SCIENTIFIC PAPER

5G-Enabled AGVS for industrial and logistics environments

Andrea Fernández Sierra[1], Raúl Lozano[1], Iván Ibáñez[1], David Gomez-Barquero[1], Manuel Lorenzo[2] and Manuel Fuentes[3].

Institute of Telecommunications and Multimedia Applications (iTEAM)
Universitat Politècnica de València
8G Building - access D - Camino de Vera s/n
46022 Valencia (Spain)

1. iTEAM: anfersi2@iteam.upv.es, raulote@iteam.upv.es, ivibza@iteam.upv.es, dagobar@iteam.upv.es
2. Ericsson: manuel.lorenzo@ericsson.com
3. Fivecomm: manuel.fuentes@fivecomm.eu

ABSTRACT

5G has changed the telecommunications industry, allowing a new generation of devices and applications to be connected. These provide a more friendly and efficient environment to operators, who manage systems and devices that require real-time connectivity as well as ultra-high reliability. One of the most exciting use cases that 5G brings is the remote driving of Automated Guided Vehicles (AGVs) in industrial and logistics environments. This work proposes, in the context of the 5G-INDUCE and iNGENIOUS projects, two different use cases that will be deployed in Valencia. The paper describes the early prototypes that have been analyzed and tested to explore the capabilities of such use cases.

Keywords: *5G, edge computing, artificial intelligence, AGV, gesture recognition, haptic gloves, tactile internet.*

1. Automated guided vehicles: impact on the Industry 4.0AGVs are highly flexible, intelligent, and versatile systems used to transport materials from different loading points of the facilities of an industrial environment [1]. The design of AGV environments needs some considerations, such as the design of trajectories, number of vehicles that comprise the system, requirements, type of materials to transport, and how, when and where the loading and unloading of materials will 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 gaining a foothold in hundreds of companies. In the industry and manufacturing areas, autonomous robots enable customization and optimization of the production lines. AGVs are more suited than humans for certain tasks, in particular for hazardous or repetitive situations given in industrial environments. AGVs used to work guided through black lines, but in the last years these guides have disappeared, allowing AGVs to freely move around the factory. For this reason, advanced AGVs are also known as Autonomous Mobile Robots (AMRs).

The migration from fixed to mobile paths is provided by two main key enablers. On the one hand, robots are in fact getting more autonomous thanks to Artificial Intelligence and Machine Learning (AI/ML), thus they can take decisions and create new paths in real time. On the other hand, 5G wireless technologies allow not only high data rates, but also with extremely low latency.

In general, the deployment of mobile robots is only possible increasing flexibility, which can be achieved by innovative network architectures such as Multi-Access Edge Computing (MEC). It consists in bringing cloud computing closer to the senders and receivers of the data, in such a way that the times in the transmission of the information are cut operating in real time. In combination with 5G, MEC will allow vehicles to talk to each other fluently, so that an external vehicle can unload in another interior without manual intervention, controlled by the network.

One of the applications of 5G in the industry is the use of collaborative robots (cobots), with hardly any human supervision. The synchrony must be almost absolute, a matter of milliseconds, and that is the reason why edge computing is a key element in the future of the industry. It is about bringing cloud computing closer to the senders and receivers of the data, in such a way that the times in the transmission of the information are cut operating in real time. In addition, 5G will allow vehicles to talk to each other fluently, so that an external vehicle can unload in another interior without manual intervention, controlled by the network.

2. The use of 5G for AGVs in manufacturing

Although being evolutionary in terms of technology, 5G is revolutionary in terms of connectivity. For the first time in a mobile system, the network adapts to the application to offer the maximum QoS. Thus, the real potential of 5G resides in the new use cases that it enables. Through the support for big game changers such as massive IoT, critical services and cloud computation, 5G NR goes far beyond LTE and targets many types of devices and applications.

The 5G system is expected to provide support for a variety of services, each of them characterized by different Key Performance Indicators (KPIs), combining reliability, latency, throughput, positioning, and availability. The 3rd Generation Partnership Project (3GPP) and the International Telecommunications Union (ITU) provide various examples of latency KPIs to support robotics use cases in logistics [2]. For remote vehicle control, an E2E latency between 10 and 30 ms is desired, combined with 99.9999% of reliability and 99.9999% of availability. The 5G URLLC use case family is expected to satisfy such requirements.

More data, transmitted with imperceptible latency will be a key enabler for digital experiences. The truth is that its impact on the industry is probably even greater. It offers speed but also productivity, and, probably most importantly, enormous flexibility and reliability.

Hence, 5G is the best resource to take advantage of robotization. So far, the best way to transmit data between machines was an industrial ethernet cable. Currently, 5G acts like an invisible cable that eliminates the stiffness of the factory. Thay way, managers can rethink the configuration of the factories with great agility.

3. 5G technology and Edge Computing

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 parts, i.e., the Next-Generation Radio Access Network (NGRAN) who supports 5G New Radio (NR), and 5G Core (5GC) [3].

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 [3].

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) [3].

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 [3].

Figure 1 compares the 5G KPIs (Key Performance Indicators) for each type of 5G service. Interpolating this to a real UC yields values that are very different from the theoretical ones.

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

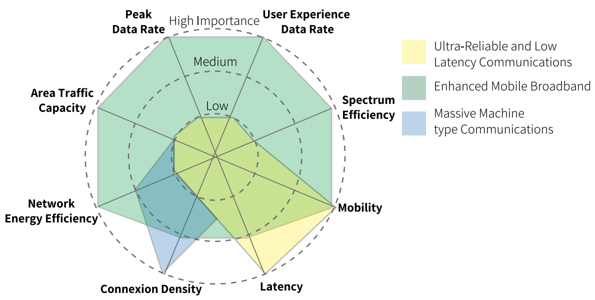

Figure 1. 5G KPIs

in relation to 4G. The improvements provided by each of the releases are brief explained below [4].

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 [5]

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, pre-emption (URLLC data transmission can pre-empt 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 [6].

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 [7].

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 [8]. 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 [9].

Modifying the location of the elements of the network allows to obtain different hybrid edge-cloud architectures in 5G networks as mentioned before. Figure 2 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.

In conclusion, this type of distribution will benefit all kind of sectors with different goals, either real-time performance of automated vehicles, high velocity response for interactive applications and video games, or the more sustainable and efficient industrial facilities. Besides, it has a narrow relationship with other key technologies

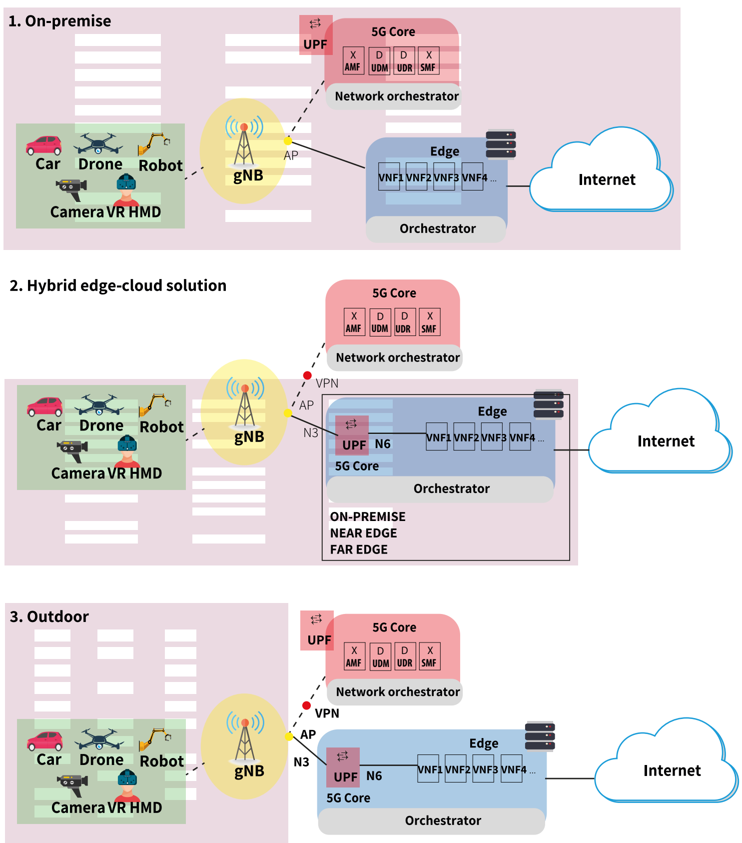

Figure 2. 5G architecture deployments

that mark this new digital revolution, as 5G, complex machine learning or big data.

4. 5G application to real use cases: iNGENIOUS and 5G-INDUCE

Among the numerous H2020 projects that tackle 5G-enabled AGVs for industrial and logistic environments, iNGENIOUS (NextGENeration IoT sOlutions for the Universal Supply chain) and 5G-INDUCE have chosen Valencia as their scenario for trials.

iNGENIOUS aims to design the next generation of Internet of Things (IoT) technology to add digital value to future supply chains, whereas 5G-INDUCE targets the development of an open 5G orchestration platform for the deployment of advanced 5G network applications.

a. iNGENIOUS testbed in the port of Valencia

Supply chains have become complex ecosystems where every process is critical and addresses a certain risk to individuals and/or resources. The way that products are made and delivered needs an evolution towards the Industry 4.0 principles, making the flow of goods and services as smart and monitored as possible. The decentralized approach of Industry 4.0 benefits the management of processes and H2M interaction within a supply chain, thus helping industries to improve efficiency and productivity.

In this context, the H2020 iNGENIOUS project aims at the digitalization and automation of the supply chain management, defining the Next-Generation IoT solution and creating new business models. It places a particular emphasis on 5G and the development of Edge and Cloud computing extensions for IoT, in addition to providing smart networking and data management solutions with AI/ML [10]. iNGENIOUS offers IoT and Tactile-IoT solutions, using both NR and 5GC to release the full potential of 5G capabilities.

One of the most exciting use cases envisioned by iNGENIOUS is the remote driving of AGVs using Head Mounted Displays (HMDs) and haptic gloves, which are key enablers for improving operation of Internet of Things (IoT) systems in industrial and logistic environments. The “Improved driver’s safety” use case aims to explore the remote transportation of goods with AGVs thanks to Tactile Internet, MEC, and immersive enablers. The final scenario is a terminal of the Valencia port that will be reserved for this use case. The idea is that an operator located in an indoor, safe environment can take control of an AGV when necessary (i.e., when automated routes cannot be followed) using MR and haptic solutions, which will be integrated in the remote indoor cockpit. The operator’s telepresence is provided by low latency video cameras and proximity sensors installed in the AGV, wirelessly connected to the cockpit via 5G and a compatible MEC infrastructure.

The use of haptic gloves and haptic sensors will improve the perception, quality and safety of the remote operators managing AGVs, which is required to guarantee the operation even in very exceptional situations where the autonomous robots cannot operate [10]. Haptic gloves will produce haptic feedback allowing operators to create a tactile experience in the shape of psychophysical stimulations including precise texture discrimination, pressure, or the sensation of holding objects. Haptic reactions and vibrations will be used as alarms for the remote driving experience in case of any detected risks. In a future prototype of the haptic gloves, biometric sensors will be implemented to monitor blood pulse, respiration frequency and body posture. This information will be processed to estimate fatigue or stress levels, detecting risk for the operator, and further avoiding accidents [11].

i. Proof-of-Concept implementation

Before the deployment in the final scenario, a Proof-of-Concept (PoC) has been developed in the Fivecomm office to test the viability of the final iNGENIOUS use case. This PoC consists of a Unity3D application that integrates the haptic gloves and the MR headset into the immersive cockpit and communicates with the AGV via 5G.

As Figure 3. (1) Varjo XR3, (2) Sensorial XR, (3) Windows PC, (4) Linux Server, (5)(6) 5G Modems. showsFigure 3. (1) Varjo XR3, (2) Sensorial XR, (3) Windows PC, (4) Linux Server, (5)(6) 5G Modems., the user is equipped with a pair of Varjo XR3 glasses and one Sensorial XR haptic glove. These are both cutting edge, premium devices despite being limited for a wired connection. The sensorial XR unique feature is the fact that the four conductive zones allow to carry out gestures, whereas the haptic capabilities are provided by ten vibrotactile actuators. On the other hand, the Varjo XR3 include passthrough cameras that enable the combination of VR and AR to create immersive MR environments.

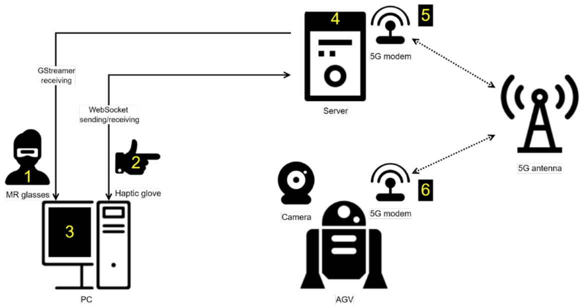

Figure 3. (1) Varjo XR3, (2) Sensorial XR, (3) Windows PC, (4) Linux Server, (5)(6) 5G Modems.

Both the glove and the HMD are controlled by a Unity3D application that communicates with the robot through an intermediary server. The aim of using two computers is that the second acts as the MEC in the near future, reducing the required computational power both in the user and in the AGV.

The UL communication only involves the specified gesture, whereas in DL the cockpit receives haptic and visual feedback from the AGV peripherals. The Unity3D application mixes a synthetic rendered scenario with real time video captured from the AGV camera which is streaming RTP H.264 video. The telemetry received from the AGV is handled by the same application for rendering visual information and creating haptic sensations. Depending on the minimum distance detected by the AGV laser, a haptic vibration is activated in the glove, the more intense the closer is the obstacle to the AGV.

The robot employed is the model RB1 Base manufactured by Robotnik. It is an AGV designed for autonomous logistics in indoors environments, but it is also used for testing or R&D applications due to its compact dimensions (515 mm of diameter and 303 mm of height). Up to 50 kg of cargo can be transported and a maximum speed of 1.5 m/s can be reached, supported by two motor wheels and three omni wheels. The motor wheels have a power of 250 W each, whereas the omni wheels are in charge of providing stability. The robot can detect obstacles from both a RGB-D sensor (depth sensing camera) and a laser sensor used for navigation and positioning. The 2D laser gives a 270° vision range and detects obstacles located at a height of 195 mm from the ground. When an obstacle is at a distance of 1 m, the robot looks for an alternative route if possible or otherwise stops. For smooth H2M interaction, Fivecomm has equipped the AGV with a humanoid torso that contains a display and two more RGB-D cameras. The display has not been used since it is not necessary for teleoperation, whereas the camera selected to be streamed has been the upper one due to a better placement, at a height similar to human head. RB1 Base is controlled by native ROS over an embedded Linux PC.

ii. Performance evaluation

A series of 4G and 5G measurements have been performed to test the current viability of the iNGENIOUS use case. The average network latency obtained has been 36.11 ms via 5G and 63.61 ms via 4G, whereas the average DL throughput measured has been 392.5 Mbps via 5G and 37.75 Mbps via 4G. On the other hand, the average E2E latency via 5G has been measured for both video streaming and gesture control, obtaining 240.71 ms and 880 ms respectively. These values far exceed the requirements due to a lack of optimization especially on the application since it represents half the E2E delay for both video and control.

b. 5G-INDUCE testbed in the Ford factory

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

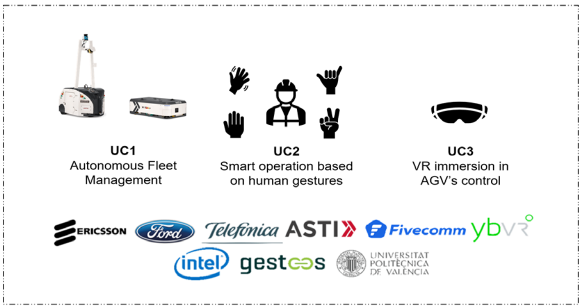

Figure 4. 5G-INDUCE Spain use cases

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.Figure 4. 5G-INDUCE Spain use cases shows the three UCs that will be tested to achieve a higher level of automation and increase human-machine iteration.

The mobile communications group oversees the developing the second use case of the project, alongside with Fivecomm. The objective is the AGVs to recognize some defined human gestures and perform a specific action, improving the

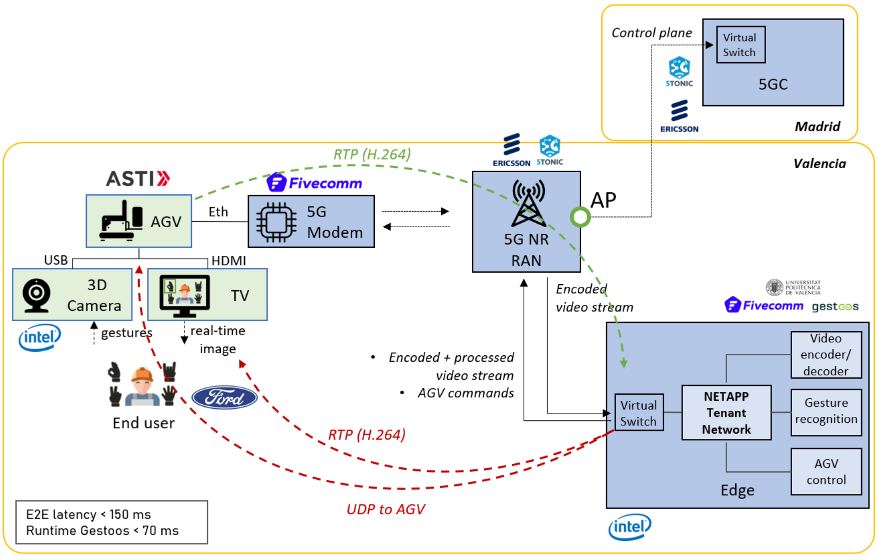

Figure 5. Second use case architecture

human machine interaction. The goal is to enable the transport robots to stop, continue or go to specific points of a route, apart from an ON/OFF listening mode.

This recognition is performed by the Gestoos software, that provides different tools to enable developers to capture several human gestures and work with them to execute different functions, depending on their applications. This is a powerful algorithm as it enables to communicate with machines with a zero-touch approach, making the communication intuitive, more secure, and easier. This tool works with a camera that receives the video stream from the user and runs its algorithm to detect some early predefined and trained gestures.

The Figure 3 shows the second use case architecture. 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 /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 worker's order.

ii. Proof-of-Concept implementation

Fivecomm, an SME created to implement 5G solutions into industry verticals to give a speed up to the 5G research and development projects, was a vital contributor to this work. An early prototype was developed before the final deployment in Ford, so the network functions and the software development kits were tested, along with the main components of the architecture to serve as a proof of concept.

The developed prototype in Figure 6 consisted of two main parts. The first involves the AGV equipped with an Intel Realsense camera to detect the user gestures. This AGV has also a screen to provide feedback to the user with the performed commands and the action that will perform the robot. The other part is the server, acting as an Edge in charge of all the computation power, including the encoders/decoders and the gesture software. Both AGV and server are connected to the network through CPEs, allowing the full E2E communication.

The video captured by the camera is sent from the AGV to the sever through an RTP protocol encoded in H264. Once the video is at the sever, it is decoded and processed by the gesture recognition algorithm, that modifies the video including a feedback interface for the user. The modified video is encoded again and sent back to the AGV together with the control command for the robot, ordering it to perform a specific action.

The developed integration scope consists of sending the AGV to specific points of a previously defined route, and the ability to stop/resume the route on its way. Besides, the AGV has a listening mode, so while it is in OFF, the AGV does not respond to any gesture made (the feedback screen shows in which mode is the AGV). This was thought as a security feature to avoid false detections.

Some considerations about the integration are, for example, the fact that if the robot is waiting for a command and we send the stop command, even if we send the order to follow a route the robot will not move unless a continue command is sent to it.

5. Conclusions

5G has driven the industry's global economic growth. This mobile technology increases connection speed, minimizes latency, and exponentially multiplies the number of connected devices. Combining 5G with other technologies such as Edge, Cloud computing and virtual reality increases its advantages.

The Gestoos software, core of the use case, needs more optimization to reach the desired latencies and include critical factors like enabling perfect detections with any kind of gadgets like glasses or gloves. Nowadays this software is perfect for demos, prototypes, or single user purposes, but it has a long way to run to fully adapt it to industrial environments, that require a 100% reliability. The

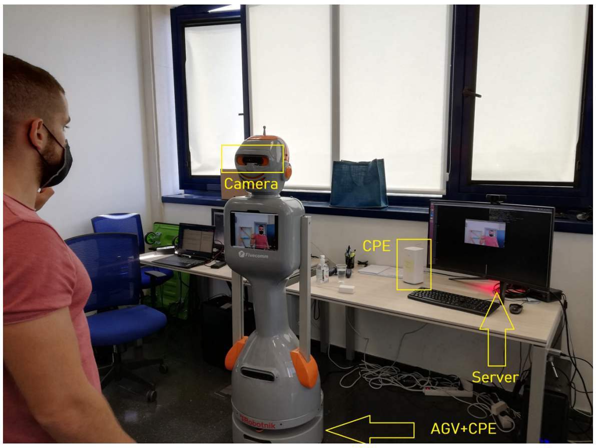

Figure 6. Second use case developed prototype

core code of the software is the critical factor in terms of E2E latency, so it needs to be optimized before entering other factors like the network, that has proven not to be the most critical factor in this integration.

As for the testbed in Valencia port, it has been demonstrated that current 5G eMBB networks improve the performance of 4G, but they do not get close to the strict latency requirements of Tactile Internet. It is expected that the installation of a mm-wave antenna compliant with URLLC will reduce network latency, but the target of 1 ms will be hard to met. Nevertheless, the network latency is negligible in comparison to the E2E latency. The obtained results show that the developed application needs further optimization specially in the AGV control, since a delay of 880 ms makes unfeasible the deployment in the Valencia port, where a real time response is needed. However, this is an innovative use case with a lot of work left, so future lines will focus on reducing latency and improving the functionalities, reaching higher levels of immersion.

References

P. A. E. J. M. Echeverri, "Caracterización de un AGV (vehículo guiado automáticamente) en el sistema de manufactura flexible," Centro Tecnológico de Automatización CTAI de la Ponticia Universidad Javeriana., 2013.

ETSI, "Service requirements for next generation new services and markets," 2019.

M. O. S. S. C. M. S. Rommer & P. Hedman, "5G Core Networks," 2020.

M. Ivezic, "Introduction to 3GPP and 3GPP 5G Releases 15, 16 and 17," 2020.

3GPP, "Release 15," 2018.

3GPP, "Release 16," 2020.

3GPP, "Release 17," 2021.

L. A. Thomas, "Edge Cloud: The Future Technology for Internet of Things," 2019.

E. Commission, "European industrial technology roadmap for the next genera-tion cloud-edge offering," 2021.

iNGENIOUS, "D2.1 Use cases, KPIs and requirements," 2021.

iNGENIOUS, "D3.1 Communication of IoT Devices," 2021.

I. Ibáñez, "Developmentof a Human-Gesture Recognition prototype for 5G-connected Automated Guides Vehicles (AGVs)," 2021.

R. Lozano, "APPLICATIONS OF HAPTIC GLOVES TO REMOTELY CONTROL 5G-ENABLED AUTOMATED ROBOTS," 2021.

A. Fernández, "Distributed 5G system architecturefor applications virtualization inIndustry 4.0 and Edge Computing," 2021.

Acknowledgment

This work was partially supported by the European Union's Horizon 2020 research and innovation programme through the project iNGENIOUS under grant agreement No 957216 and the project 5G-INDUCE under grant agreement No 101016941.