5G PPP
PUBLIC-PRIVATE PARTNERSHIP

5G INFRASTRUCTURE PPP
TRIALS & PILOTS

September 2019

5G-PPP.EU

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INTRODUCTION

The 5G Infrastructure PPP programme and its related 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 (*https://5g-ppp.eu/*).

54 projects in total have been / are so far contractually active in the PPP programme, ensuring an extremely high momentum and dynamism. The 21 Phase 2 projects, having started in June 2017, will step by step complete their work (until summer 2020), while the 3 Phase 3 ICT-17 Platforms projects and 3 ICT-18 Corridors projects, having started respectively in July 2018 and November 2018, continue to run at full speed. The 8 ICT-19 Verticals Pilots projects, having started in June 2019, are currently highly active in their ramp-up.

The PPP Phase 3 will include an impressive number of 5G Trials & Pilots in many different Vertical Sectors, covering among others Automotive, Industry, Media & Entertainment, Public Safety, Health, Energy, Smart Cities, Transport & Logistics…

The Phase 2 projects have already prototyped, validated, trialed and piloted 5G in specific Vertical Sectors. This first "5G Infrastructure PPP – Trials & Pilots Brochure" highlights 10 of these Phase 2 Trials & Pilots, selected by a PPP panel based on the assessment of the Trials & Pilots impact and potential (projects in alphabetical order in the Brochure):

- 5GCAR See Through
- 5GCAR Vulnerable Road User (VRU) Protection
- 5G-MEDIA Remote Production
- 5G-MoNArch Smart Sea Port Testbed Hamburg
- 5G-MoNArch Touristic City Testbed Turin
- 5G-Xcast Media Content
- MATILDA Public Protection and Disaster Relief (PPDR)
- ONE5G Serving Industrial Areas through 5G Technologies
- ONE5G Serving Megacity Areas through 5G Technologies
- SLICENET eHealth

Each project has now produced a 2 pages flyer, which provides a summary perspective on the Trials & Pilots overview, architecture, deployment and key results. Most of these Phase 2 Trials & Pilots will have strong social impact and/or validate a service that will be monetized and/or bring a unique disruptive innovation application or service. Besides showcasing the impact of 5G technologies from the scientific point of view, most of these Trials & Pilots already have an important socio-economic footprint, providing the technological enablers for innovative services.

The overall panoramic perspective of the 5G Infrastructure PPP Trials & Pilots can be directly accessed in the 5G Pan-EU Trials Roadmap (*https://5g-ppp.eu/5g-trials-roadmap/*) and in the PPP Verticals Cartography (*https://www.global5g.org/cartography*).

This first "5G Infrastructure PPP – Trials & Pilots Brochure" provides a summary overview of some of the PPP Trials & Pilots achievements, which will certainly encourage readers to look for more information and details, visit the PPP and projects websites, read the related documents, interact with PPP participants in meetings, workshops and conferences. More and more achievements are expected in the coming period, with the final development and completion of the Phase 2 projects and the further development of the Phase 3 projects. A second edition of the Brochure is therefore expected early 2020. Stay tuned…

SEE-THROUGH

By 5GCAR

OVERVIEW

The **5GCAR** project successfully delivered four demonstrations at the 5GCAR final event on 27th of June 2019, each representing a different automotive use-case in its corresponding environment. To that end, various 5G concepts were applied to the demonstration design of these use-cases and implemented in a realistic environment on an automotive test track in Linas Monthléry close to Paris area.

The **see-through** demonstration showcases a cooperative perception application that assists drivers and automated vehicles during overtaking manoeuvres. This helps to increase traffic safety by reducing accidents and frontal crashes. The see-through uses the exchange of real-time video between a front vehicle and a rear vehicle to extend the vehicle awareness and bypass the occluded area. It relies on a video-only based relative positioning between the two vehicles.

ARCHITECTURE

The principle is based on a stereo vision system mounted at a front vehicle capturing the front and generating a local 3D map of the environment, in which a rear vehicle can localize itself using a feature tracking algorithm. Using the relative pose (position and orientation) of the rear vehicle, the front vehicle generates a new synthetic image with the perspective of the rear vehicle, from which only the region of interest is transferred to the rear vehicle and stitched to its current view and displayed to the driver. The video data transmission is ended with the completion of the manoeuvre. During the different steps, sensor data are exchanged between the two vehicles as illustrated in *Figure 1* below.

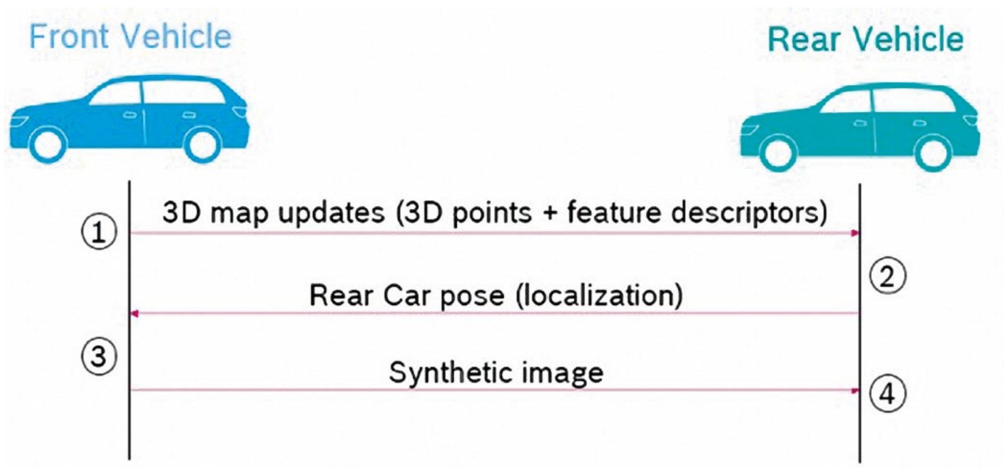

Figure 1: Different data exchange required for the see-through

DEPLOYMENT

The see-through sensor sharing scenario demonstrated by 5GCAR is shown in ***Figure 2***. A vehicle (Vehicle 1) equipped with a front-facing stereo camera system drives along a road, and a second vehicle (Vehicle 2) equipped with the same camera system and a see-through HMI follows behind. The HMI in the rear vehicle showed a seamless ‘see-through’ effect in which the front vehicle was transparent on the rear vehicle’s HMI, as illustrated in ***Figure 3***. The prototypic integration of the used communication hardware into the vehicle is shown in ***Figure 4***.

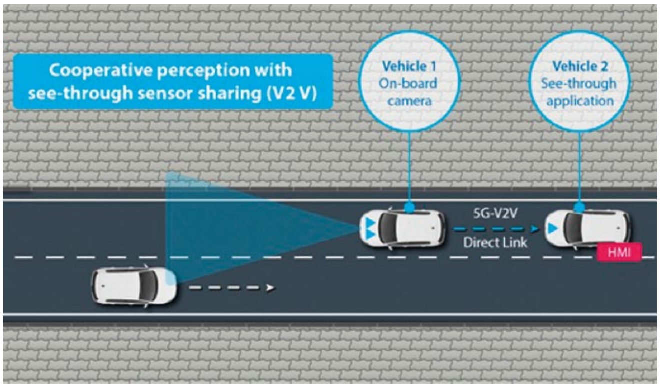

Figure 2: See-through Use Case

Figure 3: See-through HMI inside the rear vehicle

Figure 4: V2V hardware integrated into vehicle

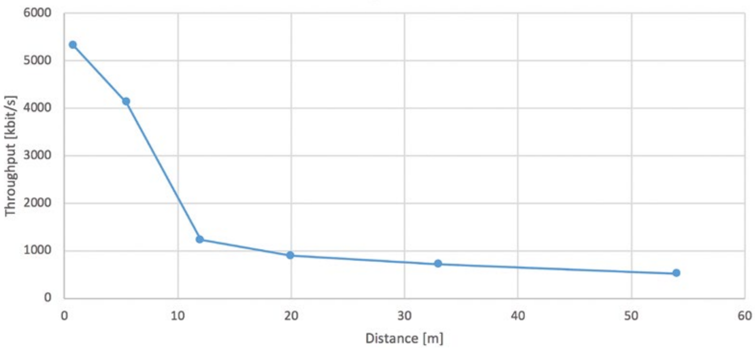

Figure 5: Throughput of the see-through application over distance of the cars

RESULT

In the demonstration work of the 5GCAR project, the seamless operation of the see-through application was ensured using a reliable and low latency link for unicast communication between the two vehicles based on a 5G-NR-V2V prototype. This low latency is particularly needed because the real-time video representing the front scene can only be transmitted after an accurate relative pose between the two vehicles is estimated. The direct communication link brings benefits over a cellular link that would induce additional delays and require a network coverage. The throughput of the application is depending on the distance (***Figure 5***) between the two cars because the see-through video overlay will be smaller if the front vehicle is further away and the front car will only transmit the necessary part of the video stream.

VRU PROTECTION

By 5GCAR

OVERVIEW

The **5GCAR** project successfully delivered four demonstrations at the 5GCAR final event on 27th of June 2019, each representing different automotive use-cases in corresponding environments. To that end, various 5G concepts were applied to the demonstration design of these use-cases and implemented in a realistic environment on an automotive test track in Linas Monthléry close to Paris area.

In the era of autonomous driving and smart mobility, the protection of **Vulnerable Road Users (VRU)** like pedestrians, cyclists, scooterists, etc. becomes increasingly important. With the aid of communication, vehicles and VRUs can be informed of upcoming dangerous situations to reduce the risk of accidents. To that end, the 5G radio network serves as an additional sensor for the vehicle, complementing the vehicle internal sensors, e.g. video and radar, offering enhanced position estimation for connected road users. Thanks to the 5G technology, obstacle removal becomes feasible using this additional sensor.

ARCHITECTURE

The overall 5GCAR **architecture** is shown in *Figure 1*. Together with other demonstrations, the VRU protection is realized in the light blue sections and common network infrastructure is shared. Most of these elements are temporarily installed at the test track, exclusive for this project. For the VRU part an innovative 5G-NR positioning prototype was developed and used for enhanced positioning of a vehicle and a pedestrian dummy, as shown in *Figure 2*. Using four synchronized prototype gNBs at the demo area, an uplink signal reception with Time of Arrival (ToA) measurements was observed in real time, which enabled position triangulation close to sub lane level. The position information of the involved road users was used to predict likely collisions, based on advanced tracking and collision prediction algorithms.

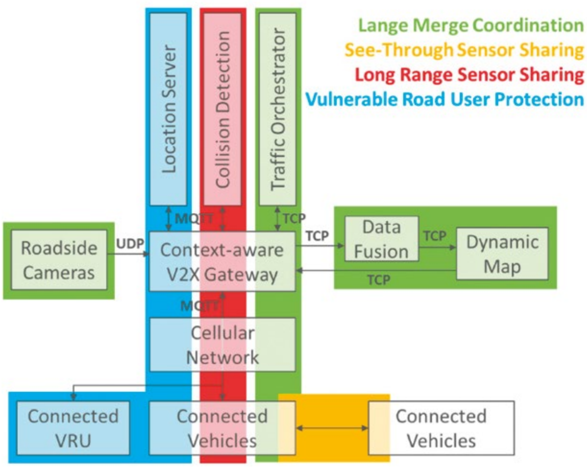

Figure 1: Overall architecture of 5GCAR

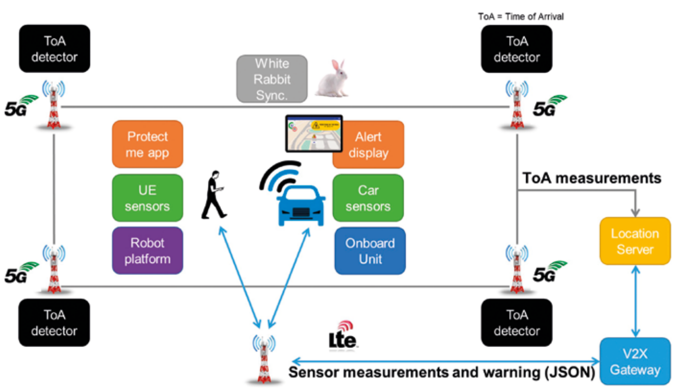

Figure 2: VRU Protection demonstrator

DEPLOYMENT

In the demonstration work of the 5GCAR project, a communication network was used to exchange status via V2X gateway sensor data and alarm messages between involved road users. By tracking such road users and extrapolating their trajectories, collisions were predicted in real time and affected road users received live warnings using alert messages displayed at human machine interface (HMI).

In *Figure 4* up to *Figure 7* elements are shown from the 5GCAR pilot deployment, specific for this VRU part.

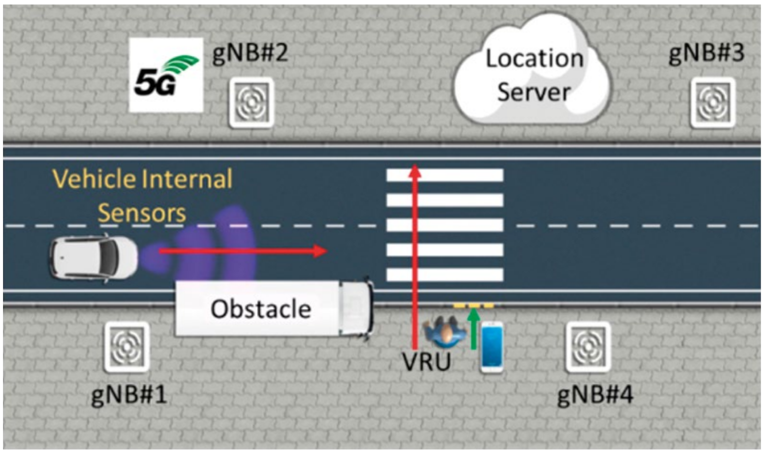

Figure 3: VRU use case obstacle/zebra crossing

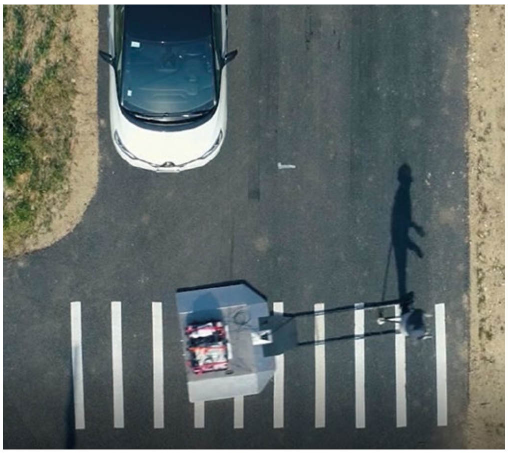

Figure 4: Implemented VRU

Figure 5: HMI developed for positions view and alert message

Figure 6: VRU Robot

Figure 7: gNB prototype

RESULT

The evaluation focused on the positioning accuracy of the 5G-NR prototype, and the collision prediction performance including the reliability of alarm messages. The positioning accuracy was found to be superior to GPS at higher quantiles in the concrete given scenario, but it should be noted that this is not necessarily universally valid. For the reliability of alarm messages, the dynamics between collision forecast time and collision warning reliability were presented, and it was shown that a time window between one or two seconds was identified as a good compromise, allowing a collision warning reliability of approximately 90%.

REMOTE PRODUCTION
By 5G-MEDIA

OVERVIEW

This use case examines how professional (remote) broadcast media productions can benefit from the advancement in 5G technology today and in the future. Today, broadcast productions of events are characterised by large teams required on location, one or several outside broadcasting (OB) vans, and long preparation times for placing and adjusting audio and video equipment. Another time-consuming part is the set-up and facilitation of a control room for the audio- and video-engineers as well as the directing team. Moreover, the steadily rising cost pressure and complexity forces broadcasters to look for new, low-cost and time-saving production methods, such as remote and smart production. In a remote production, the existing control room at the broadcaster's facilities is used. Therefore, less equipment and crew need to be present on site during the production process. Today, dedicated connections are established between the event location and the broadcasting centre to guarantee the required high performance and quality of the transmission.

5G-MEDIA aims to overcome the limitations posed today on traditional broadcast productions by implementing remote and smart production over 5G networks for low-latency and high-bandwidth media streaming. 5G-MEDIA enables remote productions from anywhere without the need for dedicated infrastructure to be specifically deployed for the event. The main innovations of the pilot are the efficient development and deployment of software-based virtualized media functions and the dynamic network and transmission optimization according to the demands of the transfer through the use of MAPE (Monitoring Analyse Planning Execute) and CNO (Cognitive Network Optimizer). The 5G-MEDIA approach is expected to lead to significant reduction in costs, personnel, time and complexity for remote production creating a high impact in the media industry.

ARCHITECTURE

The Trial / Pilot Architecture shows the setup of a Remote Production where the cameras and the audio equipment at the venue are connected via a 5G network to media production applications.

These media production applications are deployed and orchestrated by the 5G-MEDIA Service Virtualization Platform (SVP). The SVP ensures that the media processing functions are embedded within the network and cloud infrastructure, enabling low latency and high throughput as required by live streaming and media processing as shown in *Figure 1*.

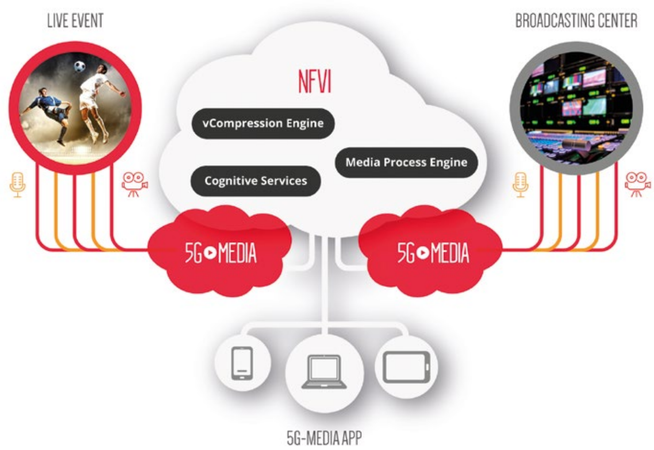

Figure 1: Remote and Smart Media production pilot

DEPLOYMENT

With respect to Performance KPIs, the focus of the pilot is to keep the maximum tolerable **packet loss rate** at the application layer within the maximum tolerable **end-to-end latency** for that application. These parameters are monitored continuously and are fed into the optimization algorithm of the CNO engine. MAPE applies a reinforcement learning algorithm to adjust video compression levels to maximize QoE in the presence of dynamically varying background traffic and congestion levels. Other relevant performance KPIs are the service deployment time (i.e., duration required for setting up end-to-end workflow required for supporting the media services) and the virtualization infrastructure scalability (i.e., ability to support, seamlessly instantiate, migrate and up/downscale media-related virtualised services).

Regarding the Business KPIs, 5G-MEDIA focuses on the reduction of "**network and service management OPEX**" for remote broadcast productions, since the 5G-MEDIA uses virtualization and MANO platforms to deploy virtualized functions and to tune technical performance parameters to meet business-level policies.

Figure 2: Images of the Remote Production Trial in Madrid

RESULT

The main achievements of the project pilot are:

- Development and flexible deployment of virtualized and flexible media services (Compression Engines, Media Process Engine, Speech to Text).
- Support of the SMPTE ST2110 video over IP standard
- Definition and implementation of a QoE Probe and Publisher to support optimization.
- Implementation of Machine Learning algorithms to adapt video quality profiles and compression levels to available network and computational resources based on Technical Guidelines from EBU, RTVE and IRT.
- Live demonstration and extensive evaluation in real environments (TID and RTVE infrastructure).

Figure 3: Setup on the broadcaster's Site at RTVE in Madrid

SMART SEA PORT TESTBED HAMBURG, GERMANY

By 5G-MoNArch

OVERVIEW

The **Smart Sea Port testbed** evaluates 5G network slicing, the reliability, resilience and security concepts, and the overall network architecture developed in 5G-MoNArch, and deploys three network slices (i.e., logical networks using the common physical and virtualized infrastructure) to address different industrial use-cases and requirements within the Hamburg port area, see *Figure 1*:

- A URLLC slice for connecting a traffic light to the port's traffic control centre, to enable the improvement of the traffic flow for trucks within the port area.
- An eMBB slice serving interactive AR for engineering teams to improve certain port operations such as asset maintenance and repair.
- An mMTC slice to connect environmental sensors installed on mobile barges to the IoT cloud of Hamburg Port Authority (HPA) for measuring air quality in the port.

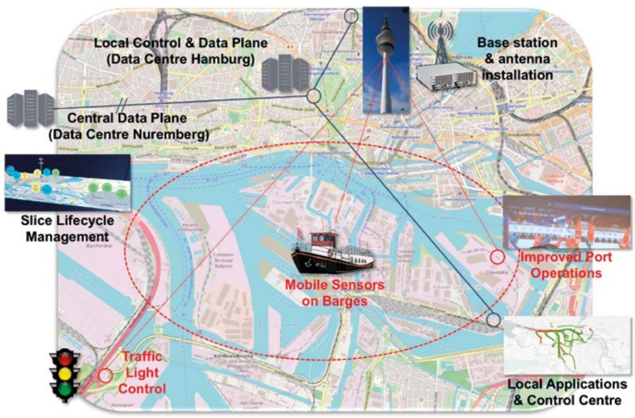

Figure 1: Schematic setup of the Smart Sea Port testbed in Hamburg (use cases in red)

ARCHITECTURE

The testbed has deployed two base stations operating at a frequency of 700 MHz that cover the area of the Hamburg port almost completely. The base stations have been built on commercial hardware with prototypic firmware / software and protocol stack providing full network slicing capabilities. Specifically, the base stations were deployed at the Heinrich Hertz TV tower in Hamburg, with one antenna connected to each base station, and with one cell provided by each base station. The antennas are installed at an elevation of 182 metres above ground.

Two terminal types using commercial router boards (multi-slice terminals for all use cases) and software defined radio with small-form-factor PCs (multi-connectivity terminals only for the mMTC use case) were deployed, both working reliably up to a distance of about 10 km over the air. For the data centres hosting the slicing-enabled 5G core, commercial servers have been deployed to a local (edge cloud) and a remote (central cloud) data centre of Deutsche Telekom. The distance between the two sites is sufficiently long for a realistic assessment of the benefits of Edge Cloud deployments in particular with respect to latency. A specific slice design and lifecycle management tool has been developed.

DEPLOYMENT

The following figure (***Figure 2***) depicts some of the infrastructure deployment realized for the testbed. These resources are located across different cities and tenants in Germany, showing the need for a multi-tenant and multi-site network architecture such as the one developed by **5G-MoNArch**.

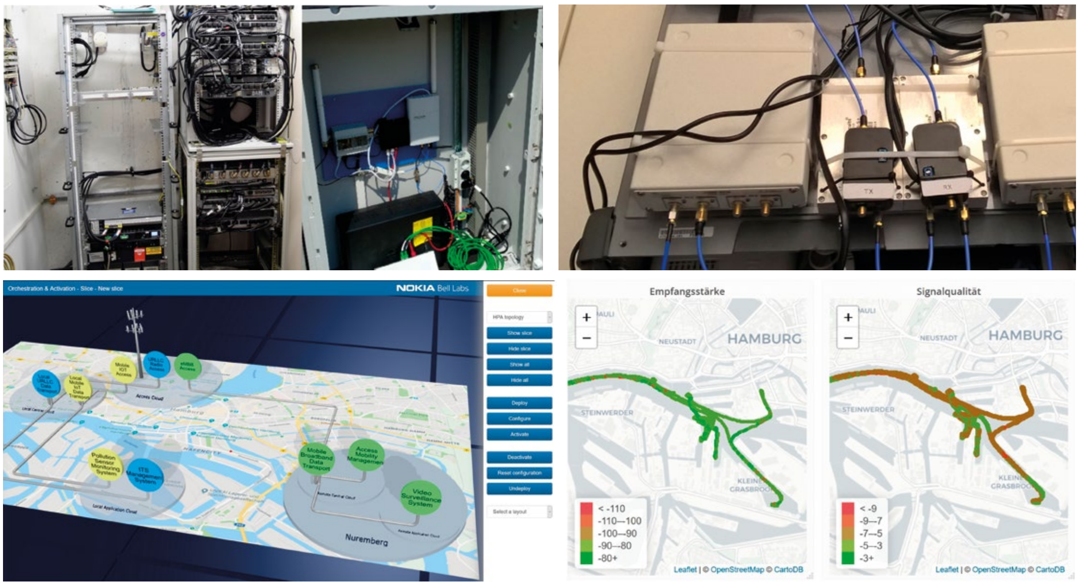

Figure 2: Base station at Hamburg TV tower (upper left), device installation for traffic light (upper middle), multi-connectivity device as installed on barges (upper right), visualization tool (bottom left), excerpt of the KPI panel (bottom right)

RESULT

The testbed has demonstrated how network slicing can be applied in a real-life outdoor macro industrial deployment with high reliability, resilience and security requirements through multi-slice capable devices which connect to more than one network slice, and targets some specific KPIs as defined by 5G PPP:

- The service creation time KPI could be reduced to a range of a few seconds.
- The latency is reduced to about 15 ms for the multi-connectivity setup in cells of up to 10 kms size.
- This testbed has demonstrated how E2E reliability can be obtained even with device mobility, based on the 5G multi-connectivity and data duplication concepts.
- A security model based on Security Trust Zones has been designed.

The deployment of the testbed in a real-world scenario using commercial data centres and transport networks, and the full integration of the use-cases with the operational environment of HPA (traffic control centre, IoT cloud) as the testbed's vertical has already shown its high economic relevance. This was clearly supported by a considerable interest and positive feedback during the public presentations of the testbed to verticals and stakeholders of the port environment and beyond (e.g., smart cities, airports, transportation) which require reliable and secure mobile connectivity for their use cases. Moreover, the GSMA awarded the testbed with the GLOMO on 5G Industrial Cooperation at MWC 2019. The socio-economic analysis conducted within 5G-MoNArch on the Smart Sea Port use-cases indicated a good return on investment for the proposed technologies such that the analysis results have started to be cited and used by various business case analysts already.

TOURISTIC CITY TESTBED TURIN, ITALY

By 5G-MoNArch

OVERVIEW

The **Touristic City testbed** evaluates the network elasticity concept and the orchestration techniques developed in **5G-MoNArch**, and deploys two network slices in order to provide visitors with an interactive Virtual Reality (VR) visit to the Palazzo Madama museum in Turin:

- An eMBB network slice that serves 360° videos to a 5G wireless connected VR headset.
- A URLLC network slice to handle all the other client-server communications (VoIP, real-time multi-user interaction or the 3D models movement control).

Generally speaking, VR is one application with a high potential and 5G is a fundamental enabling technology. The Touristic City testbed use-case provides an interactive VR environment to visit the Madama Reale chamber at Palazzo Madama, where the end-user (located in the museum bookshop) can interact with a real tourist guide (located at a small wardrobe room) through their avatars and get involved in specific activities such as thematic tutorials or instructional games. The testbed showcased this feature through the implementation of a restoration tutorial, in which the tourist was involved.

ARCHITECTURE

The testbed uses a 5G radio interface implementing PHY/MAC and higher layers in compliance with the 3GPP standard including various functionalities aligned with Release 15. The physical layer uses software defined radio with reconfigurable parameters with the baseband unit implemented on a x86 platform. The PHY layer includes some 5G NR functionality: for instance, unlike LTE, both DL and UL channels of the testbed use Cyclic Prefix Orthogonal Frequency-Division Multiplexing (CP-OFDM) based waveform as described in the standard. The eMBB and URLLC slices use different bandwidth parts aiming at satisfying the different requirements for each slice in terms of latency and reliability, as the system supports other waveforms such as W-OFDM (windowed OFDM), P-OFDM (Pulse shaped OFDM) that enables high reliability & low latency. The PHY adopts the NR concept of multiple numerologies and multiple slot configurations. It supports multiple subcarrier spacing (15, 30, 60, 120 KHz), multiple Transmission Time Interval (TTI) lengths (1, 0.5, 0.25 ms), and flexible slot format of different UL/DL configurations. Finally, the testbed implements a full orchestrator for the Virtual Network Functions (VNFs) which is based on open source MANO using OpenStack as virtual infrastructure manager. In addition, a specific GUI has been developed to access relevant service metrics and KPIs.

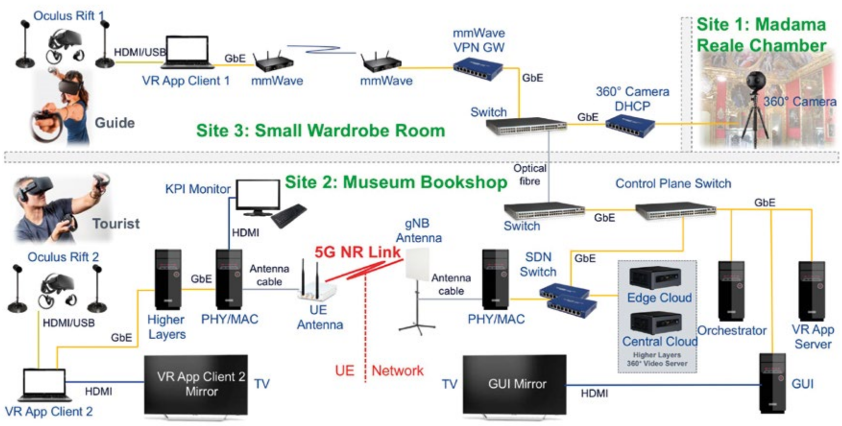

Figure 1: Schematic setup of the Touristic City deployment at Palazzo Madama

DEPLOYMENT

Figure 2: Interactive VR use case in action at Palazzo Madama (visitors side)

RESULT

The testbed has shown how Artificial Intelligence (AI) can be used to smoothly adapt the resource utilization in the network to the actual demand, namely, graceful degradation in case of overload situations which are typical for eMBB touristic or multimedia scenarios. The testbed has contributed to demonstrate the ETSI Experiential Network Intelligence (ENI) approach as a viable technology for the improvement of telecommunication networks, with the testbed being an official proof-of-concept of the group. The testbed has shown enhancements to relevant KPIs targeted by 5G-PPP:

- The service creation time KPI could be reduced to below 10 minutes.
- The usage of the 5G network slicing paradigm has been successfully applied.
- The latency values have been reduced to the range of a few milliseconds (less than 5 ms).
- The Touristic City testbed has demonstrated how innovative AI algorithms can be actually applied to the VNFs orchestration based on the ETSI ENI approach.
- The Touristic City testbed has also demonstrated an innovative VNFs orchestration approach based on the VNFs “context” migration, which is able to perform the live relocation of VNFs within very few milliseconds and avoid service disruptions.

According to the museum operator, representing the vertical involved in the testbed, enabling a solution such as the one provided by 5G-MoNArch can clearly improve the experience of a visitor at a museum and allows elderly people or people with reduced mobility in general to visit the museum remotely. The monetization of this service would be linked to its exploitation by the museum operator who was already actively involved in the requirements definition and the development of this testbed and has shown interest in continuing its use after the end of the project.

DISTRIBUTION OF MEDIA CONTENT AT SCALE IN FUTURE 5G NETWORKS

By 5G-Xcast

OVERVIEW

The continuous increase of media consumption is one of the key drivers of the evolution of networks, as users expect to access high-quality media services anytime, anywhere, on any device. The increasing demand for video imposes a big challenge for networks based solely on unicast delivery where there is simultaneous demand for a service by a large number of users. Popular live events such as football matches and major breaking news can cause unpredictable spikes in peak demand. Networks need to be over-provisioned to accommodate those peak traffic levels which requires unnecessarily large investments.

Multicast and broadcast approaches would help, but they are not widely accessible. On fixed networks multicast is usually used exclusively for the operator's IPTV service. On mobile networks, eMBMS has not seen widespread deployment, hampered by complex content service provider interfaces, non-standard APIs, poor device support and lack of flexibility in its configuration and operation.

ARCHITECTURE

The **5G-Xcast Content Distribution Framework** uses multicast and broadcast capabilities as internal network optimization features, rather than as a service to be sold. This enables conventional OTT unicast media flows (e.g. YouTube Live) to be delivered using multicast/broadcast without any changes to the end user application or the existing interfaces with Content Service Providers. It achieves this through the use of two proxies, one at the root of the multicast tree and others at the leaves of the multicast tree (*Figure 1*). As services are always available as unicast, multicast capability can be deployed on a region-by-region basis and service is available even when devices lack multicast/broadcast support.

The framework is responsive to the audience size and will allocate multicast/broadcast resources to streams as more users consume them. This decreases network load (*Figure 2*) for popular streams and makes best use of available multicast/broadcast resources. The approach is network agnostic, being applicable to fixed, mobile or 5G converged networks.

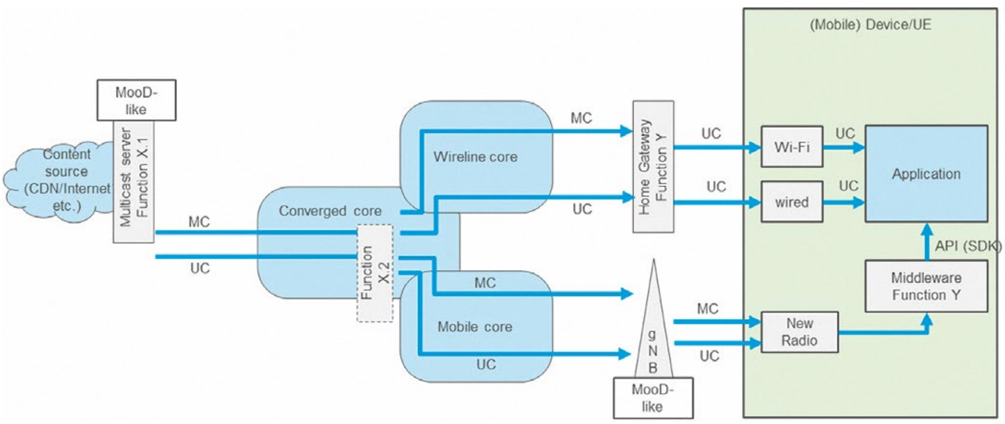

Figure 1: Content Distribution Framework in 5G converged network

DEPLOYMENT

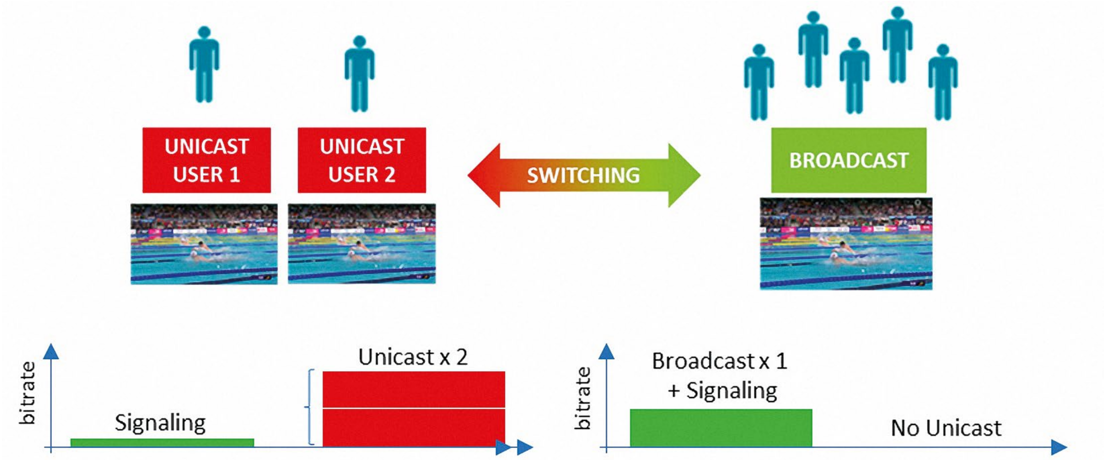

Figure 2: Dynamic audience size delivery mode switching (Red-unicast, Green-multicast)

RESULT

The trial conducted under the 5G-Xcast project proves the feasibility of the framework using the existing, unmodified BT Sport application consuming content delivered over both a fixed network and over mobile network implementing MooD (MBMS operation on Demand) with dynamic unicast/ multicast switching. This was proven over captive fixed and mobile networks to a selection of end devices. This has been supported by field measurements involving the dynamic selection of unicast or broadcast delivery across Munich urban areas (Figure 3) and additional simulator work. The trial also served to measure QoE performance according to data rate, AL-FEC or broadcast content delivery complemented by unicast.

The trial demonstrated the feasibility of the proposed approach which provides a capacity management tool for network service providers making better use of scarce spectrum. Commercialization of the complete solution is a little way off yet. However, relevant enablers such as standardized MooD has recently been commercialized in the Australian market based on LTE. The 5G-Xcast solution proposes a future-proof evolution targeting 5G.

Figure 3: Images of the trial in Munich along Englisher Garten showing multicast (green) coverage

5G PPDR
By MATILDA

MATILDA

OVERVIEW

The **MATILDA**'s 5G Emergency Infrastructure and Services Orchestration with Service Level Agreement (SLA) Enforcement pilot (**5G PPDR**) is designed to deliver tailor-made services and applications to support public safety teams in their day-to-day operations, as well as during extreme situations requiring large interventions, such as massive natural catastrophes. The core scenario targets support of a suite of reliable and survivable services and applications with SLA enforcement on top of a 5G-enabled infrastructure. For demonstration purposes, applications and services for on-site intervention monitoring are targeted, as well as a series of mobility and location tracking characteristics that can be used in the field during various types and sizes of emergency interventions.

TARGETED 5G KPIS

- Providing 1000x higher wireless area capacity.
- Saving up to 90 % of energy per service provided.
- Reducing the average service creation time from 90 hours to 90 minutes.
- Creating a secure, reliable and dependable Internet.

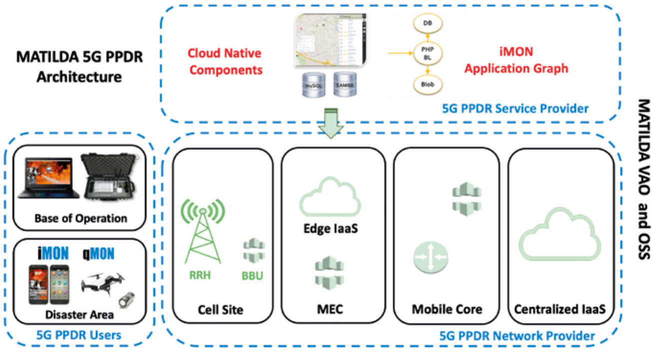

Figure 1. 5G PPDR pilot architecture

ARCHITECTURE

The 5G PPDR pilot exploits the MATILDA ecosystem comprising three distinct layers (*Figure 1*):

- **The Development Environment and Marketplace** supports all pre-deployment steps of a 5G-enabled application, through proper packaging and combination of cloud-native components.
- **The 5G-ready Application Orchestrator** layer uses component-proxying to materialize a service mesh. The proxies constitute the data-plane and abstract network traffic management aspects, by performing tasks such as dynamic service discovery, load balancing, TLS termination, circuit breaking, health checking, traffic shaping (Layer 7), publication of metrics, etc.
- **The Programmable 5G Infrastructure Slicing and Management** aims, on one hand, to facilitate the operational demands of service meshes to be handled and, on the other hand, to retrieve feedback from the infrastructure. Therefore, this part is responsible for managing lifecycles of the application graph deployment, acquiring network and computing resources as-a-Service from the underlying blocks, managing network services that compose network slices and realizing logical interconnectivity among geographically distributed points of presence.

SOLUTION FOR INDUSTRIAL VERTICALS

- Public Safety sector – e.g. Police, Fire and EMT services.
- Other mission- and business-critical communications verticals – e.g. Ports, Airports, Utilities.

DEPLOYMENT

Deployment of the 5G PPDR pilot is completed on top of a 5G infrastructure managed by the MATILDA Vertical Application Orchestrator (VAO) and Operations Support System (OSS) and is based on the implementation of 5G-enabled emergency response capabilities provided with the iMON product suite for real time intervention monitoring, extended with continuous performance monitoring engines of the qMON solution (as a VNF) for supporting active and passive service level specification (SLS) monitoring and SLA enforcement. The 5G PPDR pilot is deployed and demonstrated on a 5G pioneering band (3.5 GHz and 700 MHz) in the MATILDA testbeds at CNIT (Genoa, Italy) and INTERNET INSTITUTE Ltd. (Ljubljana, Slovenia).

DISRUPTIVE 5G PPDR PILOT ACHIEVEMENTS

- Support for cloud-native deployment and dynamic adaptation of the PPDR applications using MATILDA VAO and OSS.
- Novel provisioning technologies for distributed applications in cloud-based and virtualized 5G environments for public safety.
- Automatization (MATILDA VAO and OSS) of setup, deployment and scaling of PPDR services and 5G network slices for public safety use.
- Active and passive e2e monitoring and QoS/QoE diagnostics for cloud-based and virtualized 5G environments.

Figure 2: qMON advanced analytics for quality monitoring (top) and iMON tactical application for first responders (bottom)

RESULT

The 5G PPDR solution based on the MATILDA concepts is generic enough and can be extended also to other critical communications use cases (e.g. utilities, private communications in airports, etc.), considering the suitability of the MATILDA ecosystem for the integration of vertical applications.

KEY MARKETABLE INNOVATIONS

- 5G-ready PPDR services for real time intervention monitoring and critical infrastructure protection designed for use by first responders and public safety agencies.
- VNF-based and OSM controlled e2e monitoring engine for 5G environments to support the collection of network- and application-oriented KPIs.

PRODUCTS AND SERVICES

- iMON mobile and cloud-based application – cloud ready application component for public safety intervention monitoring with dedicated mobile app (Figure 2).
- qMON VNF – OSM 4/5 enabled virtual network function for active end-to-end networks and services measurements and monitoring.
- qMON solution – quality monitoring and testing solution used by mobile, fixed and cloud providers for quality assurance of networks and applications.

SERVING INDUSTRIAL AREAS THROUGH 5G TECHNOLOGIES

By ONE5G

OVERVIEW

Industrial areas with large factories, are areas of great potential and importance for introducing new services, mainly the support of massive Machine-Type Communications (mMTC), typically involving a very high number of low-end devices, and the support of Ultra-Reliable Low-latency Communications (URLLC), which have stringent requirements for latency and reliability (e.g. for wireless control and monitoring in the factories).

The objective of the trial is to prove the suitability of 5G technologies in supporting the requirements in industrial areas with large factories. The main KPI addressed is reliability. The trial verifies the potential of small cell multi-connectivity schemes in industrial environments for improving reliability in URLLC services. The trial demonstrates and validates the following innovations:

- Small cell 5G multi-connectivity for reliability enhancement for URLLC in industrial environments (Aalborg University testbed).
- Slice negotiation and management functionalities in industrial environments (WINGS ICT Solutions testbed).

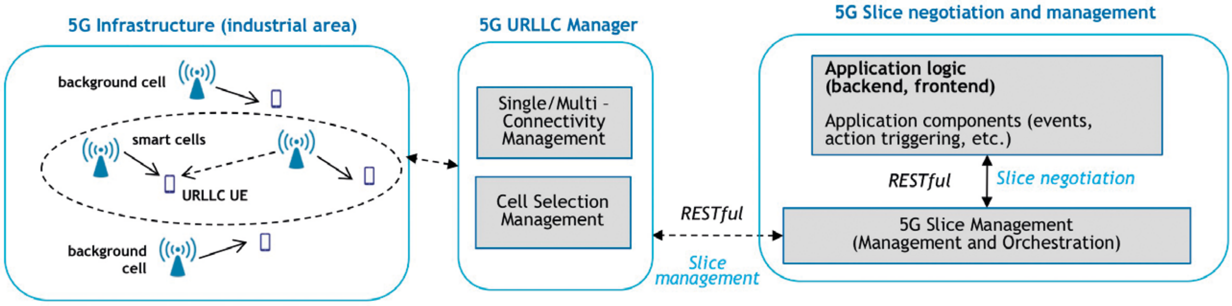

Figure 1: Trial architecture

ARCHITECTURE

The high level architecture includes 5G technologies focusing on URLLC (industrial) services. The trial includes:

- A 5G infrastructure realising an industrial environment including a set of smart cells.
- Several software components empowering both infrastructures with 5G functionalities.
- The 5G URLLC Manager is responsible for the URLLC related decisions (e.g. multi-connectivity parameters, cell selection parameters) into the industrial infrastructure. It communicates through the internet with the industrial infrastructure.
- The 5G slice negotiation and management component is responsible to perform the negotiation process between the vertical side (vertical requirements) and the operator side (operator capabilities and availability) and to forward the decisions of the negotiation process to the slice manager which is responsible for the new slices by interacting with the industrial infrastructure.

DEPLOYMENT

The industrial trials focused on the reliability aspects of the URLLC services. The trial demonstrated small cell multi-connectivity for reliability enhancement. The trial verified the potential of multi-connectivity schemes (PDCP packet duplication, Single Frequency Network, Coordinated multi-point transmission) in improving the link quality of "smart" user equipment in industrial scenarios. The objective of the trial is to verify the potential of multi-connectivity in improving the link quality of user equipment (UEs) demanding reliable communication with respect to traditional single link connection. In the trial a dense scenario was deployed in the Aalborg University premises, characterized by 4 small cells located in an industrial laboratory (Figure 2), each cell featuring 1 access point (AP) and 1 UE. Each node (AP or UE) is multi-antenna capable. Out of the 4 cells, two are "smart" cells (supporting the ONE5G technology components for multi-connectivity) and the others are background cells, i.e. meant for assessing the overall network throughput. The focus is on the downlink only, with 1 "smart" UE (benefiting from multi-connectivity), and 3 UEs associated to 3 cells in single cell mode. The UEs can be set to operate with Maximum Ratio Combining (MRC) or Interference Rejection Combining (IRC) receivers.

Figure 2: Trial industrial environment

RESULT

The targeted scenario represents a harsh interference environment given the close proximity of the cells, which may compromise the link performance in case of single connectivity. Introducing multi-connectivity is expected to lead to significant performance improvement for the UEs suffering from harsh fading or interference conditions. The smart UEs select the two cells that will provide multi-connectivity depending on their receive signal strength. Different multi-connectivity techniques are analyzed and validated: PDCP packet duplication, Single Frequency Network (SFN), coherent Joint Transmission (JT). All the nodes are controlled by a testbed server, which also collects the relevant measurement reports by the UEs, calculates the relevant KPIs and displays them live in a GUI. The goal of the trial is to assess the benefits of multi-connectivity in terms of Signal plus Interference plus Noise Ratio (SINR) improvement for the smart UE, and its impact on the overall network throughput. In particular, multi-connectivity aims at ensuring that the receive SINR by the smart UE is always above a minimum threshold which guarantees the data connection. The trial execution and results are shown in *Figure 3*. In addition, the trial implements mechanisms for the automated negotiation of price offers for providing certain quality levels of network slices fulfilling the industrial service requirements.

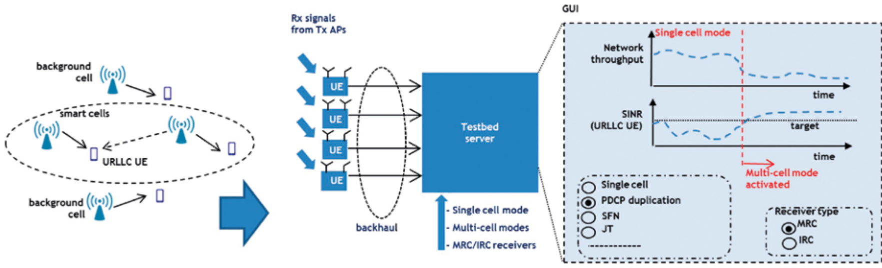

Figure 3: Trial execution and results

SERVING MEGACITY AREAS THROUGH 5G TECHNOLOGIES

By ONE5G

ONE5G

OVERVIEW

In “**Megacities**”, very high throughputs and connection densities are of the highest importance. In addition to persons with smart phones and other connected wearables, in the near future these areas will include a large quantity of wireless connected machine type communication (MTC) devices. In Megacities, various services will be intermixed to an extremely high degree, and a main challenge for 5G will be to efficiently deliver the expected quality of service/experience to all these services.

In addition, traditionally, optimization techniques have been based on improving the quality of service, based on Key Performance Indicators (KPIs). However, classic KPIs are not enough to fully optimize and grasp the network status. In this sense, service-oriented analysis and its metrics, the Key Quality Indicators (KQIs), are key features to consider in the management of 5G networks. However, the continuous gathering of KQIs presents also important challenges: the use of secure HTTP and any high-layer encrypted protocols limit the traffic inspection to measure the KQIs. The access to application layer KQIs is also very limited at both ends of the communication, being the application user-experience generally out of reach of the cellular management monitoring.

In the Megacity use case, the trial presented innovative E2E Network management for 5G infrastructures using KQI based monitoring and characterization of E2E performance. The trial demonstrated the enhancements of QoE metrics in terms of achieving a proper assessment of the network status by proper translation of low level indicators into higher layer performance metrics.

The trial demonstrates and validates the following innovations:

- E2E monitoring schemes based on the actual user QoE (Quality of Experience) as enablers for the future network management and optimization solutions in Megacity environments (integrated in a full indoor LTE network deployed in the University of Málaga).
- Slice negotiation and management functionalities in Megacity environments (implemented in WINGS ICT Solutions testbed).

ARCHITECTURE

The high level architecture includes 5G technologies focusing on eMBB (Megacity) services. The trial includes:

- A 5G infrastructure emulating a Megacity environment including a set of small cells.
- Several software components empowering the infrastructure with 5G functionalities.
- The 5G KPI to KQI modelling component is responsible to manage the Megacity infrastructure using KPI/KQI monitoring and estimation.
- The 5G slice negotiation and management component is responsible realizing the automated network slice negotiation between the vertical side (vertical requirements) and the operator side (operator capabilities and availability) and to forward the decisions toward the Megacity infrastructure.

DEPLOYMENT

The trial uses innovative E2E network management for 5G using KQIs monitoring, in terms of achieving a proper assessment of the network status by proper translation of low-level indicators into higher layer performance metrics and innovative network slice negotiation and management techniques.

In this sense, the trial implements the tools required for the prediction of the KQIs based on cellular low-layer performance metrics and configuration parameters. This can be decomposed in two main objectives: a) Representation of KPIs and the associated service KQIs under different circumstances, comparing estimated and directly measured KQI values; b) A baseline network optimization to show the capabilities of this approach. In addition, the trial implements mechanisms for the automated negotiation of price offers for providing certain quality levels of services for the Megacity scenarios. The negotiation process provided a certain price level by taking into account environment heterogeneity, variable service/traffic demand (e.g. accommodating eMBB, URLLC, mMTC) and network aspects (e.g. network utilization etc.).

The trial comprises a full indoor LTE network (*Figure 2*) accessible through a REST API, a testing UE and a remote client, running a mapping script. The mapping script translates, in real time, low-layer metrics collected from the network to service KQIs.

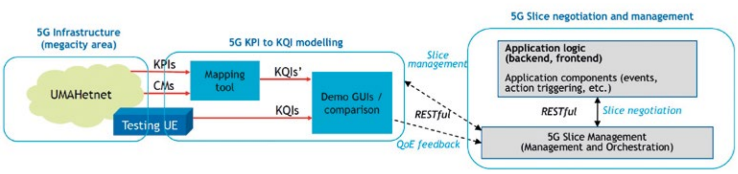

Figure 1: Trial architecture

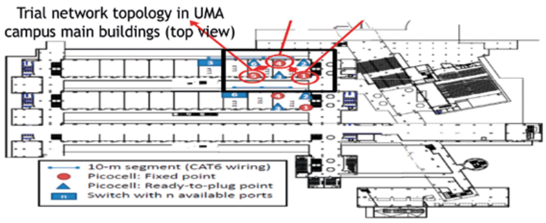

Figure 2: Trial Megacity environment

RESULT

The main KPI addressed is end-to-end latency and packet loss rate and the efficiency of the slice negotiation process.

The live prediction graph (*Figure 3.a*) shows if the estimated "a priori" end-to-end latency and packet loss rate are above a certain predefined threshold. The intervals where the estimation is above the threshold are painted in red. It also represents the values measured "a posteriori" (as a line graph), demonstrating the prediction capability of the system. Regarding the slice negotiation, an indicative scenario is presented in *Figure 3.b*. The graph in the figure demonstrates the negotiation process between the operator (blue line) and vertical (red line) offered prices. The two prices may (or may not) converge to an agreement after a set of counteroffers (service offering with lower QoE/QoS or shorter time duration).

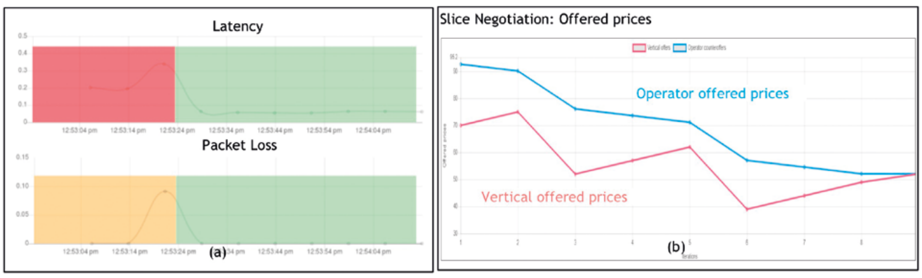

Figure 3: Trial execution and results

EHEALTH

By SliceNet

OVERVIEW

This 5G PPP Phase 2 pilot offers **dynamic 5G slicing** for in-ambulance diagnostic services for patients suffering from a stroke. The trial testbed is located at DellEMC in Cork, Ireland and will continue until March 2020, shortly after which the full testbed results will be published. In Ireland, close to 10,000 citizens have a stroke related event annually, with 7,000 acute hospital admissions and up to 30,000 people in the community living with disabilities. The direct cost to Ireland is over €0.5 billion/annum.

Accurate recognition of stroke by prehospital emergency medical services (EMS) offers significant potential in presentation and treatment for acute stroke. Through dynamic network slicing, coupled with **prioritized quality of service**, SliceNet offers "high societal value" through the deployment of mission-critical eMBB services on future 5G public cellular networks, thereby contributing to the "global competitiveness of European 5G systems" and the European Commission 5G Action Plan (https://ec.europa.eu/digital-single-market/en/5g-europe-action-plan).

By providing prioritized life-critical video-streaming from inside a high-speed moving ambulance, this pilot achieves "reliable and dependable Quality of Service (QoS) and Quality of Experience (QoE) with 'zero perceived' downtime". In addition, SliceNet's Smartly Connected Ambulance Service has developed an innovative 5G connected telemedicine system that supports **edge-based machine-learning** to provide paramedics and hospital clinicians with additional and rapid prehospital in-ambulance diagnostics that will help to enhance and improve patient treatment pathways.

ARCHITECTURE

Provision of end-to-end (E2E) slices for public safety services must have prioritization if and when contention for resources are challenged at any point along the mission-critical service chain.

A Digital Service Provider (DSP) manages network resources on behalf of the public safety entity, through the delivery of a dynamically sliced service. In the eHealth use case, the DSP prioritises a tele-stroke assessment service and delivery of a real-time HD video link from inside the ambulance back to the hospital.

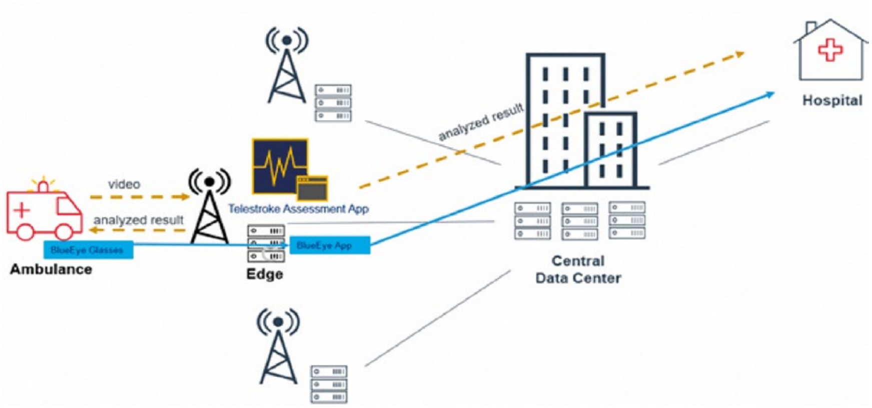

Figure 1: eHealth use case with video stream (blue) and applied machine-learning diagnostics (beige)

DEPLOYMENT

The E2E eHealth slice offered by the DSP, consists of a base slice instance. For example, delivery of real-time video streaming data from inside an ambulance back to a hospital, which includes specific requirements, such as ultra-low latency and ultra-high bandwidth. Additional sub-slices may be instantiated from different Network service providers (NSP), for example to increase the ambulance's geographical coverage. The eHealth vertical only sees the services provided by the DSP's one-stop API.

In addition, cognitive network management ensures end-user QoE, and key here is that this is achieved efficiently, by providing maximum QoE from the minimum use of network resources.

Figure 2: eHealth lab trial demonstrator showing the creation of a sliced service

RESULT

Performance measurements were taken for an eHealth service running at the cloud/core versus running at the edge with hardware acceleration. Figure 3 represents the Round-Trip Time (RTT) for all packets sent and received within the service. This RTT highlights the time taken between transmission of a packet containing data for the service, and the service responding to the client that the data has been received. RTT performance from the core is not optimal for a real-time service such as this, with several high latency spikes and a high amount of packet loss. RTT performance at the edge is much improved in comparison to the core. Latency stabilizes shortly after service instantiation, with minimal packet loss. The average RTT latency from client to core was 296.91 milliseconds. The average RTT from client to edge was 50.68 milliseconds, a 5.86x performance improvement. Average packet loss was 7.2% for the core and 0.1% at the edge, a 7.7x improvement.

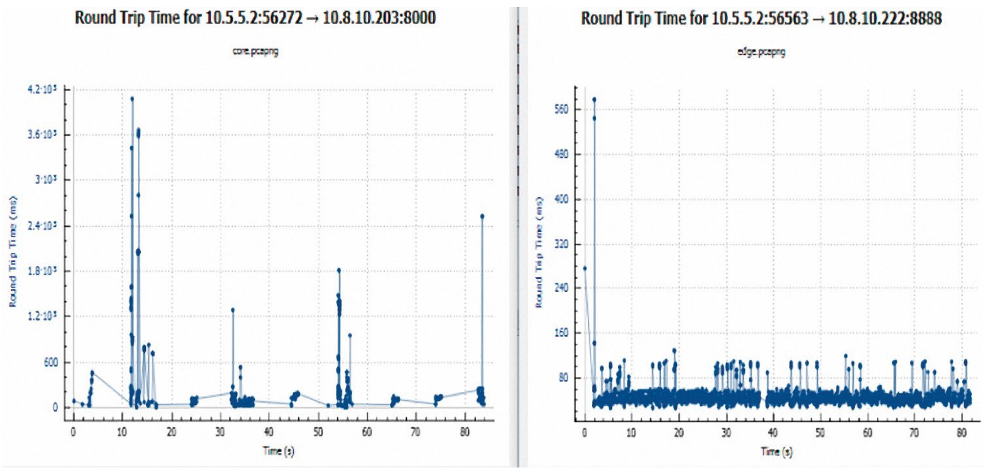

Figure 2: eHealth lab trial latency performance results for Core v Edge

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