5G PPP

PUBLIC-PRIVATE PARTNERSHIP

5G INFRASTRUCTURE PPP

TRIALS & PILOTS

December 2020

5G-PPP.EU

TABLE OF CONTENT

INTRODUCTION

The 5G Infrastructure Public Private Partnership (PPP) Programme and its related funded projects are achieving outstanding progress and impact over the three consecutive phases (specification, development, experimentation/pilots), as regularly highlighted in the PPP Programme and projects websites and news.

Until today, 62 projects in total have been or are contractually active in the PPP Programme, ensuring an extremely high momentum and dynamism. The contractual agreements for 30 additional projects will be finalized during 2020. The 21 Phase 2 projects, having started in June 2017, have step by step completed their work. At the same time the first 22 Phase 3 projects, started in 2018-2019 are running at full speed. 12 new Phase 3 projects started in September 2020 and will be joined by 18 projects, which are set to start in January 2021. These projects complete the overall PPP projects' portfolio of 92 individual projects cooperating in the overall PPP Programme for the specification and evolution of mobile networks.

The Phase 2 and Phase 3 projects have validated, trialed, and piloted 5G in many vertical sectors (e.g., Automotive, Industry, Media & Entertainment, Public Safety, Health, Energy, Smart Cities, Transport & Logistics, etc.). The first "5G Infrastructure PPP – Trials & Pilots Brochure" released in September 2019 highlighted 10 of the most impactful Phase 2 Trials & Pilots, selected by a PPP panel of experts and based on the assessment of the Trials & Pilots impact and potential. The current Brochure n°2 leverages the experience from the first Brochure (including call for inputs and selection by a panel of experts) and brings to the readers' attention 10 additional Phase 2 and Phase 3 Trials & Pilots that were recently completed. These Trials & Pilots have been evaluated and selected from over 20+ candidates, based on a number of pre-defined criteria (e.g., impact of 5G networks, achieved KPI, Technology and Market Readiness Levels, societal impact, 5G empowerment etc.).

Each of the selected projects has produced a two-page flyer including an overview of the corresponding Trial & Pilot, its network architecture, deployment aspects and obtained key results. Clearly, this document illustrates that most of these Trials & Pilots will have strong social impact or validate a service that will be monetized, or bring a unique disruptive innovation application or service. Additionally, these Trials & Pilots also demonstrate specific key features brought by 5G technology and stress the benefits and value brought by 5G networks that previous generations of mobile networks cannot provide (i.e., their 5G empowerment).

The broader context and overall panoramic perspective of the progress and achievements that the 5G Infrastructure PPP Programme has produced can be directly accessed in the PPP Verticals Cartography, through specific White Papers and via the multiple webinars organized by the 5G Infrastructure PPP at the Programme and projects levels.

Given the vast amount of work being carried out by the portfolio of 5G Infrastructure PPP projects, this Trials & Pilots Brochure n°2 can be no more than a sample of recent progress. We sincerely hope that you will enjoy reading it as much as we did while putting it together.

Didier Bourse, Carles Antón-Haro, Alexandros Kaloxylos, Miguel Alarcón and Frederic Pujol.

5G TECHNOLOGIES IN SUPPORT OF RAILWAY SERVICES

5G-PICTURE

OVERVIEW

5G-PICTURE's railway trial is Europe's first 5G rail deployment in an operational environment. It focused on the evaluation of multitenancy and slicing for critical, performance and business services for different tenants, 5G data rates on-board the train, low latency for time-critical communications and seamless mobility. The solution was integrated at a FGC line in Barcelona, Spain, on 14/11/2019. The installation comprised 1.5 km of track, providing multi-Gbit/s throughput to a train running up to 90 km/h. It implemented the 5G-PICTURE architecture supporting multitenancy, to facilitate 5G deployment in railway environments, being the cornerstone for future Railway trials in Phase 3 5G-VICTORI and 5GMED projects. The solution adopted a mmWave Radio Access Network (RAN) for vehicle-to-infrastructure connectivity and a wireless access solution inside the train. A 100GE aggregation/protection layer was used to connect the railway's core network with mmWave units installed at towers along the track. The towers were interconnected using passive dense wavelength division multiplexing (DWDM) optical connectivity and a programmable mobility server solution to preserve the session continuity as the train moves along the track.

Partners: COMSA Instalaciones y Sistemas Industriales, Ferrocarrils de la Generalitat de Catalunya (FGC), ADVA Optical Networking, Consorzio Nazionale Interuniversitario per le Telecomunicazioni (CNIT), Blu Wireless Technology (BWT).

ARCHITECTURE

The pilot architecture (Figure 1) involved equipment at two stations, a Track Access Network (TAN) and a Train Communication Network (TCN). A train was equipped with a TCN featuring two on-board dual antenna mmWave access points (APs) at the front and rear of the train at 60 GHz, a 10G ring with two Ethernet switches (one per vehicle) interconnected with fibre, a 'FlowBlaze' node to manage session continuity in the train, one Wi-Fi (AP) connected to each switch for Internet access and CCTV cameras in the cockpits connected to the 10G ring. TAN components comprised: mmWave APs, a passive DWDM interconnecting the APs over a single fibre along the track multiplexing all traffic, a 100G Ethernet ring between stations, and a FlowBlaze for session continuity.

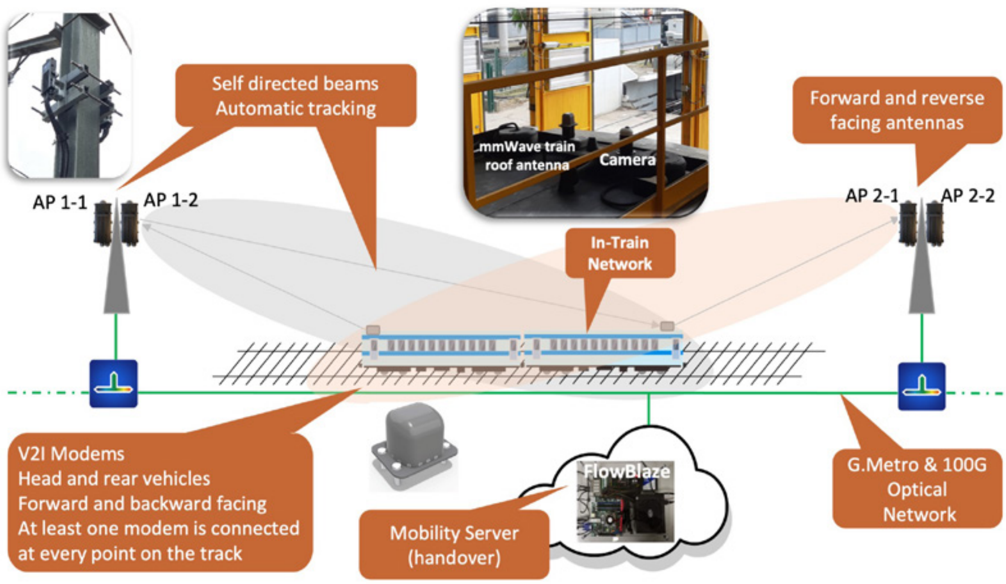


Figure 1: Railway demo architecture

DEPLOYMENT

The trial deployment spanned 1.5 km of the track segment east of Olesa station supporting commercial trains traveling with speed from 60 to 90 km/h (Figure 2). In this segment, four towers equipped with mmWave APs were interconnected with a fibre link to form a RAN infrastructure. This infrastructure maintained connection to a set of on-board devices mounted on a specific train that passes by this track section. Martorell station at the other end served as a simplified railway Operations Control Centre (OCC). A video of the demonstration: https://www.youtube.com/watch?v=bv_uJ98Evr

Figure 2: Railway demo locations

RESULT

The pilot demonstrated 3 service types defined by Future Railway Mobile Communication System (FRMCS): 1) forward-looking low latency critical video over a 5G railway experimental testbed, 2) HD video streaming with the high-throughput traffic originated by the Business Services inside the train, 3) emulated end-to-end (E2E) performance services with different traffic patterns. The demo showed end-to-end performance up to 2 Gbit/s duplex to the moving train with an average latency of 2 ms and power consumption per km railway track of 200 W. Specifically: a) Max. 1 Gbit/s and average 500 Mbit/s (for each UL/DL direction) data rates at the user terminal on train, b) Average one-way, end-to-end latency of about 2 ms (4 ms average Round Trip Time (RTT)), c) Seamless service connectivity at the maximum train speed of 90 km/h.

For more details please check deliverable D6.3 (https://www.5g-picture-project.eu/download/5g-picture_D6.3.pdf)

5G EMPOWERMENT

The solution provides the basis for future multitenant deployments with moving radio access nodes on-board of trains owned by train operators or telecom operators, and infrastructure along the track. The remote data server for surveillance and streaming is an example of how cloud-based services can be enabled by high capacity, low-latency, and reliable 5G connectivity between train and track.

This trial is of key importance for the deployment of 5G networks in the railway domain and shows the strong potential of 5G technology in support of the stringent communication requirements of the transportation domain. Overall the pilot provides a contribution to the FRMCS vision on the suitability of 5G in support of railway related telecom needs.

SMART CITY SAFETY AND VR DEMONSTRATION

OVERVIEW

The 5G-PICTURE Smart City demonstration, held in Bristol on 12/03/2020, showcased a Safety and a Virtual Reality use-case (UC). The main objective was to demonstrate the capabilities of the 5G-PICTURE disaggregated architecture and technologies to meet the forthcoming 5G service requirements. Access and transport solutions were integrated within the 5GUK test network across three different physical locations. The Safety UC monitored the surrounding area with audio and video sensors deployed in bike helmets attached to a Raspberry PI that communicated with the Cloud or Edge computing site. The overall ecosystem was designed to perform audio and video transcoding functions within the network. The Virtual Reality UC involved the creation of a 5-8 minutes AR/VR experience for 5 to 10 people at a time. A music artist led the ritual-like audio experience through a holographic persona, whilst each participant assumed the virtual form of an anthropomorphic character. The experience allowed a group of guests wearing VR headsets and headphones to get lost within a 10-metre virtual space, alongside the holographic capture of the holographic persona.

Partners: University of Bristol, Xilinx Dresden, TU Dresden, IHP (Leibniz-Institut für innovative Mikroelektronik).

ARCHITECTURE

In the pilot (Figure 1), MEC capabilities were hosted at the Smart Internet Lab (SIL), and "We The Curious" (WTC) Museum. The Time Shared Optical Network (TSON) served as transport connecting SIL, WTC and the sites across Bristol, offering multi-tenancy through virtualisation. Nokia 4G/5G radios at WTC and MShed Museum created a 5G cell at Millennium Square (MSQ) with TSON as transport. Three devices operating at the unlicensed 60 GHz band served as backhaul from WTC to MSQ. An active massive MIMO Antenna Radio Unit at WTC was connected via TSON to a Central Unit at SIL, offering functional split 7.2 eCPRI fronthaul services. TSON integrated both backhaul and fronthaul services. 5G, LTE and Wi-Fi technologies at MSQ, were used to connect UEs.

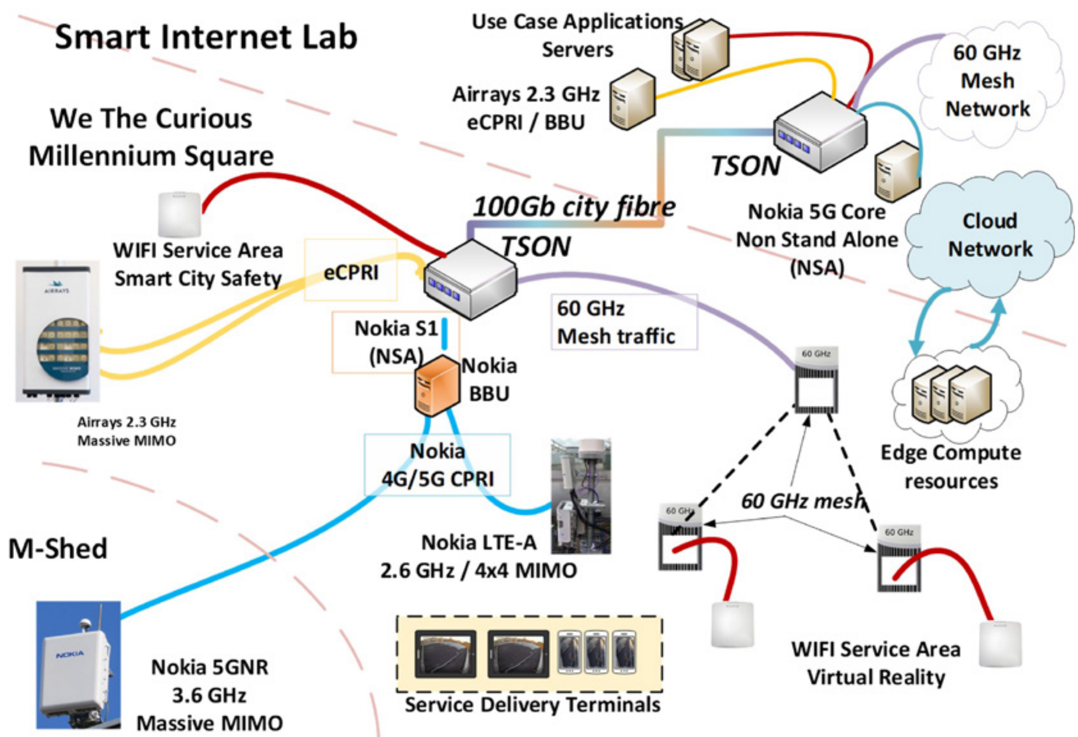


Figure 1: Overall connectivity architecture

DEPLOYMENT

The trial deployment included installation of 2 tents at MSQ to host end-users for each UC (Figure 2). Each tent was supported by 60 GHz backhaul connectivity to the WTC roof top. The tents were provided with additional connectivity via a 10-m Ethernet cable. Each Ethernet cable was attached to a 1 Gbit/s Ethernet switch connected to a Wi-Fi Access Point (AP) operating in the 2.4/5 GHz bands. The Wi-Fi APs acted as service area Wi-Fis and provided connectivity to end-users for the demo purposes.

More information can be found at: (https://www.5g-picture-project.eu/download/5g-picture_D6.3.pdf)

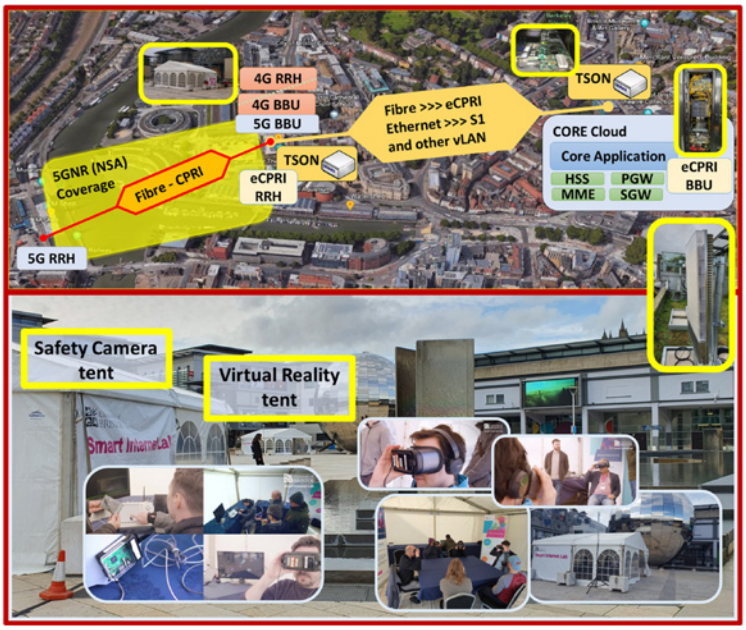


Figure 2: Smart City trial deployment in the city of Bristol, UK

RESULT

Critical performance KPIs associated with the demonstrated UCs are radio network node capacity, end-user throughout and latency. The evaluation results reveal that the 5G-PICTURE solution successfully met the expected KPIs for these UCs and for 5G services in general. The trial proved the capability of the deployment to achieve:

- 100 Gbit/s over a single optical link using TSON.
- ~1 Gbit/s over the mmWave mesh backhaul network.
- ~180 Mbit/s UL and DL per user data rate, and max. 100 Mbit/s with the Virtual Reality application with 5G NR.
- Below 1 ms average Round-Trip-Time between the mmWave units.
- Fronthaul latency (from Active Sub-6 GHz mMIMO radio unit over TSON to the associated Baseband Unit (BBU)) of ~ 70 µs.

A video on the demonstration can be found in: https://www.youtube.com/watch?v=JTK3JYBbjQI

5G EMPOWERMENT

This trial has proven that the 5G-PICTURE solution can facilitate delivery of end-user services over shared, high performance 5G networks. It is capable to support multi-tenancy and highly demanding applications directly to citizens (e.g. media and entertainment) or through service providers. Furthermore, it supports city safety applications for various city public services (e.g. police, emergency services, etc.) as well as demanding operational services such as fronthaul services for massive MIMO deployments, over a single communication infrastructure.

Such 5G solutions are expected to provide higher capacity, scalable networks with lower latency to enable the services that today's LTE or WiFi network will not be able to scale a country wide service delivery at lower Total Cost of Ownership (TCO) for Telecom Operators in provisioning of public services with considerably enhanced performance.

eHEALTH HEART ATTACK EMERGENCY

5G-TRANSFORMER

OVERVIEW

5G-TRANSFORMER vision is that Mobile Transport Networks shall evolve to an SDN/NFV-based 5G Mobile Transport and Computing Platform able of supporting a diverse range of networking and computing requirements to meet the needs of vertical industries.

This pilot took place in February 2020 and explored ways to improve the Madrid emergency communication network through (1) low-latency coordination mechanisms for services involving the public and the emergency coordination networks of Madrid, and (2) the use of medical alerts from wearables for emergency detection and healthcare coordination. This pilot monitors patients with high cardiac risk and automates an emergency actuation. Using features, provided by the 5G-TRANSFORMER architecture, the reaction time is considerably reduced and the on-site assistance is greatly improved.

5G-TRANSFORMER concepts and results will be further developed in the 5Growth 5G PPP Phase3 project. Furthermore, 5Growth will interact with 5G-EVE and 5G-VINNI 5GPPP Phase3 projects.

A video of the pilot is available at: https://youtu.be/BGHzJ1SMbzQ

Partners: SAMUR, CTTC, UC3M, Mirantis, Nextworks, NEC, Ericsson, Telefónica and SSSA.

ARCHITECTURE

The pilot is composed of users wearing a smart wearable device that periodically reports the health-rate to a central eServer. If the monitoring data shows a potential issue, the central eServer issues an alarm to the wearable device. In the case of a confirmed alarm (e.g., unusual vital signs and no feedback from the user), the central server commands a medical team that is close to the location of the user and requests deployment of an edge service closer to the user (which might be done in another administrative domain, hence implying network service federation). The edge service is deployed to lower the latency and provide features to ambulances or patients (e.g., video streaming, Augmented Reality). Once the edge service is deployed, the edge application establishes a connection to the user's hospital and with the medical teams that are involved in the emergency response.

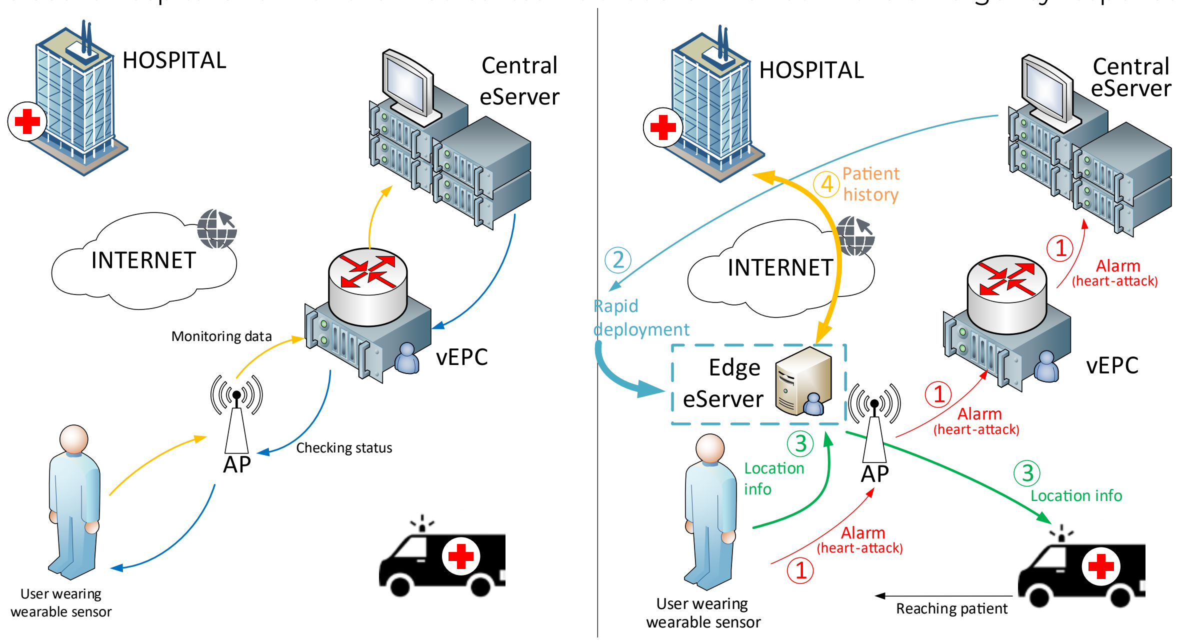
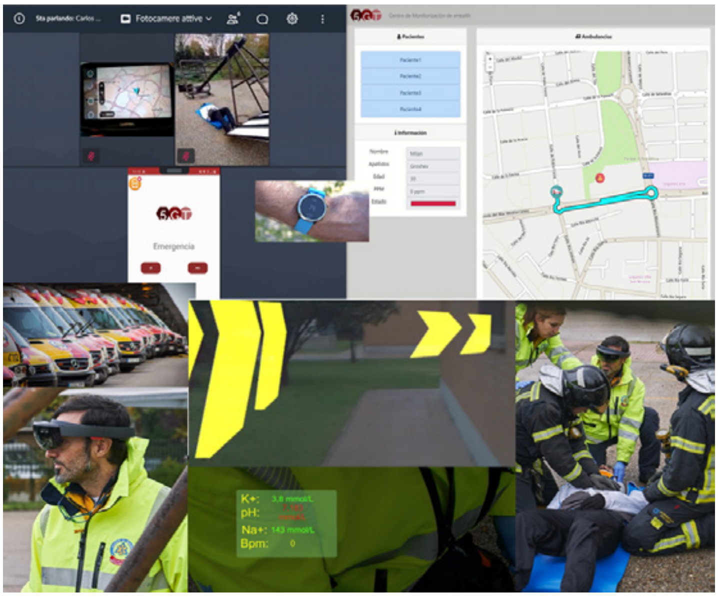


Figure 1: (Left) Monitoring of patients (Right) Emergency case

DEPLOYMENT



The pilot is set on two testbed sites in Spain: 5TONIC (Madrid) and CTTC (Castelldefels). In the 5TONIC site, a basketball player simulates a patient with heart-attack, wearing a smart-wristband or a watch that triggers an emergency and subsequently the deployment of the emergency service. The emergency service is deployed until the ambulance crew reaches the emergency site. The ambulance crew will use the AR goggles to locate the patient and obtain important information about the patient from the newly deployed local eServer (in 5TONIC). The central monitoring eServer (in the hospital servers) and the mobile core are deployed at CTTC (domain 1). When the emergency is triggered, the 5G-TRANSFORMER stack automatically deploys (in domain 2) and connects the local eServer to the original emergency service (domain 1). More details can be found in deliverable D5.3 (http://5g-transformer.eu/index.php/deliverables/).

RESULT

The pilot was validated under a realistic scenario. Furthermore, it effectively addressed the “PPP Service Creation Time KPI”.

Measurements showed that the 5G-TRANSFORMER system requires an average of 428 seconds to effectively federate required network services. Beside fulfilling this KPI, it also satisfies the requirements expressed by Madrid’s ambulance services. The emergency response time in Madrid is around 12 minutes, including around 4 minutes for issuing the alert (receiving the alarm and allocating the appropriate medical resources). The remaining 8 minutes include the time to transit towards the patient location. The first 4 minutes were reduced to milliseconds, which increases the number of lives saved and reduces the number of side effects of a stroke. Latency was also improved by deploying latency-critical components of the service (AR server) at the edge. Round Trip Time decreased on average from 49.3 ms (when deployed in a centralized location) to 35.63 ms (when deployed at the edge). Further measurements with an improved 5G RAN showed RTTs below 10 ms.

5G EMPOWERMENT

The main features brought by the 5G technology to this pilot, which previous generations cannot provide are: a) Reduced network service creation time (on the order of 5 minutes), b) Possibility of automatically managing end-to-end network services in multiple administrative domains while satisfying vertical requirements, improving emergency response time and coverage, c) Latency reduction derived from the selective location of the deployed network service, improving medical on-site assistance and enabling innovative AR solutions requiring high-throughput and low-latency, d) Efficient infrastructure usage derived from the automation of network service deployment. Once the emergency disappears, associated resources can be released.

SMART CITY INTELLIGENT LIGHTING SYSTEM

MATILDA

OVERVIEW

The MATILDA project designed and implemented a 5G end-to-end services operational framework. This included the overall lifecycle of design, development and orchestration of 5G-ready applications and 5G network services over programmable infrastructure. The key objectives of MATILDA were: a) to improve performance, security and reliability specific requirements, b) to shorten time to market, c) to create environmental friendship; d) Generate new business opportunities. One of the key use cases developed within MATILDA is the Smart City Intelligent Lighting. This use case demonstrated, with a major contribution of Orange Romania, CNIT Italy and UBITECH Greece, a unique concept for the development, deployment and management of a Smart City 5G cloud native application network. The demonstrator was implemented at the Politehnica University from Bucharest campus between June 2019 – June 2020 and built a successful collaboration among two 5G PPP projects: MATILDA and SliceNet. This was a key achievement since it proved the alignment and the complementarity of these Phase 2 projects. MATILDA is focused more on the end to end framework and on the upper layers related to marketplace and application orchestration, while SliceNet is more focused on virtualization and slicing concepts.

Partners: Orange Romania, CNIT Italia and UBITECH Greece.

ARCHITECTURE

The application development and deployment lifecycle start with the design and composition of the application graph in MATILDA development kit. Then follows the onboarding of the application into a vertical applications orchestrator and the preparation of a “slice intent” description for the creation of an application-aware network slice. The main architectural components are: a) Marketplace – environment for application development, b) Vertical Application Orchestration (VAO) – role for the proper placement and orchestration of vertical application over the created network slice, c) Operations & Business Support System (OSS/BSS) – interconnecting the VAO and Orange Romania testbed infrastructure via IPSEC VPN. d) Infrastructure as a Service (IaaS) – Orange Romania testbed.

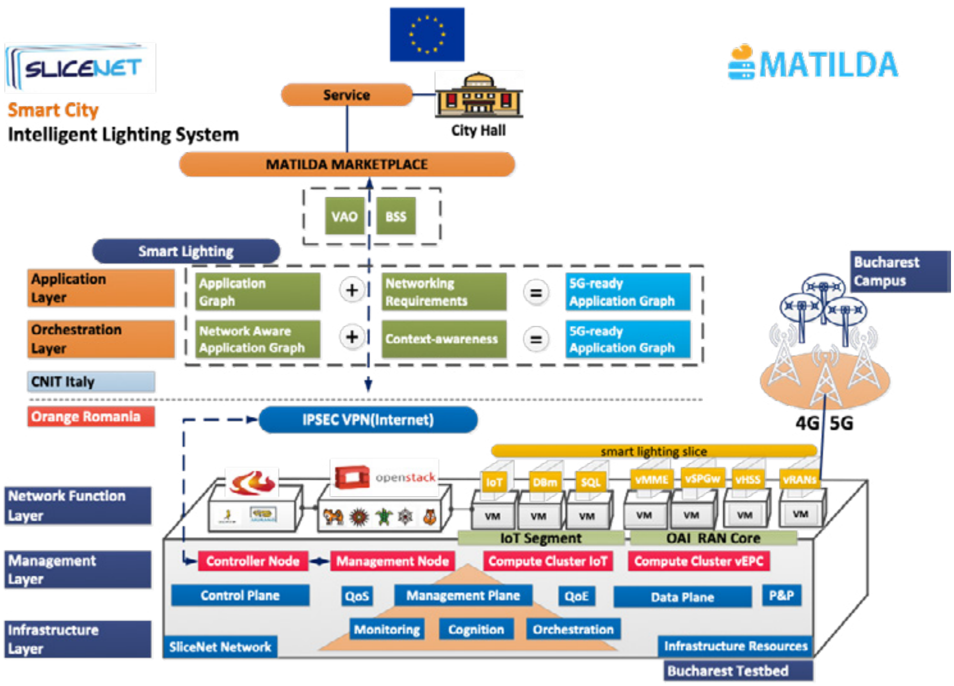


Figure 1: Smart City Intelligent Lighting System architectural components

DEPLOYMENT

The Smart City Intelligent Lighting System was successfully deployed by integrating two testbed platforms. In CNIT Italy were hosted the upper layers of the architecture (Marketplace, VAO and OSS) where the slice intent is created and requests from Telecommunication Infrastructure Provider the creation of an appropriate application-aware network slice. This consists in a chain of Virtual Network Functions (VNFs), such as virtual Evolved Packet Core (vEPC) composed by Mobility Management Entity (MME), Home Subscriber Server (HSS), Serving & Packet Gateway (SPGW), and virtual Radio Access Network (vRAN) from OpenAirInterface (OAI) Alliance. In the Orange Romania infrastructure was also deployed the application graph composed by inter-linked application components (IoT Gateway, IoT Platform, Dashboard, Monitoring, Billing, Ticketing). In the OpenStackMANO programmable infrastructure the multi-tenant approach was demonstrated by creating two different tenants for the application components and the VNFs, interconnected at the infrastructure level by the Attach Point (AP).

RESULT

The system was implemented at the Politehnica University campus in Bucharest Romania, being the PoC for city halls interested in this solution, which brings a saving of energy over 60%, comparing with halogens lamps. The demonstrated use case brought several key benefits: a) Zero touch network operation, for deployment (from days to hours) and in-life management (availability 99.99%), b) Fast time to market, c) Friendly environment for application developers to create new 5G applications. One of the key steps after finalizing both projects is to scale the solution, as this will involve both a transformation of the infrastructure provider networks and an adaptation of the operational flows.

More details on: https://youtu.be/zmxJbxpSTYQ

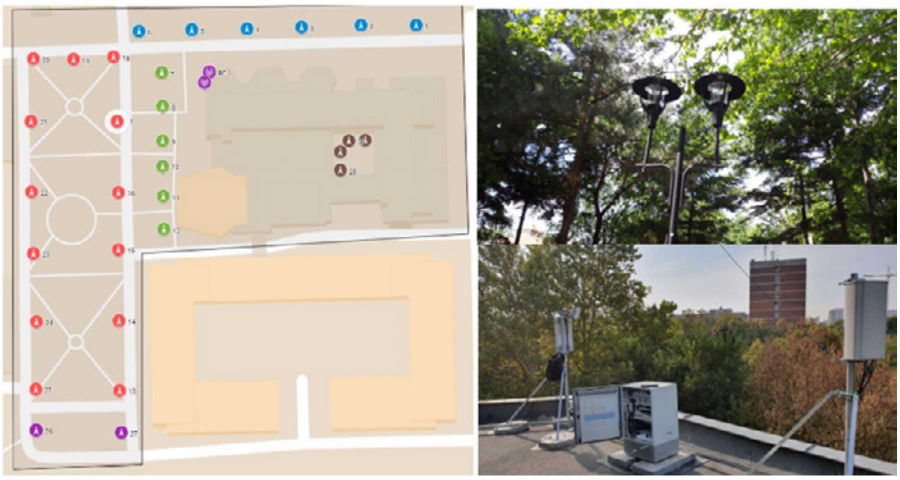


Figure 2: Deployment of lighting poles within Polytechnics campus, including the smart lamps and the antennas

5G EMPOWERMENT

The Smart City Intelligent Lighting use case was deployed and demonstrated using the 5G framework developed by MATILDA, taking also advantage of the SLICENET collaboration for the development of Orange Romania programmable infrastructure. The integration among the two projects stands also as proof for the high grade of openness and interoperability of the developed 5G framework. Therefore, it is key to conclude that the MATILDA 5G framework can be easily used to orchestrate the end-to-end lifecycle of 5G-ready applications over a multi-tenant programmable infrastructure, to create a network slice which is a logical infrastructure partitioning allocated resources and optimized topology with appropriate isolation, to serve a particular purpose of a vertical client having specific requirements (access, transport, core).

NETWORK SLICING FOR IMPROVING PUBLIC SAFETY

OVERVIEW

METRO-HAUL architected latency-aware, cost-effective, energy-efficient, agile and programmable optical metro networks, encompassing the design of metro nodes, including compute and storage capabilities, which interface effectively with both 5G access and multi-Tbit/s elastic optical core networks. The “Network Slicing for Improving Public Safety” demonstration, which was performed in September 2020, showcased a multi-layer metro network scenario for the realization of a public safety use-case employing low-latency object detection and tracking. It featured flexible deployment of network slice instances, implemented in terms of ETSI NFV Network Services, in order to support high-bandwidth low-latency public safety applications over a next-generation metro network.

Simultaneous real-time access to the data of fixed and controllable pan-tilt-zoom (PTZ) cameras allows tracking of objects and persons. Dynamically provided network slices with high bandwidth enable the transmission of video from footage of potentially hundreds or thousands of cameras, while the optimum distribution of video analytics computation and storage reduces the perceived latency.

A video of the demonstration is available at: https://metro-haul.eu/demo

Partners: ADVA, CNIT, CTTC, Fraunhofer HHI, naudit, Qognify, TID, UOB, UPC, UPCT.

ARCHITECTURE

The end-to-end demonstration of a public safety video analytics use case encompasses both the data plane as well as the control plane of a metro network consisting of three nodes: one metro core edge node and two access metro edge nodes. At the access metro edge nodes, edge data centres enable time-critical computations close to the end-user. The optical data plane uses a semi-filterless node architecture based on low-cost reconfigurable optical add/drop multiplexers (ROADM). The disaggregated network features open interfaces for all components controlled by a complete software stack including orchestrator, SDN controllers and modules for monitoring, data analytics and network planning.

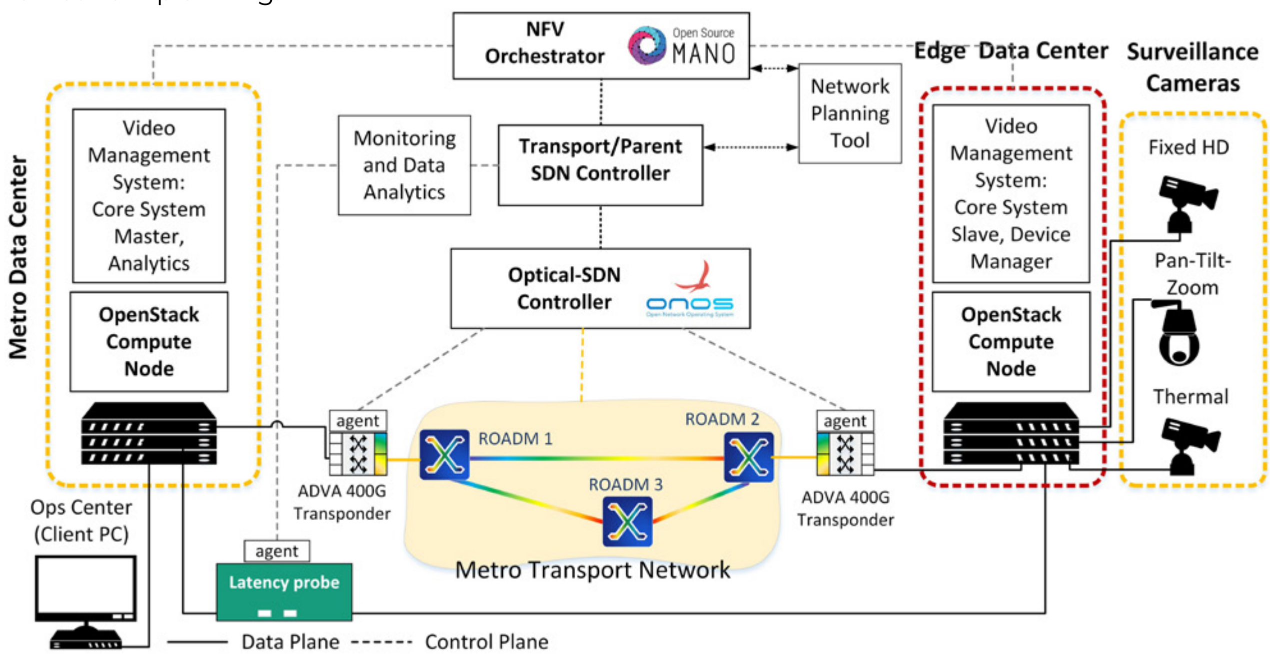


Figure 1: Architecture of the real-time low-latency video analytics demonstration

DEPLOYMENT

The demonstration was executed at the testbeds of Fraunhofer HHI in Berlin. The edge data center hosts core system slaves for the video management system and device managers to control the cameras (cf. Figure 1). The metro network connects them to a core system master hosted on the metro data center performing management and video analytics tasks. The video application requires high-bandwidth, low-latency connectivity through the metro network for video streams and remote control of the cameras.

Figure 2: Deployment of the demonstrator: (left) Surveillance zone on the rooftop of the Fraunhofer HHI building in Berlin. (right) Installed surveillance cameras and deployed optical metro network equipment

RESULT

METRO-HAUL translated the 5G PPP KPIs into required KPIs for the underlying optical metro network and demonstrated the full workflow of network planning, orchestration, deployment, and running a network slice including compute as well as connectivity resources over an optical metro network for a real-time object tracking VMS and analytics service. The following KPIs were successfully measured and validated: end-to-end service establishment time and end-to-end latency between the two data centres (cf. Figure 1: latency probe).

Measured KPI
Optical Connection Setup Time
130.259 s
E2E P2P Connection Setup Time
130.384 s
E2E Network Service Setup Time
175.816 s
Latency (80 km Link)
799.188 µs

Figure 3: (left) Real-time object tracking video management and analytics service running on the edge-computing enabled metro network testbed of METRO-HAUL. (right) Measured METRO-HAUL KPIs with respect to setup times and latency.

5G EMPOWERMENT

The key features of the demonstration not available in previous generations are: a) Latency awareness of the network provided by latency probes in the data plane to the control and management plane. b) Fast setup of end-to-end network services including provisioning of high-bandwidth optical resources. c) Latency-aware placement of VNFs to satisfy latency requirements of services and applications such as real-time object tracking enabled by video analytics. d) Flexible low-cost high-bandwidth optical metro network connectivity enabled by semi-filterless ROADM node architecture and coherent transponders.

PREDICTIVE MAINTENANCE AS A SERVICE

OVERVIEW

The Target of this Use Case is the Smart Energy vertical domain, in which a service focused on energy infrastructure by Preventive Maintenance as a Service, was implemented by NRG-5, a 5G PPP Phase 2 project. The Trial objective was to build on NFV concepts and 5G communication network architecture, the integration of application specific logic for 1) virtual Media Processing & Analysis and 2) virtual Drones Flight Control.

The specific functionalities demonstrated in this trial are: a) Predictive maintenance via automatic routine aerial monitoring. b) Incident localisation by monitoring, gas compressors and pumps from the selected monitoring centres. c) Security services upon request of fast and flexible drone missions to access areas that pose health, safety and environmental risk to humans.

The flexibility provided by drones and versatility and a multi-RAT environment of cellular, satellite and WiFi connectivity of the 5G technology features bring advantages such as: 1) Optimization of the manufacturing value stream through new technologies, by means of early detection of failures and saving money. 2) The site administration is committed to providing a high level of protection to its employees and contractors knowing the potential risk of major accidents occurrence attached to field operations.

Partners: Visiona, ENGIE, Engineering Ingegneria Informatica SpA and Hispasat.

ARCHITECTURE

Predictive Maintenance as a Service is based on the architecture in Figure 1 from which the drone functionalities are placed upon the edge cloud infrastructure and the low layer VNFs that provide the virtual functions required to discover devices and services in a network, and to allow for self-organization and self-optimization of communication and routing in the 5G ecosystem.

There are three main scenarios in which the use-case is divided: a) the first Sub-Scenario involves maintenance activities using the automatic mode with pre-selected flight plan, b) the second Sub-Scenario deals with punctual and not programmed activities caused by unexpected events, c) the third Sub-Scenario involves all activities requiring a remote control of the drone in case of an emergency where ground communications are disrupted and no reporting from the plant can be received.

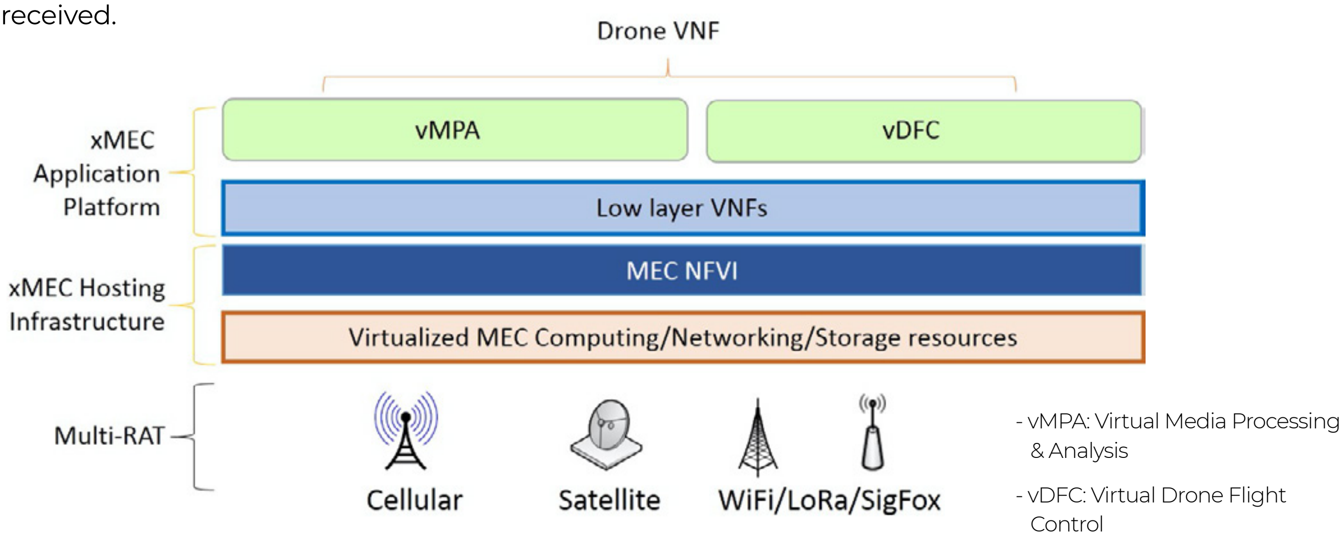


Figure 1: 5G network architecture for Predictive Maintenance as a Service

DEPLOYMENT

Chronologically, the first set of functionalities was tested in Arganda, Madrid. This place was selected to get the first feedback from the satellite link integration of the communication link with the VNFs used to build the Predictive Maintenance as a Service and drone camera module.

The second set of functionalities was deployed in Quismondo (Spain), deploying the project drone, the camera mounted on the drone and the communication from/to the virtual network functions.

Finally, the Storengy premises in Stublach (UK) (Figure 2) was selected to validate the overall UC executing: a) Realtime video processing and reaction. b) Extend drone range operation to distant sites with distributed cloud architecture. c) Enhanced multi-RAT towards broadband capacities with 5G.

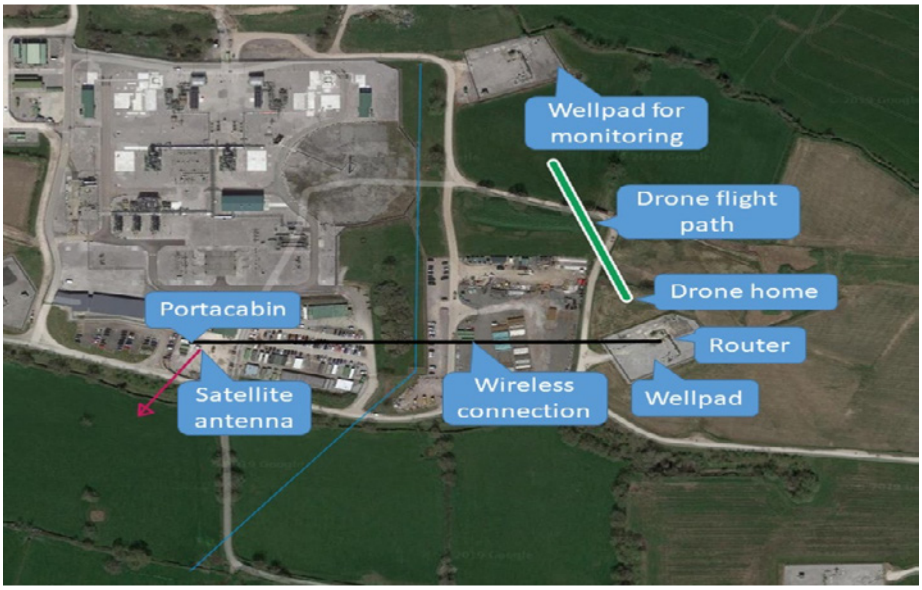


Figure 2: Stublach set up map

RESULT

The result of the trial concludes that video and telemetry are sent with good quality from the drone to the client laptop and local server. Furthermore, the UC showed a fast drone reaction with a latency of 1.5 ms when the drone communicates with edge cloud.

More information: https://youtu.be/rSiSL5F06Ho

5G EMPOWERMENT

The NRG-5 Predictive Maintenance/Security use-case using drones has shown that solutions based on artificial intelligence for detecting people, vehicles and hotspots packaged in a VNF (which was executed at the edge cloud) may have significant impact in the energy vertical.

Moreover, the development of the virtual functions defines a milestone in the maintenance operation since it allows to deploy a drone control service in a few seconds, no matter where the service is and where the drone is, while they are interconnected.

The 5G solution proposed in this trial has demonstrated how to overcome the limitations of the drone technology: 1) low range flying control. 2) low camera quality, 3) onboard storage of data, 4) no encryption mechanisms, 5) data transmission bandwidth limited to 10 Mb/s in the best case.

BLUEEYE TELEMEDICINE PILOT AND COVID-19 EXPERIENCE

SLICENET

OVERVIEW

This 5GPPP pilot from the SliceNet project has two dimensions related to eHealth video;

- A lab-based pilot focused on network slicing for eHealth. This lab pilot for 5G slicing exploits network slicing to offer guaranteed end-to-end (E2E) Quality of Experience (QoE) for remote clinical video consultations. The trial occurred in early summer 2020 at DellEMC in Cork (IE)
- Project partners response to the COVID-19 pandemic. The impact on the roll out of digital healthcare services from the outbreak of the pandemic has proved to be significant. RedZinc, an Irish SME and partner in the SliceNet project, were invited by the national I Health Service Executive (HSE) of Ireland, to deploy their remote video consultation platform, BlueEye Clinic, to help alleviate pressure on outpatient services. Applications were needed that offered a good quality video. Using the agile approach from the 5GPPP project, the team were able to support many hundreds of clinicians avoid contagion using video.

Partners: RedZinc and DellEMC.

ARCHITECTURE

E2E network slicing for delivery of healthcare services must be given network priority in an eHealth slice in order to allocate 5G network resources to emergency events.

Through integration with an eHealth service slice, a Digital Service Provider (DSP) manages network resources on behalf of the healthcare service provider. In this use case, the DSP prioritises a remote video consultation service from the paramedic in the field to remote doctors who can help.

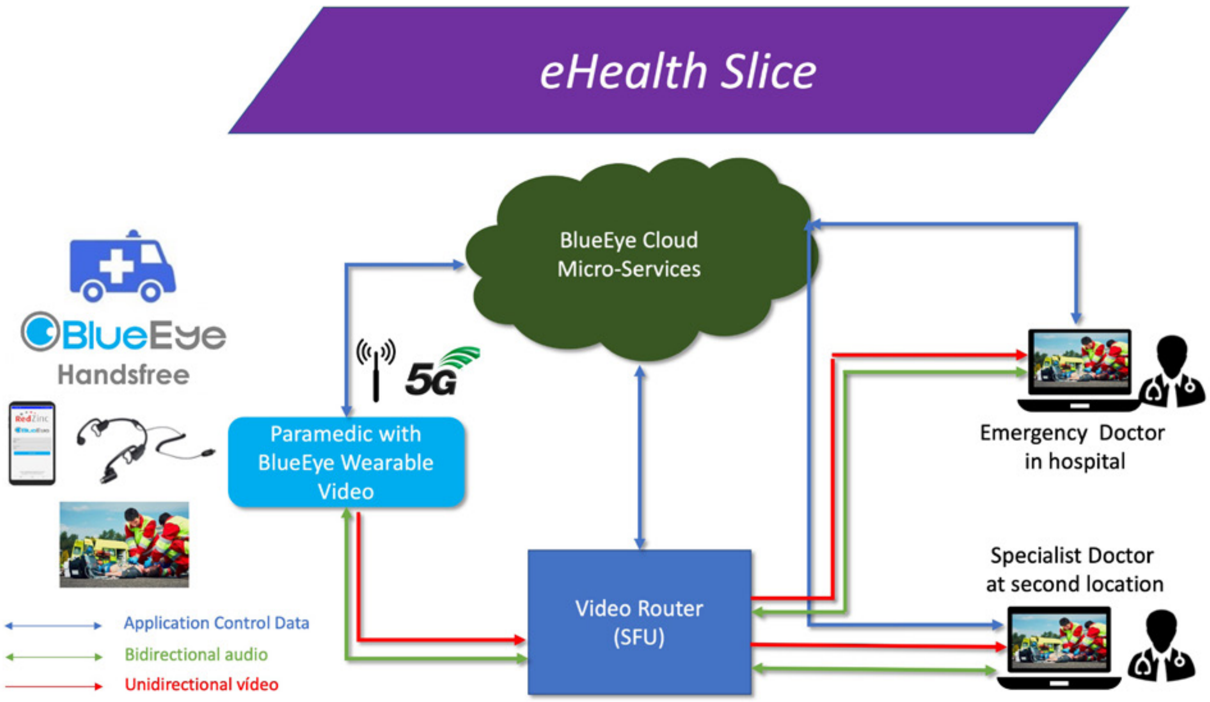


Figure 1: Architecture diagram

DEPLOYMENT

The use-case deployed in Dell/EMC highlights the subscription and onboarding process for the sliced BlueEye service. The E2E healthcare slice consists of a base slice instance that will deliver a guaranteed quality remote video consultation service from the clinician at the hospital to the patient at home. To satisfy user QoE, the slice template requirements include ultra-low latency, high bandwidth, and data encryption. Additional sub-slices may be instantiated from different Network Service Providers (NSP), for example, to increase the geographical coverage for patients outside of existing slice coverage. The eHealth vertical only sees the services provided by the DSP's one-stop API.

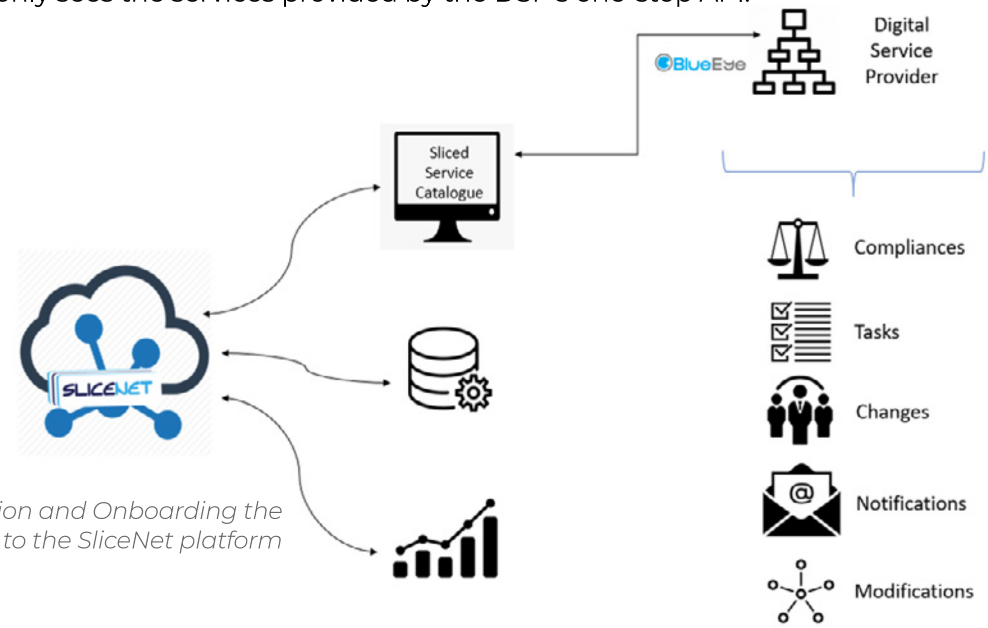


Figure 2: Subscription and Onboarding the BlueEye service to the SliceNet platform

RESULT

From the point of view of the lab pilot, key performance indicators (KPI) are related to quality of experience and perceived quality of the real time web video for the remote clinicians that is provisioned through network slicing. In the QoE tests, the effectiveness of SliceNet's network slicing in the data plane was assessed. Firstly, no network slicing was applied, and the video was streamed in a best effort mode. When background traffic was increased, the quality of the video streaming was compromised, and distortion artifacts were observed. Next, in the same situation, when E2E network slicing was enabled for the video service, the perceived quality of video was maintained, even when the competing background traffic was still in place.

From the point of view of supporting clinician during the pandemic key performance indicators were time to service deployment and provision. This was 10 days during March 2020. Key performance indicators were also the number of clinic events supported by video. In the first 6 months of the pandemic this was over 10,000.

5G EMPOWERMENT

SliceNet technology has helped healthcare providers to rapidly deploy a remote consultation service in response to the corona pandemic. H2020 has produced concrete benefits for this unexpected healthcare crisis through its foresight in 5G slicing technology investment and agile methodology. The agile methodology and foundation slicing ingredients have enabled BlueEye to be built using virtualized network functions for flexible deployment of healthcare services.

SliceNet partners, including RedZinc further envisages using slicing in a 5G environment, enabling service providers to offer priority based end-to-end services inside a single slice with rapid service deployment.

EXPERIENTIAL TOURISM THROUGH 360° VIDEO AND VR OVER 5G

5G EVE

OVERVIEW

Amplifying and improving both participation and interaction of professionals, visitors and tourists in events related to tourism businesses, resources and destinations is an area of great potential and interest for the tourism industry. VR technology, 360-degree video and 5G are instrumental for delivering immersive experience services in this sector.

The trials system enables streaming up, over a 5G Access network, 360-degree live video recorded at touristic events and locations, to a remote server in the cloud which, in turn, is responsible for world-wide rendering to end-users who enjoy an immersive experience, through VR glasses, connected to the network also via 5G, as represented in Figure 1.

Partners: SEGITTUR, YBVR, Ericsson Spain, Telefónica, UC3M, IMDEA Networks, Telcaria Ideas, Nextworks and Wings have completed this trial, leveraging ICT-17 5G EVE's validation platform and site facility in Madrid (5TONIC).

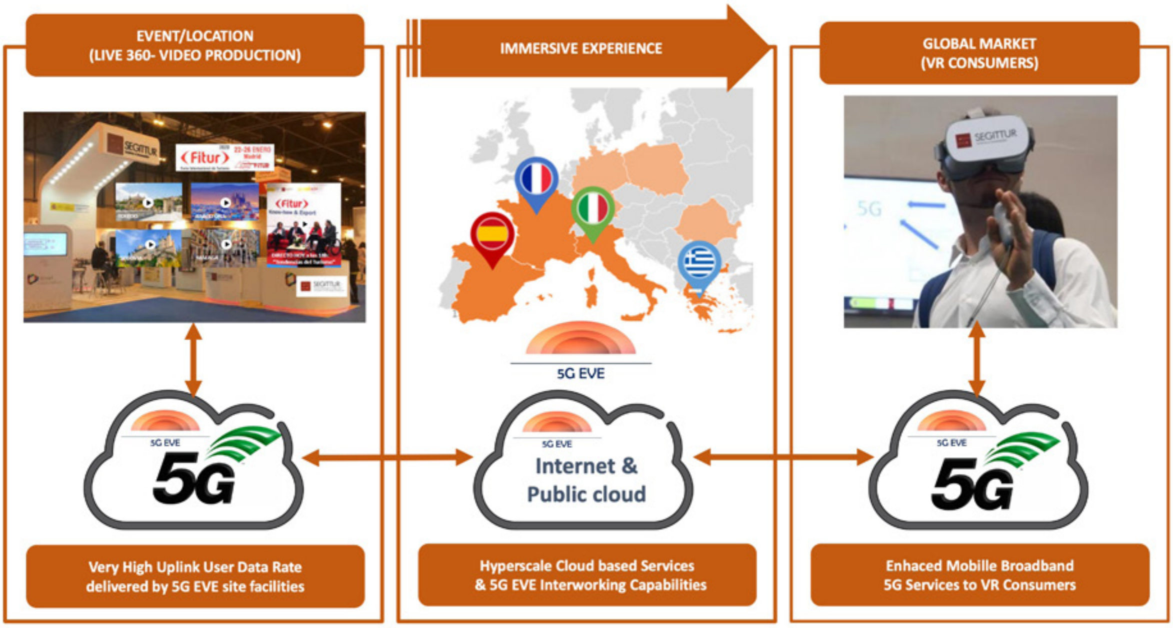


Figure 1: 5G EVE Smart Tourism Service

ARCHITECTURE

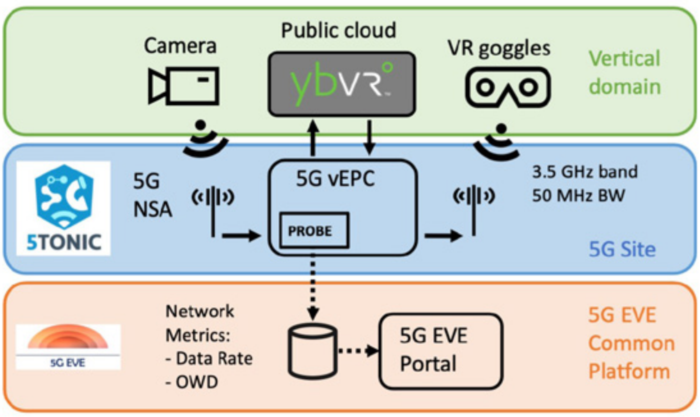


Figure 2: Pilot architecture

The architecture is based in three domains: i) Vertical domain, ii) 5G Site, and iii) 5G EVE Common Platform, as illustrated in Figure 2. The video application is deployed in the public cloud. In order to reach the application, the devices are connected to the 5G NSA network, which provides the desired connectivity. Probes are installed in the 5G network to enable real-time KPI collection. All experiments were defined, launched and monitored using the 5G EVE Portal.

DEPLOYMENT

Trial #1 validated the downlink distribution of 360-degree video over 5G. It was showcased at FITUR 2020 (22/01/20) where SEGITTUR booth enjoyed 5G NSA coverage thanks to a portable 5G kit. Along FITUR2020 event, activities carried out in the Auditorium were visualized through VR glasses connected to this 5G kit, and also broadcast live to external audience. In parallel, visitors to SEGITTUR booth, were able to travel, virtually, to destinations such as Toledo, Málaga, Geneva or Melbourne.

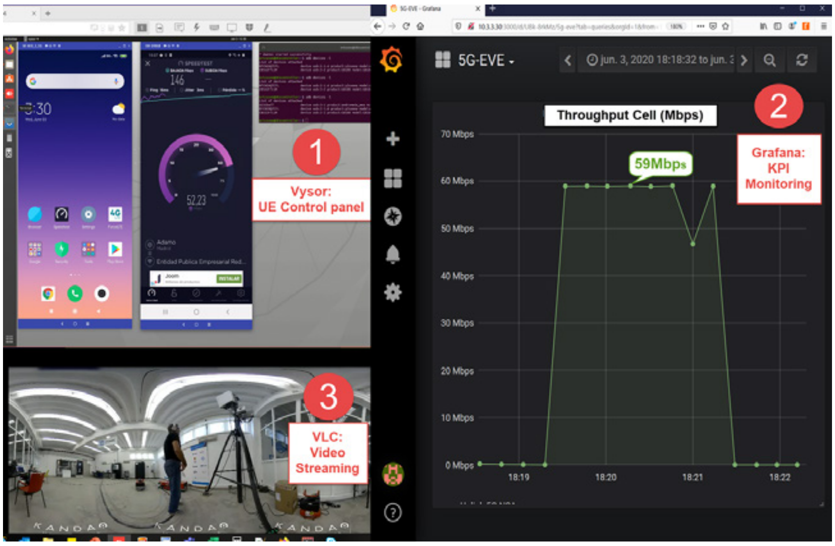


Figure 3: Testing and Monitoring set-up used for the pilot

Trial #2 validated live 360-degree video production and transmission over 5G. It was demonstrated at 5G EVE Webinar held on 23/06/20. A 360-degree camera and YBVR production and ingest server were connected to the 5G network (TDD 3.5 GHz, using 50 MHz, and TDD pattern 7:3) at 5TONIC lab. Live video was broadcast, and remote users connected could enjoy a superior immersive experience.

RESULT

Protocols tested for 360-video transmission were HTTP and rtmp, and devices ranging from industrial CPEs to low-end 5G pocket devices were used for testing.

Latency of user plane traffic introduced by the 5G network to the actual streaming service averaged 10 ms, and UL Experienced Data Rate peaked at 59 Mbps.

Under a variety of test conditions, it has been determined that within the range of 59 Mbps (upper end) and 25 Mbps (lower end) of actually consumed uplink throughput by the 360-degree video production system, a superior QoE is perceived by remote users.

- https://www.5g-eve.eu/event/5g-eve-infrastructure-training-webinar-2/
- https://www.5g-eve.eu/videos/

5G EMPOWERMENT

5G supports this Smart Tourism trial system at 5G EVE platform in two complementary ways:

- 5G high-reliability and high-throughput performance of over 50 Mbps for uplink communications are the key enablers for this solution, since it allows for reliable transmission of the vast amount of data recorded by 360-degree cameras. That removes the painful dependency of this type of remote live production video solutions with wired infrastructure (not flexible and very expensive, if available at all at the location).
- 5G NSA eMBB slice for 50 MHz bandwidth in mid-band spectrum also secures a rapid market uptake and viable business model for this type of services, being the standard service available to all subscribers of all 5G commercial networks.

REMOTE ROBOTIC CONTROL WITH 360° VR-BASED TELEPRESENCE

OVERVIEW

In February 2020, 5G-VINNI UK site demonstrated a trial of 5G connectivity being used to undertake remote robotic control. The trial used two simultaneous paths through the 5G network, one to provide a low-latency control path to the robot, and the other providing the robot's controller with a 360° view from the robot's cameras, viewed through a virtual reality headset.

The trial was conducted at the UK facility of 5G-VINNI, part of the Horizon2020 ICT-17-2018 programme. 5G-VINNI provides a set of connected end-to-end 5G testbeds across Europe with the UK facility located at BT's Applied Research centre at Adastral Park, Suffolk, and built using Samsung Networks equipment.

BT Applied Research and Interdigital Digital Labs collaborated on the trial using one of Interdigital's Turtlebot robots. The robot can move around on a flat surface as determined by the robot's controller who wears a VR headset, and who controls the robot's movement with a game controller. The robot is able to move forwards/backwards, left/right as well as being able to spin clockwise/anti-clockwise.

Partners: British Telecom and Interdigital.

ARCHITECTURE

Connections between the robot and its camera, and between the robot controller's headset and movement controller, were made over the 5G-VINNI UK facility at Adastral Park, Suffolk, UK. The experiment makes use of the 5G 28 GHz mmWave fixed-wireless access radio system deployed at the facility by Samsung. This mmWave radio system provides up to 1Gbit/s (download) connectivity to a set of Samsung indoor CPEs which then present an Ethernet interface to a laptop PC (which connects to the game controller and VR headset) and to a WiFi access point (used to provide radio connectivity to the turtlebot). This is shown in figure 1 below.

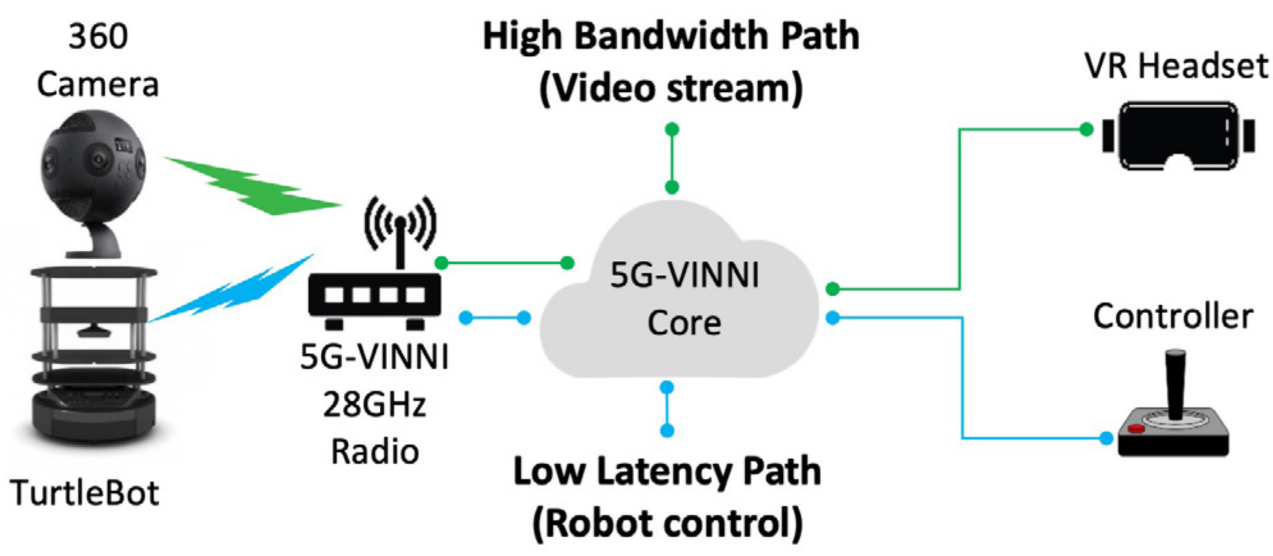


Figure 1: System architecture

DEPLOYMENT

The trial demonstrates the use of two simultaneous paths through the 5G network:

- The first is a low-latency path (typically less than 10 ms), used to control the robot, ensuring that the movement of the robot takes place without any lag. The user enacts the movement with the use of a game controller as shown in figure 2.
- The second is a high bandwidth path (up to 850 Mbit/s), used to stream the video content from the robot's 360° camera to the VR headset. This gives the user an immersive video experience in which the high bandwidth ensures that the video is received by the headset in real time. The images seen by the headset wearer can also be viewed on the laptop screen as shown in figure 2.

Figure 2: Trial deployment

RESULT

Using this configuration, full control of the robot's movement was safely demonstrated, including successfully negotiating routes around obstacles placed in the robot's path, as shown in figure 3. This is only possible through the low latency (measured value: 9 ms) exhibited in both connection paths, providing immediate control of the robot, and immediate visual reaction through the video path (using measured bandwidth of 550 Mbit/s), when the movements actioned by the controller of the robot take place. With any previous technology, the latency incurred in the network would make the control of the robot much less interactive and require persistent stop-start action.

A video of the demonstration can be seen at https://www.youtube.com/watch?v=91yIbv8aNL4

Figure 3: Robot movement around obstacles

5G EMPOWERMENT

The trial of simultaneous remote robotic control and VR-based telepresence is the first of its kind at the 5G-VINNI UK facility and has demonstrated the simultaneous delivery of the low latency and high bandwidth capabilities of 5G to support a high performance use case of this type. Previous mobile technologies are unable to provide the bandwidth and latency requirements of this trial, and without this level of performance, the degree of control shown in the trial would not be possible. Further trials are planned which will build upon this use-case, using the robot's camera to perform resource recognition and an artificial intelligence system to help determine the robot's actions.

INDUSTRY 4.0: LOW-LATENCY ON A SHARED NETWORK

5GROWTH

OVERVIEW

The 5Growth project addresses the technical and business validation of 5G from the verticals' points of view, following a field-trial-based approach on four vertical-owned sites located in Italy, Portugal, and Spain. In the Italian site of 5Growth, COMAU, Ericsson, TIM, Politecnico di Torino, Scuola Superiore S. Anna and Nextworks are deploying a joint pilot hosted in Automation Systems and Robotics floors of COMAU, in Turin.

Here, 5Growth is experimenting key enablers of the factory of the future:

- an industry-grade 5G communication, also supporting a low latency use case, on a shared network to reduce the total cost of ownership,
- a transport aware slicing to concurrently serve industrial use cases,
- novel optical transport technologies, to guarantee low latency and traffic isolation,
- an orchestration system for the automation of radio, transport and cloud resources.

The pilot was also connected to Italian 5G facilities deployed by H2020 5G EVE project. In September 2020, the pilot has successfully demonstrated that a 5G network can support a latency-critical digital twin use case by leveraging on a transport infrastructure based on optical technologies.

Partners: Ericsson, Comau, TIM, Politecnico di Torino, Nextworks and Scuola Superiore Sant'Anna.

ARCHITECTURE

The pilot architecture includes a private 5G radio network, operating on TIM's spectrum, which offers 5G connectivity to robots, machineries, sensors, and devices. Both baseband and radio core systems are located on the COMAU vertical premises. The radio network leverages on a transport fiber infrastructure based on optical add/drop multiplexers (OADM) coupled with electrical switches. The architecture also contains an orchestration system which oversees the automation of radio, transport and cloud resources and it's capable to setup and operate each vertical service. The orchestrator handles 5G slicing, suitable extended to be transport-aware, to support different traffic profiles on the same physical network.

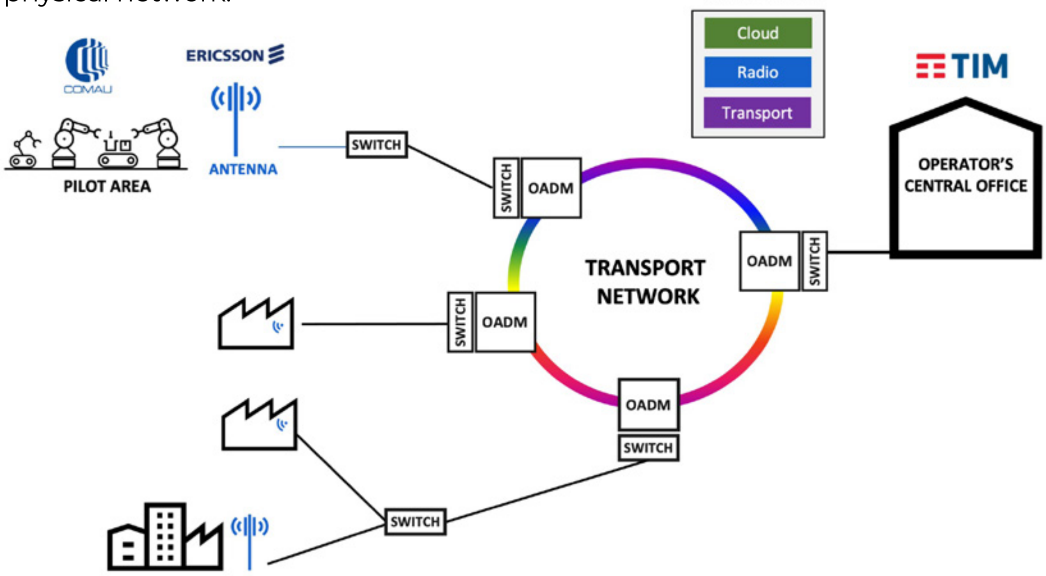


Figure 1: Architecture and main components of the pilot

DEPLOYMENT

The 5G network in COMAU uses Ericsson's radio systems operating on TIM's spectrum at 3.7 GHz. 5G terminals connects the pilot elements: robots, sensors, controllers, the platform for preventive maintenance, AR glasses.

Figure 2: Digital twin of a robotic area and 5G antenna in COMAU premises

5G serves three use case with different requirements:

- Digital Twin, requiring Ultra-Reliable Low-Latency Communications;
- Monitoring & Telemetry, requiring massive Machine-Type Communications;
- Remote Support and Digital Tutorial, requiring enhanced Mobile BroadBand.

RESULT

A tests campaign was conducted to measure the latency of the 5G link which was composed by the radio layer and by the underlying transport layer.

As for the radio contribution, results demonstrated an average downlink latency < 5.4 ms at a throughput of about 850 Mbps and an average uplink latency < 6.1 ms at about 61 Mbps.. The latency increased with throughput as the scheduler has to handle a greater rate of packets. So, the trade-off between throughput and latency is tuneable to serve each use case with the most appropriate performances. Further tests have been conducted over a fiber ring of about 9 km to measure the transport contribution to the overall E2E latency. Results demonstrate that it is two order of magnitude below the radio one.

5G EMPOWERMENT

5G enables new use cases that wired technologies cannot support. According to the 5Growth business analysis, the concurrent deployment of the three 5G-based use cases is expected to bring significant benefits to a reference plant. This includes:

- Reduction in the infrastructure cost by 20% with respect to a cabled networking,
- Reduction in the failure rate of at least 20% thanks to the digital twin application combined with a preventive maintenance enhanced by a massive deployment of sensors,
- Reduction in the cost for repairs by 30% thanks to a remote support with AR.

Transport technologies and orchestration systems enable the deployment of a shared architectures and ensure the right balance between cost and revenues for all the stakeholders.

HIGHLIGHTS ON VERTICAL SECTORS,
5G EMPOWERMENT AND COLLABORATIONS

As highlighted in (1) the PPP Brochure "5G network support of vertical industries in the 5G Public-Private Partnership ecosystem"[1], (2) the PPP Key Achievements Version 3.0[2] and (3) the PPP White Paper "Empowering Vertical Industries through 5G Networks - Current Status and Future Trends"[3], the 5G Infrastructure PPP prototypes, trials and pilots have designed, deployed and tested 5G solutions in multiple Vertical Sectors. Thus, the 5G Infrastructure PPP Programme has successfully evaluated the benefits of 5G networks for the most promising vertical sectors. The 5G verticals dimension is clearly in the DNA of the PPP Programme and projects, since the early stage of the PPP definition and through the overall PPP Programme and projects running and implementation

The Trials & Pilots included in this Brochure n°2 address the following verticals: Industry 4.0, Health, Transportation, Smart City, Tourism and Public Safety. Note that in relation to the Automotive sector, very relevant achievements and results are also captured in a recent and dedicated PPP White Paper[4].

The key 5G features described in the latest version of the PPP "Architecture White Paper"[5] and the PPP White Paper "Empowering Vertical Industries through 5G Networks - Current Status and Future Trends"[3] include Network Slicing, Mobile Edge Computing, Functional Split in RAN, Advanced Security, Smart Network Management, Location Services & Context Awareness, 5G NR Capabilities, Softwarization, Service Chaining, Traffic Steering, Spectrum and Coverage and Guaranteed QoS.

Some of the key 5G enabling features demonstrated in the Brochure n°2 Trials & Pilots include:

- Effective delivery of highly demanding applications, with different KPIs' requirements, over a single communication infrastructure.
- Enabling of cloud-based services through high-capacity, low-latency, and reliable 5G connectivity.
- Reduced network service creation time and multitenant deployments.
- Automatic management of end-to-end network services in multiple administrative domains while satisfying vertical requirements.
- Latency reduction derived from the selective location of the deployed network service.
- Efficient infrastructure usage derived from the automation of network service deployment and the constant optimization of network and computational resources.
- Orchestration of 5G-ready applications over a programmable infrastructure that allows the dynamic adaptations of network topologies and resources.
- Fast setup of end-to-end network services including provisioning of high-bandwidth optical resources.
- Latency awareness of the network provided by latency probes in the data plane to the control and management plane enabling guaranteed QoS and QoE solutions.
- Enabling multiple service providers to offer end-to-end services inside a single slice, allowing seamless integration of currently siloed corporate networks and rapid service deployment.

[1] https://5g-ppp.eu/wp-content/uploads/2020/03/5PPP_VTF_brochure_v2.1.pdf
[2] https://5g-ppp.eu/key-achievements-v3
[3] https://5g-ppp.eu/wp-content/uploads/2020/09/5GPPP-VerticalsWhitePaper-2020-Final.pdf
[4] https://5g-ppp.eu/wp-content/uploads/2020/10/5G-for-CCAM-in-Cross-Border-Corridors_5G-PPP-White-Paper-Final2.pdf
[5] https://5g-ppp.eu/wp-content/uploads/2020/02/5G-PPP-5G-Architecture-White-Paper_final.pdf

- 5G high-reliability and high-throughput performance for uplink communications allowing reliable transmission of the vast amount of data recorded by 360-degree cameras, removing the painful dependency of this type of remote live production video solutions with wired infrastructure.
- Transport network technologies and orchestration systems enabling the deployment of shared architectures which ensure the right balance between cost and revenues for all stakeholders.

Finally, this Brochure n°2 clearly demonstrates the impacting and successful implementation of the PPP Programme and projects, showing the tight interconnections and interworking between the various projects. The PPP Heritage Figure Version 1.0[6] released in June 2020 summarizes the direct projects follow-ups, the components (re-)use between projects and the utilization of (ICT-17) Platforms projects by the (ICT-19) Verticals Pilots projects

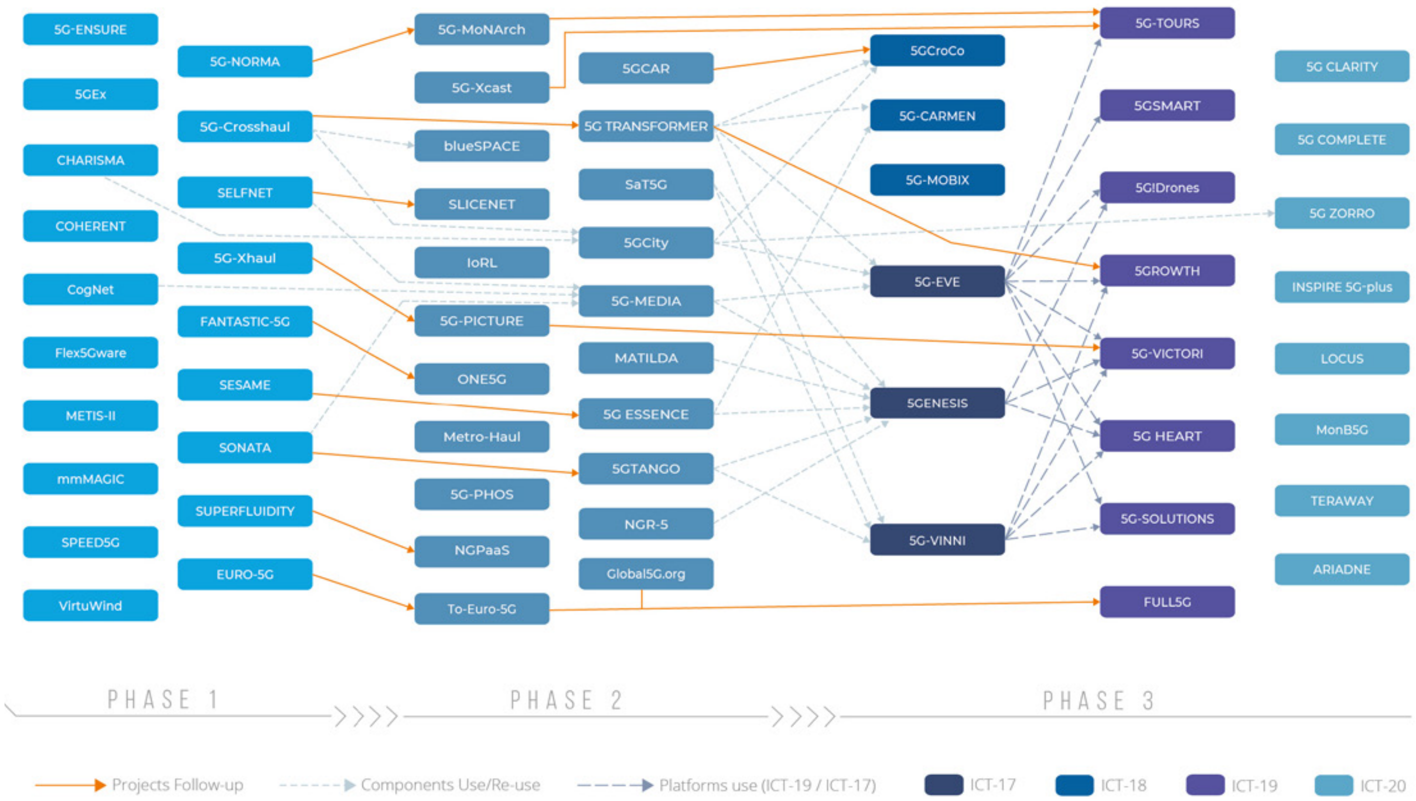


Figure 1: PPP Heritage Figure Version 1.0

A non-exhaustive list of inter-projects collaboration and networking activities highlighted in this Brochure n° 2 includes the following ones:

- Phase 2 5G-TRANSFORMER project with concepts and results further developed in the Phase 3 5Growth project.
- Phase 2 5G-PICTURE project with forthcoming trials and pilots in Phase 3 5G-VICTORI and 5GMED projects.
- Phase 2 MATILDA and SliceNet projects jointly contributing to Trials & Pilots.
- Phase 3 5Growth project interacting/interworking with Phase 3 5G-EVE and 5G-VINNI projects.

Many PPP Trials and Pilots which are currently under development leverage on Phase 3 (ICT-19) Verticals Pilots projects using Phase 3 (ICT-17) Platforms projects. Their outcomes will be included in forthcoming editions of this Brochure.

[6] https://5g-ppp.eu/5g-ppp-heritage/

CONCLUSIONS AND NEXT STEPS

From a careful analysis of the 5G Trials and Pilots reported in this brochure, it becomes apparent that 5G is not a simply a story for faster and more reliable networks. 5G brings about additional levels of flexibility in the deployment of new services with a rich and diverse set of features that 4G networks cannot support. 5G networks have been designed to be fully modular and, further, they allow for a dynamic chaining of virtual functions and allocation of resources. Thus, researchers and service developers are equipped with the tools to create rather novel services, parts of which can be even implemented over different network slices. These characteristics are the catalyst for the creation of an innovation ecosystem that is expected to shape the full digitization of vertical industries.

This Brochure n°2 provided a summary overview of 7 PPP Phase 2 and 3 Phase 3 projects Trials & Pilots achievements. While Phase 2 projects completed their work, Phase 3 projects further address key vertical industries, and the Trials & Pilots aim to measure how 5G can and will impact the performance and the overall operation of vertical industries in the path to full digitization. This Brochure n°2 started to include the first PPP Phase 3 Trials and Pilots from a list of many more that are currently running and producing significant results.

This Brochure n°2 will certainly encourage readers to look for more information and details, visit the PPP and projects websites, watch the Trials & Pilots videos, read the related documents, interact with PPP participants in meetings, workshops, and conferences.

As the 5G Infrastructure PPP has reached its peak point, many new achievements are expected in the coming months through the further development of the Phase 3 projects. A third edition of the Brochure is planned to be ready in Spring 2021.

So, please, stay tuned...

PPP TRIALS & PILOTS BROCHURE N°2 EDITORS AND CHAMPIONS

The editors of this PPP Trials & Pilots Brochure n°2 are: Didier Bourse *(Nokia)*, Alexandros Kaloxylos *(5G-IA)*, Carles Anton *(CTTC)* and Frederic Pujol *(IDATE)*. Creativity and graphic design by Miguel Alarcón *(Martel Innovate)*. The following Table summarizes the key PPP champions involved in the 10 Trials & Pilots highlighted in this Brochure n°2.

TRIALS & PILOTS	TRIALS & PILOTS CHAMPIONS
5G-PICTURE: 5G technologies in support of Railway Services	Manuel Alfageme *(COMSA Instalaciones y Sistemas Industriales)*, Jim Zou *(ADVA Optical Networking)*, Salvatore Pontarelli *(CNIT)*, Peter Legg *(Blu Wireless Technology)*, Paula Ciria *(Ferrocarrils de la Generalitat de Catalunya)*
5G-PICTURE: Smart City Safety and Virtual Reality Demonstration	Hamid Falaki *(University of Bristol)*, Arash Farhadi Beldachi *(University of Bristol)*, Jens Bartelt *(Xilinx Dresden GmbH)*, Nebojsa Maletic *(IHP - Leibniz-Institut für innovative Mikroelektronik)*, Anna Tzanakaki *(University of Bristol)*, Atul Kumar *(TUD)*
5G-TRANSFORMER: eHealt heart attack emergency	Josep Mangues *(CTTC)*, Carlos J. Bernardos *(UC3M)*, Jordi Baranda *(CTTC)*, Kiril Antevski *(UC3M)*, Francisco Javier Quiroga Mellado *(SAMUR - Ayto. de Madrid)*, Konstantin Tomakh *(Mirantis)*, Giada Landi *(Nextworks)*, Xi Li *(NEC)*, Paola Iovanna *(Ericsson)*, Luis M. Contreras *(Telefónica)*, Luca Valcarenghi *(Scuola Superiore Sant'Anna)*
MATILDA: Smart City intelligent lighting system	Cristian Patachia *(Orange)*, Marius Iordache *(Orange)*, Horia Stefanescu *(Orange)*, Jean Ghenta *(Orange)*, Roberto Bruschi *(CNIT)*, Panagiotis Gouvas *(UBITECH)*, Chiara Lombardo *(CNIT)*
METRO-HAUL: Network slicing for improving public safety	Behnam Shariati *(Fraunhofer HHI)*, Johannes Karl Fischer *(Fraunhofer HHI)*, Achim Autenrieth *(ADVA)*, Óscar González de Dios *(TID)*, Ramon Casellas *(CTTC)*, Luis Velasco *(UPC)*, Alessio Giorgetti *(CNIT)*, Javier Moreno Muro *(UPCT)*, Jorge López de Vergara *(naudit)*, Abubakar Muqaddas *(UoB)*, Bodo Lent *(Qognify)*
NRG-5: Predictive Maintenance as a Service	José María Lalueza Mayordomo *(Visiona)*, Daniel Cabagnols (ENGIE), Antonello Corsi *(Engineering Ingegneria Informatica SpA)*, Giampaolo Fiorentino *(Engineering Ingegneria Informatica SpA)*, Nuria Candelaria Trujillo Quijada *(Hispasat)*
SliceNet: BlueEye Telemedicine Pilot and COVID-19 experience	Donal Morris *(RedZinc)*, Mark Roddy *(RedZinc)*, Mustafa AlBado *(DellEMC)*
5G EVE: Experiential tourism throught 360° video and VR over 5G	Lourdes De Pedro *(SEGITTUR)*, Miguel Ángel Martínez López *(YBVR)*, Diego San Cristobal Epalza *(Ericsson)*, Manuel Lorenzo Hernández *(Ericsson)*, Juan Rodriguez Martinez (Telefonica), Ramón Pérez *(TELCARIA IDEAS)*, Pablo Serrano *(UC3M)*, Ignacio Berberana *(IMDEA Networks)*, Giada Landi *(Nextworks)*, Christos Ntogkas *(WINGS)*
5G-VINNI: Remote robotic control with 360° VR-based telepresence	Paul Muschamp *(BT)*, Hannah Taylor *(BT)*, Laurence Forgiel *(BT)*, Charles Turyagyenda *(Interdigital)*
5GROWTH: Industry 4.0: Low-latency on a Shared Network	Paola Iovanna *(Ericsson)*, Giulio Bottari *(Ericsson)*, Simone Panicucci *(Comau)*, Mauro Castagno *(TIM)*, Claudio Casetti *(Politecnico di Torino)*, Giada Landi *(Nextworks)*, Luca Valcarenghi *(Scuola Superiore Sant'Anna)*

Table 1: Trials & Pilots Champions

PUBLIC-PRIVATE PARTNERSHIP

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