is cloud. Moreover, if over the time the computing capacity increases, it is the most scalable solution. Its disadvantages are latency and security, times are longer, and the data is not on-premise, so the risk is greater (need for security mechanisms). Because of this, hybrid architectures emerge in which the part of the deployment that is not critical in latency is moved to the cloud and the rest of the deployment moves to the edge. This way the data path is shortened and latency is reduced which means an increase in the cost because hardware is necessary, but the information is closer to the source, so the control is greater.

8 Acknowlegment

It has been seven months since I started this project, and today I would like to say thank you to everyone who has been supporting me during this period.

It has been an important period of personal and academic learning. I had never been involved before in a project of this magnitude and its development has helped me to better understand the topic. At personal level, I have been resolutive with new situations and I have easily adapted to new challenges.

I would like to thank my tutor David Gómez Barquero for offering me the opportunity to develop this project and support me during the process.

I thank my Ericsson coordinators, Manuel Lorenzo Hernández and Marc Mollà Roselló (Ericsson) for their support from the beginning offering help me and facilitating everything always guiding me in the best way.

Finally, I thank my parents, my sister and my friends for their patience and understanding. For holding me day and night even from the distance. Because you always have words of encouragement that is what I feel more strength and desire to continue.

References

[1] *G. Wilson, Capgemini: Early 5G Adopters Experience Improved Efficiency, Lean Manufacturing, 2021* https://manufacturingglobal.com/lean-manufacturing/capgemini-early-5g-adopters-experience-improved-efficiency

[2] *M. Roberts & E. Siegle & J. Watson & Gareth Sims, 5G Impact 2030, Omdia, Orange, 2021*

[3] *G. Brown, et al. Ultra-reliable low-latency 5G for industrial automation. Technol. Rep. Qualcomm, 2018, vol. 2, p. 52065394.*

[4] *Ford Media Center, Ford offers Voluntary separation programs in Germany and UK as it continues to transform its business in Europe, 2019, Germany.* https://media.ford.com/content/fordmedia/feu/en/news/2019/03/15/ford-offers-voluntary-separation-programs-in-germany-and-uk-as-i.html

[5] *J. M. Echeverri & P. A. Escobar, Caracterizacin de un AGV (vehculo guiado automticamente) en el sistema de manufactura flexible, Centro Tecnolgico de Automatizacin CTAI de la Pontificia Universidad Javeriana.*

[6] *E. Fersman, What are cobots and how will they impact the future of manufacturing?, 2020* https://www.ericsson.com/en/blog/2020/5/what-are-cobots-and-the-future-of-manufacturing

[7] *S. Rommer & P. Hedman, M. Olsson, S. Sultana, C. Mulligan,5G Core Networks, Academic Press, 2020, chapter 11 - Introduction.*

[8] *D. Cheung, 5G Core Part 1 Architecture Overview, 2020* https://derekcheung.medium.com/5g-core-pdu-session-and-qos-part-1-a12852e1b342

[9] *M. Ivezic, Introduction to 3GPP and 3GPP 5G Releases 15, 16 and 17, 2020* https://5g.security/5g-technology/5g-3gpp-releases-15-16-17/?cv=1

[10] *Release 16, 3GPPP a global iniciative* https://www.3gpp.org/release-15

[11] *Release 17, 3GPPP a global iniciative* https://www.3gpp.org/release-16

[12] *Release 18, 3GPPP a global iniciative* https://www.3gpp.org/release-17

[13] *L. A. Thomas, Edge Cloud: The Future Technology for Internet of Things. In P. Raj, & S. Koteeswaran (Eds.), Novel Practices and Trends in Grid and Cloud Computing (pp. 107-131), 2019, IGI Global.*

[14] *European Commission, European industrial technology roadmap for the next generation cloud-edge offering, Report, 2021*

[15] *Kaloom and Red Hat,A Unified Solution for the Distributed Edge, 2021* http://www.kaloom.com/products/cloud-edge-fabric

[16] *The Linux Foundation, State of the Edge 2020 - A Market and Ecosystem Report for Edge Computing, 2020* http://www.stateoftheedge.com

[17] *RedHat, Virtualiacin Qu es la NFV?* https://www.redhat.com/es/topics/virtualization/what-is-nfv

[18] https://gestoos.com/

[19] https://www.ybvr.com/

[20] *Tractor AGVs, ASTI Mobile Robots* https://www.astimobilerobotics.com/tractor

[21] *Ebots, ASTI Mobile Robots* https://www.astimobilerobotics.com/platform-under-1000

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

[23] *Nokia, The edge cloud: an agile foundation to support advanced new services, White Paper, 2018*

[24] *A. Cummis, Qu es cloud computing?, 2010* https://geeksroom.com/2010/04/16293/16293/?cn-reloaded=1

[25] *Juniper Networks, Distributed Data Centers within the Juniper Networks Mobile Cloud Architecture, White Paper, 2017* https://www.juniper.net/us/en/research-topics/what-is-multi-access-edge-computing.html

[26] *Oasys, Edge Computing: Ventajas y mejora de la ciberseguridad, 2021* https://oasys-sw.com/edge-computing-ventajas-ciberseguridad/

[27] *Near By Sensor - Edge Computing Company, Edge computing VS cloud computing* https://nearbysensor.com/edge-computing-vs-cloud-computing/

[28] *H. J. Son, MEC Concept and Deployment Architecture in 4G and 5G Network, 2019* https://netmanias.com/en/post/oneshot/14276/5g-iot-kt-sk-telecom/mec-concept-and-deployment-architecture-in-4g-and-5g-network