5G PPP

5G IA

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Foreword

Peter Stuckmann,
Head of Unit Future Connectivity Systems

What a year! COVID-19 is a tremendous challenge for all people on the planet and has also impacted our constituency. First, personally – I hope all colleagues involved in the programme as well as their families are in good health. Then for the programme and our research activities themselves. Many activities could somewhat advance thanks to remote access to labs and online conferencing. However, we saw delays in most projects, in particular as we are in the third phase of the 5G PPP with many trial and demonstrator activities. Let's catch up this year as we will hopefully see a steady reduction of restrictions, in particular for the essential parts of our activities. We would like to thank you all for your efforts to contribute to the programme in such difficult circumstances!

If we look ahead, we see that R&I initiatives on 6G technologies are now starting in leading regions worldwide, with the first products and infrastructures expected for the end of this decade. In January, we launched a first set of 6G projects worth 60€ million under the 5G PPP with the Hexa-X flagship developing a first 6G system concept complemented by 8 projects investigating specific technologies for 6G, putting Europe on a par with our global competitors.

The issues at stake call for a strategic R&I roadmap set out and followed by a critical mass of European actors. Objectives with such an industrial and geopolitical dimension can only be achieved through a Joint Undertaking co-led by industry and the Commission and with close involvement of Member States.

In this context, last February the Commission adopted a legislative proposal for the upcoming European partnership on Smart Networks and Services (SNS) towards 6G, the successor of our 5G PPP. We are creating a Joint Undertaking to implement research activities on 6G technology under Horizon Europe with an earmarked Commission funding of €900 million, to be matched by the same amount through co-funding by the industry and to coordinate 5G deployment projects under the Connecting Europe Facility Digital and other programmes.

We are now looking forward to discussing the proposal with Member States in the Council and coming to an agreement on the Council Regulation establishing the Joint Undertaking

by autumn. We can then expect the first calls for proposals a few months later.

Let me call on all of you, as well as Member States and the private sector to help us in the establishment of this institutionalised partnership and to support the coordination with national investments and efforts in view of maximising the impact at a European and global level.

In the meantime, let's focus on the exciting third phase of the 5G PPP that will still run for the next few years to further deliver on the 5G trial strategy, on 5G software and hardware innovation, and start preparing for 6G. This third phase has already delivered impressive results with significant involvement of the vertical industries and clear evidence that 5G can be a game changer for their demanding digital use cases. This is a great contribution to our EU 5G strategy based on take up of 5G in vertical markets. We wish all of us, as participants of the 5G PPP, the best in our projects and activities in such challenging times. Our contribution will be key to Europe's recovery and our digital future!

Editorial

Colin Willcock, Chairman of the Board, 5G IA

The past year has been unique for all the wrong reasons. It is impossible to reflect on the last 12 months without considering the tragedy and turmoil caused by Covid. The pain and ramifications of the pandemic are likely to remain with us for many years to come.

One aspect that the Covid pandemic has highlighted is the vital nature of communication, and this is at the core of what the 5G PPP is about. The projects of the partnership have faced unique challenges but as can be seen from this annual report, the 5G PPP has made good overall progress with a strong set of projects creating significant results. I want to thank all those involved within the 5G PPP projects and the broader 5G IA community for their hard work and dedication to overcome the many obstacles and make this possible.

In the timeframe of this annual report the last set of 5G PPP projects have started. These projects cover vital areas such as 5G innovations for verticals with third party services (ICT-41), 5G core technologies innovation (ICT-42) and Smart Connectivity beyond 5G (ICT-52). These projects build a bridge between 5G and 6G technology and equally build a connection between the activities in the current partnership 5G PPP and the future partnership Smart Networks and Services. As we put together the pieces for this future partnership, we also look back to 5G PPP to learn what has gone well and what could be improved. I think it's fair to say that this reflection brings into focus the success and impact that we as a community have achieved and makes me proud to be involved in a small way in this story.

5G NOW LIVE IN MANY EUROPEAN COUNTRIES

Ten key results from the past 12 months

5G commercial launches in Europe and in other region

All 5G commercial launches are in Non-Stand-Alone (NSA) mode, connecting 5G base stations to the 4G core network. Use of the Stand-Alone (SA) core network is expected to start by mid-2021, enabling the provision of full 5G functionalities including network slicing.

24 commercial 5G services in EU 27

At the end of March 2021, 5G commercial services had been deployed in 24 EU 27 countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Netherlands, Poland, Romania, Slovakia, Slovenia, Spain and Sweden. The 5G services use the 3.6 GHz band and mainly offer mobile services but some operators offer Fixed Wireless Access services.

At the same date, fourteen MSs had published fully-fledged national 5G roadmaps including spectrum strategies (Austria, Czechia, Denmark, Estonia, Finland, France, Germany, Lithuania, Luxembourg, Portugal, Romania, Spain, Sweden, and the Netherlands.

5G commercial launches in other regions

In the USA, the four main mobile operators have already launched 5G commercial services: Verizon (October 2018 for FWA and April 2019 for mobile services), AT&T (December 2018 for network and June 2019 for mobile services), Sprint in May 2019, T-Mobile in July 2019.

5G commercial launches in South Korea were launched in December 2018 for enterprise customers and in April 2019 for residential customers. 150,000 5G base stations had been installed in South Korea at the end of 2020.

5G commercial services in China were launched by the three operators, China Mobile, China Unicom and China Telecom in November 2019. 700,000 5G base stations were in operation at the end of 2020.

Japan's three "incumbent" operators (NTT DoCoMo, KDDI, and SoftBank) launched 5G commercial services in April 2020. Pre-launches occurred in 2019, notably by NTT DoCoMo in the autumn of 2019. Rakuten Mobile, the greenfield operator, launched 5G services in 2020.

5G spectrum assignment progressing in Europe

5G pioneer bands identified at EU level are the 700 MHz, the 3.6 GHz (3.4-3.8 GHz) and the 26 GHz (24.25-27.5 GHz) frequencies. Whereas the 700 MHz band has been harmonised through an EC Implementing Decision (EU) 2016(687) of 28 April 2016, a '5G-ready' amendment of the 3.6 GHz implementing decision has been adopted in January 2019. The European Commission adopted an Implementing Decision to harmonise spectrum in the 26 GHz frequency band in May 2019.

In 18 Members States at least one spectrum auction is complete or on going as of the end of December 2020. 48% of 700 MHz spectrum, 52% of 3.4-3.8 spectrum and 14% of 26 GHz spectrum have been assigned in the EU-27 plus the UK countries as of the end of December 2020.

The 700 MHz band has been assigned in fourteen Member States: Austria, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, Luxembourg, Netherlands, Slovakia and Sweden. The UK also assigned 700 MHz spectrum in March 2021.

The 3.4-3.8 GHz band has been assigned, in accordance with 5G technical conditions, in the UK and in 15 MSs (Austria, Cyprus, Czech Republic, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Luxembourg, Romania, Slovakia and Spain) at the end of December 2020 (16 with Sweden which process ended in January 2021).

The 26 GHz band has been assigned in Italy, Finland and Greece. While it has not been formally assigned in the UK and Germany, local licences are available there.

5G devices widely available

As of December 2020, GSAcom reported 559 5G devices announced (of which 335 commercially available by 108 different vendors and 21 different categories of form factors: smartphones, tablets, indoor and outdoor Customer Premises Equipment for fixed wireless access services, routers, personal computers, head-mounted display, hotspots, modules, snap-on dongles/adapters, drones, robots, TVs, a switch, a USB terminal and a vending machine. As a comparison, in December 2019, GSAcom reported around 15,000 different LTE devices.

The vast majority of devices (73%) support sub-6 GHz spectrum bands, 19% support mmWave frequencies and 15% support both mmWave and sub-6 GHz bands. n78, n41 and n1 bands are the most supported ones.

In 2020, as lower-tier 5G solutions have been released on the market thanks to a wider 5G baseband/SoC portfolio, the premium price for 5G device has continued to decrease.

The price tag for the first 5G smartphones was generally around 1000€ in 2020. In 2021, more affordable chipsets and devices will be available on the market, with 5G smartphones below 500€.

More than 209 5G tests and experiments in EU-27[1]

As many as 258 trials have been listed so far in the 5G Observatory database[2]. The share of technical tests dropped significantly in the past year as several mobile operators have already launched 5G commercial services and others are planning 5G network deployment for 2021. In the contrary, trials concerning 5G Standalone networks and Open RAN have increased.

The most trialled verticals are media and entertainment (39 trials) followed by transport (34 trials) and automotive (24 trials).

The 258 trials were conducted in 31 countries (209 trials in 25 of the 27 EU MSs and the UK and 49 in Russia, San Marino, Norway, Turkey, and Switzerland). No trials have been registered so far in the following Member States: Cyprus, and Slovenia.

Frequency bands tested are available only in selected trials, representing 47% of all trials listed. The most used frequency band for trials is by far the 3.4-3.8 GHz (84 trials tested the 3.4-3.8 GHz frequencies out of 122 trials mentioning which band was considered). The 28 GHz band is the second band with more tests, 13 tests in total. The 26 GHz band has been used in 10 tests.

5G Global event

The EuCNC 2020 "The Connectivity Revolution" (15 June 2020 - 18 June 2020), supported by the European Commission, was planned to take place in Dubrovnik, Croatia. Due to the Covid-19 pandemic, the Steering Committee of EuCNC 2020 decided to change the format of the conference to an on-line virtual one, instead of the usual face-to-face physical one. In this format, there were no Workshops, Tutorials and Special Sessions. On the other hand, papers submitted to Regular Sessions that are accepted (the review process is being finalised) were invited to be presented in an on-line mode. The format of Keynotes and Panels was adapted to the on-line mode.

The Global 5G Event is a unique series of summits organised by the world's leading 5G organisations committed to bringing 5G technology successfully to their country or region. It has been developed in the framework of a multilateral Memorandum of Understanding in the interest of building global consensus on 5G and achieving efficiencies in the rollout of 5G technology between 5G IA (EU), 5G Americas, 5G Forum (Korea), 5G MF (Japan), 5G Brazil and IMT-2020 (China).

MoU and cooperation agreements

On 9 October 2020 in Brussels, 5G Alliance for Connected Industries and Automation (5G-ACIA) and the 5G Infrastructure Association (5G IA), co-signed a Memorandum of Understanding (MoU) to foster cooperation and synergies on 5G for Smart Manufacturing.

5G-ACIA and 5G IA signed a MoU to facilitate the roll out of future plants and factories supported by a secure and trustworthy 5G communication network in Europe and across the globe. This new partnership aims to accelerate wireless research and development in smart manufacturing and process automation. In their respective domains, 5G-ACIA/ZVEI and 5G IA intend to cooperate, build and consolidate a successful

1. *in March 2021*
2. *http://5gobservatory.eu/*

global ecosystem for Industrial 5G. The MoU aims to strengthen the cooperative relationship and to foster a closer channel for exchanging views, joint marketing and promotion activities, as well as the identification of research needs, for example, supporting the framing of suitable public funding programmes and initiatives.

Two months later in December 2020, 5G IA and another seven organisations – AIOTI, the Alliance of Internet Of Things Innovation – BDVA, the Big Data Value Association – CLAIRE, The Confederation of Laboratories for Artificial Intelligence Research In Europe – ECSO, the European Cybersecurity Organisation – ETP4HPC, the European Technology Platform for High-Performance Computing – EU-Maths-In, the European Service Network of Mathematics for Industry and Innovation and the HIPEAC project, High Performance Embedded Architecture and Compilation- signed the foundations of the work to be carried out by the TranContinuum Initiative (TCI).

The TransContinuum is the unison of related digital technologies which offers solutions for the operation of complex data workflow systems. In this continuum, HPC plays a central role as the engine propelling AI, Big Data, IoT, Cybersecurity, and Mathematical components to work together.

The Transcontinuum Initiative, or TCI, is developing a vision of the characteristics of the infrastructure required for the convergence of data and compute capabilities in many cutting edge industrial and scientific use scenarios. A paradigm change is needed: we will have to design systems encompassing millions of compute devices distributed over scientific instruments, IoT, supercomputers and Cloud systems through LAN, WLAN and 5G networks.

Workshops organised by 5G PPP projects

5G PPP projects and 5G IA organised a significant number of workshops in 2020:

- 5G-HEART webinar series: Webinar #2 – Transport vertical trials (4 December 2020)
- 5G-DRIVE 2nd webinar on roadmapping 5G technologies and services (3 December 2020)
- Joint 5G-EVEV / 5G Tours demo Webinar (December 2020)
- Full5G Webinar on 3GPP Release 18 – Opportunities for Industry Verticals (30 November 2020)
- "Beyond 5G Evolution" webinar co-organised by 5GROWTH, 5G-DIVE and EMPOWER (19 November 2020)
- 5G EVE Webinar – Italian Site Demo (18 November 2020)
- 5G PPP Webinar: 5G for Cooperative, Connected and Automated Mobility (CCAM) – 6 November 2020
- 5G-VINNI/Telenor @3rd Nordic Conference on ICT: 5G for Industry & Society (5 November 2020)
- 4th 5G PPP/3GPP Webinar (November 2020)
- IoRL online Workshop @IEEE BSMB 2020 (26 October 2020)
- 5G-IA / NetWorld2020 co-Workshop on 22.10.20
- 5G ZORRO Tech Talk (20 October 2020)
- 5G SMART webinar on 5G Process Monitoring in Manufacturing (13 October 2020)
- 5G-HEART webinar #1 – Healthcare vertical trials (12 October 2020)
- Webinar on Driving Innovation in Healthcare with 5G and Smart Networks (October 2020)
- 5G SMART Webinar on Industry and 3GPP RAN latest status in smart manufacturing (22 September 2020)
- 5G MOBIX Evaluation Framework: webinar nr. 4 (16 September 2020)
- Webinar: Empowering Vertical Industries through 5G Networks – The 5G PPP experience (9 September 2020)
- Webinar: 5G for Healthcare, Social Care, and Public Safety (15 July 2020)
- 5G EVE Webinar – French Site Demo (9 July 2020)
- 5GROWTH webinar: Powering 5G in Industry (9 July 2020)
- 5G EVE Webinar – Greek Site Demo (7 July 2020)
- 5G Tours Webinar on multi-device XR experiences (July 2020)

- 5G-MOBIX webinar on "Presentation of the Greek-Turkish cross-border corridor activities & Objectives" (29 June 2020)
- 5G Tours webinar – Multidevice XR experiences. WebXR + 5G (25 June 2020)
- 5G Tours webinar – The role of broadcast and multicast (25 June 2020)
- 5G EVE Infrastructure Training Webinar #2 (23 June 2020)
- Webinar: 5G Spectrum for Industry Verticals co-hosted with EU 5G Observatory (18 June 2020)
- 5G end-to-end experimentation by verticals in EU projects (9 June 2020)
- SliceNet Webinar #7 – 5G Integrated Multi Domain Slicing Friendly Infrastructure (19 May 2020)
- 5G EVE Infrastructure Training Webinar (6 May 2020)
- SliceNet webinar from the webinar series on System integration and demonstration (5 May 2020)
- SliceNet webinar "Cross-Plane Orchestration and Use Cases Prototyping" (21 April 2020)
- 4th SliceNet webinar in the webinar series on System Architecture (7 April 2020)
- 3rd Slicewebinar on 5G Multi-Domain Slice Management (31 March 2020)
- SliceNet 2nd webinar as part of the SliceNet webinar series (17 March 2020)
- 5G-VINNI webinar on Verticals Onboarding, Testing and Monitoring in 5G-VINNI (12 March 2020)
- Training webinars for testing in 5G-VINNI (3 March 2020 & 19 May 2020)

White papers

During the reporting period the following white papers have been produced by the 5G PPP Initiative WGs the 5G IA WGs and the NetWorld 2020 WGs:

- White Paper on "Edge Computing for 5G Networks" (February 2021). This white paper provides a) a brief introduction to the Edge computing concept, b) an exhaustive technology review focusing on virtualisation, orchestration, network control, and operational frameworks, c) a discussion about the role of security, and d) an analysis of several business aspects around the Edge ecosystem.
- INSPIRE-5Gplus Whitepaper on "Intelligent Security Architecture for 5G and Beyond Networks" (November 2020). The White Paper introduces the overall INSPIRE-5Gplus framework's High-Level Architecture, its main functional blocks and their role in enabling intelligent closed-loop security operations. To illustrate how the INSPIRE-5Gplus framework can be applied as a zero-touch security management solution for 5G systems, the White Paper presents a representative set of advanced security use cases. The presented use cases cover different advanced security problems, including: (i) trustworthy composition of network slices using Blockchains (DLT) and secure deployment of E2E network slices in compliance with agreed SSLAs for automotive verticals; (ii) detection of network attacks over encrypted traffic in Service-Based Architectures; (iii) enforcement of E2E encryption policies while leveraging TEE to enable trustworthy execution of encryption-decryption operations; (iv) reactive and proactive protection of E2E network slices using, respectively, anomaly detection and Moving Target Defence mechanisms.
- 5G PPP projects impact on Standards Development Organisations (SDOs)– (Technical Report, October 2020). This technical report summarises the outcome of a 5G-IA Pre-Standardisation Working Group survey on the achieved and planned impact of 5G PPP Horizon 2020 projects on Standards Development Organisations (SDOs). The ultimate goal of the survey was to identify weaknesses and strengths, preventing or facilitating the transfer of 5G PPP research results to standardisation bodies. The report includes the highlights from the survey, as contributed by 5G PPP projects on a voluntarily basis. It also summarises main conclusions which will be a valuable input to improve the impact on standards of the next EU Research Framework Programme.
- 5G Trials for Cooperative, Connected and Automated Mobility (CCAM) along European Cross-Border Corridors – (October 2020). This white paper introduces the scope, use cases, trial sites and particularities of each of the three H2020-ICT-18-2018 5G PPP

corridor projects: 5GCroCo, 5G-Carmen and 5G-MOBIX. The White Paper presents their preliminary results, based on currently available technological enablers, with the capacity to mitigate and/or resolve the above mentioned challenges. It also identifies and elaborates on the main concerns and challenges arising from deploying advanced CCAM use cases at regional borders.

- 5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe – (October 2020). As part of Europe's 5G Action Plan for pan-European deployment of 5G connectivity infrastructure along major transport paths by 2025, these "5G corridors" are expected to be a key enabler for connected and automated mobility and for the development of innovative ecosystems around cars and other means of transport. Connected vehicles will be able to access mission-critical information in real time. This will contribute to road safety, to a lower carbon footprint, and to a broad range of digital services for drivers and passengers.
- Empowering Vertical Industries through 5G Networks – (September 2020). Prepared by the 5G PPP Technology Board and the 5G IA Verticals Task Force, this white paper summarises the progress and results produced by 5G PPP projects, while developing some innovative 5G network services for vertical industries. It provides information about requirements and addressed business cases. It also discusses in detail several exemplary use cases from eleven different vertical sectors and identifies key 5G features that have been used to meet the specified requirements.
- Business Validation in 5G PPP Vertical Use Cases – (June 2020). This white paper, prepared by the Vision and Societal Challenges Working Group – Business Validation, Models, and Ecosystems Sub-Group (BVME-SG) describes how the BVME-SG carried out an initial survey of various 5G PPP projects with the objective of finding common approaches and processes to business validation.
- 5GCity White Paper on 5G Neutral Hosts: 5GCity Architecture and Business Model (May 2020). The document briefly presents the key functional aspects of the 5GCity platform architecture, the inspiring Neutral Host concept and a potential business model regulating its deployment in production.
- On Board Procedure to 5G PPP Infrastructure Projects – (April 2020)
- 5G PPP 5G Architecture White Paper – Consolidated Version – (February 2020)
- 5G PPP Software Network WG Paper: "Cloud-Native and 5G Verticals' services" (February 2020)
- 5G network support of vertical industries in the 5G PPP ecosystem, (February 2020)

Covid-19 impacts on 5G

The world has been hit hard by the pandemic since the cancellation of MWC 2020. Lockdowns, restrictions on businesses and travel have been put into place in a great many countries. These measures have naturally had a considerable impact on the global economy. Every sector of the economy has been affected to some degree, including the telecoms sector and 5G. And this even though telecoms have been vital to keeping the economy going, as the Internet is a strategic necessity for the entire global economy.

Covid-19 drove several (especially European) countries to postpone their 5G spectrum auctions, which had been scheduled for the first half of 2020. Some are now planned for later in 2020 (e.g. in Austria, France, Luxembourg, Portugal, Czech Republic and Sweden), 2021 (Canada), 2022 or at some unspecified future date. Some spectrum awards have also been postponed for different reasons, e.g. in Latvia.

Covid-19 also had an impact on standardisation. In March 2020, 3GPP cancelled all in-person Working Group (WG) and Technical Specifications Group (TSG) meetings. Release 16 Stage 3 freeze was delayed by 3 months until June 2020. 3GPP reached a consensus in December 2020 that remote working would be the norm until June 2021. The proposed date for Stage 3 Release 17 shifted to December 2021 and was further delayed to June 2022 in December 2020. Release 18 package Approval is scheduled for early 2022.

Longer term trends have some positive impacts as this crisis gave a boost to the following sectors: tele-working and vertical's applications (e.g., telehealth). Also, the current crisis has proven the significance of modern state of the art networks for society. Higher network capacity, increased throughput, and all features supported by 5G networks are expected to play an important role in the years to come.

At last, the European Commission has identified 5G and fibre infrastructure as a key area of investment for a digital and green recovery and will grant more than €130 million to infrastructure and digital capacities. In July 2020, Member States agreed on the NextGenerationEU recovery package (2021–2027) to mitigate the effects of the pandemic. The package is made of €672.5 million in loans (up to €312.5 million) and grants (up to €360 million) to the Member States. The Recovery and Resilience Facility (RRF) will help investments in key areas for global economic digital (20% of investments) and green (37% of investments) growth.

6G already on tracks

Nine 5G PPP phase 3 part 6 projects covering 6G were launched early 2021 and cover smart connectivity beyond 5G. 6G will use THz frequencies and will have 6 Key Dimensions:

- New classes of applications: XR, Holographic coms, Internet of Senses
- Fully Automated Infrastructure: Autonomous management, Artificial Intelligence
- Ultra low energy/EMF: Optical techs, architecture, optimising computing vs networking, EMF aware
- Industrial use cases beyond 5G: higher capacity, xGbs speed, new spectrum, sub ms latency, location, reliability beyond 5x9, ultra-high device density
- Ultra high security: Quantum, blockchain, from component to application
- Sustainable Development goals: affordability of tech, infrastructure access, climate change

CONTRIBUTIONS FROM 5G PPP PROJECTS

This chapter presents contributions from H2020 projects for phase 2 and phase 3 projects still active in 2021. The link between all ICT-19s to ICT17s projects is shown in the table below:

	5G EVE	5Genesis	5G-VINNI
5G!DRONES	✓	✓	
5G HEART	✓	✓	✓
5GROWTH	✓		✓
5G SMART	✓		
5G Solutions	✓		✓
5G Tours	✓		
5G-VICTORI	✓	✓	✓

Table 1: Link between all ICT-19s to ICT17s projects

5G PPP PHASE 2 PROJECTS

5G-PHOS

Goals of the Project

The main goal of the 5G-PHOS project is to create an ultra-broadband Fibre-Wireless (FiWi) Point-to-Multipoint (PtMP) fronthaul network, capable of supporting the required 5G New Radio fronthaul bandwidth, while at the same time alleviating the need to install fibre terminations at every Mobile Network Operator (MNO) site. Thus, the 5G-PHOS solution becomes a very appealing proposal for both vendors and MNOs, since, to the best of our knowledge, it is the only solution that specifically aims to reduce the costs of 5G densification by combining the high capacity of the analogue Radio-over-Fibre transmission with the flexibility of wireless links enhanced by Optical Beamforming and massive MIMO mmWave antennas. The 5G-PHOS fronthaul network solution builds upon the prevalent enhanced Common Public Radio Interface (eCPRI) standard and creates the necessary infrastructure to interconnect eCPRI-capable equipment, in a PtMP manner, meaning that one central location hosting the centralised equipment can be concurrently connected to several remote locations that contain the remote equipment through a FiWi network. Thus, 5G-PHOS transforms the current all-digital Point-to-Point fronthaul, which necessitates direct and dedicated links from the centralised location to all remote locations, to a PtMP digital and analogue converged FiWi fronthaul that addresses the problem of 5G densification and affordability by allowing flexible wireless last-mile equipment placement.

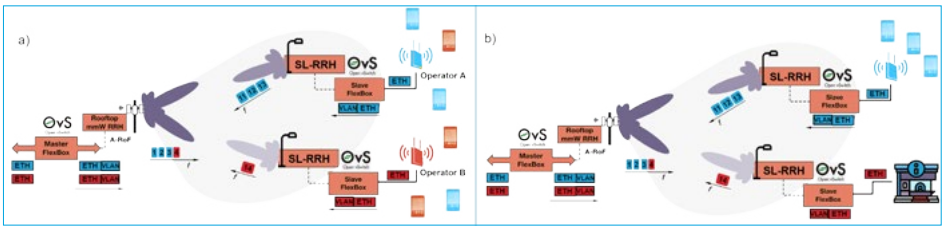

Fig. 1: 5G-PHOS a) multi-operator and b) multi-domain use cases definition

Recent major achievements and innovations

During the last year the 5G-PHOS project has made remarkable progress and met major milestones:

- **Architecture, topologies, use-cases and KPIs:** The 5G-PHOS project has produced updated 5G-PHOS Use Cases containing advanced architectural instantiations that can support, amongst others, multi-operator and multi-domain applications, as shown in Figure 1. The updated Use Cases have been presented in a deliverable that focuses on the applicability and description of the 5G-PHOS solution as a product, with the target of promoting the project's results and appealing strongly to MNOs and vendors alike. In addition, the consortium has taken on a 5G densification and power consumption study to predict future needs of 5G network planning and translate that to capital and operational expenditures, thus acting as an early roadmap for 5G deployment.
- **Experimental demonstrations:** A bandwidth-reconfigurable mmWave Fibre Wireless

fronthaul bus topology was experimentally demonstrated for spectrally efficient and flexibly reconfigurable 5G C-RANs, allowing to flexibly allocate four 1 Gbps IFoF analogue radio channels among two in-series Reconfigurable Optical Add/Drop Multiplexer (ROADM) integrated nodes and supporting in total 8 V-band 32-element Phased Array Antenna RRH terminals. The integrated silicon photonic ROADM was fabricated using the ultra-low loss Si3N4 TriPleX waveguide integration platform of LioniX International, while the V-band Phase Array Antenna developed by SIKLU supports RF beamsteering within a 90°-sector. Each of the Fibre Wireless links can transport at least 1 Gbps rate per end user beam on a 250 MBd QAM16 waveform, meeting the 5G Key Performance Indicator (KPI) user-rate requirement and paving the way towards flexible and reconfigurable 5G mmWave C-RAN architectures.

Resource allocation algorithms and SDN functionality: During this year, the project has greatly enhanced the 5G-PHOS Network Planning and Operations tool, which now features a redesigned high level User Interface, that hides low-level details from the user (either the MNO or the infrastructure owner) and offers a simple, yet intuitive, interface for assigning the converged optical/wireless resources in order to achieve the desired capacity or latency. The consortium has also performed a detailed study of higher-layer splits (6 and above) employment while testing the performance of various queueing priority schemes, in order to offer increased performance for the tight-requirement fronthaul traffic.

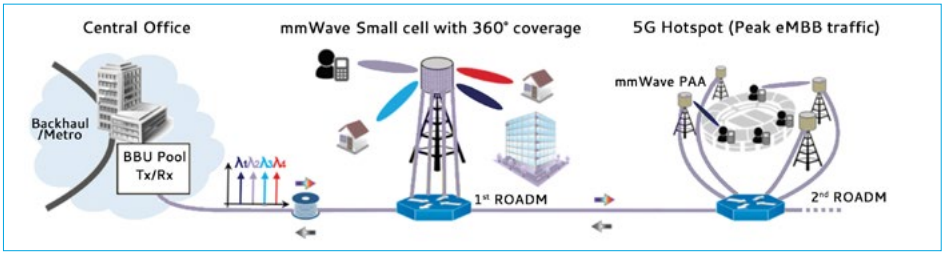

Fig. 2: Demonstration of a two-stage reconfigurable optical transport network through two cascaded low-loss integrated silicon photonic ROADMs

5G-PHOS demonstrators

5G-PHOS will carry out three main demonstrators during its duration. The first demonstrator has already taken place in Turin in February 2020 and has successfully demonstrated the 5G-PHOS solution in a real environment showcasing coexistence with already deployed equipment and running live traffic. The trial was conducted over TIM's in-field legacy PON infrastructure and included transmission of the 5G-PHOS analogue signal over FiWi with capacity up to 1.6 Gbit/s on single frequency band and single optical channel, expandable up to 16 Gbit/s with 10 frequency bands per optical channel and up to >60 Gbit/s aggregating multiple optical channels.

The project consortium now focuses its efforts towards the implementation of the next two demonstrators described below:

- 5G-PHOS Demo 2, which will take place in August 2021, will focus on ultra-dense networks and will interconnect two different sites, i.e., the "server site" located at the COSMOTE building and the "client site" located at the NTUA premises in Athens. A mixture of services will be validated over an Ethernet-over-5G-PHOS infrastructure, emulating an eCPRI-over-5G-PHOS fibre-wireless fronthaul scheme employing real MNO equipment.
- 5G-PHOS Demo 3, which will take place in May 2021, focuses on hot-spot scenarios and will be carried-out in the PAOK FC stadium, located in Thessaloniki. This demo will showcase dynamic optical capacity allocation to be validated through the delivery of high-bandwidth WiFi services over the 5G-PHOS infrastructure.

5G PPP PHASE 3, PART 1: INFRASTRUCTURE PROJECTS

3 Projects have been selected from the 16 proposals received by the EC in response to the 5G PPP ICT-17-2018 call. These three projects started in July 2018 and are running for 3 years implementing and testing advanced 5G infrastructures in Europe.

5G-EVE

5G European Validation platform for Extensive trials

Project goals

The 5G EVE concept is based on further developing and interconnecting existing European sites to form a unique 5G end-to-end (E2E) facility. The four interworking sites in France, Greece, Italy and Spain provide both indoor and outdoor facilities. Each site is operated by a telecoms network operator, i.e. Orange in France, OTE in Greece, TIM in Italy, and Telefónica in Spain (see Figure 3). The four sites are interconnected to provide a seamless single-platform experience for experimenters from vertical industries. The 5G EVE end-to-end facility enables experimentation and validation with full sets of 5G capabilities – initially 3GPP Release 15 compliant and by the end of the project initially 3GPP Release 15 compliant in NSA and SA modes.

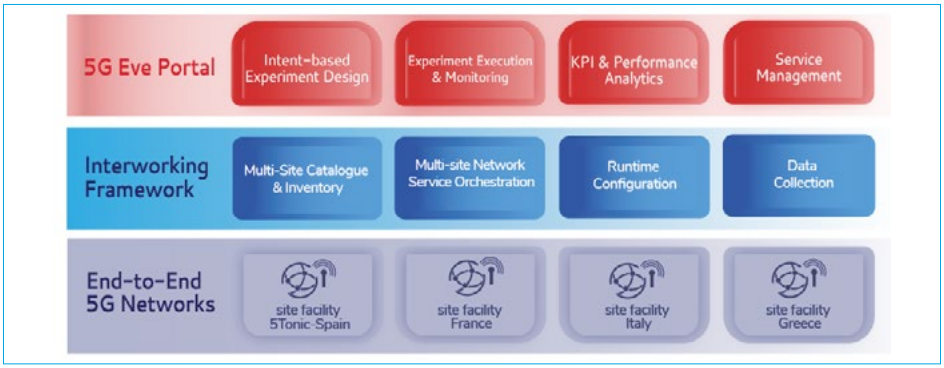

Fig. 3: 5G EVE Platform – Interworking of Multiple End-to-End 5G Site Facilities

Specifically, the technical objectives include: (i) Implementing Release 15 NSA and SA technologies in the four sites and starting some few R16 features that should be available for supporting ICT-19 projects; (ii) Creating intent-based interfaces to simplify access to the 5G end-to-end facility; (iii) Designing and implementing site interworking and multi-x slicing/

orchestration mechanisms; (iv) Implementing a vertical-oriented open framework; (v) Creating advanced 5G testing and measurement mechanisms to validate advanced 5G features and KPIs; (vi) Advanced data analytics on the output of monitoring processes for anticipating network operations.

Major achievements

In 2020, 5G EVE achieved the following major results:

(i) Completion of the 5G EVE functional framework for design, scheduling and monitoring of automated validation activities: The framework has been developed, launched internally for use and iterative testing by use case experimentation activities, and finally released in June 2020. The released framework includes all functional features for serving a fully automated workflow for design, scheduling, execution, monitoring, result analysis and performance diagnosis of experiments across all 5G EVE site facilities. (ii) Readiness and evolution of 5G EVE site facilities' 5G equipment, orchestration, and performance monitoring tools as well as secure interconnection of all sites: All site facilities in 5G EVE have deployed and upgraded with the required 5G Non-Standalone (NSA) and Standalone (SA) capabilities (Rel-15), assessed network performance level for the deployed technologies and the chosen configurations.(iii) Use case readiness and progress of actual validation campaigns for fully-automated test cases: All 5G EVE use cases have been fully developed, thoroughly integration-tested, executed and showcased on either manual or semi-automated mode. Since May 2020, the 5G EVE framework is in use on a daily basis by about twenty registered users, and all 5G EVE use cases have completed the design and preparation phase for fully-automated test-case execution over the released 5G EVE framework. The first ICT-19 projects have benefited from the 5G EVE framework for running experiments. (iv) 5G EVE achieved the opening of two Work Items in ETSI INT on the KPIs monitoring and validation. The action backed and promoted by the project has got a wide support also among other partners in ETSI and represents a good success in the standardisation footprint of the project.

Overall, 5G EVE progressed as planned in executing, validating, and supporting the pilots in 2020. The project successfully deployed 5G capabilities in all sites and upgraded the 5G EVE framework with added-value services in the first major release of the 5G EVE platform.

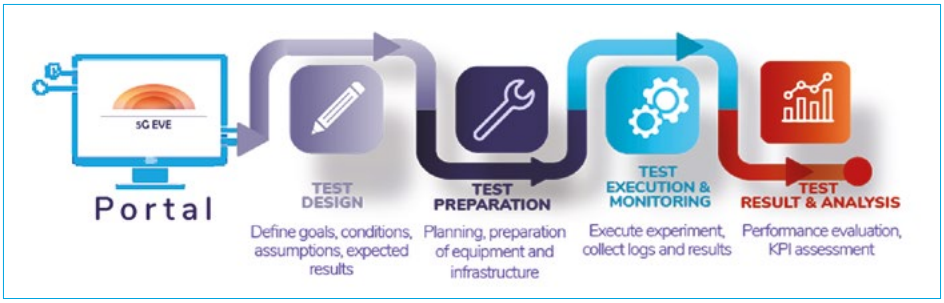

Fig. 4: 5G EVE Portal – The 4-Step Process to 5G Validation

Vertical use cases

At its four interconnected sites, the 5G EVE platform has enabled 12 vertical use cases, including the experimental validation of services and applications by verticals.

France – The French site facility has integrated and tested the first two use cases: (i) A 360° video virtual visit (eMBB) use case, which aims at immersing the visitor in a virtual reality scene located in a real environment. Fully automated deployment was achieved by the end of 2020. ii) A use case on critical utilities of smart energy (URLLC and mMTC), which focuses on fault management for distributed electricity generation in smart grids. For both use cases, data throughput and API service latency have been evaluated when using 5G networks.

Greece – The Greek site deployed use cases on Smart Cities, Industry 4.0, and Smart Energy. The Smart Cities scenarios include air quality monitoring and remote health monitoring. For them in-depth experimentation has taken place including testing and validation as well as network diagnosis and root cause analysis. For the Industry 4.0 use case, autonomous control of an AGV vehicle via 5G connectivity has been demonstrated. Finally, extensive experimentation was carried out with 5G-powered management functionality for addressing outages in smart grids.

Italy – The Italian site facility offers 5G-wide live in-field coverage and lab coverage as well as OpenStack VMs on the service side for the use cases Smart Transport, Smart City and Public Safety as well as Smart Tourism. Most of the services have been implemented. The Italian site has also started supporting use cases coming from ICT-19 projects. The Italian site has been described in a dedicated workshop in November 2020.

Spain – The Spanish site has deployed several use cases. The first one, related to Industry 4.0, includes the implementation of virtual PLCs and real-time video processing at the network edge for the operation of Automated Guided Vehicles. In addition, the Spanish site demonstrated the use of 5G for immersive virtual reality in tourism applications at the world's largest tourism fair, FITUR. Two additional use cases deployed at the site are an edge processing platform for TV distribution to 5G mobile devices and the support of online gaming with 5G access. The Spanish site also supports ICT-19 use cases, specifically one proposed by the 5GROWTH project that focuses on remote operation of quality equipment by a 5G-connected worker.

5G-VINNI

Objectives of the project

5G-VINNI's main objective is to provide and enable the longer term evolution of an end-to-end (E2E) 5G facility demonstrating that the key 5G PPP network KPIs can be met, accessed and used by vertical industries to set up research trials, to further validate core 5G KPIs in the context of concurrent usages by multiple users, by serving end users with flexible and reliable services ranging from low bit rate high latency services to high bit rate low latency services and everything in between.

The 5G-VINNI facility sites ecosystem is modular. This modularity guarantees the highest degrees of freedom of both 5G-VINNI facility site configurations and facility interworking. The conceptual E2E facility architecture is organised in three layers, as defined in the 5G PPP Architecture white paper[3], which are the Service layer, the Network layer and Resources & Functional layer.

The Resources and Functional layer of the 5G-VINNI E2E facility is comprised of the RAN, Backhaul, Mobile Core and Cloud Computing facilities, Edge or Centralised Clouds. The Resources & Functional Level will provide the physical resources to host the Service Level and Network Level elements (e.g. VNFs). These elements are interconnected to build dedicated logical networks, customised to the respective telco services, e.g., eMBB, V2X, URLLC, mMTC. Any Service layer or Network layer VNF from any 5G-VINNI facility can be called upon to be included within the logical network of a

3. http://doi.org/10.5281/zenodo.3265031

use case driven from another facility, allowing to test use cases using the consolidated shared capabilities of all facilities, rather than limiting vertical industries to individual sites, offering the potential for new business models and partner relationships whereby the service provider may both expose and consume service at different levels in the network.

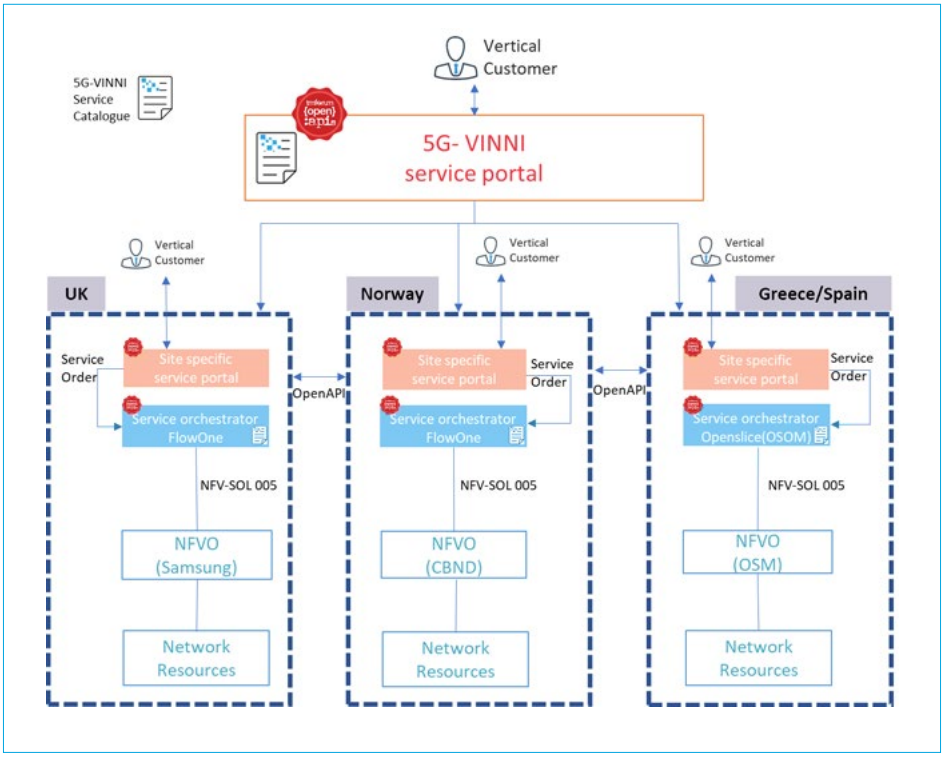

Fig. 5: 5G-VINNI NSaaS delivery model architecture

Major achievements/innovations and performance KPIs

- **Network Slice as a Service (NSaaS) delivery model** – 5G-VINNI adopts the NSaaS delivery model to offer customised service experience to verticals, basing its architecture on guidelines from telecom industry organisations and the normative specifications from standards bodies to ensure interoperability and reproducibility. For validating the NSaaS model, 5G-VINNI has assembled an end to end facility with the latest 5G technologies for radio access, backhaul, core networks, leveraging the most advanced virtualisation technologies and optimisation algorithms to test the model with demanding vertical sector driven applications and services. Each vertical uses the slice that has been provided to meet their requirements for trialling activities, setting up different use cases and assessing their KPIs under different network conditions.
- 5G-VINNI incorporates into its architecture the guidelines from telecom industry organisations and the normative specifications from standards bodies to ensure interoperability and reproducibility. The 5G-VINNI high level architecture which allows NSaaS delivery model is shown in Figure 5, where the 5G-VINNI portal and service catalogue expose TM Forum Open APIs towards verticals to allow them to directly trigger necessary operations for service ordering. The 5G-VINNI

Service Catalogue derives content from Facility Service Catalogue offerings hosted by the respective Service Orchestrators (SO). The service order is then passed to the SO in one of the main 5G-VINNI facility sites which are located in UK, Norway, Spain and Greece. The SO, which implements the 3GPP Network Slice Management Functionality specified in 3GPP TR 28.801, then instantiates the network slice by subsequent calls to the respective network function orchestrator (NFVO). The NFVO implements the northbound interface specified in ETSI NFV (GS NFV-IFA 013 and GS NFV-SOL 005). This normative specification defines the protocol and data model for the interface capabilities in the form of RESTful APIs which have become de-facto solutions for most of the industrial and open-source NFVOs.

- **Research Items** – 5G-VINNI has identified a number of research items that advance the state of the art in several areas. In the area of backhauling automation a contribution was made to ETSI's 3rd mWT plugtest event. In the area of service based architecture the work is investigating potential decentralised features of service based interface techniques for 5G and beyond. In the area of satellite integration in 5G and flexible architecture for verticals in 5G and beyond, the project presented the progress in scientific papers and contributions to standards developing organisations (e.g. 3GPP SA2, SA5 and ETSI ZSM). Concerning measurements of KPIs progress in being made in sub-6GHz and mmWave spectrum as well with respect to measurements in an experimental Open Air Interface testbed and 5G NR SDR-based set-ups. The project finalised a comparative analysis of business models for interworking of facilities sites. In the general area of slice orchestration the work focused on the preparation of the ETSI ISG ZSM PoC#2, and has the ambition to demonstrate auto-scaling between the facility sites using OSM and Openslice.
- **ETSI ZSM PoC** – The 5G-VINNI team is working on the ETSI ISG ZSM PoC#2, entitled "Automated network slice scaling in multi-site environments", a description of which is available at the ZSM wiki[4]. The PoC#2 has the aim of demonstrating the capacity to automatically scale out a deployed network slice instance across multiple administrative domains. The management and orchestration capabilities of individual facility sites, and the enablers allowing for the interworking across them, are aligned with ZSM architectural design principles. The first PoC#2 report provides an overall description of the PoC, including the in-scope use case and the related user story. The pre-/post-conditions and workflow detailed in the PoC user story will define the acceptance criteria to be used for PoC execution.

Description of demos

5G-VINNI recorded to date a total of 28 trials and pilots that are executed over the 5G-VINNI facility ranging from co-operations with verticals applications projects (5GROWTH, 5G-VICTORI, 5G Solutions), co-operation with members of the External Stakeholder Board as well as experiments with external entities demonstrating the openness of the facility.

A large pilot is executed in collaboration with the Norwegian Defence for which 5G-VINNI is deploying dedicated network slices fulfilling extremely high requirements.

The trial on Remote Robotic Control with 360° VR-based Telepresence executed at the 5G-VINNI UK facility site in Adastral Park, is featured in the 2nd edition of the 5G PPP Trials & Pilots brochure[5]. A further trial at the UK facility site, demonstrates drone based face recognition exploiting the high bandwidth rates offered by 5G. A trial at the Spain facility demonstrates the harmonisation of multi-cloud and MEC management platforms for service continuity scenarios. Two trials at the Portugal site address safety critical communications for railway signalling systems and critical signal and data exchange for smart grids.

A number of additional trials and pilots support vertical applications in eHealth (neuro-rehabilitation, mobile ultrasound), agrifood (aqua-culture), UAV multi-user remote control, low latency streaming, media production and distribution, eMBB under high speed mobility conditions in railway environments, as well as technology solutions for autonomous edge, and satellite backhauling.

4. *https://zsmwiki.etsi.org/index.php?title=PoC_2_Automated_Network_Slice_Scaling_in_Multi-Site_Environments*

5. *https://5g-ppp.eu/wp-content/uploads/2020/12/5GInfraPPP_10TPs_Brochure2.pdf*

Project Goal

The main goal of the 3-year collaborative research EU-funded project 5GENESIS (*https://5genesis.eu*) is to validate 5G Key Performance Indicators (KPI) for various 5G use cases, in both controlled set-ups and large-scale events. This will be achieved by bringing together results from a considerable number of previous EU projects as well as the partners' internal new R&D activities in order to realise an integrated End-to-End (E2E) 5G Facility, called OPEN5GENESIS suite (*https://github.com/5genesis*).

The OPEN5GENESIS Suite is in depth described in the project public deliverable D6.2 'trials and experimentation (cycle 2)' (*https://5genesis.eu/deliverables*). D6.2 presents the progress of 5GENESIS in the second period of activities (2nd cycle) and the results actually do reveal the benefits on several system KPIs from the adoption of 5G technology. In some specific set-ups that is also verified for preliminary implementations of 5G verticals applications.

The OPEN5GENESIS Suite has been used to facilitate the experimentation of 5G-related use case and scenarios. 8 main KPIs and 4 application specific validation trials have been run so far, by using 123 experiments focusing on very specific aspects of 5G deployments. The performed tests mainly focused on the evolved 5G infrastructure deployments that include radio and core elements in non-standalone (NSA) deployment configurations based on commercial and open implementations. Under the 5GENESIS project activities the OPEN5GENESIS Suite has been used to allow each of the 5 Platforms running under the project to independently execute, test and validate its own specific features. The performed tests are based on the detailed Test Case description as specified in the project public deliverable D2.3 'Initial planning of tests and experimentation' (*https://5genesis.eu/deliverables*), and should be carried out through the Portal / Experiment Lifecycle Manager (ELCM) components of the Rel. A of Open 5GENESIS Suite.

Regarding the run tests, one can summarise the main achievement per Platform as follows:

- **Athens**: includes baseline tests for throughput and RTT KPIs, Service Creation Time of a 5G connectivity service, one-way delay and RTT under different load scenarios.
- **Berlin**: includes baseline tests for throughput and RTT KPIs, 360o live video streaming Quality of Experience (QoE), RAN coverage and UE density.
- **Limassol**: includes baseline tests for throughput and RTT KPIs as well as Service Creation Time of 5G component deployment.
- **Málaga**: includes baseline tests for throughput and Round-Trip Time (RTT) KPIs, as well as Mission-Critical-Push-To-Talk (MCPTT), RunEl 5G Radio Access Network (RAN) solution physical layer latency and content delivery streaming service.
- **Surrey**: includes baseline tests for throughput and RTT KPIs, NB-IoT coverage, IoT application specific latency.

The main part of D6.2 contains a basic presentation of the validated KPIs and measured metrics followed by explanations. The detailed test cases and result tables are available in the Annex of the same document. It should be noted that the original Test Cases (the ones available in the annex of the previous public deliverable D6.1 'Trials and experimentation - cycle 1') have been refined and are delivered as a separate Testing and Validation companion document. This document includes all the test cases templated (i.e. the measured KPI, the System Under Test (SUT) definition, the measurement process and tools) that have been used throughout D6.2 and D6.1. In addition, in a separate section the common 5GENESIS measurement statistical analysis methodology is summarised.

Updates from the 5 5GENESIS Platforms

The **Surrey Platform**, hosted in the 5G Innovation Centre (5GIC) at the University of Surrey, UK, supports commercial 4G/5G 64x64 MIMO Radio Access Network (RAN) with 100 MHz bandwidth and features such as network slicing, function virtualisation, Software Defined Networking (SDN) control and Multi-Access Edge Computing (MEC). Both stand-alone (SA) and non-standalone (NSA)

network configurations are supported, providing coverage and operating in the 700, 2600, and 3500 MHz bands. The fully virtualised 5G core, which is compliant with 3GPP Release 15/16 standards, is developed in-house by 5GIC researchers and engineers. In 5GENESIS, the Platform is used to demonstrate the capability of 5G networks to use and exploit multiple Radio Access Technologies (Multi-RATs), 3GPP and non-3GPP, supporting mobile broadband (MBB), enhanced mobile broadband (eMBB) and massive Machine Type Communication (mMTC). The Platform use case demonstration considers a range of services that will be provided as a mix between high data rate multimedia services (upload and download) and a continuous flow of low bandwidth sensor readings collected through environment sensors. The objective is to achieve the ITU target density of 1 million devices per km^2 (which translates, at an even distribution to 1 device per square metre). The services provided and delivered over the same infrastructure will be a mix between mMTC and eMBB. The Platform will collect, analyse and process the multimedia and sensor content in real-time.

The **Limassol Platform** has carried out a 5G deployment configuration with satellite backhaul, suitable for rural/underserved areas, as well as for maritime 5G communications. Trials have been conducted with 5G agricultural applications deployed at the satellite edge, including weed detection and removal using AI-enabled image analytics."

The **Málaga Platform** run a first trial of 3GPP Mission Critical Services (MCS) and live video with Malaga Police involving the UMA's 5G NSA outdoor deployment, Telefonica's EDGE node, Nemergent's 3GPP MCS and Police Department's mobile control centre and vehicles (Video available at *https://www.youtube.com/watch?v=9H6OkjX74iw*).

The **Athens platform** is an E2E experimental 5G Facility, showcasing features of next generation networks, with particular focus on software network technologies (NFV and SDN) and MEC/LBO. It comprises an open 5G Platform consisting of 3 different sites in the Athens area: i) The campus of NCSR "Demokritos", in north-east Athens, offers 5G NSA/SA deployments based on AMARISOFT and ATHONET equipment, as well as software-defined 5G New Radio (NR), based on OpenAirInterface; ii) The COSMOTE building (OTEAcademy), in north Athens, is a multi-functional complex, combining various indoor and outdoor usage scenarios, such as MEC solution based on 5G Nokia Airscale small-cells. This site is connected with an optical backbone with NCSR "Demokritos" campus supporting experimentation with distant, local and edge computing environments; iii) The Stadium of Egaleo, in west Athens, equipped with edge computing cabins and network infrastructure to host demos in a more realistic environment and focusing on backhaul issues. This site is connected with P2P Microwave wireless link with NCSR "Demokritos" campus.

The **Berlin Platform** aims at providing a flexible and scalable E2E integration of 5G technologies including 5G Core, transport network, and mmWave backhauling. The platform provides multi-vendor, commercial 5G NR upon availability and supports network slicing, function virtualisation, and mobile edge compute. It supports SA and NSA configurations, utilising indoor- and outdoor-coverage based on commercial LTE and 5G NR operating in 700, 2600, and 3700 MHz bands.

5G PPP PHASE 3, PART 2: AUTOMOTIVE PROJECTS

5G-Carmen

Goal of the project

The 5G-Carmen project has the ultimate goal of providing a safer, smarter, connected and cleaner mobility. Setting on the 600 km corridor connecting three countries in Europe, namely Italy, Austria and Germany, the project aims to enable 5G based Cooperative, Connected, and Automated Mobility (CCAM), putting special focus on the cross-border scenarios.

To achieve this goal, the 5G-Carmen consortium will leverage on key technological enablers for 5G in vehicular networks, including 5G NR, C-V2X, Mobile Edge Computing (MEC), predictive Quality of Service (QoS) and highly accurate geo-localisation to run on-field demonstrations of 5G based CCAM services. In addition to the pilots, 5G-Carmen intends to analyse the innovation proposed also from business and impact points of view, as well as through simulations and laboratory studies.

2020 major achievements

In 2020 the project worked on the E2E architecture and system-level technical specifications design, focusing on topics as the elaboration of technical interfaces for MEC, Precise Positioning and Predictive QoS, integration of AMQP Broker and GeoService in the architecture, security of in-vehicle embedded solutions, distributed MEC control and network service orchestration.

Preparation for the on-field trial focus was put on network connectivity aspects (5G NSA RAN infrastructure covering the two cross-border sections, optimised routing of the user plane during roaming, improved network reselection when roaming), MEC implementation, inter-MEC communication and on providing overall connectivity to central cloud instances outside the mobile networks, including to lab infrastructures of partners developing the first implementations of the Edge Orchestration Platform for CCAM services. The platform is the result of the project's effort towards the development of a multi-tiered, multi-domain orchestrated platform for CCAM. It integrates the components of a MEC system with resources and service orchestration. Security mechanisms have been developed through an identity management system as well as a cloud-based intrusion detection system to protect the orchestrated platform of the CCAM.

Since the use cases, system architecture and CCAM platform are now defined, the implementation and internal simulations are in progress. The local sites and borders where each use case will be trialled are also in preparation with first results expected by mid-2021. First pilot tests were carried out at the end of 2020 to evaluate vehicle-to-MEC connectivity and vehicle sensing capability. The Edge Orchestration Platform lab tests are well advanced. Local lab tests will continue in 2021, while the on-boarding on all MECs in the Corridor started at the beginning of 2021. In order to monitor and evaluate the impact of the 5G-Carmen systems, a set of Key Performance Indicators (KPI) have been discussed and agreed in the consortium. These KPIs will assess not only the performance of the final use cases that will be delivered in the pilots, but also investigate the role of various components in the overall architecture that has been proposed in the project. Test drives on the Corridor for these specific KPI tests and/or 5G/AD-relevant components/functionalities will continue in Q1 2021 and will be used to verify the KPIs as well as simulation and business modelling assumptions, and to re-evaluate the architecture if needed.

Simulations are foreseen to evaluate the scalability of 5G-Carmen solutions, and to provide input to business analysis. With this aim, 5G-Carmen has already developed a simulator for CCAM services, reproducing the cross-border scenarios at the Brenner Pass between Italy and Austria (see Figure 6).

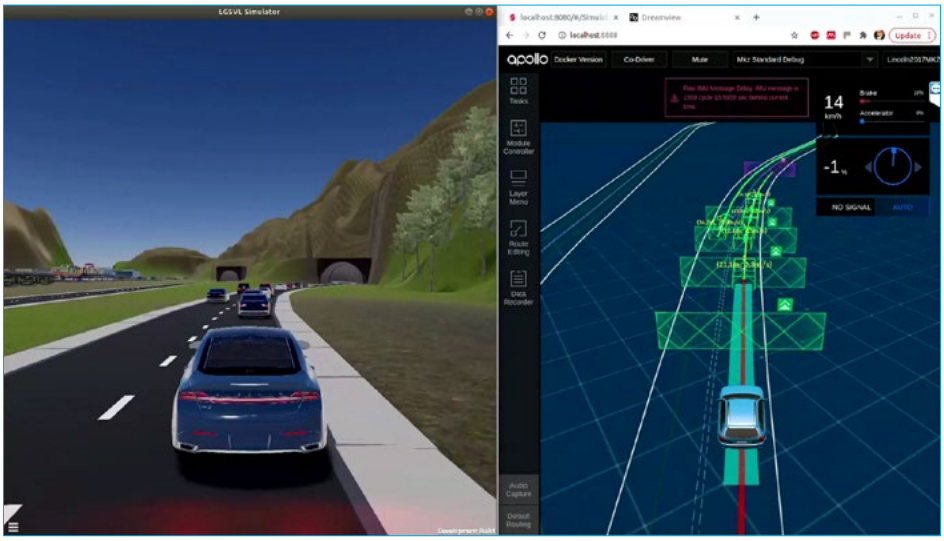

Fig. 6: 5G-Carmen use case simulation

Description of demos

In the second part of the project, the consortium will refocus the efforts on two key use cases for connected and L4 automated driving. The use cases stem from the original Cooperative Lane Merge (CLM) and Situation Awareness (VSSS, BSA) UCs but target 5G connectivity to enable L4 automation, thanks to improved awareness of the surroundings, by sharing sensor information at very high frequency and relying on vehicle-edge service cooperation. Hereafter a description is given.

1. **Cooperative and automated lane-change maneuvers.** A vehicle needs to change lane from overtaking to first lane or vice-versa. It performs lateral control in level 4 (L4) thanks to a very accurate and timely awareness of the surroundings, enabled by 5G. The use case includes two sub-use cases: the cooperative lane merge in the new lane as originally planned by the AD vehicle, and the lane change in presence of oncoming emergency vehicles.
2. **Cooperative and automated in-lane manoeuvers.** A vehicle is on the first lane and plans to exit the motorway in moderate-high traffic situation, with vehicles in front obstructing the view. A queue or obstacle on the exit lane would require the driver to take over. Thanks to 5G, however, the vehicle can sense what the vehicle in front senses and thus decide to keep L4, and stay in lane, re-planning the exit without disturbing the driver.

The pilot tests will initially take place locally, near Munich in Germany, and near Trento and Modena in Italy, and will then move to the cross-border sections of the Brenner pass and to Kufstein (Figure 7), where issues about continuity of service in the transition from one national network to another will be addressed.

Fig. 7: 5G CARMEN Test sites.

5G-MOBIX

5G for cooperative & connected automated mobility on X-border corridors

The 5G-MOBIX EU-funded Innovation Action (2018-2022) is testing automated vehicle functionalities over 5G (NSA and some SA) networks along two Cross-Border Corridors (CBC), Greece-Turkey and Spain-Portugal, and six local Trial Sites (TS), France, Germany, Netherlands, Finland, China and South Korea. 5G-MOBIX trials address five defined categories of Cooperative, Connected and Automated Mobility (CCAM) use cases, which are aligned with the work of 3GPP: Advanced Driving, Platooning, Extended Sensors, Remote Driving and Vehicle quality of Service Support. The trials will allow 5G-MOBIX to evaluate the benefits and challenges of provisioning 5G-enabled CCAM services in cross-border conditions, as well as to conduct impact assessments and cost/benefit analysis. As a result of these evaluations, 5G-MOBIX will identify new business opportunities and propose recommendations and deployment scenarios.

To enable these trials, a tremendous design, development and deployment effort has been undertaken by the project partners, resulting in the creation of the following components:

- 8 5G-NSA & 4 5G-SA fully operational networks;
- 29 5G fully operational gNBs operating in multiple bands including mmW bands;
- 10 Vehicles capable of SAE Level 4 functionality & 2 vehicles capable of SAE Level 3;
- 30 On-Board Units (OBUs) equipped with 5G chipsets;
- 24 MEC/Edge nodes connected to the 5G networks;
- 22 fully operational Road-Side Units (RSUs);
- 13 ITS / Cloud application centres;
- A multitude of embedded sensors & specialised equipment such as lasers, lidars, traffic radars, UHD cameras, proximity sensors, x-ray scanners, GNNS sensors, satellite modems, smartphones/tablets, etc.

The 5G-MOBIX CBCs/TSs, comprised of the above components, will allow the in-depth investigation of multiple cross-border issues for CCAM, **such as service & session continuity, inter-PLMN HO latency, application status transfer across border, security/privacy in cross-border environments** and more (Figure 8). A multitude of 5G relevant technologies/features/enablers will be tested during the trials and a thorough performance evaluation and analysis will be conducted. Among others, 5G-MOBIX trials will investigate the following aspects: **NSA/SA to SA/NSA roaming, GRX vs direct network interconnection, Home Routing (HR) vs Local Break Out (LBO) routing, inter-MEC connectivity alternatives, multi-PLMN/multi-SIM solutions, handover to satellite, multi-edge/multi-instance CCAM application deployment, GDPR and data management solutions** and more.

Deployment Enablers

5G-MOBIX's work on Deployment Enablers allows to uncover challenges to cooperation, business, technical and regulatory innovations and propose targeted recommendations to overcome them. It aims to prepare the path with targeted suggestions and knowledge sharing across the 5G/CCAM stakeholder value chains. This will create awareness and build trust on the topic of 5G as a CCAM cornerstone. The research conducted so far[6] has revealed several challenges in weak areas, calling for improvement of technologies, processes and legislation, e.g.: simplifying Service Level Agreement negotiations for IPX connections; flexible leasing of additional spectrum to MNOs on the process side; particularisation of the current Roaming regulations in Europe, to account for the specificities of vehicular Roaming, etc.

6. 5G Trials for Cooperative, Connected and Automated Mobility along European 5G Cross-Border Corridors - Challenges and Opportunities, https://5g-ppp.eu/wp-content/uploads/2020/10/5G-for-CCAM-in-Cross-Border-Corridors_5G PPP-White-Paper-Final2.pdf

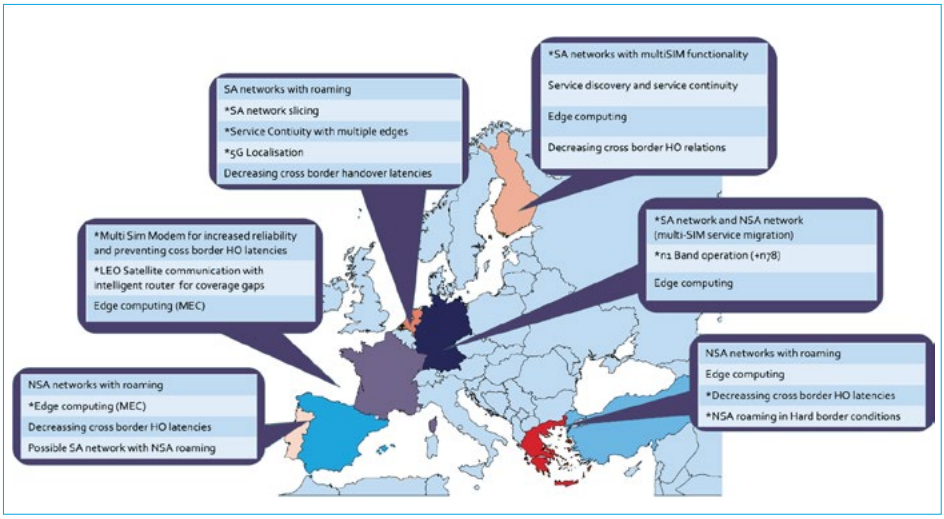

Fig. 8: 5G-MOBIX key features under investigation per CBC/TS

Trials & Evaluation Framework

A set of complementary user stories[7] executed at the CBCs and TSs will cover a broad spectrum of challenges such as telecommunication infrastructures, application security and privacy or regulatory issues. During the trials, various protocols, scenarios, 5G-features and SW/HW solutions will be tested, and their performance will be evaluated and benchmarked based on the collected Key Performance Indicators (KPIs).

5G-MOBIX has established a multi-faceted evaluation methodology for the assessment of the various 5G deployment options and network and application configurations considered. A rich set of CCAM- and network-level KPIs has been defined and realised through a series of measurement tools. As such, the resulting measurement framework will therefore assess the CCAM-level experience of users, while also exploring in depth 5G performance on multiple facets: at different layers (application, transport, access), network segments, e.g. access, edge and planes i.e., control and data. More than 100 test cases will be realised, targeting both application-specific and application-agnostic scenarios, and investigating important cross-border challenges. Contributing to the community, 5G-MOBIX has devised a Common Data Format for the unified representation of measurement data, across trial sites and use cases, and its final exposure through a publicly available data repository (once trial data are available).

On 3 December 2020, the Dutch trial site performed a live virtual demonstration[8] of their remote driving setup in 5G-MOBIX. Two vehicles where connected to a 5G Standalone Network. The vehicles were operated remotely from a remote driving station and showcased two manoeuvres, namely a Stop-test and a Slalom-test.

7. Details available in White paper published in October 2020: https://5g-ppp.eu/wp-content/uploads/2020/10/5G-for-CCAM-in-Cross-Border-Corridors_5G PPP-White-Paper-Final2.pdf

8. Available at https://www.5g-mobix.com/hub/5g-mobix-demo-remote-driving

Fig. 9: Remote driving virtual demonstration of the Dutch trial site in December 2020

5G-MOBIX CBCs/TSs are currently finalising their roll-out, integration and initial testing to enter into the first *"early-trials"* phase, where localised 5G for CCAM trials will take place at the TSs and controlled environments near the CBCs. The trial period at both CBCs and TSs will last approximately 14 months, (February 2021 - March 2022). Once the first insights offered by early trialling a processed and all solutions are integrated in the cross-border corridors, the "full" trial phase will start (June 2021) and multiple cross-border test-scenarios will be executed for the validation of CCAM functionality over 5G connectivity.

5GCroCo

Fifth Generation Cross-Border Control

Project Goals

The 5GCroCo project (http://5gcroco.eu), aims at validating 5G technologies in the Metz-Merzig-Luxembourg cross-border corridor, traversing the borders between France, Germany and Luxembourg. 5GCroCo is an Innovation Action partially funded by the European Commission where key European partners from both the telco and automotive industries join efforts to trial and validate 5G technologies on a large scale in a cross-border setting with the mission to reduce uncertainties before CCAM services running on top of 5G communication infrastructures are offered to the market. 5GCroCo also aims at identifying business opportunities and defining new business models for disruptive CCAM services which can be possible thanks to 5G technology, as well as ensuring the appropriate impact into relevant standardisation bodies both from the telco and automotive sectors.

5GCroCo Use Cases

Three use cases have been identified to be representative for the automated driving application domain. These three use cases are: 1) Tele-Operated Driving (ToD), 2) High Definition (HD) map generation and distribution for autonomous driving (HD Mapping), and 3) Anticipated Cooperative Collision Avoidance (ACCA), (see Figure 10). The three use cases have been already specified in detail together with the requirements that are imposed by them [1].

As it was concluded in [2], to allow a successful deployment of 5G-enabled CCAM services, some 5G performance requirements are mandatory. In that context, the 5GCroCo use cases listed in the previous paragraph are defined to validate these required performances, in particular: high reliability and very short latency with ToD, asymmetric communication (high data rate in uplink, lower data rate in downlink) with ToD, high throughput with HD Mapping, short latency in both uplink and downlink with ACCA, QoS prediction with HD Mapping and ToD.

It is also key that CCAM services do not suffer from any performance degradation of the service during mobility across countries and do not suffer from a service discontinuity when crossing a border. For this reason, 5GCroCo use cases are also defined to validate the service continuity at border crossing or at MNO handover and validate the performances when the vehicle is under the coverage of a visited MNO.

One of the major challenges imposed by the selected use cases on the radio networks is that the different defined performances need to be available jointly and at any-time. In today's networks, there is often good performance only at specific areas while other areas suffer from a degradation of the service performance. In addition, some KPIs are fulfilled while others are not. Such degradations are not acceptable anymore for CCAM services and failure of the communication would lead to a standstill of the vehicles or even generate serious dangers to other road users. It is the intent of the 5GCroCo use cases to demonstrate that CCAM services can be safely deployed because 5G features have the required performances.

5GCroCo Network Architecture

5GCroCo has developed network and application architectures based on commercial 5G systems as described in [3] and [4], respectively. In particular, [4] provides an overview of 5GCroCo's end-to-end network architecture including solution concepts like cross-border / -MNO handover, predictive and end-to-end QoS, MEC, virtual network management and orchestration (MANO) and precise positioning. A key goal for such architecture has been to assure cross-border, cross-MNO, cross-car-OEM, and cross-telco-vendor (cross-X) interoperability from the start by at least identifying potential interoperability issues and ideally, already providing solution options. Some of the solutions are already standardised and often well evaluated, but not in such "cross-X" context. This is particularly true for MEC and end-to-end QoS aspects. In other cases, especially in the context of QoS prediction, interfaces are not standardised yet and only first ideas about how to use these interfaces and on performance of different prediction algorithms exist. Within this context, [4] describes and discusses solutions in the field of enabling cross-border / -MNO handover, cross-MNO virtualisation and SDN techniques, 3GPP QoS framework, including its 5G evolution, adaptive connectivity to most suitable MEC hosts, QoS prediction with and without networks support, and three precise positioning solutions.

The final goal for the architecture put forth by 5GCroCo is to be scalable and realistically applicable to continent-wide deployments, as enabler for solid business models for CCAM.

5GCroCo Test and Trial Sites

5GCroCo is conducting 5G large-scale trials on cross-border roads at the French-German and German- Luxembourgish borders since the end of 2020. The different use cases of 5GCroCo were rolled out in this large-scale corridor as described in [5]. As a first step towards our large-scale tests, small-scale test site deployments in France, Sweden, Germany, and Spain have been carried out (see Figure 10), despite the difficult situation imposed by COVID-19. All use case implementations planned for this first round of trials were finished and have been validated from a functional perspective. The tools to measure the KPIs have been set up and the components that need to report their measurements were also properly validated. As a summary, all small-scale test and trial sites are finished and almost all intended tests and trials were successfully completed. The obtained results for all small-scale test and trial sites together with initial large-scale results are reported in [6].

Business Innovations

In addition to the 5G trials for CCAM, the study and definition of new business models and cost/benefit analysis is a fundamental part of 5GCroCo to understand the business possibilities that emerge from CCAM services which can operate across borders. The possibility of having advanced 5G functions operating in a cross-border, cross-telco-vendor, cross-car-OEM, cross-MNO fashion generates a new arena for innovation.

5GCroCo has started to analyse the cost/benefit relationship of deploying 5G in such a complex scenario and to develop tools which can allow for the definition of valid business models. This process is being done in parallel with the deployment of the trials, learning from the experience acquired, understanding the needs of all stakeholders, and reducing the uncertainties of deploying a 5G infrastructure to offer unprecedented 5G-enabled services for CCAM as described in [7].

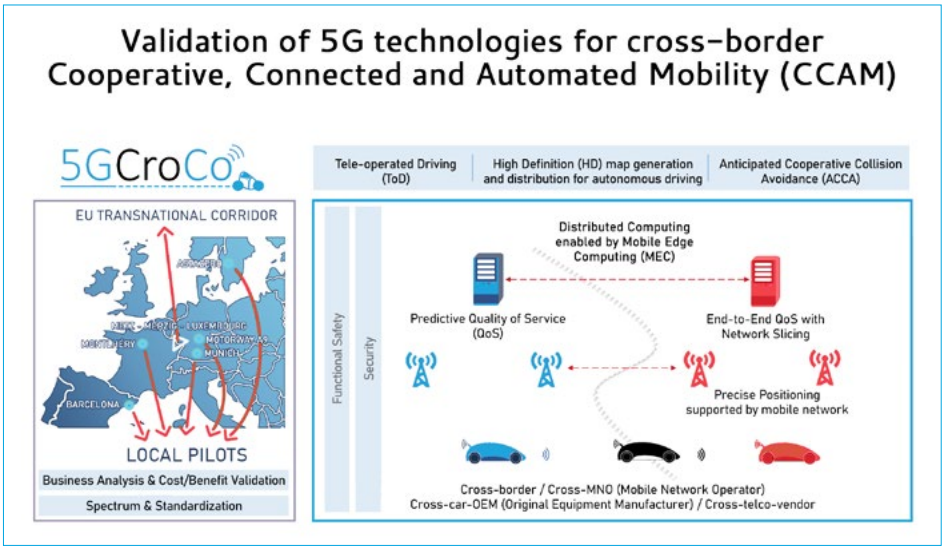

Fig. 10: 5GCroCo test-sites and use cases in a nutshell

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[1] 5GCroCo D2.1, "Test Case Definition and Trial Site Description Part 1", July 2020.

[2] 5GCroCo D2.2, "Test Case Definition and Test Site Description for Second Round Tests and Trials", November 2020.

[3] 5GCroCo D3.1, "Final Application Architecture", January 2021.

[4] 5GCroCo D3.2, "Intermediate E2E, MEC & Positioning Architecture", January 2021.

[5] 5GCroCo D4.1, "Report Validating Development and Integration in Network, Vehicle and Backend on Small- and Large-Scale Trial Sites", January 2021.

[6] 5GCroCo D4.2, "First Phase Trial Execution Report and Analysis of 5GCroCo KPIs", December 2020.

[7] 5GCroCo D5.1, "Description of 5GCroCo Business Potentials", September 2019.

5G PPP PHASE 3, PART 3: ADVANCED 5G VALIDATION TRIALS ACROSS MULTIPLE VERTICAL INDUSTRIES

5G SMART

Goals of the project

5G SMART[9] aims at demonstrating how 5G can improve manufacturing, through its work on industry field trials, business models and research concepts. Within three 5G-enabled industry field trials, 5G SMART is demonstrating, evaluating, and validating 5G systems for manufacturing applications in real manufacturing environments. The business model activities in 5G SMART are exploring the 5G ecosystem while investigating regulatory and spectrum aspects, including also mobile network operator engagement options. The concept work in 5G SMART contributes to the future evolution of 5G with a focus on 5G features to be developed targeting the manufacturing sector. This includes, for instance, the integration of 5G with time-sensitive networking, and critical cloud platforms enabling flexible software development while providing low latency and high reliability.

Achievements

In 2020, 5G SMART has succeeded in designing and installing 5G deployments at all 3 trial sites. Having all 3 trial sites operational has been a major milestone of the project. The importance and relevance of 5G SMART's trials has moreover been recognised by 5G-ACIA where all testbeds have been presented as candidates for 5G-ACIA endorsement.

The design and implementation of the testbeds within 5G SMART consider recent 5G technology developments and state-of-the-art communication devices that are based on 3GPP Release 15 specifications as well as factory equipment.

Further details on the trial sites and related achievements can be found below.

Kista Ericsson smart factory

The Kista trial site is located in an Ericsson factory in Kista (Sweden) and has its focus on 5G enhanced mobile robotics applications. Here, a setup including both stationary robots and a mobile robot is being built up. One distinctive feature of the use cases is that the robot control logic governing the collaboration and interaction is offloaded to the edge cloud. Functionalities, like motion planning, robot localisation and human avoidance control logic have been removed from the robot itself and are now deployed in the Edge cloud node instead.

Aachen Fraunhofer IPT shop floor

The Aachen trial site is located at the machine hall of the Fraunhofer Institute of Production Technology IPT in Aachen (Germany) and has its focus on 5G enhanced industrial manufacturing processes. Here, 5G SMART is working on the realisation of two use cases: 5G for wireless tool condition monitoring and 5G for wireless workpiece monitoring for digital twin. For the first use case a 5G-based wireless acoustic emission sensor system has been developed by Fraunhofer IPT and Marposs Monitoring Solutions. A first prototype of a 5G-based process monitoring sensor has been demonstrated[10] for process monitoring in machining processes. The sensor is able to detect critical process conditions and trigger an instant reaction of the machine tool thanks to the URLLC capabilities of the 5G transmission. For rapid processing of measurement

9. www.5gsmart.eu

10. https://www.youtube.com/watch?v=puoFAayVpZk&t=142s

signals with high scalability, a factory-located edge cloud has been integrated with the 5G and the shop floor network. The edge cloud is configured to flexibly provide microservices and virtual machines.

Reutlingen Bosch semiconductor factory

The third trial site of 5G SMART is a Bosch semiconductor factory in Reutlingen (Germany) where industrial Automated Guided Vehicle (AGV) applications and industrial control communication are being explored. Here, 5G SMART is working towards the realisation of two use cases: Cloud-based mobile robotics and TSN/Industrial LAN over 5G. The intelligence of an Automated Guided Vehicle (AGV) is being completely removed and reimplemented in a cloud native manner in the edge cloud, reducing the cost of the robot and simplifying scalability. For this use case, a first demo[11] has been developed that showcases the coordination of the mobile robots using a common map stored in the Edge cloud.

Furthermore, 5G SMART has undertaken two measurement campaigns in the Bosch semiconductor factory. The first measurement campaign has been conducted aiming to better understand the propagation characteristics of 5G radio waves in industrial environments. The initial assessment of the mid band channel measurements show that mid band frequencies are promising for providing coverage across the factory floor, while higher frequencies are more challenging. In the second measurement campaign electromagnetic compliance has been studied, showing that for a large number of devices investigated, the radio signals did not have any adverse effects on the production and testing.

Concept work

The concept work within 5G SMART goes beyond the industry field trials, looking at proof of concepts of specific features targeting 3GPP release 16 and beyond. Here, 5G SMART has provided a comprehensive overview of different radio network deployment options for smart manufacturing, discussing and analysing the input data necessary to select the most feasible deployment options for a desired industrial 5G scenario and service. Furthermore, a thorough gap analysis has been made between the state of the art and the smart manufacturing use cases, identifying new 5G features necessary to be further developed to close the gap. Different network architectures and the impact on different stakeholders has been discussed both from a deployment perspective and an architectural perspective. Taking the trialed use cases of 5G SMART as examples, different 5G architecture options have been analysed and assessed.

11. https://www.youtube.com/watch?v=xBWDwmFGPm8

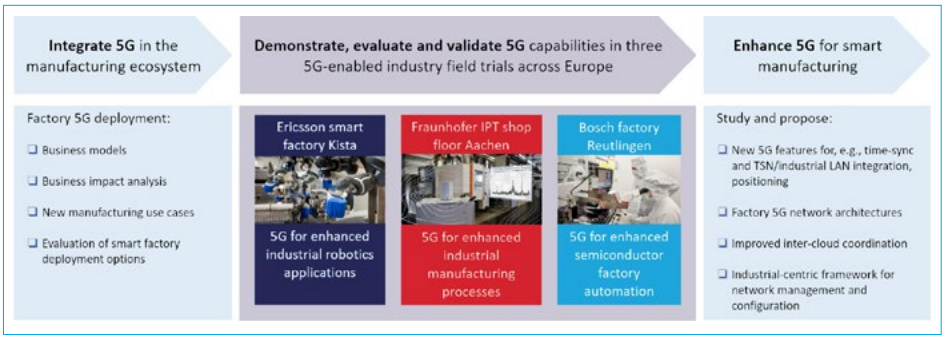

Fig. 11: 5G SMART overview

5G Solutions

5G Solutions is the ICT-19 flagship project supporting EC 5G policy by implementing the last phase of the 5G cPPP roadmap (5G Platforms and Vertical Large-Scale Pilots).

The overall objective is to conduct advanced field trials of innovative and thematically diverse digital services that require 5G capabilities and performance in the vertical domains of Factories of the Future, Smart Energy, Smart Cities, Smart Ports and Media & Entertainment, directly engaging with end-users, so as to validate the technological performance of 5G technology in successfully serving them, as well as validating the business models and potential of these use cases prior to commercial deployment.

The project is part of both a scientific (e.g. it contributes to standard bodies as well as 5G PPP frameworks and other H2020 projects) and citizens' society, for whom the project aims to be a reference for a 5G that facilitates societal and citizens' needs. On the contrary, considering research as an isolated Castalia (referring to "The Glass Bead Game" by H. Hesse), may cause fake-news, so that 5G appears as harbinger of inconvenience, unnecessary costs and even illness.

The project has reached its half lifetime. At this date the KPIs were defined with great precision under the relevant context and conditions. This allowed the project to ascertain (and demonstrate) what was already under suspicion, i.e. 5G becomes a fundamental technology for most use cases. However, even for use cases where the performance of 5G would not be strictly necessary in the test phase, it would become so in a massive diffusion of the service, when the requirement of scalability and cost-effectiveness is also added.

The KPIs have not only been clearly defined, but, since conducting trials in a 5G testbed ecosystem is complex and challenging a robust and common approach to the validation of the KPIs is required.

The use cases leverage on ICT-17 5G-VINNI and 5G-EVE infrastructures, and for some of the UCs the applicable 5G infrastructures are extended for the purpose of 5G Solutions facility sites. The integration with ICT-17 facilities is achieved through APIs with Nokia CSDO orchestration system. The importance of orchestration, the mapping of the different UC components, identifying the integration points and the flow of the experiments have been carefully considered and designed. For mature UCs and facilities these artifacts have also been implemented and tested. A special role is played by artificial Intelligence, providing zero-touch automation mechanisms for 5G service and operational lifecycles.

Furthermore the 5G Solutions' KPI Visualisation System is used within the scope of the project to analyse and validate the KPIs measured in each UC. The system design has been completed, the underlying infrastructure comprising of several VMs has been setup, and a first version of the platform is already deployed whilst the integration with 8 UC applications is complete.

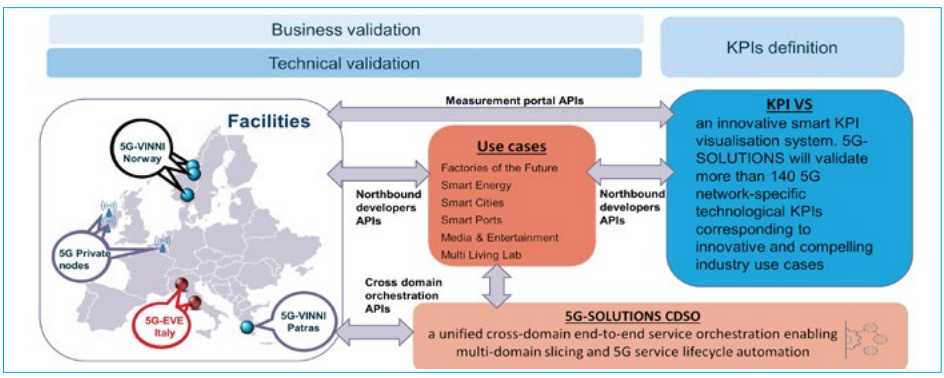

Fig. 12: 5G Solutions – project main blocks

A scheme of the project main blocks is depicted in Figure 12.

The project initiated the first tests on the majority of UCs, belonging to 4 baseline living labs:

- The Factory of the Future LL addresses in-process monitoring and real-time product quality assessment, new sensor provisioning directly to the production plant, augmented reality aided maintenance, and machinery and robot remote controlling through 5G.
- The Smart Energy LL validates 5G technologies in advanced industrial verticals domains as Demand Side Management in new electricity value chain. 3 use cases of technological and business interest, covering from utility applications to electro mobility scenarios, are ongoing.
- The Smart Cities & Ports LL covers the aspects of smart public lighting, urban parking, smart city, smart buildings and campuses, as well as smarter and safer ports.
- The Media & Entertainment (M&E) segment has high expectations for the introduction of 5G. The M&E LL is testing various UCs and sub-scenarios of: high-fidelity video viewing, multi-CDN viewing, immersive experiences in AR/VR and gaming, professional video production and remote multi-cam production.

Furthermore, a multi-living lab (MLL) is testing and validating the business and technological performance of multiple vertical UCs concurrently. Having as the main objective to quantify the performance of running concurrent UCs. In the mature and advanced MLL UC scenarios multiple 5G slice instances will be deployed, managed and used concurrently.

The fact that these use cases cover multiple areas, both industrial and inherent in the life of ordinary citizens, will demonstrate that 5G will represent a real revolution capable of radically changing our lives. Implementing and verifying that the KPIs are met will say that application is technically feasible. This is innovation. The ambition is to turn innovation into progress. H. Ford said "Real progress happens only when advantages of a new technology become available to everybody". For this reason, the technical activities that demonstrate the feasibility of UC are continuously accompanied by economic validations and those that evaluate their social impacts. Under this umbrella there is also ethics and legal monitoring, performed during the whole lifecycle of the project by delivering guidelines to the consortium.

5G Solutions will also disclose its results to be used by the target audience to progress their own work, i.e., to fertilise the advancement of technology, science, industry and policy.

5G Tours

5G Tours Project Overview

As the early technology platforms of 5G start to mature the wireless industry will seek to enable growth in markets beyond those existing in a maturing mobile broadband sector. 5G Tours focusses on three significant economic value creation sectors for Europe; namely Tourism, Health and Transport and seeks to evidence growth potential through 5G platforms. Through an ambitious focus on the trials of thirteen use cases 5G Tours will demonstrate the advantages of 5G technology in pre-commercial "customer friendly" trials environments. Now close to embarking on the third year of the project the emphasis of the realising value propositions of the use cases for end users like tourists, citizens and patients come to the fore.

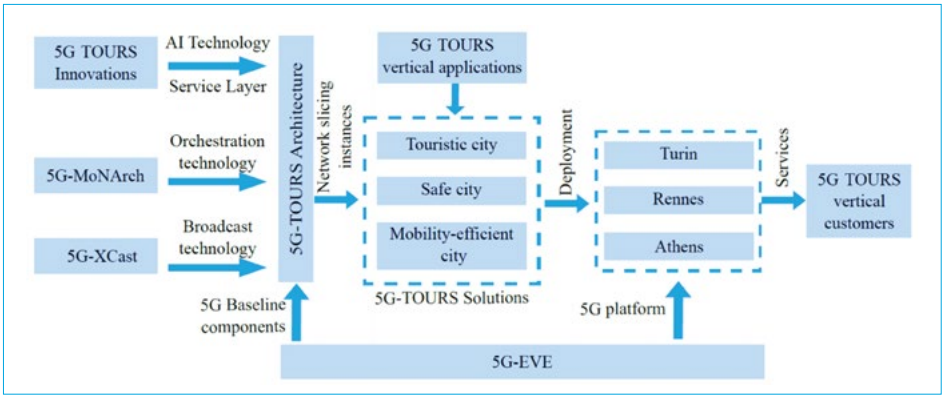

Fig. 13: 5G Tours – value proposition

A very close collaboration with the 5G-EVE trials platforms in three different European City deployments has (despite the COVID challenges) led to the successful continued deployment of network infrastructure and early trials of critical aspects of the use cases. As an example of one of the challenging use cases the vision for an immersive media experience integrating a remote and distributed video production system utilising 5G capability as well as working with a distributed itinerant orchestra is well underway with demonstrations of the in-situ capability. Installed in such a way as to limit impact and be sympathetic to the historic building context, already this use case is gaining interest of the local city and regional communities.

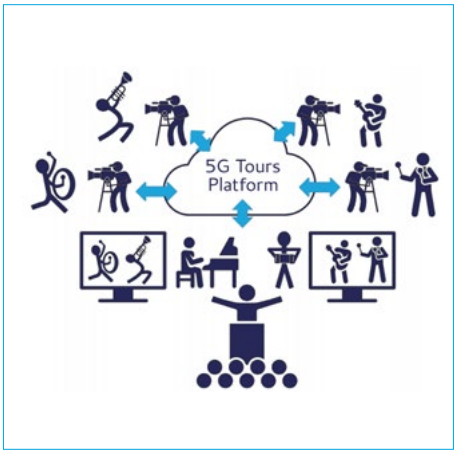

Fig. 14: 5G Tours Platform

5G Tours establishes an engaging platform to bring those in the verticals to experience a view of the possible experiences and provide their feedback to business researchers on the willingness to pay and the techno-economic levers that need to be pulled to deliver business models that have a fighting chance of being sustainable and that will gain traction in the market.

Across the portfolio of use cases 5G Tours establishes scenarios that integrate humans and not just eMBB but also IoT services depending on lower latency, high location accuracy or increased reliability. Innovations in the health sector comes to the fore as 5G plays an integral part in bringing to life of new health monitoring systems that can be deployed in Hospitals or Ambulances for society and quality of life benefit. In the venues and tourism sector 5G Tours has demonstrated the connectivity and autonomy balance needed for a robot that will guide tourists around a complex Museum environment.

Emergent Innovations

5G Tours is designed to provide services that are close to commercialisation, and thus relatively high on the technology readiness scale, whilst addressing very different requirements on the same infrastructure. Emphasis is placed on discovery of innovations around key thematic areas; dynamic use of the network, virtualisation, orchestration of transmission, demonstrating the ability to meet extreme and contrasting KPIs. Aware of the high economic value of the sectors 5G Tours is deploying use cases that have been defined in such a way so as to use services that are believed to underpin a substantial share of

the likely revenues generated by the vertical sector – in some cases estimated to be up to 50% of the revenues generated by the verticals.

Infrastructure technology areas that are being productised through planned exploitation of project partners or seeing impact in the standards include, but are not limited to; Enhancements to the Management and Orchestration of networks with focus on the latest Open Source MANO (OSM) Rel8; AI driving slicing; integration of broadcast infrastructure into the 3GPP domain.

In each of the principle industrial sectors of interest 5G Tours now matures innovative propositions, with more to come. For the Health sector a teleguidance solution for diagnostics and intervention support through 5G mobile transmission of real-time ultrasound images, video and audio streaming and smart glasses use. For the tourism sector an autonomous 5G operated robotic system for telepresence and museum guide. For the transport sector a large scale IoT deployment using 5G mobile networks standards for identifying carpark availability and driver guidance in large car parking environments.

Key trials planning

As an ICT-19 project 5G Tours has progressed well into the definition of requirements, design and execution timelines of the use cases. An end-to-end architecture has been established and deployment progressed such that each of the 13 use cases can be demonstrated in the final phase of the project, along with hosting of workshops to deliver on the objective of "enabling the verticals". The project aims to secure full trials capability of the use cases from Q4-2021.

Readers can learn more about 5G Tours and download project deliverables from our website *https://5gtours.eu/*

5G-HEART

Goals of the project

The 5G for HEalth, AquaculturE and Transport (5G-HEART) validation trials project performs vertical validation trials on top of all three ICT-17 facilities (5G-VINNI, 5G-EVE and 5Genesis) and two national 5G test platforms (5GTN and 5Groningen) with use cases from three different vertical domains: healthcare, transport and aquaculture. In the health area, 5G-HEART validates PillCams for automatic detection in the screening of colon cancer and vital-sign patches with advanced geo-localisation as well as 5G AR/VR paramedic services. In the transport area, 5G-HEART validates autonomous/assisted/remote driving and vehicle data services. Regarding food, the 5G-based also focus on the transformation of the aquaculture sector. 5G-HEART takes important steps for progressing the synergy between telecom and vertical industries. These three vertical industries and related connectivity use cases pose diverse technical requirements on wireless network connectivity.

Major achievements

In 5G-HEART healthcare vertical trials, we have selected three major use cases for e-health which will challenge the performance and availability of 5G services. All the use cases share a common vision of remote care or 'hospitals without walls' as shown in Table 2.

Use case H1: Remote Interventional Support	Use case H2: Automatic pill camera anomaly detection	Use case H3: Vital-sign patches with advanced geo-location
The use of advanced, rich media communications for remote monitoring, education and robotics in patient diagnostics and treatment	Colon wireless capsule endoscopy with automatic polyp detection for early detection of colon cancer with high mortality	Direct-to-Cloud, disposable, vital-sign patches to enable continuous monitoring of ambulatory patients, anytime and anywhere
·Educational surgery ·Remote ultrasound examination ·Paramedic support ·Critical health event	·Pill based endoscopy for early anomaly detection ·Remote wireless capsule polyp detection	·Vital-sign patch prototype ·Localizable tag

Table 2: 5G-HEART healthcare vertical trials

Among 5G-HEART healthcare vertical trials, One trial "Robot-assisted remote ultrasound examination concept verification" has already done system verification tests using cabled connections as shown in Figure 15.

In 5G-HEART transport vertical trials, we have selected four major use cases as shown in Table 3.

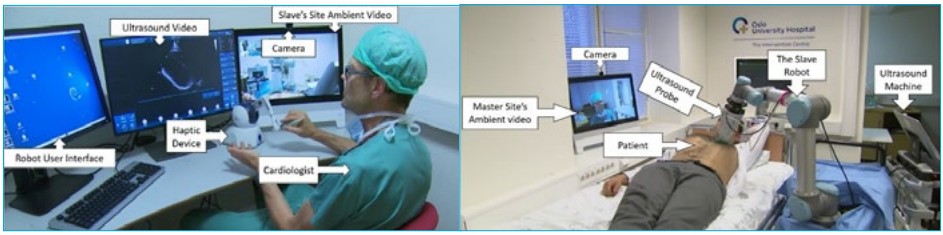

Fig. 15: Robot-assisted remote ultrasound examination concept verification.

Use case T 1: Platooning	Use case T 2: Autonomous/ assisted driving	Use case T 3: Support for remote driving	Use case T4: Vehicle data services
Vehicles forming a tightly coordinated "train" with reduced inter vehicle distance, thus increasing road capacity and efficiency.	Semi- or fully- automated driving for safer traveling, collision avoidance, and improved traffic efficiency.	Remote operation of a vehicle by a human operator or cloud based application.	Interconnecting third party data sources to connected and automated vehicles via the available 5G infrastructure
High bandwidth in vehicle situational awareness and see through for platooning Dynamic channel management for traffic progression	Smart junctions and network assisted and cooperative collision avoidance Quality of service for advanced driving Human tachograph	Tele operated support	Vehicle sourced HD mapping Over the air updates Smart traffic corridors Location based advertising End to end slicing Environmental services

Table 3: 5G-HEART transport vertical trials

In 5G-HEART aquaculture vertical trials, two pilots are going to be deployed, one in Greece and one in Norway, covering different requirements that exist in two completely different environments. The scenarios that are going to be executed are listed below:

- A1S1: Sensory Data Monitoring (Athens, Oslo)
- A1S2: Camera Data Monitoring (Athens, Oslo)
- A1S3: Automation and actuation functionalities (Athens)
- A1S4: Edge and Cloud-based computing (Oslo)
- A1S5: Cage to cage – on site communication (Oslo)

One configuration of aquaculture vertical trials in Norway is shown in Figure 16.

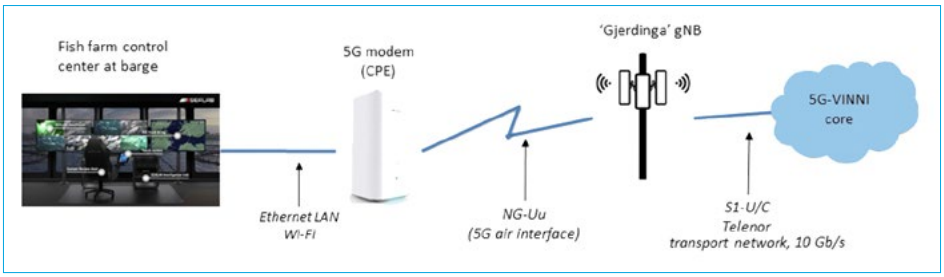

Fig. 16: 5G-HEART aquaculture vertical trial configuration in Norway using 5G-VINNI network.

5G-VICTORI

Project Goals

5G-VICTORI focuses on largescale trials for use case (UC) verification in commercial 5G environments including Transportation, Energy, Media and Factories of the Future verticals and cross-vertical UCs[12]. The project develops an open and extensible reference ecosystem integrating verticals into interconnected 5G facilities across Europe (3 ICT-17 facilities plus 5GUK)[13] (Figure 17). Several service blueprints will be developed and exposed to the 5G-VICTORI ecosystem through a common framework. This will allow KPI testing, monitoring and benchmarking over the interconnected facilities, offering fast vertical deployment times, and improved technology and business KPIs.

12. 5G-VICTORI deliverable D2.1, "5G-VICTORI Use case and requirements definition and reference architecture for vertical services", March 2020, https://www.5g-victori-project.eu/wp-content/uploads/2020/06/2020-03-31-5G-VICTORI_D2.1_v1.0.pdf

13. 5G-VICTORI deliverable D2.2, "Preliminary individual site facility planning", May 2020, https://www.5g-victori-project.eu/wp-content/uploads/2020/05/2020-05-21-5G-VICTORI_D2.2_v1.0.pdf

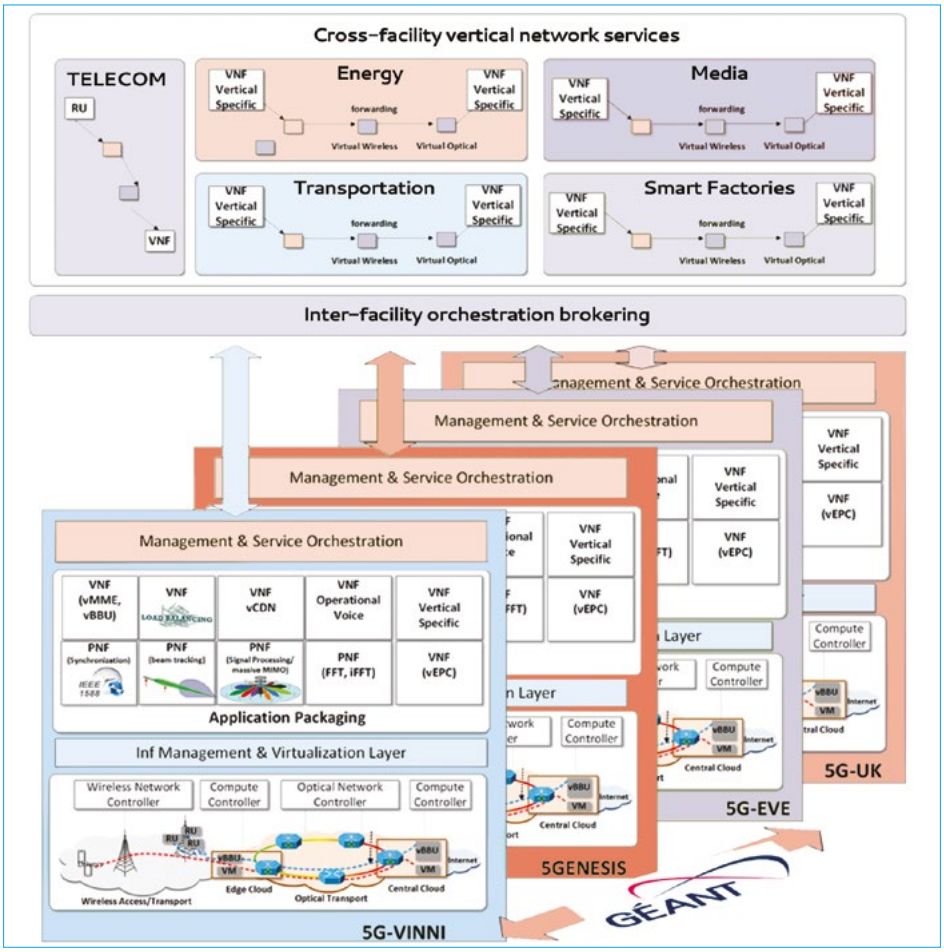

Fig. 17: 5G-VICTORI reference architecture

2020 Major achievements & innovations

The 5G-VICTORI management framework aims to create a common infrastructure to enable interconnection and interworking of the four facilities. A multi-domain orchestration brokering platform, the 5G-VICTORI Operating System (5G-VIOS)[14] resides over the facilities' individual orchestrators, allowing brokering of experimentation procedures to the facilities or their direct orchestration (Figure 18). 5G-VIOS enables management of slices, resources and orchestration of E2E vertical network services across multiple 5G-VICTORI domains, offering a common entry point to the 5G-VICTORI system. Key innovations include mobility management, profiling and extension of the inter-domain orchestration capabilities with L3 connections.

Description of trials

5G-VICTORI trials aim to validate a set of vertical service KPIs. Architecture and technology validations will take both a technology and a business perspective and include:

14. 5G-VICTORI deliverable D2.5, "5G-VICTORI Infrastructure Operating System – Initial Design Specification", July 2020, https://www.5g-victori-project.eu/wp-content/uploads/2020/10/2020-07-31-5G-VICTORI_D2.5_v1.0.pdf

"Enhanced Mobile broadband under high speed mobility": Transportation – Rail.

In 5G-VICTORI, Future Railway Communication System (FRMCS) services are deployed and showcased in operational railway environments. These aim at demonstrating eMBB functionality over innovative network deployments meeting stringent performance KPIs of FRMCS services. Emphasis is put on the deployment of new hand-over management functions to preserve network sessions as trains move and the deployment of innovative technologies for trackside to train and train to core interconnection.

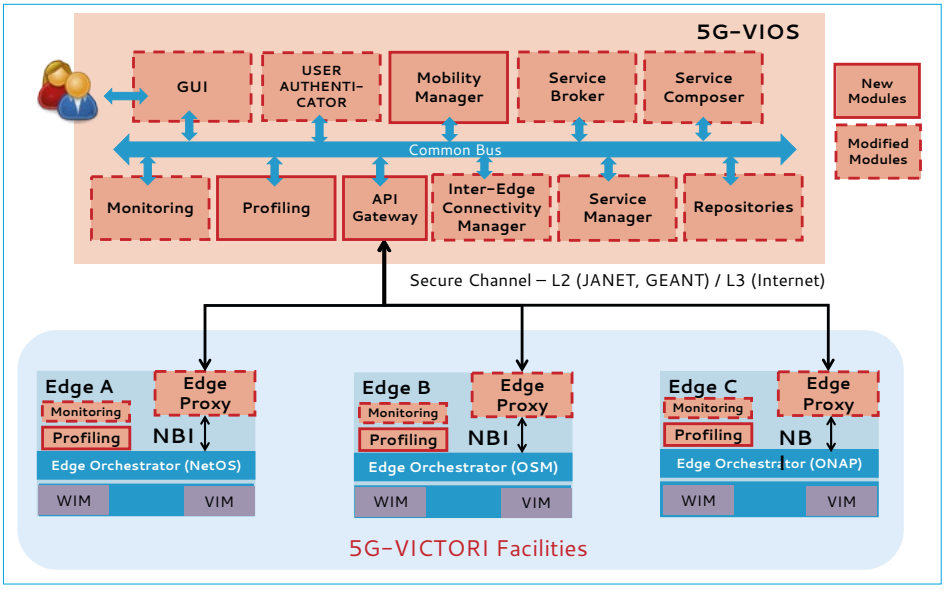

Fig. 18: 5G-VICTORI Architecture

"Digital Mobility": Transportation and Media.

5G-VICTORI develops a common framework for innovative mobility applications to be showcased in Berlin and Bristol: 1) synchronous 360° video tour guide to be viewed by a group of travellers with 5G seamless connectivity while moving; 2) 360° VR Multicamera Live stream for large scale user connectivity attending real-time classes via VR; 3) demonstration of passengers' guidance with multi-modal transport journey planning, while on the move.

The provision of infotainment services and public safety critical services will be trialled in Alba Iulia City buses for the display of public information via a Captive portal and TV services and the identification of emergency situations (e.g. violence, health emergency and theft/lost using Artificial Intelligence algorithms. Communication to the Command and Control Centre will be realised via a 5G dedicated slice, assuring real time management, e2e orchestration and QoS control.

"Critical services for railway systems": Rail.

This trial will provide an infrastructure with enhanced throughput, safety and security features, supporting future needs of both rail signalling systems (on-board and ground) and 3GPP Mission Critical (MC) based FRMCS services for voice and data connectivity in emergency scenarios. The 5G-VICTORI solution will be compatible with existing signalling systems and will be designed to support fast and easy deployment. Rail Critical Services include: Rail signaling, CCTV monitoring, Telephony (Cab Voice and Emergency Calls), Mission Critical Push-To-Talk, Sensor data and Point-machine Object controller signalling.

"Smart Energy Metering": Energy and Rail.

The trial aims to demonstrate different energy metering services for High Voltage (HV) transmission grids, supporting industrial clients, and Low Voltage (LV) distribution grids in cities. For the HV scenario, smart energy metering in railways will be demonstrated, as well as real-time power consumption information exchange between an HV substation and an electric train through a private network deployment. This deployment will meet the FRMCS services strict performance requirements for exchange and correlation of synchronised measurements and facilitate power quality improvement and cost reduction for both Railway and Transmission System Operators. The LV scenario involves energy metering data collection from endpoints across Alba Iulia and their transfer to the telemetry platform in the cloud, via 5G mMTC. These measurements will be collected, processed and analysed to offer real time & historical view of status and parameters and real time energy audit & potential fraud detection.

"Digitization of Power Plants": Smart Factory.

Advanced monitoring solution to support simultaneously different smart factory services (preventive maintenance, security, monitoring of critical infrastructure), through an isolated private 5G network. A scalable platform will collect and analyse measurements from newly established and legacy sensors, spread into two different sites. Leveraging the infrastructure cloud-edge capabilities, different modules will be hosted either at a central cloud or the edge subject to service requirements.

"CDN services in dense, static and mobile environments": Media.

This deployment focuses on the integration of multi-level CDN platforms with private 5G network deployments, using mmWave, edge computing capabilities, and edge caching on-board the train. The solutions enable multi-CDNs capabilities via "Data Showers", taking advantage of the 5G network high data rates. "Data Showers" can be installed at selected locations along the train route. This UC will be demonstrated at Berlin Central Station and Patras' train facilities, using VoD and time-shifted live-TV streams. This UC will showcase 360° cameras for remote surveillance in railway infrastructures.

5G!Drones

Goals

The main goal of the 5GDrones project is to enable safe and secure BVLOS flights using 5G mobile networks. The project will produce solutions in order to enable better business models for the use of 5G network in UAV operations. 5G networks leverages the mission planning, automation of flight operations, and post-flight data analysis, all of which is within the scope of the use cases and scenarios being carried out in the project. Alongside the use cases, the project will also aim to deliver viable and sustainable business models for the use of 5G networks in the context of UAVs.

Major achievements and milestones of year 2020

A crucial milestone for the project advancement was that the initially outlined VTOL UAS missions were precisely defined and planned.

In addition to this, Key Performance Indicators KPI's on the project activities, with regards to both the VTOL UAVs and 5G operations were set.

The 5G use cases were defined, which set a stable foundation for the particular regional and transdisciplinary project activities on the use cases.

Demonstration sites, scenarios and operations were planned and performed at all 5 geographic and organisational project centres.

Additionally, two major workshops were organised.

Workshops

Aerial Communications in 5G and Beyond Networks (AERCOMM) workshop, co-organised by 5G!Drones and EU-Korea PriMO-5G project, co-located with IEEE Wireless Communications and Networking Conference on 25th –28th of May 2020 (Virtual Conference), Beyond Connectivity: What Comes After 5G was performed.

"5G Experimentation Facilities and Vertical Trials: Current Status and Future Perspectives" online workshop on 14 Oct 2020 was organised by the Institute of Informatics & Telecommunications of NCSR Demokritos (Athens, Greece), EU projects 5GENESIS and 5G!Drones and with the support of the 5G PPP partnership.

Trials and demonstrations

Orange France, 5G!Drones partner, conducted an experiment of a tethered drone embedding a cellular base station based on Open Air Interface, acting as a connectivity bubble, at French championships of Windsurf in Saint-Pierre-Quiberon France, from 1st to 3rd of November, as part of 5G!Drones use case #4 (UC4) initial tests.

In May 2020, NCSRD team, 5G!Drones partner, performed the first feasibility flight of a drone piloting over 5G, i.e. transmitting the C2 (Communication and Control) channel over 5G. The feasibility flight was performed using the 5GENESIS Athens 5G experimentation platform located at NCSR Demokritos campus as initial trial of the 5G!Drones Athens use case.

On June 30, 2020 5G!Drones partners NCSRD, CAFA Tech and Unmanned Life conducted remote feasibility tests related to 5G!Drones Use Case 4 "Drone based 5G connectivity extension" scenario.

5G!Drones partners conducted flight trials under 5G network in Aalto and Oulu, Finland, on August 24-28 2020 for collecting preliminary inputs for 5G!Drones next developments and actions. In these tests, 5G infrastructure owners of Aalto University and Oulun yliopisto – University of Oulu, and technology companies CAFA Tech, HEPTA, NOKIA and robots.expert participated, conducting physically tests of 5G!Drones use cases UC1 and UC3.

Nokia, 5G!Drones partner, executed 5G!Drones pre-trial measurements during 27-28 August 2020, which focused on the Nokia lead Use Case 3 Scenario 3: Location of UE in non-GPS environments. These feasibility tests were successfully conducted in Nokia premises in Oulu, Finland.

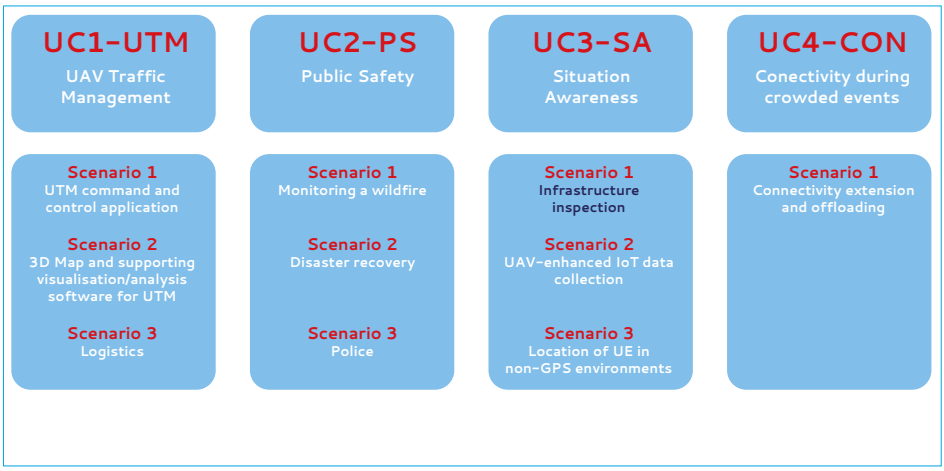

Fig. 19: 5G!Drones use cases and scenarios

5G!Drones partners NCSR Demokritos, Cosmote, HEPTA, CAFA Tech, robots.expert, Municipality of Egaleo and INFOLYSiS, conducted flight trials under 5G network in Municipality of Egaleo stadium (part of 5GENESIS 5G Athens platform, Greece), on October 19-20 2020, for collecting inputs and verifying the interaction between 5G and drones under 5G!Drones UC4. Two videos available at 5G!Drones YouTube channel. An overview report on Egaleo Stadium trials is available online.

5G!Drones partners NCSR Demokritos, Cosmote, CAFA Tech, robots.expert and INFOLYSiS, conducted flight trials under 5G network in OTE-Cosmote Academy premises (part of 5GENESIS 5G Athens platform, Greece), on October 21 2020, for testing the offering of a better level of network services with drones under 5G and avoiding dropped calls and degraded Internet connectivity during mass events (UC4). A video is available at the 5G!Drones YouTube channel. An overview report on OTE-Cosmote Academy trials is available online.

5GDrones partners Eurecom, Cafatech, Airbus, Drone Radar, Frequestis, and robots.experts conducted remote Feasibility tests using Eurecom (France) and CAFA Tech (Estonia) facility on 17th and 18th December, 2020 to test how 5G!Drones containers (C2+U-Space-, Mission Critical Services platform- and latency measurement container) work in Eurecom's servers and the connections with these containers´ client applications in smartphones. A video on it is available at 5G!Drones YouTube channel.

The key value from the performed Feasibility Tests in 2020 are as follows:

- for all participants a common understanding of 5G!Drones technical solutions and testing procedures was reached;
- inputs for the Trial controller and Enablers development were provided;
- Insights on container-based Cloud Native solutions use on the 5G Edge server.

5Growth

5G-enabled Growth in Vertical Industries

The 5Growth project (*http://5growth.eu/*) is investigating the technical and business validation of 5G technologies from the verticals' points of view, following a field-trial-based approach on vertical sites (TRL 6-7). Multiple use cases of vertical industries are currently being field-trialled on four vertical-owned sites in close collaboration with the vendors, high-tech SMEs, and academic partners.

5Growth Pilots

In COMAU's industry 4.0 pilot, three use cases are identified based on the three 5G profiles based on Industry 4.0 cases: The digital twin use case, which is also illustrated below, leverages on the Ultra-Reliable Low-Latency Communications (URLLC) and allows the plant manager to receive live information about the production line through a digital representation of the factory (Figure 20). The Monitoring and Telemetry use case leverages on the Massive Machine-Type Communications (mMTC) that provides deeper information, monitoring the status of the equipment installed in the stations (robots, conveyors, motors, and so on), by installing a high number of sensors that use 5G communication technologies. The Remote Support and Digital Tutorial is based on the Enhanced Mobile Broadband (eMBB), enables a high-resolution interface to remotely train and assist the worker on certain tasks. Currently, end-to-end (E2E) 5G infrastructure is up and running at COMAU site connected with TIM (HSS) and features Ericsson Italy transport equipment. Measurements of the mobile and transport networks of pilot applications were also performed. For an overall view of the COMAU pilot, a comprehensive video is available on YouTube and on the project web site.

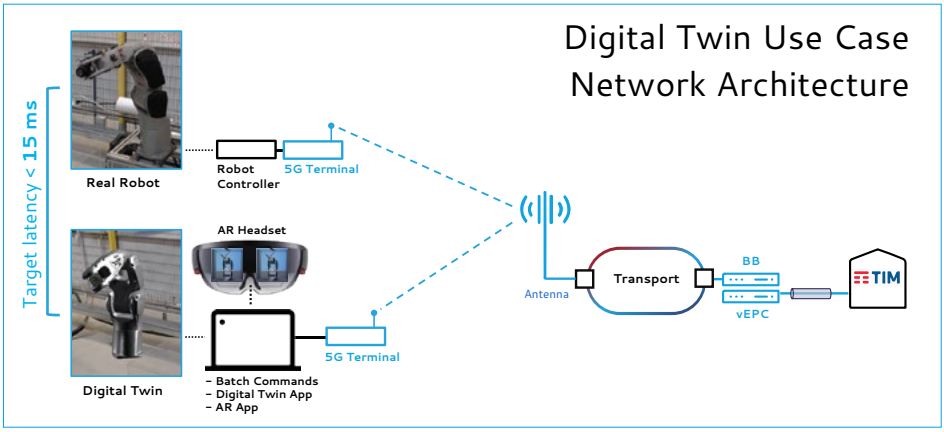

Fig. 20: COMAU Pilot digital twin use case ensures a stable and low delay in the connection of a real robot with its digital replica.

INNOVALIA's industry 4.0 pilot focuses on the deployment of two use cases targeting Industry 4.0 scenarios. The first one is Connected Worker Remote Operation of Quality Equipment, that explores how 5G technologies can be used to enable remote access to the M3BOX, an edge device used to control the Coordinate Measuring Machine (CMM), to perform setup and configuration operations that nowadays require an expert to travel to the customer's premises. The second use case is on Connected Worker Augmented Zero Defect Manufacturing Decision Support System that involves the development of a Machine to Machine (M2M) collaboration system using 5G technologies that will improve the flexibility and productivity of the CMM. Currently, the 5G infrastructure required to execute and validate these use cases is deployed and integrated with commercial INNOVALIA equipment at 5TONIC Lab. The actual remote operation of 3D optical scanner and the performance of the end-to-end service in terms of latency and throughput have been real-time monitored and analysed. A video of this pilot is also available on YouTube.

EFACEC Energia's energy pilot involves the deployment of two more use cases. The Advanced Monitoring and Maintenance Support for Secondary Substations MV/LV Distribution Substation use case consists of a system to assist the maintenance team when repairing the substation by providing information with augmented reality. The Advanced Critical Signal and Data Exchange Across Wide Smart Metering and Measurement Infrastructures use case will deploy a system to use the last gasp of energy before an outage, to save and transmit important information to identify and prevent greater problems. A video of this pilot is also available on YouTube. Currently, the E2E 5G infrastructure is up and running at each experiment site and the first use case has been implemented.

EFACEC Engenharia e Sistemas's transportation pilot proposes to replace the wired communication used nowadays on a railway level crossing by 5G-based wireless devices and is based on the deployment of two use cases: Safety Critical Communications, which are focused on railways signalling operations and Non-Safety Critical Communications, which provide additional information, to reinforce the security and to avoid accidents at Level Crossing areas, both to the train driver and to the level-crossing maintenance team. Currently, E2E 5G infrastructure is up and running at each experiment site and two use cases are currently implemented and deployed. A video is under preparation as of the time of writing.

Integration of 5Growth with ICT17 platforms

The 5Growth stack also interoperates with ICT-17 platforms (5G-EVE and 5G-VINNI projects) to assess multi-site support and non-public network-public network integration. 5Growth implements multi-domain support at three levels: (i) the communication service level follows a CSMF-to-CSMF approach (CSMF stands for

communication service management function) where the communication service provider (CSP) decides how to split the vertical service and which of its components can be delegated to other peer CSPs; (ii) the network slice level follows a CSMF-to-NSMF approach (NSMF, or network slice management function) where the CSP decides how to split the vertical service into multiple network slices and which network service provider (NSP) provides each of them; finally, (iii) the network service level follows an SO-to-SO approach and the CSP is customer of a single NSP that, in turn, interacts with peering NSPs at NFV-NS level transparently to the CSP.

For the INNOVALIA pilot, the integration of 5Growth with 5G-EVE follows a CSMF-to-CSMF approach and the 5Growth vertical slicer interacts with the 5G-EVE Portal and requests the deployment and instantiation of the vertical service in the 5G-EVE domain. For EFACEC_S and EFACEC_E pilots the integration of 5Growth with 5G-VINNI follows a CSMF-to-NSMF approach and the 5Growth stack interacts with 5G-VINNI and a network service can be requested by the 5Growth vertical slicer.

5Growth innovations

In addition to the 5Growth MANO stack, the 5Growth pilots integrate innovations such as AIML-based closed-loop control, multi-domain interaction, or RAN in network slices. For instance:

- In the "ML-driven Scaling of Digital Twin Service in 5Growth" demonstration, scaling is automated through the integration of an AIML platform, closed-loop scaling control, a vertical-oriented monitoring platform and scaling algorithms.
- In the "Hardening 5Growth interdomain interfaces with Moving Target Defence" demonstration, innovations on security/multi-domain, moving target defence, and hierarchical multi-domain integration are investigated.
- Finally, in the "Performance Isolation" demonstration, innovations such as smart resource control, interoperability and bandwidth isolation are investigated.

Full5G

The Full5G project has a prime objective to facilitate the activities of the European 5G Initiative, as outlined in the 5G contractual Public Private Partnership (5G PPP), during its third phase from June 2019 to September 2021.

In addition to this, the Full5G project has a second prime objective to capture and promote the achievements of the 5G PPP and monitor the impact these results have had on the evolution of 5G in Europe over the period of life of the 5G PPP. This work will also look to the future and consider what additional actions are necessary to maintain the European momentum and leadership in 5G, as it moves towards Smart Networks, and facilitates the uptake of 5G by the European vertical sectors.

During the planned Full5G project period the first 5G products and "near-5G" services will start to reach the marketplace. However, a lot of the 5G developments, global 5G regulations and integration of 5G into sectorial business models and processes, still need to happen before we can enjoy the full potential of 5G networks, services and devices. Our vision of a full 5G implementation as the enabling infrastructure of the holistic life-enhancing inter-connected and secure society is still the overall goal that the 5G PPP initiative is supporting.

3GPP Release 15 introduces many of the essential components of 5G but it does not really make 5G the core infrastructure of our future lives. Release 16 (Dec'19) has taken a step further towards facilitating this new vision.

Right now, the 5G PPP really needs to prepare the European vertical sectors for their use of 5G Release 16 and to show these industrial sectors

how they can gain a competitive advantage by being early 5G adopters. The work should also contribute feedback from the 5G PPP projects to the definition of future 3GPP releases. These are the goals of the 5G PPP Phase 3 as represented in the commitments of the 5G PPP contractual arrangement and the strategic objectives of the 5G Industrial Association (5G IA) and therefore they are logically part of the high-level ambition of the Full5G project.

Full5G Strategic Goals

The Full5G project will work to progress the 5G PPP high level goal of maintaining and enhancing the competitiveness of the European ICT industry and seeking European leadership in the 5G domain. Part of the strategy to do this will be to support activities where the 5G PPP can contribute to the implementation of the European 5G Action Plan. The Full5G project also has the underlying ambition to ensure that European society, via the Vertical sectors, can enjoy the economic and societal benefits these future 5G networks will provide.

Another key part of the Full5G project work is the review and promotion of the results of the 5G PPP as a whole. The project will prepare an Impact Analysis that will capture the impact of the PPP on the evolution of 5G in Europe and seek to correlate this to the social and economic trends emerging from the uptake of 5G. It will be early for this report as the full impact of 5G will not be experienced within the life of the project, but the objective is to document the value added to the European economy and society by this strategic investment in 5G. This is an essential step contributing to planning of future private and public investments for 5G-enabled smart networks the Horizon Europe vision builds upon.

Dissemination of key 5G PPP results

The dissemination of the 5G PPP results is of the outmost importance for the success of the Partnership. For this reason, a number of supporting tools are being used by the Full5G that indicatively include:

1. The 5G PPP web page[15] is the main place where significant information is compiled from all 5G PPP activities and presented to the outside world. The web contains information related to the 5G PPP projects, publications (e.g., white papers, cartographies, roadmaps, brochures, etc.), the list of future and past events (e.g., workshops and webinars), a brokerage platform, a list of European 5G activities etc.
2. Annual Journal: captures the progress and the main achievements of all projects and working groups at an annual basis[16].
3. White papers: as discussed in the previous section, a number of white papers are being produced by all WGs in 5G PPP that are publicly available through the web site.
4. Top technical documents: During 2020 a new web page has been introduced at the 5g-ppp.eu web site[17] that captures the latest most significant technical documents from WGs and projects (e.g., deliverables, journal and conference publications, white papers etc.). The scope of this page is to serve as one-stop place where all the latest technical achievements are captured.
5. Key achievements: A list of key achievements for all 5G PPP phases has being collected and processed for all three phases of the 5G PPP. The results are available through the 5G PPP web site[18].
6. Web page for each project: All 5G PPP projects have their own web site and also a 5g-ppp web page that points to them and includes information about the project objectives their key achievements and the project participants.
7. Workshops and webinars: A list of 5G PPP events is maintained and supported by Full5G.

15. *https://5g-ppp.eu/*
16. *https://5g-ppp.eu/annual-journal/*
17. *https://5g-ppp.eu/top-ten-papers/*
18. *e.g., https://5g-ppp.eu/phase-3-key-achievements/*

5G PPP PHASE 3, PART 4: 5G LONG TERM EVOLUTION

8 Projects have been retained from the 66 proposals received by the EC in response to the 5G PPP ICT-20-2019 call. These eight projects started in November 2019 and will run for about three years to work on the longer term vision.

5G ZORRO

Goals of the project

5G ZORRO incorporates novel enabling technologies to develop solutions for zero-touch service, network and security management in multi-stakeholder environments and Smart contracts for 5G Telcos. In 5G ZORRO, Operational Data Lakes act as logically centralised reservoirs of network operation data; Data-driven and AI-based solutions transform network orchestration into a cognitive process through which the network can self-adapt and self-react to changing conditions; DLTs enable distributed security and trust across the multiple parties involved in the 5G service chain; Cloud-Native technologies increase the level of flexibility, scalability and resilience of SDN/NFV 5G based services.

Key Innovations

The combination of the aforementioned technologies is the basis for realisation of the 5G ZORRO innovations.

Zero-touch/Automated Resource discovery using DLT/Blockchains.

The automatic (zero-touch) resource discovery is based on the extensive use of AIOps and DLT solutions. On the one hand, it allows different stakeholders to publish their own resource/service offering: on the other hand, it enables the business logic to automatically discover the most suitable set of resources while minimising human intervention. For resource/service trading, 5G ZORRO offers a set of modules that build a Marketplace Application where business agents can discover and classify the available resources, services and network slices.

Intelligent 3rd party resource selection, request and access/usage.

Once resources have been made available on the DLT-based resource catalogue and automatically discovered and classified, an automatic AI-based process can select the most suitable ones, request them from the owners and, after the business transaction has been completed into the DLT, finally use them. The Intelligent 3rd Party resource selection heavily applies the zero-touch management paradigm that guarantees that different resources/services offered by different providers (administrative domains) can be seamlessly composed (service creation/service stitching) across the different domains. AI-based mechanisms apply the correct configuration of the services/resources while guaranteeing that the Service Level Agreement is properly applied in the service chain across the different domains.

Trust establishment among multiple parties.

5G ZORRO offers a mechanism that guarantees the trust and the security among the parties involved, with end-to-end security for the deployed services. Each stakeholder that

wants to deploy a slice/service needs to be sure that all the resources/services provided by the 5G ZORRO framework are secure and provided by trusted sources. The level of security and trust of each party is established in the smart contracts between the parties.

As depicted in Figure 21, operators use 5G ZORRO DLT-Based marketplace to publish and to check for new resources (see spot 1, Zero-touch/Automated Resource discovery in Figure 21). Then, in order to build a cross-operator service, the framework intelligence (AI) automatically selects proper resources (see spot 2 – Intelligent 3rd party resource selection in Figure 21) whose usage and chaining is automatically formalised through the mechanism of the Smart Contracts (see spot 3 – Trust establishment among multiple parties). Smart Contracts and trust establishment is established via a distributed ledger technology which does not request trust a priori between involved parties.

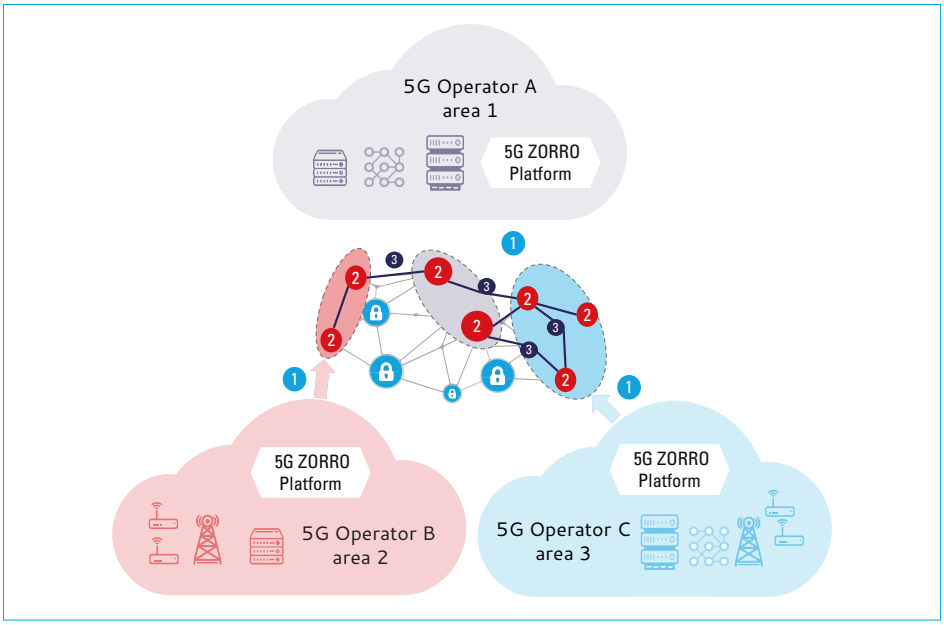

Fig. 21: Zero-touch/Automated Resource discovery (1), Intelligent 3rd party resource selection, request and access/usage (2) and Trust establishment among multiple parties (3) in 5G ZORRO.

Major achievements of the period

In its first 15 months (project started on Nov-2019), and despite the COVID-19 pandemic impact on all the joint activities of the Consortium, the project produced the following achievements:

- **Detailed use case descriptions *(Smart Contracts for Ubiquitous Computing/ Connectivity; Dynamic Spectrum Allocation; Pervasive vCDN Services)***, each with more than 3 relevant scenarios to clearly identify requirements for the architecture and the software platforms in relation to the aforementioned innovations (see D2.1: Use cases and requirements definition[19]);
- **A *high-level reference architecture design*** which follows the principles of service-based architectures similar to the 5G Service-based architecture defined in 3GPP, and the ETSI Zero-touch Network and Service Management. It allows separation of responsibilities & scopes per domain/inter-domain via open interfaces and implements cross-layer

19. *https://www.5gzorro.eu/wp-content/uploads/2021/03/5G ZORRO_D2.1_v1.5-with-watermak.pdf*

Communication Fabric mechanisms (see D2.2: Design of the 5G ZORRO Platform for Security & Trust[20]);

- The ***first version of the software platform design for Marketplace, the Governance and the Cross-domain Analytics & Intelligence for AIOps***, which are currently under implementation (see D3.1: Design of the evolved 5G Service layer solutions[21])
- The ***first version of the software platform design for Security and Trust Orchestration, Intelligent and Automated Slice & Service Management, and NFV MANO and Network Slicing Enhancements for 5G ZORRO***, which are currently under implementation (see D4.1: Design of Zero Touch Service Management with Security & Trust Solutions[22])

20. *https://www.5gzorro.eu/wp-content/uploads/2021/03/5G ZORRO_D2.2_v1.0-OA-PC_fixed_references-water-mark-1.pdf*

21. *https://www.5gzorro.eu/wp-content/uploads/2021/03/5GZORRO_D3.1_v1.3-with-WM.pdf*

22. *https://www.5gzorro.eu/wp-content/uploads/2021/03/5G ZORRO_D4.1_v1.0_final-with-WM.pdf*

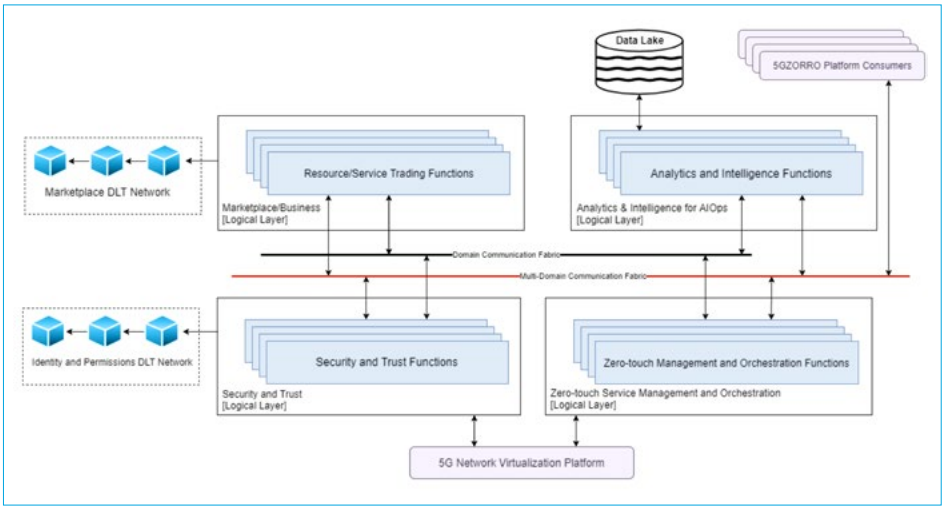

Fig. 22: 5G ZORRO High Level reference architecture

From these designs, a number of internal demonstrations originated for Marketplace solutions for VNFs, Security establishment across VNFs based on WireGuard, and Network slicing creation across different domains.

These initial prototypes are being evolved to implement the produced software module and system design, in order to form the 5G ZORRO-core platform planned for release in Q2-2021 on GitHub (https://github.com/5G ZORRO). Through the 5G ZORRO-core platform, the Consortium plans to execute from Q2-2021 initial tests of

- Resource discovery and offering in the 5G ZORRO marketplace
- Cross-domain connectivity establishment
- End-to-end Slice creation across domains

both in lab and in reference testbeds at 5GBarcelona (Barcelona, Spain) and 5Tonic (Madrid, Spain).

5G-CLARITY

5G-CLARITY is a 5G PPP Phase III project (ICT-20-2019 call: 5G Long Term Evolution), started on November 1, 2019, and is planned to be concluded on July 31, 2022. The consortium consists of 12 strong industrial and academic partners from across EU and UK.

5G-CLARITY brings forward the design of a system for beyond 5G private networks by addressing the main challenges in this area.

The emergence of private networks guarantees the delivery of voice, text, data and video, and connection to machines, sensors, devices, and computing systems, as well as people in the privately owned venues and enterprises. Much as the private networks are popular within the industry and research communities, their widespread adoption will only become a reality if their operational costs are small, and a seamless interworking between 5G access and other industry technologies (e.g. wired Ethernet, Wi-Fi and emerging technologies such as LiFi) is made possible. Among the technical challenges, spectrum management, multiple wireless access technologies (multi-WAT) and multi-tenancy support, software defined networking (SDN) and network function virtualisation (NFV) powered infrastructure slicing, and data-driven network management could be named as outstanding. 5G-CLARITY aims at the design and integration of innovative solutions, beyond 3GPP Release 16, in regard to these challenges in a structured format.

5G-CLARITY proposed architecture, presented in Figure 23, is structured in four strata to allow for a rich set of capabilities in private networks. These capabilities can be flexibly adapted, combined and extended to support a wide variety of services for both public and non-public use, including infrastructural services and communication services. Each 5G-CLARITY stratum has a specific scope and technology pace as, i) Infrastructure Stratum, formed of all the on-premise hardware and software resources building up the 5G-CLARITY substrate, including user equipment and a wide variety of compute, storage and networking fabric; ii) Network and Application Function Stratum, which conveys the 5G-CLARITY user, control and application plane functionality, including all virtualised network and application functions that can be executed atop the 5G-CLARITY cloud infrastructure; iii) Management and Orchestration Stratum, which encompasses all the necessary functionalities, including provisioning functions (for lifecycle management), monitoring functions (for data collection and processing) and other supporting functions, to deploy and operate the different 5G-CLARITY services (and associated resources) throughout their lifetime, from their commissioning to their de-commissioning; iv) Intelligence stratum, which hosts the Machine Learning (ML) models and related policies to provide Artificial Intelligence (AI)-driven and intent-based operation capabilities to the overall 5G-CLARITY stratum.

Regarding the Network and Application Function Stratum, 5G-CLARITY introduces out a number of innovative solutions on multi-connectivity, resource management, and multi-technology indoor positioning. The project formulates a multi-access-based multi-connectivity framework that integrates 3GPP access networks such as 5G new radio (5GNR)/4G-LTE and non-3GPP access networks such as Wi-Fi and LiFi. This is formulated by employing an enhanced Access Traffic Steering, Switching, and Splitting (AT3S) functionality to provide real-time control of traffic flows to each available access network according to the requested service and Service Layer Assurances (SLAs) requirements. On resource management, the project is primarily focusing on traffic routing to the available access networks and then multi-user access to physical resources that are available in each access network is being considered. 5G-CLARITY solution for indoor positioning is based on a localisation server that makes an intelligent use of available access networks/technologies such as 5GNR, millimetre wave, LiFi and Optical Camera Communications (OCC) to improve positioning accuracy by merging the position estimates obtained from each available access technology.

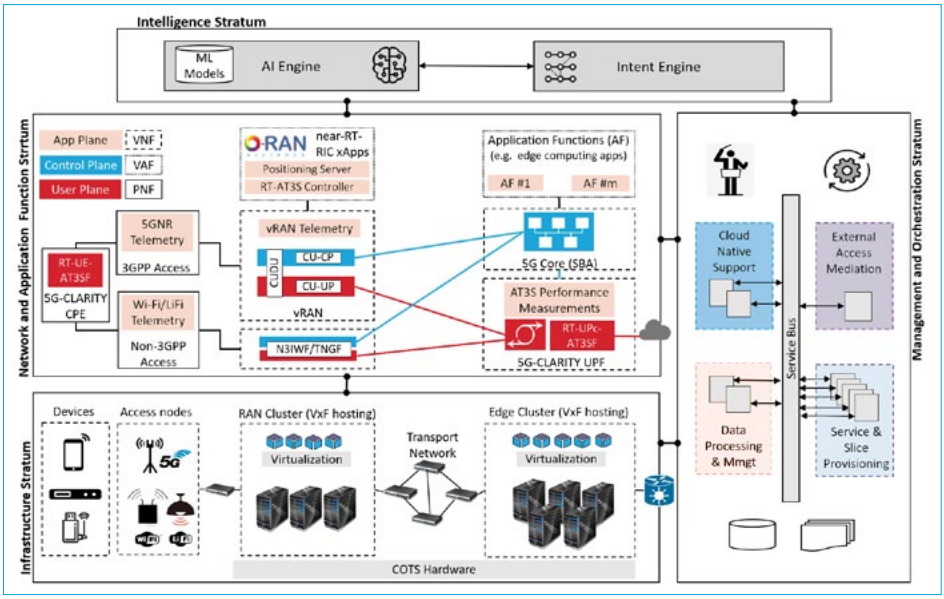

Fig. 23: 5G-CLARITY system architecture.

For the Management and Orchestration Stratum, the initial design for the Slice Manager and the multi-WAT non real-time RAN intelligent controller (RIC) are provided. Moreover, a subsystem to gather multi-WAT telemetry in a RIC is designed for which the main components are the Data Semantics Fabric, which can gather and manipulate streaming data from multiple sources in the network, and the Data Lake that makes data available to the ML models living in the Intelligence Stratum.

For the Intelligence Stratum, a set of 9 distinct ML models are identified that can be used to optimise network performance, including both non-real-time and near-real-time optimisation. An AI-engine is defined as a containerised execution environment that can manage the lifecycle of ML models. Moreover, an intent-based networking for facilitating customer interaction in private networks is devised, and a set of eight use cases are identified to illustrate the use of the intent-engine within the 5G-CLARITY system, e.g. interactions between the network operator and the intent-engine, and between individual ML models and the intent-engine.

These solutions and innovations for user, control, and management planes are being implemented and integrated according to the proposed architecture, and will finally be demonstrated in three use cases for Smart Tourism and Industry 4.0 (Smart Factory) scenarios as listed below:

- 'Enabling enhanced human-robot interaction' (Smart Tourism), at M-Shed City Council Museum, Bristol, UK.
- 'Alternative network for production-data exchange' (Industry 4.0), at BOSCH factory, Aranjuez, Spain.
- 'Enhanced automated guided-vehicle (AGV) positioning in intralogistics' (Industry 4.0), BOSCH factory, Aranjuez, Spain.

Further information and updates regarding 5G-CLARITY project, including all project deliverables are available in project website: www.5gclarity.com

5G-COMPLETE

5G-COMPLETE approach

The 5G-COMPLETE project proposes an architectural approach inspired by state-of-the-art standardisation activities pursued by ETSI, 3GPP, IEEE and the Open-RAN (O-RAN) alliance that efficiently integrates a variety of advanced wireless technologies including digital and analogue transport schemes as well as mmWave and THz solutions with optical and packet networking to support the required network connectivity for 5G. In addition, 5G-COMPLETE proposes full integration of network with compute and storage resources in support of the very demanding current and upcoming 5G services. The architectural principles of 5G-COMPLETE exploit the benefits of softwarisation migrating from the notion of network elements to network functions, the separation of user plane and control plane and Radio Access Network (RAN) disaggregation. RAN disaggregation refers to functional decomposition of the RAN baseband processing functions, corresponding to the relevant protocol-layer stack, to a set of functions that can be processed independently at the Remote, the Distributed and Central Units (RUs, DUs, CUs), placed either at one or more locations supporting a variety of functional splits. Another architectural principle of 5G-COMPLETE relates with the adoption of cloud computing in support of the processing requirements of the various Fronthaul (FH) and Backhaul (BH) services the solution will support. The proposed approach introduces flexibility in the way compute resources are allocated across the 5G-COMPLETE infrastructure as it allows both integration of a central cloud solution as well as more distributed approaches where smaller scale compute and storage resources are placed at the network edge closer to the end user in accordance with the Mobile Edge Computing (MEC) paradigm. MEC will play a key role in order to further guarantee the capability of the 5G-COMPLETE solution to support demanding requirements associated with reduced end-to-end latency and transport network capacity.

5G-COMPLETE Functional Connectivity

5G-COMPLETE project adopts a flexible architectural approach that allows integration of a variety of technologies able to support a large number of different telecom and vertical industries related use cases and services with very different requirements and characteristics. These include transport network technologies such as advanced wireless networks and optical as well as packet transport network solutions integrating compute and storage resources in line with the MEC and Central Cloud approaches. The different 5G NR deployment options supported by the project along with the technologies used to implement these are summarised in Figure 24. These options combined can be used to provide any service with highly variable Key Performance Indicators (KPIs) for Ultra-Reliable Low-Latency Communication (URLLC), Massive Machine-Type Communication (mMTC) and enhanced Mobile Broadband (eMBB) services.
5G-COMPLETE demonstrations

All systems and components developed within the 5G-COMPLETE project will be demonstrated at several lab-scale and live field-trial demonstrators.

Two separate lab-scale demos will be held in Athens, Greece:

- The objective of the first demo, which will be hosted by NKUA/IASA and COSMOTE, is to evaluate the 5G-COMPLETE architecture in a lab scale environment through the end-to-end provisioning of infrastructure slices supporting smart energy metering services.
- Within the second demo, ICCS/NTUA will validate through lab-scale experiments the potential of the THz transceiver and of the optical hybrid node supporting mixed analog/digital optical transport to meet the specifications of the 5G-COMPLETE infrastructure. These blocks will be also used to provide proof-of-concept experiments that showcase the potential of these technologies towards B5G networks.

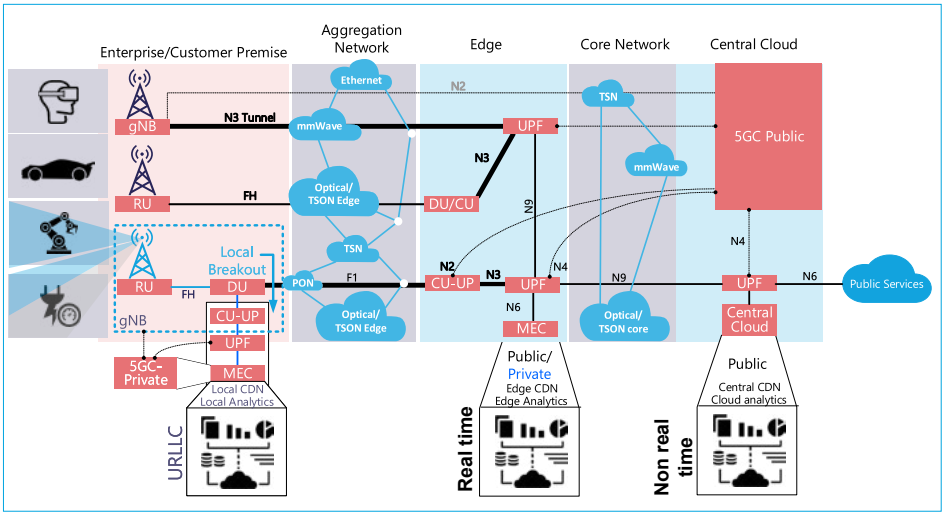

Fig. 24: 5G-COMPLETE deployment options

Also, three Live demonstrations will be held in Athens, Lannion and Bristol, respectively:

- The first phase of the incremental integration of 5G-COMPLETE technologies will be demonstrated in Athens, focusing on the management and orchestration of the infrastructure virtualisation layer comprising transport network and compute infrastructure resources. In this first technology demo, non-3GPPP access nodes will be considered connected through a flexible mmWave mesh network to MEC and Central Cloud infrastructure. The end-to-end service deployment and resource provisioning will be supported by the MANO framework.
- The demo that will be hosted in Orange's facilities in Lannion, will be performed over a converged architecture, involving several types of physical connections, physical and virtual resources as well as 5GRAN deployment options. The performance of multi-technology transport network will be assessed under realistic traffic flows provided through a virtualised 5GRAN solution comprising vCU/vDU/vRU. From an application point of view, the demonstration will permit to evaluate the transmission of the interfaces connecting the different equipments of a mobile network. It will also permit to validate that the optical network infrastructure can cope with the needs of the mobile users.
- The 5G-COMPLETE project's final demonstration will be held in Bristol 5G UK Testbed. University of Bristol will develop a 5G-COMPLETE network integrating its technologies within the 5GUK test network and will create service slices to demonstrate a set of 5G-COMPLETE Use Cases. The deployment of 5G-COMPLETE technologies includes among others: Open RAN deployment of a 5G cellular network, a mix of access connectivity using wired and wireless solutions in licensed and unlicensed bands for the service delivery, fibre network connectivity across the city of Bristol, TSON demonstrating high capacity and flexible optical transport connectivity between two sites in the city of Bristol, central cloud services, MEC technologies and an NFV Orchestration framework.

ARIADNE

Artificial Intelligence Aided D-band Network for 5G Long Term Evolution

The ARIADNE project will enable spectral-efficient, high-bandwidth, intelligent wireless communications by developing three complementary, critical new technologies for 5G networks:

- New radio technologies for communications above 100GHz D-Band frequency range
- Advanced connectivity based on reconfigurable intelligent metasurfaces
- Machine Learning and Artificial Intelligence techniques for management of high-frequency communications resources and reconfiguration of the metasurfaces.

After year one, ARIADNE has specified its system model as a basis for future project work. ARIADNE has performed an analysis of the D-band directional link, including suitable channel modelling approaches, ways forward in performance evaluation, and preliminary studies on the appropriate application of machine learning techniques. Furthermore, we laid the basis for the application of Reconfigurable Intelligent Surfaces and reconfigurable antennas for D-Band.

ARIADNE Vision and System Concept

ARIADNE aspires to transform the current 5G wireless thinking from focusing on "local" network improvements to realising a longer-term vision of pervasive mobile virtual services. The project envisions bringing together a novel, high-frequency advanced radio architecture and an Artificial Intelligence (AI) network processing and management approach in a unified system beyond 5G concept. ARIADNE will investigate, theoretically analyse, design, develop, and showcase in a proof of concept demonstrator an innovative wireless communications concept addressing networks beyond 5G. In this concept, ultra-high spectral-efficient and reliable communications in the D-band can be dynamically established and reconfigured by Machine Learning (ML)-based design and intelligent network management, in both "Line of Sight" (LOS) and "Non-Line of Sight" (NLOS) environments.

Sustaining a flexible, ubiquitously available 100 Gbps network for backhaul and access in systems beyond 5G will require the exploitation of higher frequency bands, the adoption of novel hardware technologies and advanced materials, and rethinking the Communication Theory framework and traditional design principles and architectures. In this way, in the beyond 5G era, the conventional system concept of a 5G network as a universal resources manager will be transformed into the system concept of a fully adaptive, power-efficient distributed computer and highly reliable connectivity provider.

On D-band directional link analysis

High frequency systems, such as D-band, suffer from large path losses requiring utilisation of high gain antennas, where – if line-of-sight is available – traditional beamforming at the transmitter and receiver sides can help with mitigating the channel losses and providing the ability for tracking mobile users. In non-line-of-sight situations, the D-band systems can benefit by applying Reconfigurable Intelligent Surfaces (RIS), allowing intelligent manipulation of radio propagation towards the mobile user as required.

An important aspect of ARIADNE is to explore radio propagation via RISs that are expected to significantly increase the received signal power in NLOS situations where the LOS path is blocked. However, transmission in high-frequency bands requires highly directional antennas to provide enough gain to overcome large propagation losses in the channel. On the other hand, due to the decreasing electric size of antennas as a function of frequency, D-band suffers from high path losses, even on the LOS path. As a consequence, high-gain antennas have to be used to compensate for the losses while also allowing multiple-input multiple-output (MIMO) communications by applying beam steering.

In practice, the antennas are not always stationary, even in static backhaul/fronthaul configurations, e.g. due to environmental effects such as wind, small structure deformation, or stochastic tracking estimation errors. This is not a major problem at lower frequencies, but the D-band high-gain antennas are very sensitive to misalignment.

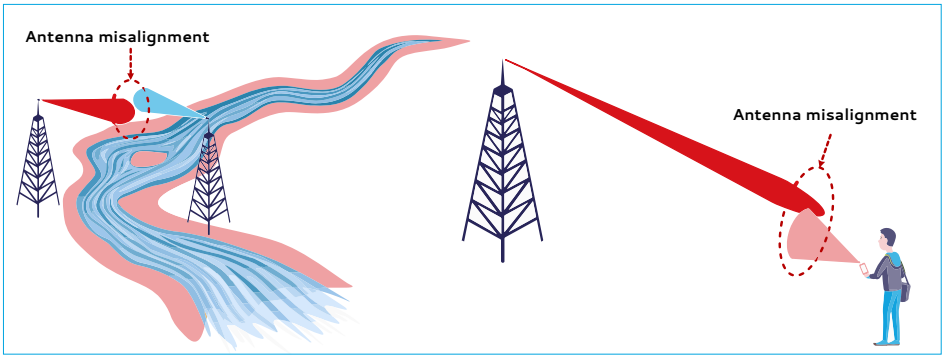

Fig. 25: ARIADNE – Backhaul misalignment

This causes a need for accurate and efficient channel estimation to constantly update the beamformers in order to minimise beam misalignment and maintain sufficient link conditions. Mobile users require novel beam tracking algorithms to estimate the user position to ensure maximum gain regardless of the user movement patterns. As future systems will use higher frequency bands, beamforming becomes a major issue to guarantee good signal quality at the receiver. Accordingly, important future research topics are related to beamforming in general, channel estimation of sparse directional channels, and beamforming algorithm design to maximise the performance of systems depending on high antenna gains. The RISs will help by providing the possibility to modify the propagation environment, in order to provide good signal quality, also in NLOS situations, in combination with the application of appropriate ML techniques.

Reconfigurable Radio Technologies for D-Band

Radio technologies will be impacted at the physical layer by the rise of AI. The driving idea behind it is that link-level information may improve AI predictions on reliability, outage and performance of wireless communication networks. Thus, cognitive functions and reconfiguration possibilities, which have been neglected at THz frequencies so far, will become ever more important.

Looking at D-band radio, ARIADNE distinguishes between cell-level and site-level technologies, affecting the radio propagation and the base stations respectively. ARIADNE aims to combine those two areas through new concepts, involving a multidisciplinary approach across all its activities.

Addressing the cell level, the development of metasurfaces for frequencies beyond 100 GHz has been an open research field so far, and the physical layer implementation is still in its infancy. ARIADNE has started to classify and screen candidates that are attractive from the functional and fabrication point of view. Prototypes for planar and corrugated structures are being studied with a focus on their frequency selective properties.

For more information about the project and its recent results, please, visit the ARIADNE website at *www.ict-ariadne.eu.*

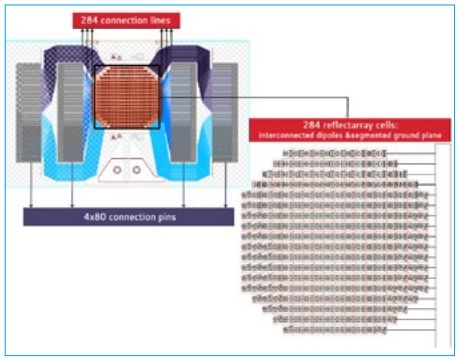

Fig. 26: ARIADNE – reconfigurable radio technologies

Intelligent Security and Pervasive Trust for 5G and Beyond

Goals of the project

The INSPIRE-5Gplus (Intelligent Security and Pervasive Trust for 5G and Beyond) project is part of the ICT-20 call funded by Horizon2020. It is a project dedicated to the definition and implementation of, to our knowledge, the first ever security reference architecture for 5G and beyond (B5G) mobile networks. It is one of the few main projects addressing the critical security concerns that need to be considered in future multi-tenant and multi-domain Software Defined and Virtualised Networks (i.e., SDN/NFV-based infrastructures) with the objective of obtaining Zero-touch network and Service Management (ZSM) whose initial architecture was defined by ETSI.

In this context, the main goals of the project are: 1) Identifying the threat landscape, security requirements and future trends and technologies, and identifying the limitations and gaps related to the security of in B5G networks; 2) defining a more concrete high-level architecture; 3) identifying, implementing and integrating the different enablers required; and 4) validation based on different use cases and test scenarios. The project has analysed and is leveraging different technological trends such as, AI/ML, TEE, DLT, MTD, SSLA, TLA, POT, CTI, RCA, Liability concepts, data plane programmability, data-centric security, etc.) and is developing novel mechanisms for obtaining intelligent autonomous end-to-end cyber security services, and fostering trust/liability in B5G for supporting confidence between parties and compliance with regulations.

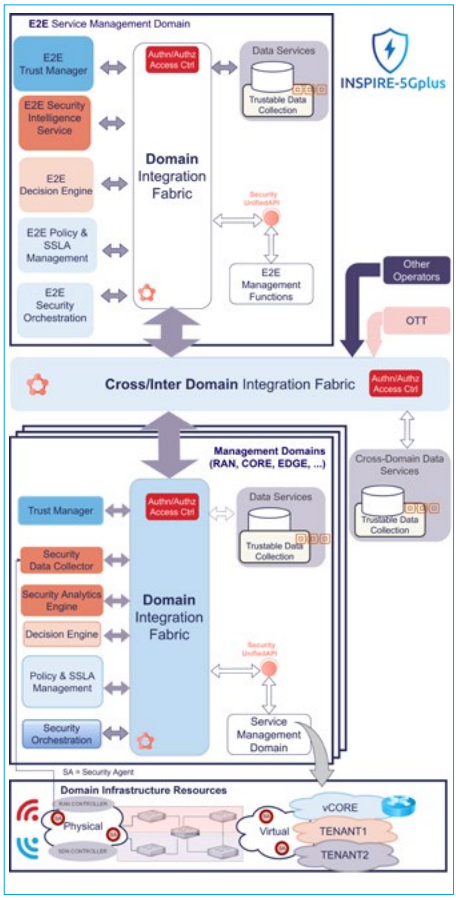

Fig. 27: INSPIRE-5Gplus architecture

Major recent achievements and innovations

INSPIRE-5Gplus has defined its High-Level Architecture (HLA) composed of different functional blocks depicted in Figure 27 and further described in INSPIRE-5Gplus' online whitepaper. The main HLA blocks are the means for providing ZSM, as well as policy, AI and trust-based management. To give an operational example, a zero-touch management loop could function in the following way:

1) the users define the security policies and SSLAs that will be deployed using the Policy & SSLA Management function; 2) Security Agents will collect information that needs to be analysed to verify that the policies are respected; 3) the information is aggregated, transformed and stored by the Security Data Collector and the Data Services; 4) the Security Analytics Engine and Trust Manager retrieves and analyses this data and informs the Decision Engine; 5) the Decision Engine then decides

on the best actions to be taken balancing the security level, risks involved and performance costs from a holistic point of view, and informs the Security Orchestrator; and, finally, 6) the Security Orchestrator triggers the necessary reactions to mitigate, remediate or stop any security breaches, and informs the Orchestrators and Controllers that are in charge of changing the network and service configurations or the deployed network slices and virtualised network functions.

Test Case validation and KPIs

To evaluate the architecture and enablers, the INSPIRE-5Gplus project has defined a set of KPI that allow validating both performance and security aspects. The performance KPIs are those defined in many of the current 5G PPP projects: 1000-times higher wireless area capacity, saving up to 90% of energy, reducing the average service creation time, zero-perceived service downtime, very dense deployments, and advanced user-controlled privacy. On the other hand, the defined Security KPIs are the following: Mean Time to Detect (MTTD) a potential security incident; Mean Time to Contain (MTTC) a detected potential security incident; Mean Time to Resolve (MTTR) potential security incidents; Transaction Speed (TS) understood as the number of transactions per second that can be performed; Packet Loss Ratio (PLR),which directly impacts the effectiveness of the security monitoring; False Positive Rate (FPR); False Negatives Rate (FNR); Initial Processing Time (IPT); Migration Time (MT),which measures the time required to migrate assets (e.g., VNFs) or scale computing/network resources; Blocked Adversarial examples Rate (BAR); Automated Model Generation (AMG), understood as the percentage of the actual network that can be modelled automatically; Automated Vulnerability Assessment (AVA), which is the percentage of identified vulnerabilities that can be used to exploit the network; and Cyber Security insights (CSI), that represents the percentage of cyber-insights that were used to improve the security posture of a 5G network.

These KPIs will be employed to evaluate the performance of INSPIRE-5Gplus advances in the following test cases.

Test Cases	Scope	Category with respect to High Level Architecture									
		Slice Management	SSLA Manager	Security Orchestrator	Security Analytics	Security Function	Security Enforcement	Policy Repository	Security Assessment	Security Data collector	Security Agent
TC1: Secured Anticipated Cooperative Collision Avoidance	Network slicing in autonomous vehicle scenarios	●	●	●							
TC2: Definition and Assessment of Security and Service Level Agreements (SSLA) and Automated Remediation	SSLA management and implementation		●	●					●		●
TC3: Network attack detection over encrypted traffic and prevention of evasion techniques in SBA	Attack detection and security functions protection using Trusted Execution Environments				●					●	●
TC4: E2E Encryption TEE secured SECaaS	E2E cryptographic protection to provide extra privacy and origin authentication	●	●	●	●	●	●	●		●	
TC5: End-to-End Slice Protection based on Moving Target Defence and Anomaly Detection	Security mechanisms for active network slices and services based on dynamic VNF placement	●			●						●
TC6: GDPR aware counterparts for cross-border movement	Enforcement of law and directives on cross-border scenarios for connected cars	●	●	●	●	●		●			●
TC7: Intelligent and Secure Management of Shared Resources to Prevent (D)DoS	Protection of shared resources within slices from (D)DoS attacks	●	●		●		●		●		●
TC8: Security posture assessment and threat visualization of 5G networks	Use of modelling language to express the assets of 5G networks and facilitate the security assessment								●		
TC9: Secure and privacy enabled local 5G infrastructure	Network slice broker as mediator between network operators and end users for SSLA compliance	●									

Table 4: test cases of the INSPIRE-5Gplus project

LOCUS

Goals of the project

The goal of LOCUS is to design and develop a location management infrastructure not only capable of improving localisation accuracy and security, but also to extend it with physical analytics, and extract value out of it, meanwhile guaranteeing the end user's right to privacy. To this end, LOCUS builds upon the work of 3GPP Rel. 17, which is currently extending the functionality of 5G infrastructures to enable positioning reference signals, measurements and procedure information. Building on top of these components, low-complexity algorithms and scenario-dependent deployment designs are developed in LOCUS to enable cellular networks to: (i) provide accurate and ubiquitous information on the location of physical targets as a network-native service, and (ii) derive complex features and behavioural patterns from raw location and physical events, which can be exposed to application developers. Localisation, appropriate dedicated analytics, and their combined provision "as a service" will greatly increase the overall value of the 5G ecosystem and beyond and allow network operators to dramatically expand their range of offered services, enabling holistic sets of users, location- and context-targeted applications. Accurate localisation of terminals will also be exploited to improve network performance and to better manage and operate networks.

Major Achievements/Innovations of the project during last year

The main high-level achievements and innovations of the project so far are listed below:

- Definition of scenarios and use-cases, which are representative of trends and market drivers, the operators' perspective and indicative vertical application needs.
- A high-level functional architecture, together with the description of all functions and components of the LOCUS Platform (see Figure 28).
- Techniques to capture IMSI/SUPI, in the framework of large-scale experiments for testing location security; adaptive (deception/masking) attack detection strategies via statistical signal processing techniques.
- Development of innovative signal processing techniques for enhanced 5G localisation and considering also the integration with heterogeneous technologies. Experimental results have been obtained and presented.
- Framework for device-free localisation in cluttered environments together with theoretical bound considering the 5G numerology.
- Smart network management functionalities. Some of the functionalities are already in an advanced level of design and/or development, and preliminary results have been presented.
- Analytics techniques targeting several LOCUS use-cases. The techniques proposed rely on machine learning and neural networks and have been validated using open data sets. The use of real data is planned for a later stage of the project.
- Extension of the use cases envisaged in the original project description of work to include tracing solutions for keeping track of contacts between people to help fight the COVID-19 outbreak.

Description of demos (Use cases for proof-of-concepts)

LOCUS will demonstrate its solutions through three proof-of-concepts that are currently under definition and will be addressed in the next phases of the projects. The proof-of-concepts will concern use cases related to smart network management and the provision of new services. A short description of the use cases that will be interested by PoCs follows.

1. **Network-management:** this PoC will concern smart network management through the LOCUS platform to identify network issues, increase network resilience, and empower the optimisation of service performance. The demonstration will be carried out within a campus venue, where the users will access educational multimedia content under mobility. In this scenario, mapping student groups to different multimedia contents can dramatically increase the network load. Network localisation and context-awareness provided in LOCUS will help the operator to balance network capacity, define active off-loading

strategies and even in-network caching techniques. On the other hand, the automatic recovery of network failures developed in LOCUS can predict, elude, or minimise service interruptions.

2. **Self-driving objects:** this PoC will concern the handling of general cargo freights by means of AGVs in a seaport terminal. A VR simulated environment reproducing a real terminal of the Livorno's seaport will be implemented for shuttling cargo freights between the terminal reception area, the storage and the loading place in front of the ship. A virtual model of AGV will be managed and guided using a dedicated mission/navigation system. The latter will use the position information provided by the 5G network to determine the next moves on the planned path.
3. **People mobility:** this PoC will concern flow mobility and crowd analytics in indoor environments. The LOCUS analytics service will be leveraged to provide the best routes, smart notifications/recommendations adapted to individual preferences (walking, shopping, food, etc.) – when offered – and current flow and contextual information, through a mobile application and/or smart panels. Using location information, the venue will be able to elaborate statistics on people's flow to optimise their organisation and signalling to customers and passengers, offering services such as (a) identifying different mobility profiles through an augmentation and fusion process and (b) extraction monitoring options to users through an App/Dashboard. In this proof-of-concept, data manipulation, data fusion, and ML methods offered by LOCUS will be verified

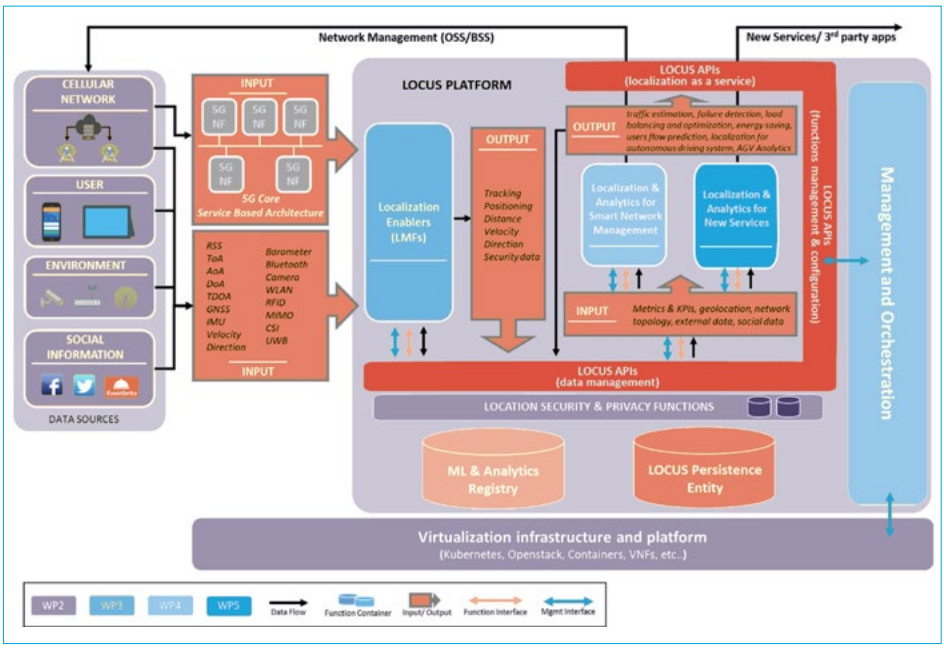

Fig. 28: LOCUS high-level functional architecture

Project description and overall objective

MonB5G aims at deploying a novel autonomous management and orchestration mechanism framework by heavily leveraging distribution of operations together with state-of-the-art Artificial Intelligence (AI) based mechanisms. The developed system is based on a hierarchical approach that allows the flexible and efficient management of network tasks, while at the same time, introducing a diverse set of centralisation levels through an optimal adaptive assignment of monitoring, analysis, and decision-making tasks. The MonB5G approach focuses on the design of a hierarchical, fault-tolerant, automated data driven network management system that incorporates security as well as energy efficiency as key features, to orchestrate a massive number of parallel network slices and significantly higher types of services in an adaptive and zero-touch way.

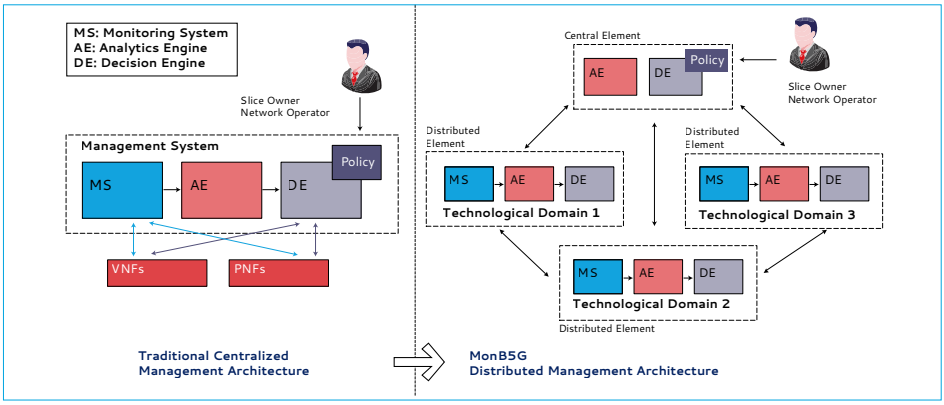

Fig. 29: MonB5G vision

Specific Objectives

To achieve the overall objective of MonB5G, a series of specific objectives have been specified:

1. Devise a distributed management plane to handle the deployment of a massive number of network slices
2. Define network slice service-level KPIs that consider not only a single Virtual Network Function (VNF), but all the network slice components, i.e., VNFs, Physical Network Functions (PNFs) and networking components
3. Devise data-driven management system components (i.e., Monitoring System, Analytics Engine, Decision Engine), based on State-of-the-Art federated learning AI techniques
4. By combining the Intent-based policy definition and the cognitive management entities, MonB5G will target multi-domain zero-touch network configuration of sliced 5G and beyond networks
5. Define decision algorithms tailored to the Radio Access Network (RAN). The envisioned decisions should allow to update the RAN configuration, when the latter is detected as the root cause of network slice performance degradation or when considered necessary to meet the heterogeneous performance requirements of multiple coexisting slices
6. Elaborate advanced security schemes and plans to empower secure smart network slice LCM
7. Provide AI-assisted techniques to optimise energy efficiency in all technological domains (i.e., Cloud, RAN, Core and Multi-access Edge Computing)

8. Dissemination, standardisation and exploitation of technologies developed in the MonB5G project.

Special focus is given to push the solutions regarding the cognitive Analytics and Decision Engines to ETSI ZSM and ENI bodies

Demos and Proof-of-Concept

Proof of Concept 1: Zero Touch Network and Service Management with end-to-end SLAs

- **Experimental Scenarios (ESs)**
  - ES1: Zero-Touch multi-domain service management with e2e SLAs
  - ES2: Elastic e2e slice management
- **Key Performance Indicators (KPIs)**
  - Reduce the number of SLA performance violations by **20%**
  - Improve network energy efficiency by a **factor of 10**
  - Reducing Static Slicing overhead will result in **30%** higher utilisation (will be achieved with dynamic reconfiguration techniques)
  - Compared to Static Slicing, demonstrate the **same or better SLA tolerances (or risk of missing SLAs)** when dynamic slicing techniques are used
  - **10x** reduction in signalling / monitoring overhead with the use of federation techniques

Proof of Concept 2: AI-assisted policy-driven security monitoring and enforcement

- **Experimental Scenarios (ESs)**
  - ES1: Attack identification and mitigation
  - ES2: Robustness of learning algorithms in the face of attacks
- **Key Performance Indicators (KPIs)**
  - **10x** faster identification of security attack/anomaly
  - **10x** faster attack remediation and reconfiguration in the order of **10s**
  - End-to-end slice availability **> 99%**
  - Per slice component availability **> 99.999%**
  - Slice isolation: **<5%** performance degradation during attacks on coexisting slices. **Full protection** against cross-slice confidentiality and traffic steering attacks at the mobile edge
  - False positive rate in attack classification below **1%**
  - Learning robustness: Precision, recall, fall-out, Area Under Curve values above/below specific thresholds vs. specific ratios of misreporting slice components

TERAWAY

Terahertz technology for ultra-broadband and ultra-wideband operation of backhaul and fronthaul links in systems with SDN management of network and radio resources

Vision & Goals

TERAWAY is a 3-year Research and Innovation Action launched on November 1st, 2019 and it has run through the first period of its life-cycle. Aligned with 5G vision for a fully mobile and connected society, TERAWAY is designed to address wireless network challenging requirements imposed by 5G verticals and B5G/6G use cases i.e. ultra-high capacity, ultra-broadband connectivity, reliability and latency requirements, exploiting Terahertz (THz) wireless communication technology and the abundance of bandwidth offered by carrier frequencies in the 300 GHz regime.

THz technology is still in its infancy as it concerns its applicability in mobile networks. Yet, the range of mmWave frequencies (above

24 GHz) is actually considered for the new 5G-NR air interface, signalling growing interest in exploring the higher end of the frequency spectrum.

TERAWAY, by leveraging optical concepts and photonic integration techniques, will design and fabricate ground breaking transceiver modules operating at the range 92 – 322 GHz, offering up to 241 Gbps data rate with transmission reach more than 400 m. Four independently steered wireless beams will be used to establish BH and FH connections between fixed terrestrial and moving network nodes. The solution will be integrated by the implementation of a new software defined networking (SDN) controller responsible for the management of the network and the radio resources in a unified manner, and network services slicing.

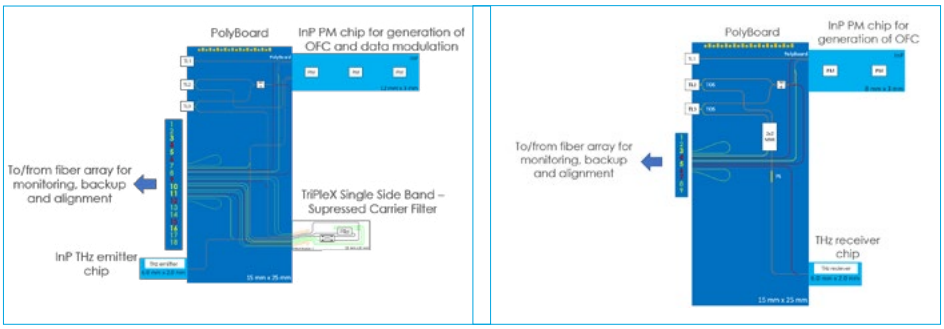

Fig. 30: Functional schematic of the Module 1 – Tx and Rx photonic integrated circuit

Major achievements during the first period of the project

Starting from the TERAWAY use case definition - the provision of high capacity mobile communication services for the coverage for highly crowded outdoor special events (e.g. mega cultural event, disaster recovery cases, refugee hot spots), complemented by video services and implemented by aerial access points (drone mounted), a set of technical requirements was identified and translated into specifications, as the basis for the system, nodes and modules design.

The most significant achievements in the course of the project for year 2020 are as following:

Design of optochips for the first generation of THz transmitters and receivers, and start of their fabrication: the design and layout of the different photonic components, as well as the hybrid photonic integrated circuit (PIC) configuration of both the transmitter and receiver part of Module-1, are completed.

Design of state-of-the-art high-bandwidth and low noise trans-impedance amplifiers (TIAs) for THz detection, and start of their fabrication: the first design of TIAs circuits exhibiting broadband operation (20 GHz) with improved, beyond state-of-the-art, noise properties (3pA/√Hz)) has been realised and first fabrication is in process.

Development of optoelectronic assembly and packaging concept for the TERAWAY THz transceivers: a 3D model of the transceiver modules has been developed, and potential influences of the device packaging on the radiation properties of the TERAWAY modules has been investigated.

Design of driving electronics for the first generation TERAWAY THz TRx: the driving electronic units that will control the operation of the optical components on the PIC devices, will comprise two different platforms. The first one involves a multi-channel current source that can simultaneously drive up to 120 channels and the second one involves a multi-channel high-voltage driver that can simultaneously drive up to 160 piezo-electric-transducer- (PZT) -based phase shifters.

Design and manufacturing of the intermediate interface (IF) unit for the generation of the low bandwidth signals: the required IF unit for the up- and down-conversion of low-bandwidth signals to the 5 GHz IF frequency has been designed and manufactured.

Design of TERAWAY SDN based controller for integrating 3GPP compliant network and radio management functions: the TERAWAY system is complemented by an SDN controller that monitors and controls the links between the moving gNB (next generation Node B) or RRHs (Remote Radio Heads) mounted on the drones, and the fixed switch, delivering reliable end-to-end mobile backhaul or fronthaul connectivity (Figure 31). The software implementation of the controller is based on the open-source OpenDaylight project, that integrates Radio and Drone System controlling modules, as well as the overlay Transport Network Controller.

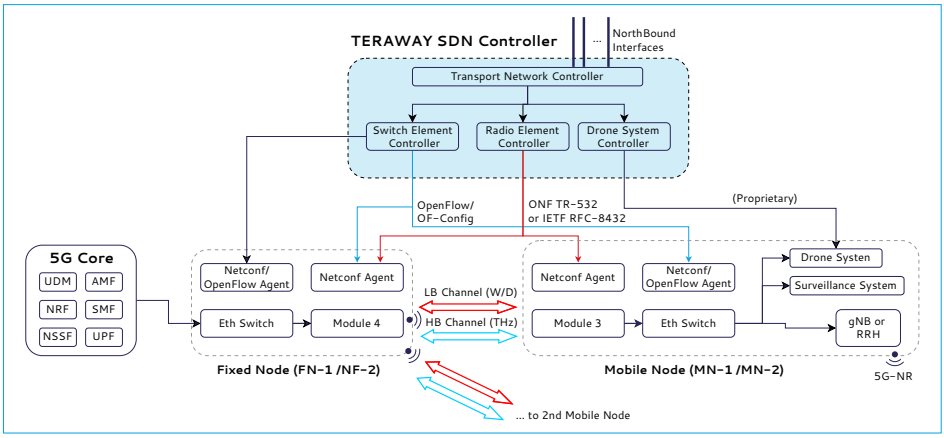

Fig. 31: SDN logical architecture

The way forward

The outbreak of the COVID-19 pandemic and the distancing measures that were applied across Europe affect the pace of work of the project consortium. Although during the first year of the project, the delays caused by the restrained access to lab facilities and/or suppliers were absorbed, the prolongation of the measures in 2021 may impose delays in the delivery of specific technology blocks. Yet, the full impact of this crisis to TERAWAY cannot be fully estimated.

Viewed from a different angle, the pandemic has introduced significant alterations in the way we live, work, socialise and ultimately communicate. Some of these changes are here to stay and they will ultimately alter the known traffic patterns. A study will be conducted to validate the relevance of the TERAWAY use cases during and after the "Covid era".

For the next period the main steps forward include: a) the production – single fabrication run for both Modules -1 and -2, b) the final component specification (in terms of physical sizes and geometries) of the remaining three modules and the PIC configuration and mechanical setup, c) the upgrade of the current OpenFlow SDN controller to support ONF TR-532 protocol and standard 5G core functions will be implemented, d) preparation of the test bed for the implementation of the outdoor field trials and evaluation scenarios.

5G PPP PHASE 3, PART 5: 5G CORE TECHNOLOGIES INNOVATION AND 5G FOR CONNECTED AND AUTOMATED MOBILITY (CAM)

5G BLUEPRINT

The transport sector in Belgium and the Netherlands faces a significant labour market shortage, with the demand for truck drivers growing strongly in the last few years and the supply not following suit. There is a clear need to find solutions in the short to medium run to help the sector overcome this structural personnel challenge. Teleoperated trucks and barges constitute a solution to alleviate the shortage of professional truck drivers and shippers to a large extent.

5G BLUEPRINT project aims to design and validate the technical architecture and business and governance models for uninterrupted cross-border teleoperated transport based on 5G connectivity. The project outcomes should be usable as the blueprint for subsequent operational pan-European deployment of teleoperated transport solutions in the logistics sector and beyond. The objectives can be further broken down into three categories: technical, business, and regulatory.

The main technical goal is to tailor and implement the prototype of a teleoperated transport system. To do this, we will design and implement a 5G network for connected and automated mobility (CAM) services. As one of the objectives is to guarantee the safety of the system, we will implement the enabling functions to it. Finally, the proposed solution of having end-to-end teleoperated transport in a real-life scenario, including the cross-border conditions will be validated.

On the business side, the project aims to do a market analysis of 5G teleoperated transport, along with exploring the commercial possibilities. For that, we will analyse the position of a possible role of teleoperated transport based on 5G and then investigate the market adoption. To further cope up with the regulations, this project will identify the regulatory issues regarding the deployment of cross-border teleoperated transport based on 5G connectivity and recommend actions. Figure 32 presents the project in a nutshell.To cater to the 5G technology within the mobility domain, four use cases and a series of enabling functions will be addressed in the course of the project – one focusing on waterway transport and three focusing on roads. The project will also demonstrate how the combination of teleoperation and automation will be developed, trying to bridge the gap between the autonomy and the human driver. Figure 33 presents the use cases that will be explored by 5G BLUEPRINT.

Automated barge control

Within this use case, the channel navigation of the barges will be teleoperated along with partial automation. Cross-border passing will be given a priority whereas channel navigation, port entry, and exit efficiency will be enhanced by reducing crew requirements for barge navigation. Vessel navigation during barging will be performed entirely by the vessel captain in collaboration with a teleoperating captain in the shore control centre, therefore eliminating further crew interventions. Pilots are located in the ports of Antwerp andVlissingen (Belgian and Dutch sites), while the validation in the cross-border environment will be piloted near the Zelzate site.

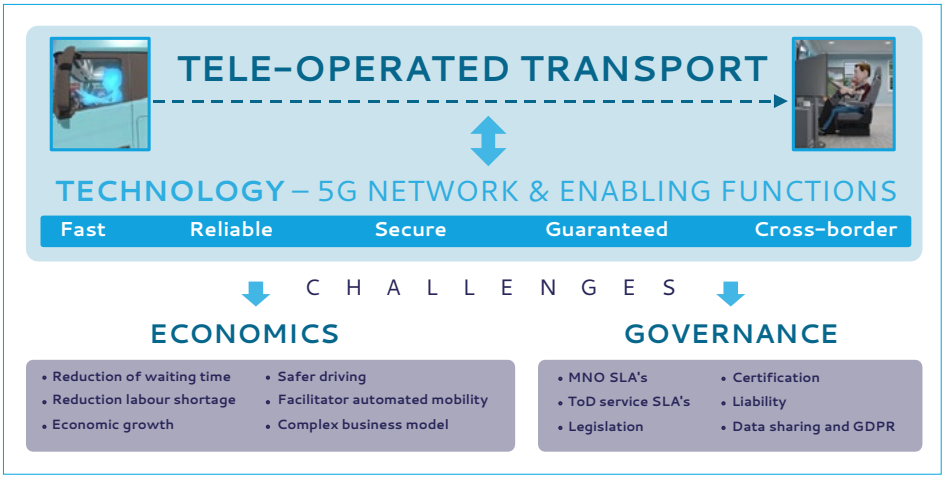

Fig. 32: 5G BLUEPRINT in a nutshell

Automated driver-in-loop docking functionality

This use case has been divided into two subcases namely a) automated docking and b) teleoperated crane. The first subcase propounds on the idea of a driver assistant system

for docking articulated vehicles within warehouses and distribution centres by integrating 5G technology. The focus of this subcase is to develop a bi-directional controller to control the vehicle along the desired reference path. Trucks will be equipped with standardised 5G connectivity solutions for an optimised docking operation with respect to time and space requirements. Within the second subcase, a mobile harbour crane will be retrofitted with teleoperation functionality so that it can be operated from a remote control centre by a teleoperator.

Cooperative adaptive cruise control based platooning

The platooning of trucks has been a widely discussed topic in the area of logistics for a while now. A platoon of trucks happens when two or more trucks follow one another in close proximity to each other on dedicated stretches of the highway. This is achieved by using a combination of adaptive cruise control, a lane-keeping system, and the V2V communication and leads to cost savings due to the reduced aerodynamic drag resulting in lower fuel consumption and emissions. This use case revolves around the fundamental strategy of platooning by relying on 5G, where the driver is removed from the cabin of the truck and placed in a remote location from where they control the vehicle.

Remote takeover operations

In a remote takeover, a remote operator takes control of a distant vehicle. To enable remote takeover, it is necessary to monitor and adjust the vehicles to steer and drive remotely from the control centre. Subsequently, the vehicle must be equipped with an onboard unit and cameras providing teleoperation functionality. Another essential component is the teleoperation centre, which must provide the technical means to manage vehicles, remote operators, ensure connectivity, and control vehicles' access.

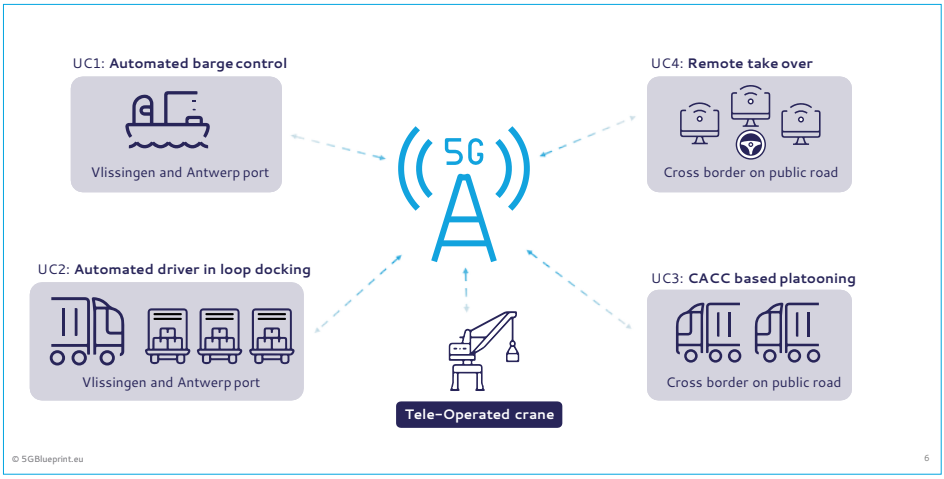

Fig. 33: Use cases

5GLOGINNOV

Goals of the project

5GLOGINNOV will focus on seven 5G PPP Thematics and support the emergence of a European offer for new 5G core technologies in 11 clusters of use cases. 5GLOGINNOV's main aim is to design an innovative framework addressing integration and validation of Connected Automated Driving/Mobility (CAD/CAM) technologies related to the industry 4.0 and port domains by creating new opportunities for LOGistics value chain INNOVation. 5GLOGINNOV is supported by 5G technological blocks, including new generation of 5G terminals notably for future Connected and Automated Mobility, new types of Industrial Internet of Things 5G devices, data analytics, next generation traffic management and emerging 5G network architectures, for city ports to handle upcoming and future capacity, traffic, efficiency and environmental challenges. 5GLOGINNOV will deploy and trial 11 clusters of use cases targeting beyond TRL7, including a GREEN TRUCK INITIATIVE using CAD/CAM & automatic trucks platooning based on 5G technological blocks.

5GLOGINNOV will open SMEs' and start-ups' door to these new markets using its three pilot sites as facilitators and ambassadors for innovation in future European ports. 5GLOGINNOV's promising innovations are key for the major deep-sea European ports in view of the mega-vessel era (Athens, Hamburg), and are also relevant for medium sized ports with limited investment funds (Koper) for 5G.

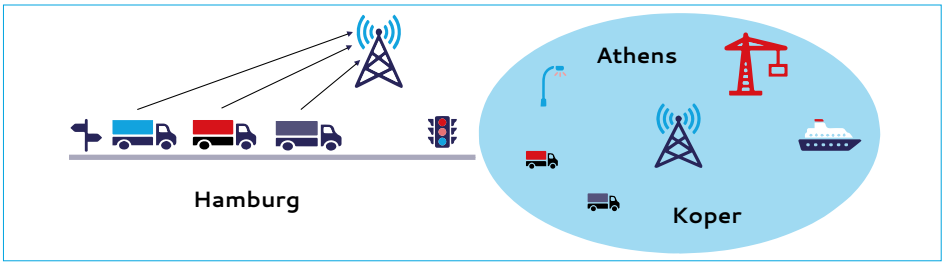

Fig. 34: 5GLOGINNOV port and hinterland use cases and cities to pilot them

A section covering last year's major achievements

The complete architecture with all the actors involved such as tenant, network slice provider and network slice agent- and their roles have been designed where a tenant is a user of a network slice who creates a service with a particular network slice type. A network slice type distinguishes the kind of network resources needed to fulfil service requirements. A Network Slice Provider provides network slice as a service to tenant for control and operations of resources in the service and a Network Slice Agent is a network slice entity in infrastructure provider's domain. It understands processes and maps Network Slice Provider information within its domain.

Description of demos

The objectives and the pilot sites related use cases can be grouped as in the schematic scenario shown in Figure 34. Whereas Hamburg has a focus on hinterland use cases, Athens and Koper will pilot their use cases inside the operational area and responsibility of the local Port Authority.

In Hamburg a test field will be set-up that will be available to all OEMs and mobility service providers for Car2X data exchange and other C-ITS functions. A total number of 26 traffic lights will be currently available for Connected Automated Driving (CAD) test runs. The test field is located in the heart of the city close to the ferry boat terminals (see Figure 35).The arms of the Elbe spread the grounds of the handling terminals and show the storage areas for containers delivered by ship. If a port basin has no connection to a rail network, a freight forwarder intending to use rail freight is forced to transport the containers from a port basin to the freight yard by so-called repositioning, which is frequently needed in case of transfer of containers from depot to terminal, to customs inspections, etc. Repositioning of containers by a Logistics Service Provider and its trucks occurs up to 100 times per day inside port and public roads.

Fig. 35: Connected and automated driving test field (TAVF) in the city centre of Hamburg

Edge computing is a pioneering technology that enables the evolution to 5G and beyond architectures, designed to put applications and data closer to devices and their users in order to overcome the intrinsic problems of the traditional cloud, such as high latency and the lack of security. Far-edge computing will be exploited by 5GLOGINNOV in the Athens pilot site to address the proposed use cases related to optimise port operations through a diverse set of use cases, including the optimal assignment of container jobs based on localisation (and other) data of internal trucks, improvement of personnel safety through analytics of 4K video streams, predictive maintenance of yard equipment and reduction of the environmental footprint in port operations.

In the Luka Koper pilot site, two mobile systems will be deployed and operated (see Figure 36):

- Private mobile services provided by the national MNO (Mobile Network Operator) that will be provisioned and operated over the public MNO infrastructure.
- Dedicated private mobile system that will be built as standalone and self-operated 5G network and services platform infrastructure.

Combined private mobile services assured by the national MNO and the private 5G infrastructure will enable various scenarios and 5G operational modes to be tested and demonstrated on a single 5G port facility, including support for various vertical industries (transport and logistics, mission critical port operation) and private 5G standalone network operation for private security and port services. Hybrid private-public 5G network operations will also be supported with the demonstrated features, such as 5G slicing, MANO, NFVI (Network Functions Virtualisation Infrastructure) and multi-IaaS (Infrastructure-as-a-Service) scenarios.

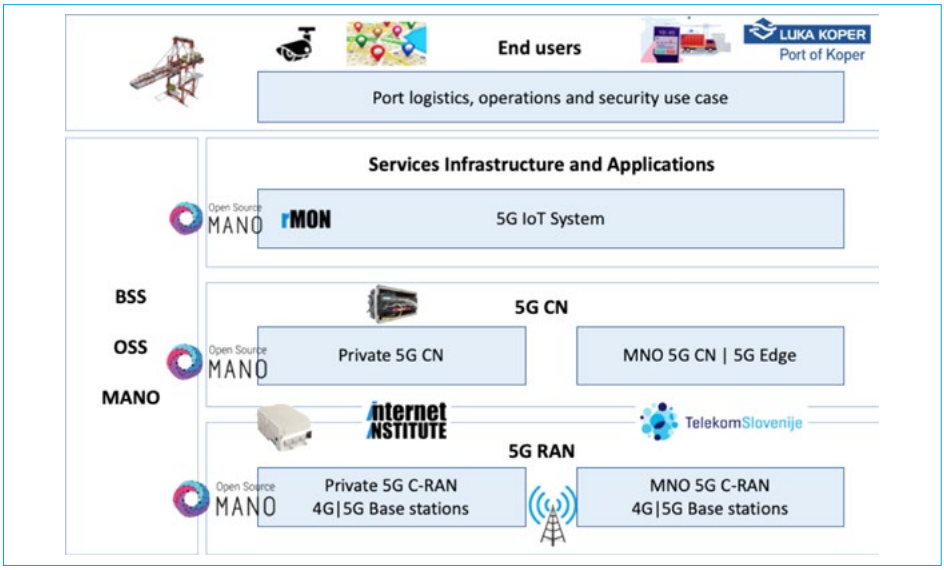

Fig. 36: Luka Koper - Layout, network and services

5GMED

Project Goals

5GMED will demonstrate advanced Cooperative Connected and Automated Mobility (CCAM) and Future Railway Mobile Communications System services (FRMCS) along the "Figueres – Perpignan" cross border corridor between Spain and France.

The project is deployed on 65 km of area. Its value proposition is to design and deploy a single 5G network infrastructure with AI functions to be used by multi-stakeholders (OEM's, MaaS, Road operators, MNO's,...), high-speed trains and highway users. Highway and railway infrastructure is very close in a significant part of that 65 km, and our goal is to find synergies from the 5G network point of view and share resources between both worlds.

The key topics that we are working on the 5GMED project are:

- Cross-operator service orchestration.
- Multi-connectivity innovations to increase mobility experiences in high-speed (vehicles and trains).
- Deploy self-sustainable 5G access network infrastructure when power and backhauling resources are scarce.
- Create a Private network for mobility services open to mobility stakeholders and MNO's.
- Enhancements to speed up roaming transitions across MNOs and neutral hosts.
- Novel high-speed access network architectures for railways.
- The ability to support AI-enabled functions executing at the edge of the network.

The primary technology and impact 5GMED objectives are:

Technology	Impact
Specify and validate a scalable, cross-border and multi-stakeholder 5G and AI-enabled system architecture supporting CCAM and FRMCS services that can be replicated along European.	Contribute to standardisation activities through key 5G, automotive and FRMCS SDOs, while collaborating with relevant joint public-private platforms of industry and public authorities, building a harmonised voice towards the implementation of CCAM.
Design and develop cross-operator service orchestration that enables MNOs, neutral hosts and road/railways Infrastructure Operators to deliver service continuity to end-users.	Perform a cost/benefit analysis of the 5G infrastructure deployment involving MNOs, neutral hosts, and Infrastructure operators in the Figueres-Perpignan cross-border corridor, considering other business stakeholders' impact.
Propose and establish novel practices on how MNOs, neutral hosts, OEMs and road operators can cooperate to deliver Remote Driving, Advanced Traffic Management and Infotainment use cases in cross-border scenarios.	Define innovative business models for CCAM/FRMCS service provisioning, involving MNO and road/railways infrastructure operators while providing new market opportunities for third-parties beyond the automotive/railways sectors and positioning the role of Public Authorities.
Identify and establish MNOs and railways operators' cooperation priorities to deliver advanced FRMCS performance and business use cases across cross-border scenarios.	Promote a broad and sustainable impact of 5GMED outcomes through dissemination, communication, and active engagement of the industry.
	Ensure the scalability and replication of 5GMED technical and policy outcomes, accelerating and shaping the deployment of 5G cross-border corridors across Europe.

Table 5: 5GMED technology and impact objectives

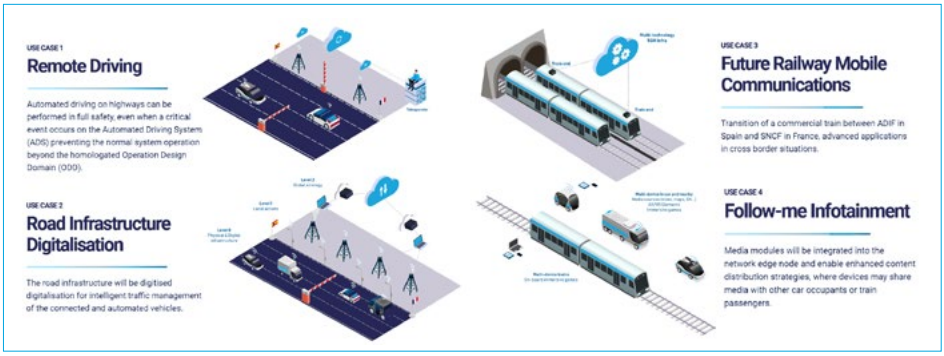

Fig. 37: 5GMED demos

Description of demos

The 5GMED project has defined four specific use cases to demonstrate 5G Network performance in cross border corridors:

The considered CCAM use cases include:

- Remote Driving in cross-border open roads to enable safe fall-back operation in SAE Level4 autonomous driving and
- the need for massive deployment of road infrastructures' sensors enabling AI-powered traffic management algorithms in the presence of legacy vehicles.

The considered FRMCS use cases include performance services for both inside and outside the convoys, where:

- Inside the train: increase the delivery of advanced telecom services so that passengers can experience access to high-speed internet based upon in-train neutral hosting capabilities to MNOs.
- Outside the train: AI-functions running on the infrastructure side, i.e. analyse camera feeds from high-speed trains in real-time for safety purposes.

A Follow Me Infotainment use case will also demonstrate live migration of media functions across cross-border scenarios both in automotive and railway environments.

Corridor description

Between Figueres and Perpignan, we have four different network situations:

- Zone 1: between Perpignan and Mas Cantarana (11 km approx). Railways and E-15 are away from one another.
- Zone 2: Mas Cantarana – Le Boulou (12 km approx.). Railway and E-15 are very close.
- Zone 3: Le Boulou – La Junquera (14 km approx). 8.3 km tunnel across France and Spain.
- Zone 4: La Junquera - Figueras (25km approx.). Railway and E-15 are very close.

Fig. 38: 5GMED – corridor description

Cellnex France will roll out a 5G private network (5G RAN and SA Core) specific for 5GMED along the French side. The network dimensioning will be based on all the 5GMED use cases' service requirements, covering both the train track and the highway.

Vodafone will roll out 5G NR on their existing 4G sites along the corridor to a 5GSA core on the Spanish side. 5G coverage will be complemented by c-V2x pc5 / ITS-G5 communications and 26GHz areas to provide seamless service for the 5GMED use cases.

We have special network scenarios (Railway tunnel between France and Spain) with no cellular 3.5 GHz 5G coverage in the tunnel, and where it's necessary passenger service continuity. 5GMED will combine different technologies (c-V2x, mmW, Mobile Edge nodes, ...) and solutions (AI, Predictive tools, orchestration, ...) to archive that objective.

Part of the corridor, where the train track and the highway are further apart (north of the corridor toward Perpignan) may require 3.5GHz specific coverage for both the highway and the train track.

Besides, in exploring a new mobile network deployment model by the neutral host, attention may be paid to how the new 5G sites along the corridor could complement the MNO coverage in the vicinity.

5GMETA

Industrialised connections through 5G

Goals of the project

The main goal of 5GMETA is to provide an open, modular, flexible and trusted platform to pipeline data to innovative services for Cooperative, Connected and Automated Mobility (CCAM) applications. To this end, 5GMETA integrates innovative solutions for computing management and IoT messaging into 5G architectures on top of a scalable edge platform. Here, 5GMETA implements network functions at the 5G edge including capturing, packaging, processing, and delivery according to service-driven slicing strategies and under privacy and security constraints. Then, the 5GMETA cloud platform connects CCAM applications to configured regions of interests applying licensing policies, thus granting access to relevant data flows from target geographical areas.

The motivation of 5GMETA is to widen the mobility data marketplace beyond traditional automotive industries, comprising Original Equipment Manufacturers (OEMs), TIER1s, road side operators and new entrants, such as tech companies, start-ups and high-tech SMEs, service, mobility and connectivity providers, insurance companies and policy makers. 5GMETA will catalyse the generation of innovative services by transforming their common needs into technical solutions. So, 5GMETA will flatten barriers to create innovative data-based CCAM services and applications producing new revenue flows, reducing costs and enforcing safety to application users. 5GMETA has a business-driven design with APIs and architecture ready for fast prototyping, training and operation of new services. From there, 5GMETA will state the foundations of new data-centric business models and data licensing for data monetisation. In this regard, 5GMETA will focus on technology transfer activities to capture attention to a platform leading to new opportunities in an incoming profitable market.

5GMETA will also validate interoperability of the platform demonstrating heterogeneous innovative use cases, in terms of data heterogeneity, value creation and business models, to ensure that third parties and new players' interests and requirements are considered.

Major achievements & innovations

5GMETA generates data flows with relevant data for specific services subscribed to live feeds from specific geographic areas as depicted in Figure 39. Thus, 5GMETA means an open API-based platform providing IoT messaging for CCAM services and applications feeding them with live data where the security, privacy,

scalability, interoperability and licensing features are provided by the 5G networks functions executed at the edge to gain zero latency, capillarity and geo-based labels.

For interoperability, 5GMETA implements drivers/bindings to push live and heterogeneous data, in terms of format, sensors and vendors, from systems onboard the vehicle, such as driving dynamics, road conditions, driving behaviour and passengers' activity with personal devices, and road infrastructures, such as traffic density, average speed and issues ahead, to 5GMETA platform, recording timestamps and geo-positions. In terms of security, anonymization and standard ITS encryption technologies are shipped. Data ownership is a key aspect, to control, register and account the access to data according to declared licensing models. This license-driven approach can lead to diversify the market and improve the return on investment for producers by getting other revenue streams referred to data re-use. Going deeper in the economic aspects, 5GMETA enables a modular-based scalable management booking assets at the 5G network edge to process the incoming data flows according to Service Level Agreements (SLAs) fitting to a well-balanced data throughputs and processing infrastructure costs trade-off. Finally, 5GMETA platform combines edge processors to centralised platform combining lightweight IoT message proxies with scalable IoT message servers to provide services and applications real-time data flows from specific areas reducing platform management and processing needs while allowing services to focus on relevant data.

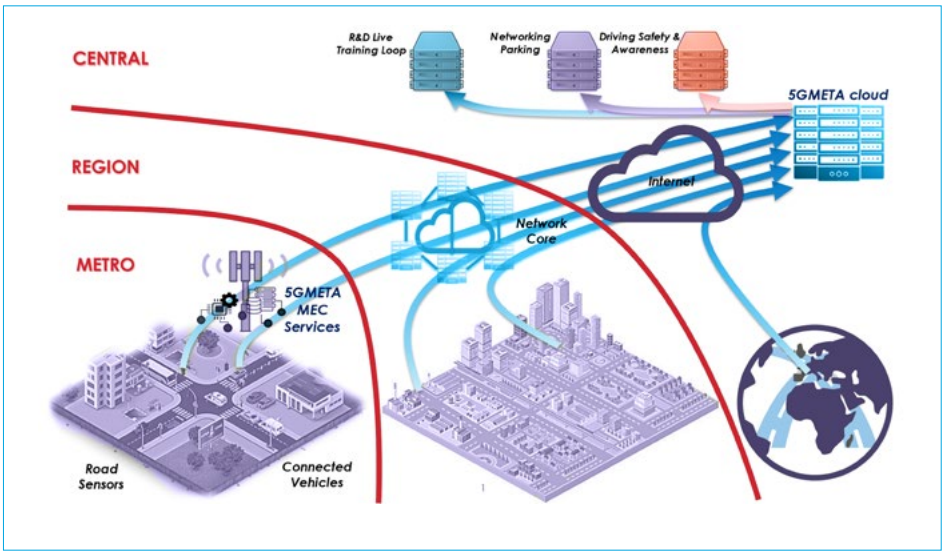

Fig. 39: 5GMETA workflow

Use Cases & scenarios

5GMETA targets a direct impact in the value chain including the generation of new data-centric business models, i.e. direct monetisation from data consumers, product optimisation, i.e. reducing costs through efficient design and training iterations, or increased safety and security, i.e. casting data to multiple entities to reduce time for intervention.

5GMETA will realise representative demonstrators, where each use case targets more specifically a 5G enabled scenario in terms of enhanced Mobile Broadband (eMBB), massive Machine Type Communications (mMTC) and Ultra Reliable Low Latency Communications (URLLC).

Use case 1: R&D Live Training Loop

5GMETA pipelines live data flows including novel and singular data to improve features of new

systems under development from a research and development (R&D) department. This platform bridges real-field prototypes from real driving conditions and R&D facilities, accelerating the testing and training loop of new autonomous driving and mobility systems will reduce costs of the R&D activities.

Use case 2: Networking Parking

5GMETA pipelines the required information to accurately and dynamically predict the departure time and the optimal path to reach a destination in a target arrival time and to quickly find a free parking lot. The data delivered by the platform generate revenues from the added value to the users of an eHailing and parking service which are re-scheduled in real-time to avoid any incident meaning a late arrival.

Use case 3: Driving Safety & Awareness

5GMETA provides data from Misbehaviour Detection & Response (MBDR) systems in the context of driver health or erratic driving. The aim is to protect the safety/security of road users meaning to prevent any possible collisions with surrounding vehicles and ultimately take required countermeasures to stop the misbehaving vehicle.

5GRAIL

The main objective of 5GRAIL is to validate the first set of the Future Railway Mobile Communication System (FRMCS) specifications (also called FRMCS V1) by developing and testing prototypes of the FRMCS ecosystem, for both trackside infrastructure and on-board.

FRMCS will be the 5G worldwide standard for railway operational communications, conforming to European regulation as well as responding to the needs and obligations of rail organisations outside of Europe.

The project will first define the functional tests. From a standardisation standpoint, the set of functionalities to be taken into account will be the FRMCS specific functions defined in 3GPP Release 16, the ones pre-defined for 3GPP Release 17 (at least from 3GPP stage 1 and stage 2), and also some specific interworking elements defined at the level of ETSI TC-RT and completing 3GPP FRMCS standard.

One of the key objectives of 5GRAIL, is to ensure a confirmation, amendment or modification of FRMCS Specifications following the conclusion of the tests and measures, with the target to stabilise a sound version of FRMCS to be formally introduced in the European CCS TSI (Control-Command System Technical Specifications for Interoperability) for railway regulation. Additionally, it will permit to define some elements of simulation and measurement related to FRMCS usage depending on frequencies (coverage depending on radiating power, handover delay in various situations, behaviour at cell edge, etc.), that are absolutely key for future deployments of FRMCS, due to the sensitivity of the very high quality of service required by railway essential operational communications.

Then 5GRAIL project will provide the activities to develop TOBA (Telecom On-Board Architecture), prototypes within an adaptable IP communication system based on standard technologies with enhanced throughput, safety and security functionalities to take advantage of new technologies, supporting the current and future needs of signalling systems (e.g. ETCS and ATO) and voice services, and more globally lead a path to smoothly integrate applications needed for Digital Rail. This development will work to the latest version of 5G specifications as available from 3GPP standards, FRMCS specification and chipsets (i.e. 5G radio modules).

The TOBA prototypes will fulfil the main key design paradigm expected by an FRMCS On-Board subsystem:

- Decoupling of Applications and Communication Services/Transport;
- Bearer Flexibility (e.g. variety of bearers or Radio Access Technologies simultaneously);

- Resource Sharing (e.g. providing transport services for multiple applications of any category using the same

FRMCS on-board system considering the individual QoS requirements of the application and possibly priorities among applications).

The main target applications are the existing ETCS (European Train Control System) and new ATO (Automatic

Train Operation), all train-to-ground communications for train control applications including voice, data and video applications. It will cover as well more specifically TCMS application (Train Control Management System) as well as PIS (Passenger Information System) and CCTV. The system will enable easy migration from existing systems and will provide enhanced throughput, safety and cybersecurity functionalities to support the current and future needs of signalling systems and voice emergency services and will be open to radio technology evolution.

Prototypes will be tested in two 5G reference lab environment which both include specific network functionalities, which are not fully standardised yet and therefore have not reached commercial maturity.

The first 5G reference lab for end-to-end FRMCS 5G system will be setup in Budapest/ Hungary where the tests performed will provide validation of the main FRMCS functionalities related to specific applications prototypes including ETCS, Voice, TCMS and CCTV/Video pre-integrated within TOBA.

The second 5G reference lab for end to end FRMCS 5G system will be setup in Paris/France where the tests performed will provide validation of the main FRMCS functionalities related to specific application prototypes including Data (e.g. PIS), ETCS, ATO, Cybersecurity of an application and a minimum set for Voice pre-integrated within TOBA.

The tests will be executed, articulated around:

- Integration of all FRMCS ecosystem elements;
- Functional & Performance tests in nominal and simulated conditions.

The 5GRAIL project will then provide a railway field test environment to evaluate technical solutions and prototypes. The prototypes will be integrated into real railways environment, i.e. rolling stock running on rail tracks with dedicated 5G radio coverage, which will allow evaluation of their functionalities and performances.

This field test will demonstrate the usability of 5G to answer railways needs using railways applications and application simulators. Testing will be performed in two test-sites (France and Germany), each having different characteristics. The testing will be conducted in parallel in the two sites with different scopes. Some similar initial end-to-end connectivity tests will be executed in both test sites to compare the results in different deployment conditions.

Some cross-border simulations will be executed with different and complementary scenarios in each of the two test sites. It will allow to evaluate different configurations for cross border scenarios, which correspond to different choices of 5G frequencies and stages of GSM-R to 5G migration. The field test border crossing tests will be executed with a focus on voice services in Germany and data services in France.

The project will finally deliver test report conclusions to update FRMCS V1 specification where needed and to identify technical constraints related to implementation issues.

5GRECORDS

Project overview

5G mobile networks are profoundly changing the way the media industry is creating efficient and scalable solutions for society. They offer improved performance in terms of bandwidth, reduced latency, support for accurate timing, assurance of quality of service and scenario flexibility. Furthermore, it is expected that standardised 5G-based solutions would bring down production costs, reduce the environmental impact and increase the operational efficiency and flexibility of production workflows, particularly, in news gathering, remote production and coverage of live events. In this context, 5GRECORDS (5G key technology enablers for Emerging media content production Services, *www.5GRECORDS.eu*) is an European H2020 project that aims to explore the opportunities that new 5G technology **bring to the professional audio-visual (AV) content production sector**, including Programme Making and Special Events (PMSE) and taking advantage of 5G key features such as Non-Public Networks (NPNs), network slicing for guaranteed Quality of Service, Time Sensitive Network (TSN) support, and Dynamic Spectrum Access (DSA).

5GRECORDS will build on 5G components developed within previous 5G PPP projects and earlier R&D investments and will further develop them for applications in content production, thus enforcing the industry rollout of 5G. Three use cases will be demonstrated in the project: live audio production, multiple-camera wireless studio and live immersive media production.

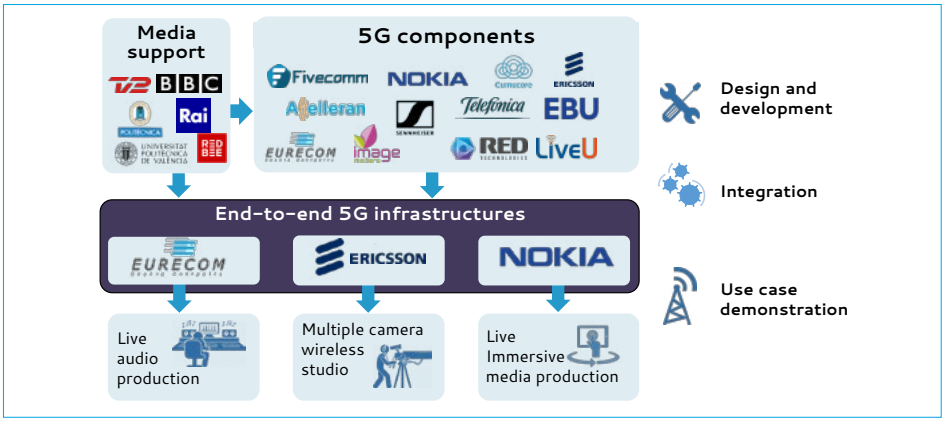

Fig. 40: 5GRECORDS overview.

Goals

5GRECORDS aims to develop, integrate, validate and demonstrate specific 5G technologies in end-to-end 5G infrastructures consisting of core network (5GC), radio access network (RAN) and end devices for professional AV media content production. The main objectives are:

1. Design 5G components for professional media content production.
2. Develop state-of-art 5G prototypes based on 3GPP Rel-15, Rel-16 and beyond.
3. Integrate and validate them into end-to-end 5G infrastructures.
4. Performing live trials in 2022, one of each use-case.
5. Influencing standardisation and regulation bodies thanks to the results achieved in the project.

Expected impact

5GRECORDS will play also an important role on 5G R&D and deployments in general thanks to a comprehensive exploitation, communication and dissemination activities. The main expected impacts are: (i) demonstrating the potential value that 5G brings to the content production vertical, (ii) proposing/exploiting new business models and opportunities, (iii) influencing standardisation in 3GPP and other bodies, (iv) promoting the rise of virtual production environments and, (v) reducing logistic efforts to allow the production team to work remotely over more events.

Use Case 1 (UC1): Live audio production

The activity of a live audio production use case is carried out in locations like theatres, production studios or music festivals, where one or several artists are performing live. Artists on stage are equipped with PMSE equipment, i.e. 5G wireless microphones and in-ear monitoring systems (IEM). This UC aims to deploy a local 5G wireless high-quality ultra-low latency audio production network, by designing a 3GPP Rel-17 New Radio Reduced Capacity (NR-Redcap) audio devices prototype and by deploying specific enhancement into the RAN and Core. In addition, this use case will explore how new licencing schemes (based on local licences and leases, in a dynamic spectrum sharing environment) can be applied to PMSE, in order to make optimal use of spectrum resources. The demo will take place in EURECOM's infrastructure, a fully functional network demonstrator and test-bed in **Sophia Antipolis, France**.

Use Case 2 (UC2): Multiple camera wireless studio

Live or pre-recorded media content production usually requires deploying large amounts of equipment and crew on the event location or studio, all connected to the production facilities. The focus of this UC is to demonstrate the potential of 5G to implement a wireless interconnected content production system providing all the functionalities needed by the broadcasters. This use case will deploy a wireless studio with the necessary cameras, microphones, talkback, etc. for a remote live production.

Use Case 3 (UC3): Live immersive media services

This use case will allow real-time immersive capture of sport events. This means that each user can access a specific angle live, offering a unique Quality of Experience (QoE). It will also be possible to reproduce content both live and on demand. The content can then be distributed not only to people attending the event, but also to third parties. E2E infrastructure based in **Segovia, Spain**, will incorporate every 5G component needed for the use case deployment. As integration comes to a mature state, end-to-end tests will be performed in terms of network performance and QoE.

Current achievements

Partners have been defining the use cases so that every integration team can work jointly to complete the initial phase of the project. UC1 is currently developing a NR-Redcap & URLLC audio device prototype based on 3GPP Release 17, and a way forward has been proposed to integrate them into the vRAN and 5G core network. The partners involved in UC2 have defined the architecture of the 5G-ST2110 gateway and of the Operational Control Gateway that will be responsible for the orchestration of the media services running, over 5G, between the event premise and the production islands. A set of preliminary tests have been also defined to be performed in Q1 2021 in **Aachen, Germany**. In UC3, collaborators have been working together to configure and set up the key infrastructure pieces: 5G mmWave RAN, GPU-enabled MEC, and delivery SDN. In addition, the setup for the capture server and FVV cameras is being designed.

Conclusion

5GRECORDS kicked-off in September 2020 but even if it's is still at an early stage the development of the first prototypes has already started and the first tests are expected to take place soon, COVID permitting. In the future, they are expected to evolve faster as long as the current pandemic situation improves and meeting restrictions change. The dissemination activities have already started and are being promoted on the website and social media. Stay tuned.

Fig. 41: 5GRECORDS Use Cases and key enablers

5GROUTES

5GROUTES aims to validate through robust evidence the latest 5G features and 3GPP specifications (R16 & R17) of Connected and Automated Mobility (CAM) under realistic conditions. In particular, it will conduct advanced field trials of most representative and innovative CAM applications seamlessly functioning across a designated 5G cross-border corridor ('Via Baltica-North') spanning across 3 EU member states borders (Latvia-Estonia-Finland) in order to validate the latest 5G features and 3GPP specifications under realistic conditions, so as to accelerate the widespread deployment of 5G E2E interoperable CAM ecosystems and services in digitised motorways, railways and shipways throughout Europe.

The partner consortium is driven by industry heavyweights and renowned organisations the majority of which participate in 30 out of 63 5G PPP projects and in several 5G PPP Working Groups.

Specific objectives

To achieve the overall objective, the following specific objectives have been defined:

1. Innovative use cases defined with key industry experts: To develop innovative and commercially exploitable CAM use cases for automotive, railway and maritime sectors within the cross-border context.
2. Requirements analysis elaboration: To analyse the technical and business requirements for the use cases to enable extensive large-scale CAM field trials in the 'Via Baltica-North' 5G corridor.
3. Enabling Technologies: To advance and optimise the enabling technologies using AI for

the reliable, seamless and uninterrupted delivery of interoperable CAM services across borders.

4. Infrastructure development, integration & setup: To leverage and upgrade key assets from previous results and commercial products; to integrate the technological enablers in an end-to-end CAM ecosystem, to setup the 5G corridor and to facilitate lab and large-scale field trial validation.
5. Field Trials Validation: To demonstrate the potential and the user value in advanced CAM deployments at cross-border areas, by characterising and optimising 5G technologies at both lab tests and large-scale trials, so as to validate applicable standards and key target KPIs.
6. Exploitation & Innovation Management: To develop and validate the business models of advanced CAM use cases that can be offered on top of existing services in a multi cross-border 5G operator environment, demonstrating benefits from potential operational cost reductions and new revenue generation streams.
7. Contribution to Standardisation: To identify and validate applicable standards as well as provide rationalised contribution to key standardisation bodies. To promote a proactive and joint approach through consortium partners, members of pre-standardisation bodies and fora and Standards Developing Organisations suggesting specific planning actions and contributions for the 2nd and subsequent phases of 5G standardisation.
8. Scale-up: To ensure long-term success through wide dissemination of the project's results; to exploit synergies with other 5G PPP projects and 5G CAM initiatives; to actively contribute to the 5G Action Plan strategic initiative with results from 5G technologies validation in CAM trials for the benefit of the European 5G, automotive, railways, maritime, transport & logistics industries, the university education and training of young and other professionals.

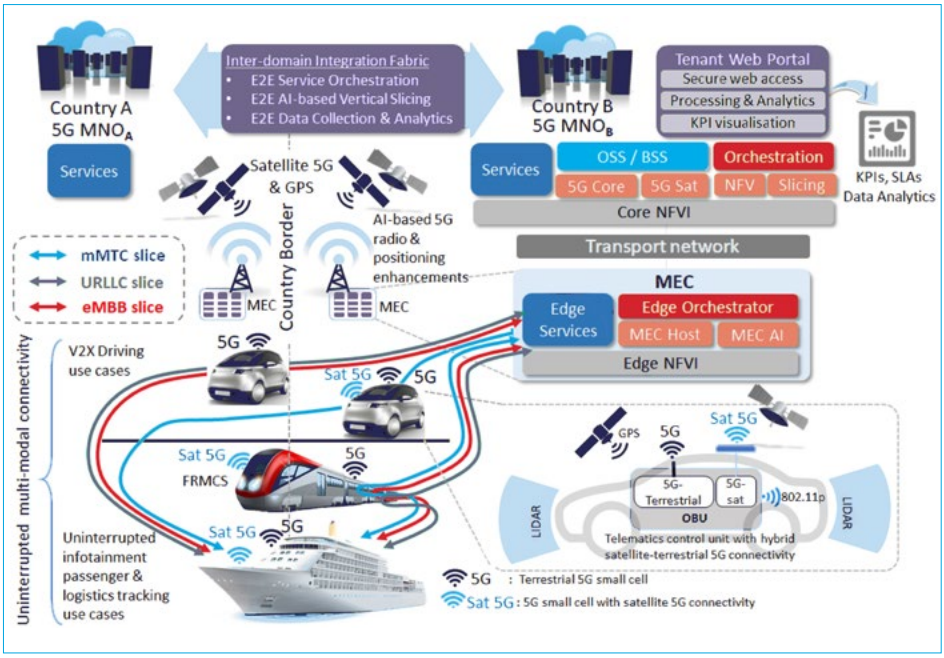

Fig. 42: 5GROUTES high-level unified CAM architecture

Innovative use cases in CAM pilots

The CAM pilots will allow to better understand the roles, relations and responsibilities of market players within the CAM ecosystem. For the following use cases, the network, service-level and business perspectives will be validated against pre-defined target KPI values during the trials:

Use Case 1: Automated Cooperative Driving

To achieve the vision of fully autonomous driving, several key enabling capabilities need to be implemented both in vehicles as well as in communication networks. 5G connectivity associated with V2X communication functions, dynamic mapping, accurate positioning, edge-based and AI solutions are expected to overcome most of these challenges by providing more visibility and cooperative decision-making mechanisms through communication with the infrastructure and surrounding vehicles.

Use Case 2: Awareness Driving

To enable the reliable exchange of road traffic status data, such as enhanced real-time traffic video feeds and control in complex intersections via V2X communication.

Use Case 3: Sensing Driving

To enable connected vehicles to share observations gained by sensors, and advanced environmental information, to gain enhanced situational awareness especially for the presence of noncommunicating VRUs who are beyond the direct line of sight of drivers, as well as to create a preventive maintenance framework with predictive analytics, to enable long-term maintenance and repair services throughout the lifetime of vehicles. In this way, other traffic participants may be warned in advanced against dangers they could not perceive themselves, whilst protecting VRUs in different traffic situations.

Use Case 4: Uninterrupted infotainment passenger services on the go

To allow and enable multimodal passengers to exploit the high-performance capabilities of 5G networks while on-route and when crossing EU member states borders. The expectations are for the same seamless user experience everywhere, both for productivity purposes and for entertainment. In this regard, 40-50 end-users will be provided with 5G enabled smartphones.

Use Case 5: Multimodal services

Future Railways Mobile Communication Systems (FRMCS) as the successor of GSM-R is a key enabler for rail transport digitalisation. It is important to have uninterrupted and seamless service delivery to passengers and visibility of tracked goods through different modes of transport. In this regard, the QoE for the service should remain unaltered irrespective of the change of transport means, the 5G network provider and country.

AFFORDABLE5G

AFFORDABLE5G, led by ATOS, aims at creating a 5G network that will deliver a complete and affordable solution covering the needs of private and enterprise networks through technical innovation that span across all parts of 5G network. AFFORDABLE5G leverages the need of cell densification, RU/DU/CU disaggregation on RAN, hardware acceleration, edge computing and core network virtualisation, seamlessly combined with the adoption of Open RAN, MEC deployments and open source MANO solutions, for cloud-native and micro-service based 5G roll-outs. With the combination of several European SMEs products with open interfaces, AFFORDABLE5G will offer a first-class opportunity to SMEs to become frontrunners in the global 5G competition, facilitating them in their commercialisation paths in 5G private networks. A private 5G network is a particular realisation of the 5G system designed and configured for a private use by an enterprise or an exclusive group of users. It can be deployed to cover the needs of a specific application, or multiple applications or even a vertical domain.

The project goals and achievement will be evaluated and validated in **three vertical use cases that will be demonstrated in two pilots and a proof-of concept**. The use cases are used to identify and characterise the system requirements that allow the selection of the network elements and the 3GPP, ETSI and O-RAN specifications that are taken as a reference in the AFFORDABLE5G system architecture led by National and Kapodistrian University of Athens.

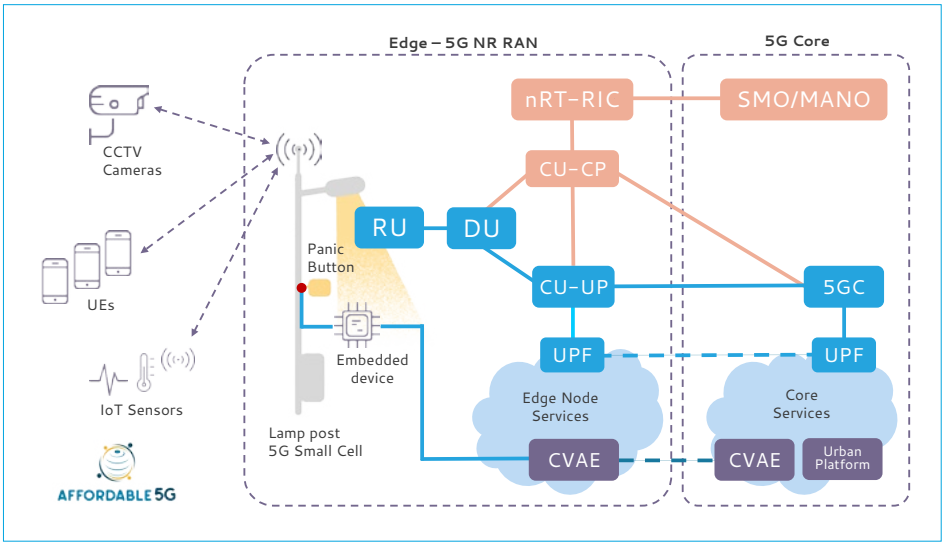

Fig. 43: AFFORDABLE5G - architecture

The first use case is related to emergency communications. Led by Nemergent Solutions, it aims to demonstrate the 5G private network concept, and the performance and reliability requirements of Mission Critical Services (MCS), allowing the owner to control their 5G network to serve a limited geographic area with optimised services using dedicated equipment. The pilot will enable the implementation, validation and demonstration of a robust solution that will leverage the cloud native functions of monitoring, flexible deployment and scaling, as well as standardised 3GPP-compliant MCS communication channels, mainly including Mission Critical Push To Talk (MCPTT), Mission Critical Video (MCVideo) and Mission Critical

Data (MCData). Network slicing capabilities and low latency in both access and transport network are key requirement here.

The scope of the scenarios within this pilot is to achieve the provisioning of a responsive service that is able to cope with drastic service consumption increase or adverse network conditions so that the first responders are able to keep communicating regardless of outages, communication demand increase, detection of poor communication quality, and other challenging events.

The second use case is related to smart cities. In this context, AFFORDABLE5G will validate the 5G technology for efficient smart city monitoring, combining IoT data collection sensors integration and edge processing. This will allow deploying new applications for enhancing urban sustainability, mobility and safety and reducing deployment costs.

Project partner Ubiwhere leads the Smart Cities use case pilot in a sports cars circuit (Circuit ParcMotor) in Castellolí (Barcelona), Spain. Ubiwhere will provide a smart urban infrastructure product, Smartlamppost, as an integrator of diverse modules delivered by the partners (such as Edge Computing processing) and its Urban Platform for unified data collected within the facilities. End-user devices, such as CCTV cameras, User Equipment's and IoT devices, will connect to the small cell via 5G NR. Here the EMBB traffic and mMTC connectivity are key elements of the scenarios. The architecture developed by Affordable 5G will allow the creation of a network and edge computing hardware marketplace for the partner entities operating in this business. In the pilot, by integrating a CCTV camera into Smartlampost, partners will become capable of assisting security agents in detecting safety issues.

The third pilot consists of two use cases covering different parts of the manufacturing process and will be demonstrated only as lab proof of concept (PoC) regarding Time Sensitive Network (TSN) and the offer of 5G LAN functionality:

- The first use case deals with Process Automation. The automation of various processes of the Factory of the Future (FoF) can be enhanced with advanced wireless features (increased data rates, reduced latency), enabled by 5G mobile networks.
- The second use case concerns the benefits arising from the introduction of TSN concept to manage Automated Mobile Robots (AMRs) and mechanical robotic arms within a manufacturing shop floor.

COREnect

European Core Technologies for future connectivity systems and components

COREnect is a 2-year Coordination and Support Action project selected by the European Commission in the frame of the Horizon 2020 Research & Innovation programme, starting from 1st July 2020. In COREnect, European industry and R&D leaders from both the microelectronics and telecommunications sectors are jointly developing a high-level strategic roadmap of core technologies for future connectivity systems and components, targeting 6G, the next generation telecommunications networks and services.

COREnect has the potential to significantly impact European research and innovation (R&I) and the industry landscape of future connectivity systems, strengthening Europe's position in the global digital scene. The consortium consists of the most prominent European industrial and academia players in the telecommunications sector (Ericsson, III-V Lab (Nokia), Technische Universitaet Dresden/Barkhausen Institut) and the microelectronics sector (Infineon, NXP, STMicroelectronics, IMEC, CEA), industrial associations that represent the SNS (5G IA)

and KDT (AENEAS) communities and the corresponding proposed partnerships, a leading industry player in 5G related vertical (Bosch) and one of the major promoters of the European SME ICT community (AUSTRALO). The project is coordinated by Technische Universität Dresden.

Fig. 44: COREnect consortium

Goals of the project:

COREnect´s main goal is to develop a strategic roadmap of core technologies for future connectivity systems, to help diversity and reduce European dependence on other continents, and build technological sovereignty in 5G and 6G in the next 10 years. COREnect wishes to create the condition for one or more European champion(s) in core technology to attain technology sovereignty in future connectivity systems. To achieve this, COREnect brings together major European players in microelectronics and telecommunications. In addition, the COREnect project is engaging relevant organisations and experts: KDT (Key Digital Technologies) and SNS (Smart Networks Services) stakeholders have started to be involved in "Expert Groups", as they constitute the foundation of the COREnect community. The concept of project is depicted in Figure 45.

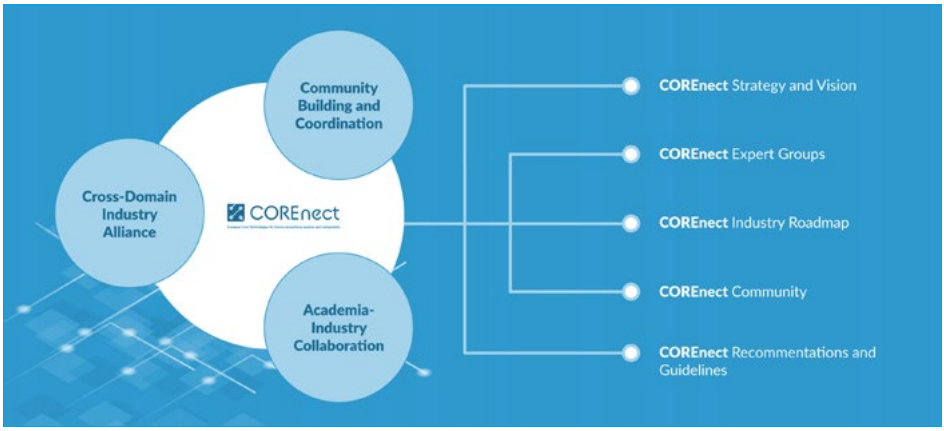

Fig. 45: COREnect concept

Major Achievements:

a)Strategy & Vision

Europe must invest now to be a frontrunner in evolved 5G and 6G networks. The COREnect project has during its initial phase identified technology gaps in the European ecosystem. These represent key factors to sustain leadership in the race towards 6G and can summarise the European position as follows:

European strengths

- Leading position on the cellular infrastructure market
- Strong (Integrated device manufacturer) IDM players with local connectivity solution portfolios and derivative technology offerings
- Leading position on the local connectivity market
- Strong (Microcontroller Unit) MCU ecosystem well suited for IoT and 6G use cases

European weaknesses

- No position on the consumer cellular connectivity market
- No advanced CMOS manufacturing facilities
- Disability to develop advanced CPU or AI accelerators
- Limited SoC design capability using advanced manufacturing processes available in Asia

Going forward, the COREnect project and associated expert groups will focus on strategic measures to address the weak spots by leveraging on the aforementioned strengths. This includes investment proposals, coordination actions, and the role of different private and public entities. The goal is not to reach complete autonomy but to secure long term European relevance in the global ICT ecosystem. Given the road towards a fully connected world, such investments will fuel job creation across all European business segments and industry verticals.

More information is available in the "Initial vision and requirement report" available at *https://www.corenect.eu/publications.*

b)Expert Groups (EGs)

Based on the identified technological gaps, three expert groups are established with more than 80 leading experts coming from both Smart Networks and Services (SNS) and Key Digital Technologies (KDT) communities:

- EG1 Compute & Store, which focuses on CPU, operating system, system architecture, etc.
- EG2 Connect & Communicate, which focuses on Modem, Transceivers, Antennas, Packaging, Converters, Technologies, Industrial and consumer grade connectivity, etc.
- EG3 Sense & Power that deals with Core Process Technologies, System & Component Architectures, Power Management, Accelerators, User interface, etc.

Those experts will provide their expertise and insights on core components that will strengthen and preserve Europe's leading position in the telecommunications' sector in the next 10 years.

As an initial result, the Expert Group 1 identified challenges regarding KPIs, instruction set architecture, storage, multiprocessor system on a chip, operating systems as well as system architecture. Expert Group 2´s initial outputs are gap analyses for each focus area, e.g., covering hardware design in very advanced CMOS (Complementary Metal Oxide Semiconductor), availability of and access to advanced CMOS processes, and silicon photonics technologies. Expert Group 3 has identified key challenges within the Peripheral technologies – as essentials for controlling the telecommunication and vertical value chain.

Initial findings from the COREnect Expert Groups are described in Deliverable 3.1 "Report on the Activities of the Expert Groups" available at *https://www.corenect.eu/publications.*

c)Impact Creation

To best engage the SNS and ECS communities, COREnect promotes its outcomes to stakeholders in both private and public sectors through press releases, webinars, deliverables, and workshops. The 1st COREnect workshop was organised in colocation with EFECS 2020[23] and it was entitled "Building European technological sovereignty in 5G and beyond''. It attracted about 130 participants from both the ECS and the SNS communities. The 2nd COREnect workshop is planned to be held within the EUCNC2021[24] in June. The project also uses social channels to actively attract relevant stakeholders.

23. https://www.corenect.eu/publications

24. https://www.eucnc.eu/announcement-eucnc-2021/

DRAGON

D-band radio 5G network technology

Goals of the project

All telecom operators in Europe have the main objective to get hold the 5G core technologies and concretise the 5G ecosystem infrastructure able to provide to their customers at the same time wireless bit-rate higher than 20 Gbps, latency less than 1 ms and connectivity density higher than 1 million per km^2. Transport is the part of the network that comprises the intermediate links between the Core Network or backbone and the small sub-networks at the "edge" of the entire hierarchical network. Backhaul plays currently a vital role in mobile networks by acting as the link between RAN and the Core, as, later, will play the front hauling by acting as the link between RAN and a centralised radio protocol remote processing.

DRAGON reaps the fruits of earlier R&D investments in mmW backhaul enabling technologies (H2020 DREAM project *http://www.h2020-dream.eu/*) to develop a high capacity D-band (130-174.8 GHz) wireless back/front haul solution able to address the needs of 5G transport network (Figure 46). Opening to the introduction in 5G networks of frequencies beyond 100 GHz towards 100 Gbs capacity, DRAGON supports the deployment of different applications and use cases for high capacity x-haul systems having hop distances of up to 1 km. DRAGON offers prospects for new semiconductor, antenna and packaging technologies and the consequent hardware devices to enter the market and to create economic opportunities. European advanced SiGe-BiCMOS process technology, enabling highly integrated mixed analogue-digital functionalities for active antenna array systems, supplies the project demo trial on-field with all the hardware components, derived from the previous RIA project DREAM, but properly scaled and optimised in terms of performances, power consumption, compactness, quality and production costs.

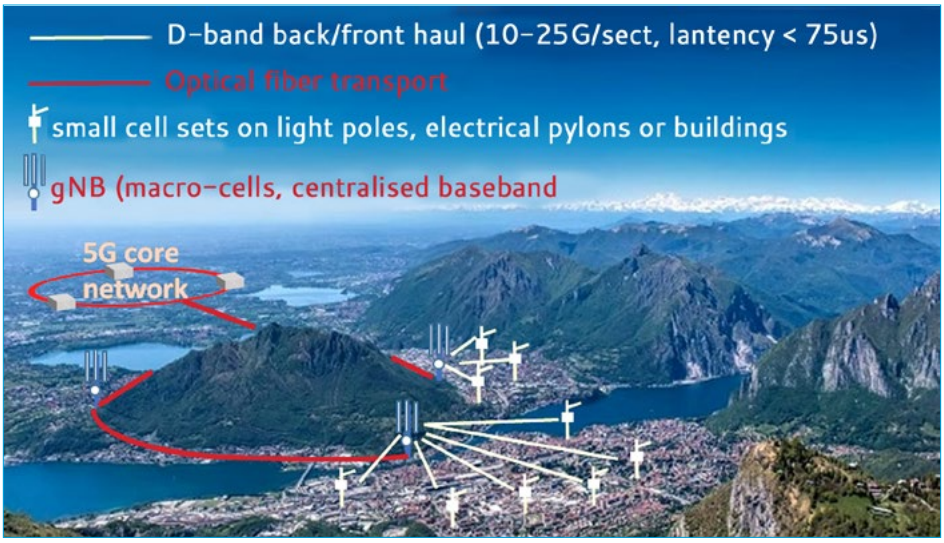

Fig. 46: Picture of wireless front/backhaul network with Point to Point and Point to Multi Point configurations

Challenges and Technologies

DRAGON aims at developing low cost and small form factor components, systems and algorithms, which will enable flexible, high throughput (≥100 Gbps) and power efficient D-band backhauling/front hauling into current and beyond 5G mobile networks. The

projected leverages and advances a mix of cutting-edge technologies facing major 5G technical challenges:

- Prototyping and engineering a highly integrated D-band transceiver analogue front-end chip set in low-cost SiGe BiCMOS process and a reliable mmW substrate technology for active antenna array packaging and industrial-ready assembling. Advanced SiGe:C BiCMOS process, having a new stack up to 9 metal layers, including the 2 upper layers with thicker copper for improved passive component (inductor, capacitors and transmission lines) quality factor at mmWave. The process includes also new CMOS transistor for higher speed digital function integration;
- Developing segmented Active Phased Array Antenna Systems (SAPAAS), having ≥1024 elements. Sub-groups of antenna elements may be driven either by a single transmitter or receiver front end, as compromise between complexity and need for fine beam steering. A beam steering within +/- 5 degrees is achievable by such architecture with an acceptable beam form. Four to sixteen transmitter (or receiver) phase-shifted signal chains are integrated in single IC dice and assembled on the embedded antenna substrate;
- Integrating an inexpensive and mass producible SiGe BiCMOS with multilayer antenna-in-package (AiP) and proper thermal management for SAPAAS power dissipation technologies to make low-cost, low-power large segmented phased arrays possible. The mmWave packaging technology to connect the antenna elements to the driving ICs must provide outdoor enclosure and new materials for D band radome will be adopted.
- Implementation of a fully digital management of the transceiver including beam-steering / beam-forming functionalities. Inclusion of all the features enabling factory calibration, facilitating installation and improving overall radio-link performance during normal operation in field including energy saving, ATPC, RTPC, controlling, pointing, focusing and beam nulling.
- Prototyping a base-band processor with integrated dual carrier solution, with embedded cross polarisation interference cancelling (XPIC) technology, configuration ready for LoS-MIMO and/or FD-canceller. Support of 25Gbps network Interface (towards ≥100Gbps throughput), with an optimised network traffic signal processing including the carrier aggregation. The base-band processor lowers its cost to enable the massive deployment of small cells in urban environments.

Description of demo

The goal of DRAGON is on-field network demonstration of a wireless link at data rate up to 100 Gbs in D-band, based on:

- low-cost SiGe BiCMOS transceiver analogue front end;
- ≥1024 element phased array active antenna;
- ≥256-QAM digital base band processor with Adaptive Modulation;
- Flexible Duplexing (fFDD), Full Duplexing (FD) and LoS-MIMO functionalities.

Simplified schematic view of the proposed transceiver with a segmented active phased array antenna is shown in Figure 47.

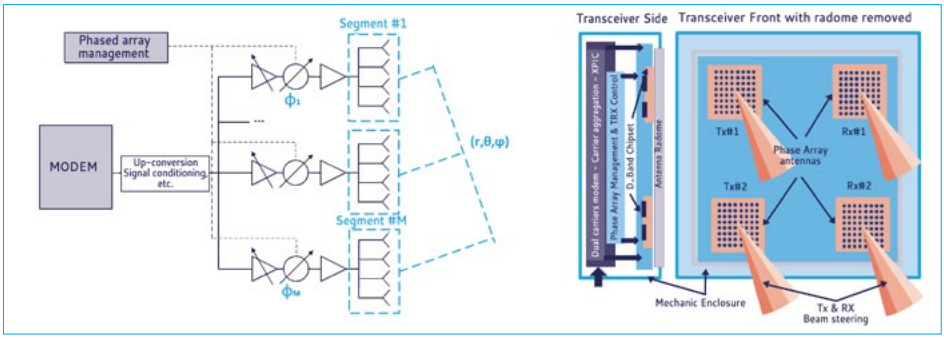

Fig. 47: D band transceiver with fine beam steering

FUDGE-5G

The main objective of FUDGE-5G is to devise, assess and demonstrate a conceptually novel and forward-looking cloud-native, unified and secured service-based 5G architecture, solutions and systems for Non-Public Networks. FUDGE-5G will allow for extreme interoperability and customisation for verticals among wired and wireless access infrastructure, eSBA platform, multi-vendor mobile 5GC, service orchestration and vertical applications.

Five vertical use cases will be used for validating the FUDGE-5G technology solutions. Each use case is associated with a vertical stakeholder, which will be involved both in the use case definition and in the field trials.

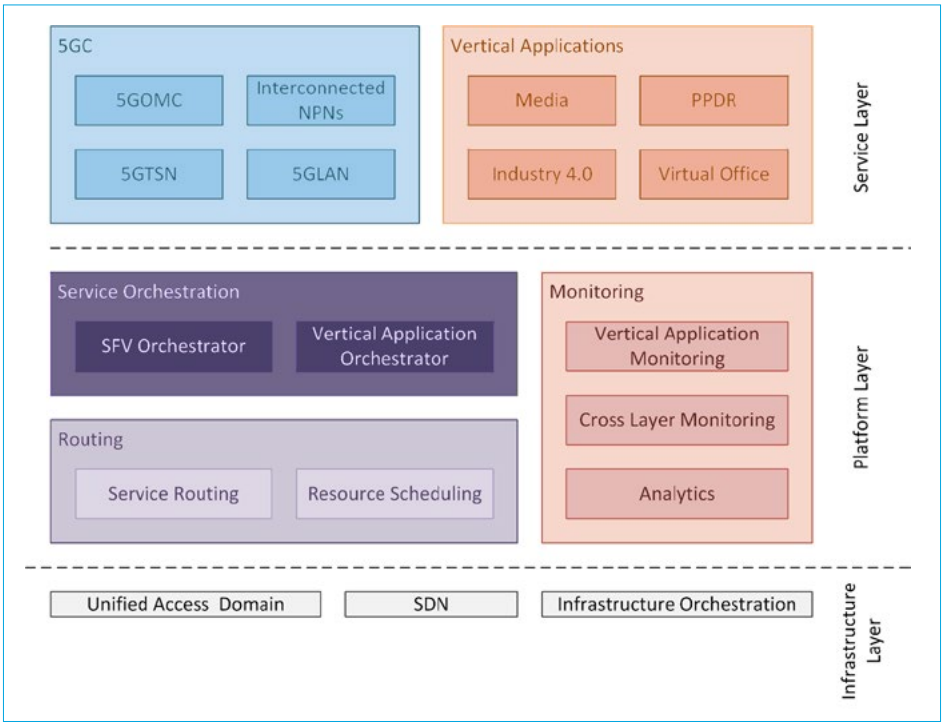

Fig. 48: FUDGE 5G - architecture

Use Case 1 – Media Showroom and Remote Production

Multimedia delivery is a central pillar of global networking traffic and estimations predict that 85% of all traffic will be multimedia by 2022. The objective of this use case is to utilise a localised 5GLAN connectivity among many mobile users to facilitate the 5G multicast for opportunistic multimedia delivery for popular content, allowing the multimedia content to be delivered efficiently.

The project will showcase a massive video and audio streaming media showroom with interactive content where the mobile operator can optimise downlink traffic while performing media distribution on a highly dynamic basis. Each component can also change dynamically in terms of network location, effectively realising a dynamic mobile function offloading capability. This combined with QoS will enable remote content production scenarios.

Use Case 2 – PPDR (Public Protection and Disaster Relief)

This use case will provide custom Mission Critical Services, such as Mission Critical Push-to-talk, Mission Critical Video and Mission Critical Data, albeit realised as service applications over a pure 5GLAN, each one having its own requirements in terms of performance and reliability.

Three scenarios will be showcased. In the first one, FUDGE-5G will enable rapid deployment of tactical bubbles using 5G NPNs. These tactical bubbles are autonomous networks that can be used by emergency teams in their operations, and they are usually deployed in vehicles.

In the second scenario, these tactical bubbles will be able to make opportunistic use of intermittent backhaul links to achieve higher processing power with the help of a remote cloud.

Finally, in the third scenario, the tactical bubbles will be able to coexist with public networks and use their resources. Public networks could provide both best effort connection and Mission Critical Services via a custom Network Slice.

Use Case 3 – 5G Virtual Office

A 5G Virtual Office provides secure access to a specific set of corporate services without any restriction to the coverage range or proximity. This means that a 5G device can communicate with any other device that is member of the 5G Virtual Office, as long as there is 5G NPN coverage, both in private and public settings.

This use case will demonstrate the FUDGE-5G platform capabilities of deploying "all-Ethernet" NPNs with 5GLAN support for eHealth applications of a 5G Virtual Office in three major scenarios: Ward Remote Monitoring, Intra-Hospital Patient Monitoring and Ambulance Emergency Response.

The first scenario uses the NPN deployment to enable remote monitoring of ward patients using a set of bio sensors, allowing smart processing and analysis to trigger alarms in case abnormal values are detected as well as doctor to patient remote interaction. The second scenario aims to ensure uninterrupted monitoring with quality when patients are transported inside the hospital, in contrast to what current technologies provide. Finally, the third scenario extends the hospital network towards ambulances and emergency response using a 5G NPN deployed over a public 5G network, ensuring security, privacy, isolation and connectivity at all times.

Use Case 4 – Industry 4.0

FUDGE-5G will showcase an Industry 4.0 Campus Network with ultra-low time synchronisation requirements (5G-TSN). In the factory, a controller will interact with many sensors and actuator devices, located within a small area (up to 100 m^2). A 5GLAN-type of service can be provided enhancing existing wireless and/or fixed LAN solutions deployed in the Industry 4.0 factory.

These applications have high performance requirements such as low latency, high reliability, and deterministic delivery of messages. 5G NPNs are perfect for them, because they allow organisations to use licensed spectrum, therefore bandwidth is guaranteed. NPNs also allow full control of the QoS and Network Slicing, a key feature to provide URLLC.

Replacing wired with wireless connections will be beneficial because it allows to cut costs, and in some cases, like hazardous environments, it might even be a requirement.

Use Case 5 – Interconnected NPNs

This use case will focus on roaming among NPNs, a feature not officially supported by 3GPP technical specifications. The architecture will be based on the Eduroam network, allowing seamless connectivity while visiting other organisations. Users will always authenticate using the credentials of their home network. When the users try to access a visiting network, the petitions will be authorised by the home network. The resources users can use can be different whether the users are in their home network or in a visiting network.

To demonstrate its capabilities, three separate 5GLANs will be deployed (in Fraunhofer FOKUS site, in a Telenor site and at the UPV) and thanks to Interconnected NPNs use case, users from any network will have access to network resources.

Int5Gent

The Challenge

The necessity of an enabling 5G infrastructure, from the data plane technology blocks to the control plane and application deployment layer, is of paramount importance to maintain the market penetration momentum of 5G, generating in turn the functional requirements for meeting the expected 5G key performance indicators and therefore supporting the creation and growth of truly innovative vertical markets. From the networking point of view, the increasing interest in new use cases with strict latency requirements, fast service deployment times, dynamicity and trustworthiness generates a clear trend towards distributed network models implemented through the edge computing concept. According to this concept, the execution resources (compute and storage) are positioned at proximity to the end users and data generation sources. This denotes the deployment of an advanced infrastructure at the access and metro segments able to provide sufficient data transport connectivity and management of physical and virtualised network functions for a large number of distributed nodes. The complexity increases further by considering different types of edge nodes that may span from simple gateway servers to mini-data centres (DCs), thus having different connectivity requirements.

From the data plane point of view, the new technology building blocks should enable the 5G network infrastructure to provide the flexible high capacity and expandable connectivity between 5G terminals and edge computing nodes as well as among mobile edge, computing and content delivery nodes, and the core infrastructure also supporting the legacy cloud computing level. For this purpose, the move towards higher operating bands (V, W and even D-band) and the deployment of photonic interconnection solutions are necessary and require efficient elements for data distribution and demanding RF electronic system designs. In addition, the service level requirement for low latency in combination with new intelligent processing algorithms at the edge node denotes the deployment of edge processing units able to handle such services in real time and flexibly in terms of resource usage.

Within this highly demanding environment, Int5Gent aims to deploy a holistic 5G system platform that combines new technological blocks for the data plane infrastructure orchestrated by flexible PNF-VNF instances over a generalised NFV Infrastructure (NFVI) that is extended to edge computational, storage and networking resources. The overall goal is to integrate innovative solutions at different development layers of the 5G stack and combine them optimally in the quest to promote true 5G enabling solutions for new technology and service provisioning vertical markets.

Project Goals

Empowered by its ambitious vision, Int5Gent aims to seamlessly interconnect access nodes supporting any type of IoT device and related services over a bandwidth flexible and adaptive fronthaul/backhaul infrastructure and control and manage the network and computational resources, as well as orchestrate the lifecycle of the deployed service functions. More specifically, Int5Gent will:

- Develop a mmWave point-to-multipoint (PtMP) mesh node to enhance the connectivity of IoT devices in support of low-latency computing at the edge.
- Develop D-band 5G Terminal Nodes supporting flexible co-packaged electro-optics interfaces for practically unlimited fronthaul/backhaul transport capacities.
- Develop a multi-stream bit-interleaved sigma-delta modulated interface for bandwidth-efficient, low-power interconnection between edge box and frequency agnostic 5G RRH nodes.
- Edge-Box deployment based on advanced baseband processor platforms for MEC-oriented use cases.
- Architect a truly flexible 5G C-RAN with reconfigurable optical fronthaul interfaces and "on-demand" optical bandwidth-capacity steering functionalities.
- Dynamic application driven orchestration of network slices in distributed 5G infrastructures with edge-fog computing capabilities.

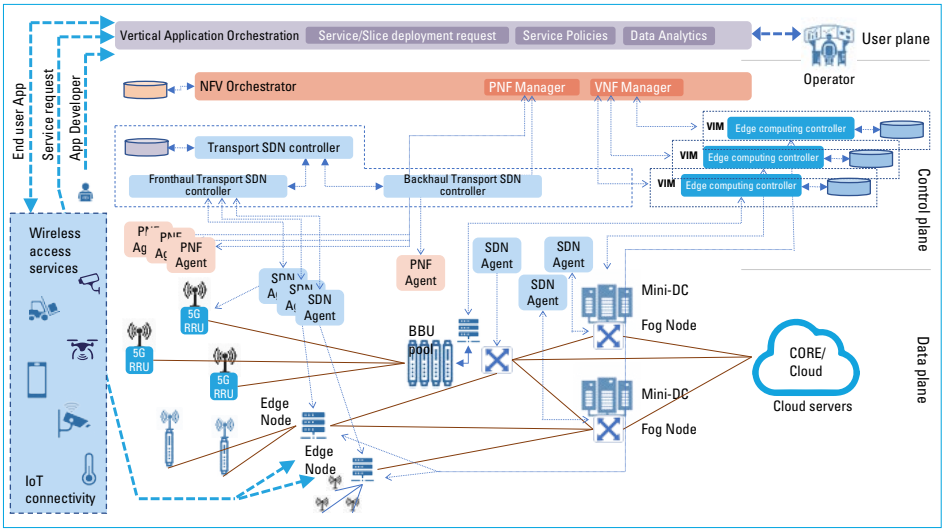

Fig. 49: Int5Gent architecture

- Develop an end-to-end 5G network slicing management and orchestration framework to dynamically reconfigure a multi-technology network at service runtime.
- Validate 5G technological blocks in a series of scalable lab- and field-trial demonstrators targeting service-oriented use cases.
- Deliver a holistic roadmap for transforming Int5Gent innovations into business opportunities with strong 5G market potential.

Technology Exploitation

Int5Gent builds upon a suite of innovative 5G technological solutions spanning hardware, software, and networking systems that have been conceptualised and developed under the latest 5G PPP initiative projects and are now taken to TRL-7 and above. It also combines novel and state-of-the-art solutions able to further upgrade the capabilities and maturity level of cutting-edge 5G core technologies enabling the creation of an innovative 5G ecosystem. A sample of the developed and offered technologies include flexible multi-RAT baseband signal processing, beam steering, mmWave technology solutions at 60 GHz and 150 GHz bands, hardware-based edge processor with TSN, GPU processing capabilities, innovative 5G terminals and elastic SDN-based photonic data transport. The integration of the technology blocks is performed as part of an overall 5G architecture that promotes edge processing and is orchestrated by an NFVO compatible framework with edge node extensions at the network layer and an overlay vertical services application orchestrator at the user plane layer.

The overall platform is implemented in two extended testbeds which include actual field deployed segments and managed by the network operators of the consortium. The validation and showcasing testbeds host 3 use case scenarios covering the deployment of services related to multiple vertical sectors as well as innovative applications for smart IoT networked devices.

PHASE 3 PART 6: 5G INNOVATIONS FOR VERTICALS WITH THIRD PARTY SERVICES & SMART CONNECTIVITY BEYOND 5G

5G ERA

5G enhanced robot autonomy (5G ERA) is oriented towards a user-centric paradigm of integrating vertical knowledge into the existing standardised 5G testing framework to improve Quality of Experience (QoE). The project addresses the new challenges on experimental facilities for the vertical developers and designers through the following activities: 1) integrating operational processes of essential autonomous robotic capabilities into Open Source MANO (OSM), ensuring the vertical specific adaptation of existing experimentation facilities, 2) realising an intent-based networking paradigm by aligning the end-to-end (E2E) resource optimisation with the autonomous operations, ensuring effective policy to be designed 3) Cloud native Network Services (NSs) on the experimental facilities will create, ensuring robotic applications exploiting NFV/SDN infrastructures efficiently, 4) extending the experimentation facilities into robotic domains thorough standard APIs under Robot Operating System (ROS), prompting third-parties' experimentation activities as well as engagement from new players. The emphasis of 5G ERA on 5G technologies to produce a solution to the long-standing problem of autonomous robotics, leading diverse applications of robots to particularly the innovative and yet challenging areas such as automated mobility, health and Industry 4.0, and hence contributing to the European economy.

Fundamental to the 5G ERA is the implementation of a reliable communication layer capable of dealing with collective intelligence, dense data, variety of information and real-time intervention in future autonomous robots. It maps the robotic concept of autonomy into networking objective of quality of experience. 5G promises to be a key enabler for robotic vertical applications with enhanced autonomy. It will not only deliver an evolution of mobile broadband networks; it will provide the unified communication platform needed to disrupt with new business models and to overcome the shortcomings of current communication technologies. As such, 5G technologies have the potential to amplify and accelerate the ongoing transformation, and to unlock a next level of efficiency gains in robotics even for the vast community of European manufacturing SME.

5G ERA is a 5G PPP Phase 3 (part 2) project starting in year 2021. It will utilise experiences gained from 5G PPP Phase 1, Phase 2 and Phase 3.1 into innovative vertical solutions. Build on top of ETSI OSM, the 5G ERA intent-based networking, cloud naive reference design and standardised APIs, enable the interoperability and security to be shared by NetApps which following the reference design across the targeted vertical applications. The capability will be verified in field trials using standardised testbeds with NFV. It leads to the latest progress on ML and AI to be used for automatic configuration/decomposition/mapping of NetApps on existing experimental infrastructure. 5G ERA network applications, including 5G ERA middleware, reference NetApp, and vertical specific NetApps will be opensource to encourage the reusability of project results. Detailed examples with tutorials will be provided to maximum engagement from all players, especially from robotic platform developers and vertical end users.

The project will verify and validate by 5G PPP KPI "Service creation time in minutes" through application driven network optimisation. KPIs have been sketched for all use cases. Performance optimisation will be showcased in different vertical sectors to ensure the repeatability of the project approach. Within the project period, four new NetApps which are specifically designed for PPDR (public protection and disaster relief), transport, logistical robots (in hospital), and manufacturing process will be validated and showcased in three existing testbeds (Greece, Spain and U.K.), All testbeds were built from previous 5GPP projects and national projects. These NetApp solutions will be sharing 5G ERA progression on enhanced robot autonomy and representing their respective vertical configurations. The 5G ERA test and validation will open a new window for further development of NetApp in related vertical sectors. In particular, this process will be accelerated in the robotic community by the integration of ROS, which is the most commonly used open-source framework for robot software development.

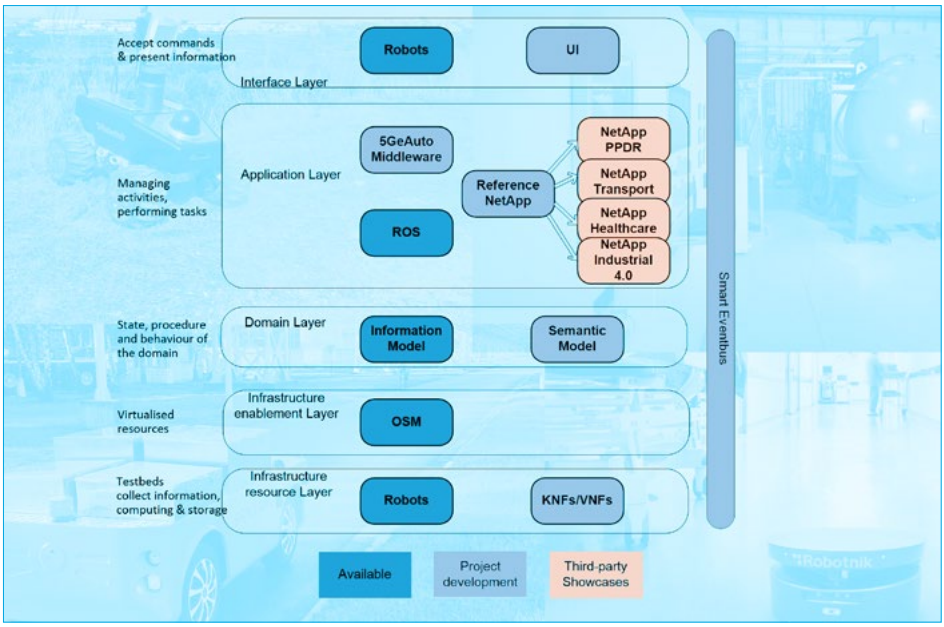

Fig. 50: 5G ERA architecture and Robots

5G INDUCE

The 5G INDUCE Overall Concept

5G INDUCE addresses the smooth and costless porting of NetApps to the 5G ecosystem, thus making the Industry 4.0 sector (and in principle any emerging vertical sector) ready to exploit its full potentials, such as production automation, robotics technologies, smart logistics and metering. The 5G INDUCE vision is realised with the deployment of two linked frameworks: i) a NetApp Orchestration (NAO) framework,

interfacing with the end users and serving their Application requirements, and ii) a Network Functions Virtualisation (NFV) Orchestration framework (NFVO) that manages the distributed resources over the virtualised infrastructure.

The overall 5G INDUCE system architecture follows a four-axis structure as depicted in Figure 51, these four axes highlight the core activities of the project:

Axis #1 – Full-stack NetApp Management Platform: Takes state-of-the-art research technologies, developed and tested in the previous 5G PPP research project initiatives, to a substantially higher technology-readiness level required by the Industry 4.0 standards, while at the same time offering the first ecosystem for advanced overlay 5G NetApps. Specifically, the 5G INDUCE platform integrates state-of-the-art control and data plane developments ranging from industrial IoT devices and 5G radio access nodes to a state-of-the-art OSS and a scalable microservices-based cloud orchestration platform, each with a clear evolution roadmap towards an integrated full-stack 5G NetApp management platform.

Axis #2 – Advanced Industry 4.0 NetApps: Showcasing the support of a variety of innovative Industry 4.0 market verticals through the demonstration of advanced use cases, meeting demanding Industry 4.0 and 5G KPIs, such as ultra-low latency, fast service deployment, high service reliability, while accommodating industrial-grade scalability demands.

Axis #3 – Industrial & 5G Experimentation Infrastructure: Heterogeneous real-world industrial fields at scale provided by both global (with active presence in Europe) and European industrial players, on key industrial sectors, such as automotive, energy, and home appliances. 5G INDUCE partners the aforementioned industrial players together with large European mobile network operators and vendors, aiming to build a unique fabric of tightly interconnected 5G infrastructures with industrial fields, which will lead the Industry 4.0 activities in Europe. Prior to the deployment of 5G INDUCE NetApps on the real experimentation infrastructure, 5G INDUCE utilises a state-of-the-art 5G platform integrator and NetApp DevOps testbed for pre-deployment testing and validation.

Axis #4 – End Users (Enabling Businesses): Creates huge impact for key market stakeholders through a win-win-win (win3) business model that generates mutual benefits for: (i) industrial players, (ii) network operators, and (iii) a large pool of heterogeneous SMEs/start-ups acting as NetApp developers, while maintaining discrete and distinct roles for each of these stakeholders.

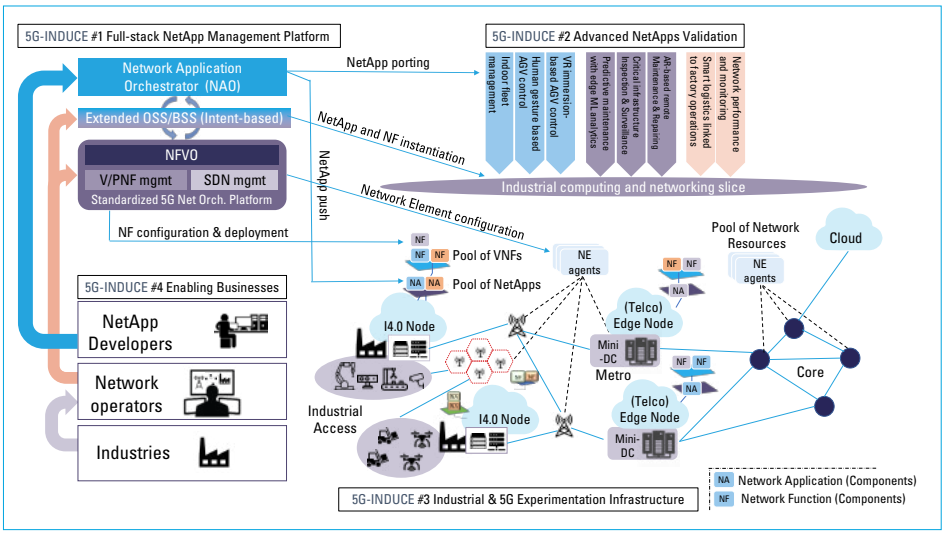

Fig. 51: The 5G INDUCE vision and the adopted approach for easy (i) porting and/or (ii) development of industry 4.0 NetApps over advanced Experimentation Facilities combining real 5G and private industrial networks.

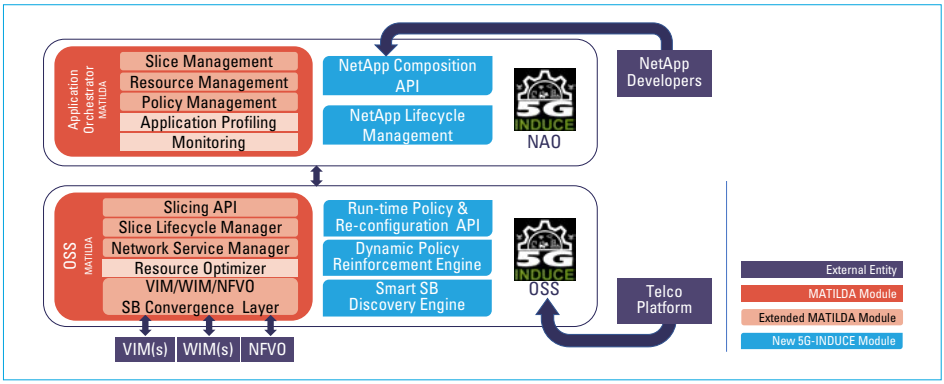

Fig. 52: Structure of the NAO and OSS and extensions/additions of components in support of the NetApp developers.

5G INDUCE NetApp Management platform and Testbeds

The full-stack 5G INDUCE NetApp Management platform consists of two main parts: (i) an underlying network platform realised as an advanced 5G INDUCE Operations Support System (OSS) and (ii) the overlay 5G INDUCE NAO (Figure 52).

The 5G INDUCE OSS leverages a standardised 5G Network Orchestration Platform (bottom part in Figure 52). This platform interacts with the SouthBound convergence layer of the extended OSS through a number of standard direct interfaces towards well-known and widespread building blocks, such as the Open-Source MANO (adopting the standard ETSI NFV Os-Ma-nfvo reference point), Kubernetes as Virtual Infrastructure Manager (VIM) for both the NFV Orchestrator and the edge computing support, and an ONF based Wide-area Infrastructure Manager (WIM).

The most radical contribution of the 5G INDUCE project is the NAO, which interacts with the enhanced 5G INDUCE OSS layer as exposed by the telco provider. In a nutshell, the scope of the NAO is to undertake the deployment, real-time management, and graceful un-deployment of Industry 4.0 NetApps, while inherently providing elasticity and compliance with certain high-level NetApp policies.

The 5G INDUCE platform is intended to be deployed over 3 realistic 5G infrastructures comprising innovative industrial sector environments interconnected to 5G core at operator premises. The 3 sites are: Ford factory in Valencia interconnected through Ericsson's edge node technology to 5TONIC test-bed in Madrid, the Public Power Corporation industrial site in Lavrio, Greece, interconnected to COSMOTE 5G laboratory infrastructures in Athens, and the Whirlpool factory in Biandronno (Varese), Italy, interconnected to CNIT's lab infrastructure in Genoa through Wind3 network, serving also as the DevOps testbed for new NetApps. The goal of the three experimentation sites is to demonstrate the seamless integration of the modular NetApp management solution over different platforms, while also covering a large and diverse number of Industry 4.0 use cases related to different industry types: automotive, energy and appliances.

Finally, it is important to highlight that the idea behind the 5G INDUCE concept is twofold:

a. On a more technical view, the goal is to setup the platform required for the NetApp porting, lifecycle management and showcasing through standardised network orchestration approaches and an efficient slice and resource management framework.

b. On a more innovative and business-oriented perspective, the goal is to initiate the European ecosystem of associated key players (from within and outside the consortium), with the goal to open up new business opportunities for SMEs and start-ups that try to enter the huge I4.0 market with innovative applications that will bring added-value to industrial verticals.

5G MEDIA HUB

Introduction

5G MEDIA HUB aims to realise EC's vision to make Europe a global leader in 5G, by boosting the testing and validation of innovative 5G media and entertainment applications. This will be accomplished by providing 3rd party experimenters and Network Application (NetApp) developers of media and entertainment services an end-to-end experimentation infrastructure that encompasses an easy to use 5G enabled assessment space for the relevant stakeholders. To this end, 5G MEDIA HUB will offer a secure and trusted service execution environment through the 5G MEDIA HUB Experimentation Facility, an open integrated all-in-one experimentation system. This Facility will include i) a web-based Experimenters Portal for users to easily schedule their experiments and monitor results; ii) a fully-fledged Testing as a Service environment based on the latest DevOps practices, iii) a rich set of Experimentation Tools, iv) a set of re-usable vertical-specific and vertical-agnostic NetApps, v) a re-usable open-source NetApps Repository, vi) an umbrella Cross-Domain Service Orchestrator, vii) access to two well-established 5G PPP 5G testbeds, and viii) an innovative Security Framework. The project also aspires to offer validation for 5G network and service-level KPIs relevant to the media sector through 3 novel use cases requiring 5G performance characteristics.

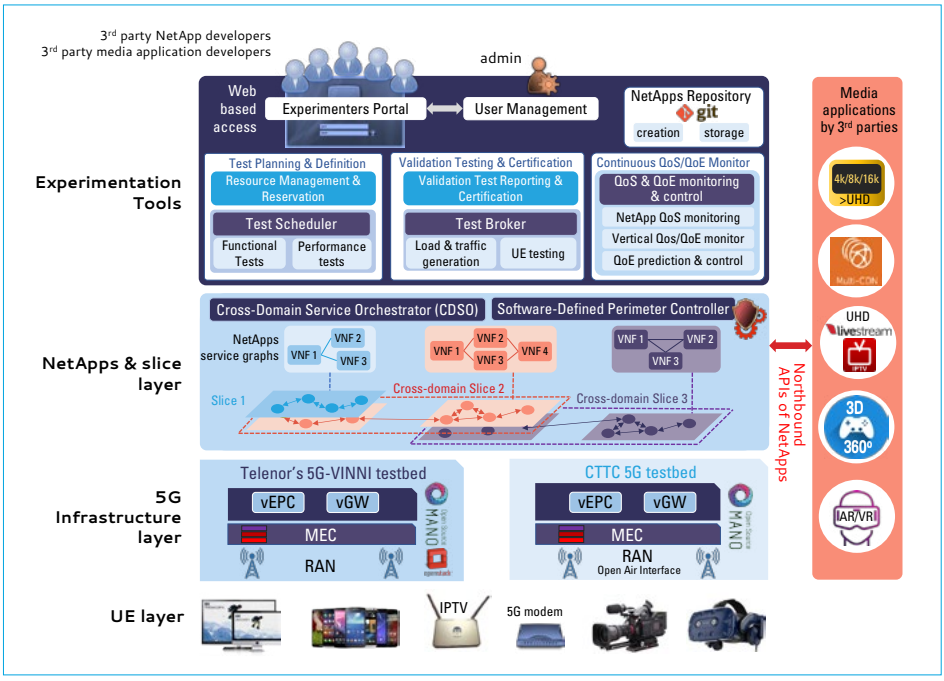

Fig. 53: 5G MEDIA HUB Experimentation Facility concept

Major achievements and innovations

5G MEDIA HUB advances the state-of-the-art in a series of key Innovation Streams. Instead of merely predicting traffic, 5G MEDIA HUB will break new ground, aiming at predicting NetApps KPIs and SLA compliance. Further, 5G MEDIA HUB will meaningfully extend previous efforts that focused on Continuous

Development and Integration DevOps workflows by adding support for Operations, Administration and Management (OAM). Specifically, the 5G MEDIA HUB Experimentation Facility will support continuous QoS and QoE monitoring, allowing 3rd party media applications developers and experimenters to qualify and verify their applications and NetApps with a set of tools they already use in their production environments. Also, they will be enabled to deploy tests directly at User Equipment (UE) through an innovative, centrally managed "UE farm", which enables end-to-end testing of a variety of media applications.

Another key innovation feature provided through the UE farm infrastructure is the measurement of QoE directly at UE level, hence achieving higher scoring objectivity, also taking into account the impact of the RAN on video quality. Furthermore, the NFV complexities will be abstracted from vertical application developers by leveraging the cross-domain NetApps layer. Thus, vertical application experimenters or NetApp developers will have the ability to focus on their application's functionality, effectively delegating orchestration of network services to a Platform-as-a-Service (PaaS) Orchestration NetApp.

5G MEDIA HUB will integrate Software Defined Perimeter (SDP) in 5G NFVIs with PaaS capabilities for the first time, allowing vertical applications, 5G internal services and 5G Core functions to share NFVI resources with unprecedented granularity. Finally, the 3GPP SEAL architecture will be adopted, ensuring that the project will align with the ETSI MEC ISG PaaS extensions in order to define, for the first time, SEAL services for the Media industry.

Use cases

Three use cases will be deployed for carrying out experiments and validating the KPIs targets set in order to ensure that the 5G MEDIA HUB Experimentation Facility aligns with the latest 3GPP standards. For each use case two scenarios will be demonstrated.

Use case 1: Immersive AR, VR and XR applications

This use case will test that the 5G MEDIA HUB Experimentation Facility efficiently supports the execution and operation of immersive technologies.

In the 1st scenario, remotely-located teachers will enter a VR classroom environment to explain a concept to similarly immersed users, who will sense the teacher's presence. This use case will leverage 5G technologies to facilitate untethered operation, which will significantly improve quality of rendering and facilitate an unobtrusive 360° view.

The 2nd scenario will explore the future of media consumption, which involves UHD 8k and 360° VR media content streamed over 5G, offering collaborative, interactive experiences.

Use case 2: Smart media production

This use case aims at testing the SLA compliance of media vertical applications, and qualifying NetApps via the Experimentation Tools of the 5G MEDIA HUB Facility that include traffic generators and synchronised video stream emulators via pre-recorded content.

The 1st scenario involves testing a User Generated Content (UGC) media service scenario in the UGC production domain, highlighting the catalyst nature of 5G networks in significantly advancing the state of the art.

The 2nd scenario will evaluate "edge-based field production" through the 5G MEDIA HUB Experimentation Facility to cover for the exponentially growing segment of outdoors production. The demo application facilitates local sports events to be recorded and produced in real time by a remote TV production team, which stays physically in the studio.

Use case 3: Smart media content distribution

The objective of this use case is to test cross-domain media distribution through the 5G MEDIA HUB Experimentation Facility, and evaluate how it affects QoS and QoE.

The 1st scenario involves a Multi-Content Delivery Network (MCDN) management interface, where broadcasters will configure their desired weighting, e.g. for several Content Distribution Network (CDN) configurations, at both the 5G Edge and Core tiers. For this purpose, various dependencies such as times of day or geolocation can be defined in flexible rulesets according to each broadcaster's individual requirements.

The 2nd scenario demonstrates how visual media can be reliably distributed in multiple remote sites or domains, enabling interactive co-creation between citizens and the city.

5G-EPICENTRE

Goal of the project

5G-EPICENTRE aims at serving the needs of public protection and disaster relief (PPDR) by delivering an open end-to-end experimentation 5G platform focused on software solutions.With 5G considered to be the next decade mainstream broadband wireless technology, it can leverage the efficiency and effectiveness of everyday high demanding operations such as the ones performed within the scope of PPDR.The platform will act as an enabler for SMEs and developers who want to acquire knowledge on the latest 5G applications for first responders and crisis management processes, as well as provide them with the space to build and experiment with their solutions.Every technical activity including optimisation algorithms, network orchestration APIs and novel analytics ML and visualization solutions will be addressed in an iterative and incremental approach, as proposed by the SCRUM scientific and technological methodology.

Envisioned architecture

The 5G-EPICENTRE platform will be based on an Open Service oriented Architecture, following the current best DevOps practices (containerisation of micro-services).The platform will additionally be able to accommodate and provide open access to 5G networks' resources acting this way as a 5G open-source repository for PPDR NetApps. To assess the 5G-EPICENTRE platform, the project engages in the realisation of 8 use cases which will be realised as a PPDR vertical. The main purpose of the project's use cases is to expand along the entire range of the 3 ITU-defined service types: eMBB, mMTC and URLLC; while also providing the floor for overseeing the platform's secure interoperability capabilities beyond vendor-specific implementation. The engaged SMEs and organisations that will participate in the realisation of the use cases constitute active players in the public security and disaster management, thus will hold the roles of key enablers for the assessment of 5G-EPICENTRE with regard to the real needs that should be addressed.

5G-EPICENTRE carefully selected four geographically dispersed E2E private networks deployed in the context of previous EC calls that support key 5G KPIs and allow cross-site orchestration and experimentation for PPDR solution vendors to validate NetApps reliant upon those KPIs. The experimentation platform will result from federation of the 5G testbeds: 5G-VINNI, Semiotics, 5G-Berlin and 5GENESIS. Capitalising on these open, evolutionary 5G networks across Europe, 5G-EPICENTRE will develop all necessary new 5G features, specifically targeting the needs of the PPDR operational framework.

Within the 5G-EPICENTRE, PPDR will be approached as a vertical responding to organisations and agencies with the two-fold common goal to protect the public and the environment. 5G-EPICENTRE aims to address different PPDR operational scenarios through a series of first-party experimentation activities. Each scenario will be provisioned by a consortium partner to act as piloting activities for the platform. For each such case, elements of each respective solution will be converted into CNF/VNFs and deployed to the orchestration environment of the 5G-EPICENTRE facilities. The goal will be to convincingly demonstrate a facility that is open enough to provide the network functionalities needed for the PPDR applications.

Use Cases

UC1 Multimedia MC Communication and Collaboration Platform: The 5G-EPICENTRE platform will be utilised to experiment with a Mission Critical Multimedia and Collaboration platform and Mission Management applications and integrate them with project partners applications or engaged SMEs applications.

UC2 Multi-agency and multi-deployment mission critical communications and dynamic service scaling: to provide common coordination between first responders under standard 3GPP MCS communications and scaling mechanisms to deal with resource deficiencies.

UC3 Ultra-reliable drone navigation and remote control: demonstration of super reliable drone navigation and remote control by utilising the federated testbed resources. Efficient means of controlling drones via voice channels in the mobile network will be deployed in the form of VNFs on top of the 5G-EPICENTRE platform facilitating a two-way communication.

UC4 IoT for improving first responders' situational awareness and safety: A situational awareness platform will be used to meet the pre-set goal of aiding C&C Centres to obtain a full awareness of field operations. This includes monitoring of agents in the field through a set of geographical/indoor positioning, environmental and wearable biological sensors, as well as real-time text, audio and video transmissions.

UC5 Wearable, mobile, point-of-view, wireless video service delivery: Experiment with wearable point-of-view (POV), wireless video in two distinct EMS scenarios, to increase efficiency and accelerate time to treatment by more rapidly characterising acute pre-hospital situations.

UC6 Fast situational awareness and near real-time disaster mapping: System for a range of emergency services using AI to analyse, enhance and extract individually determined datasets for PPDR. Creation of an app and associated hardware for using the 5G infrastructure via the defined NetApp developer interfaces, are intended.

UC7 AR and AI wearable electronics for PPDR: Real-time semantic segmentation, instance segmentation and edge detection will be used to overlay useful information directly on top of

the real world through the optical see-through display worn by police officers, who patrol or operate in a designated area.

UC8 AR-assisted emergency surgical care: Experiment with holographic AR technology for emergency medical surgery teams, by overlaying deformable medical models directly on top of the patient body parts, effectively enabling surgeons to see inside (visualising bones, blood vessels etc.) and perform surgical actions following step-by-step instructions.

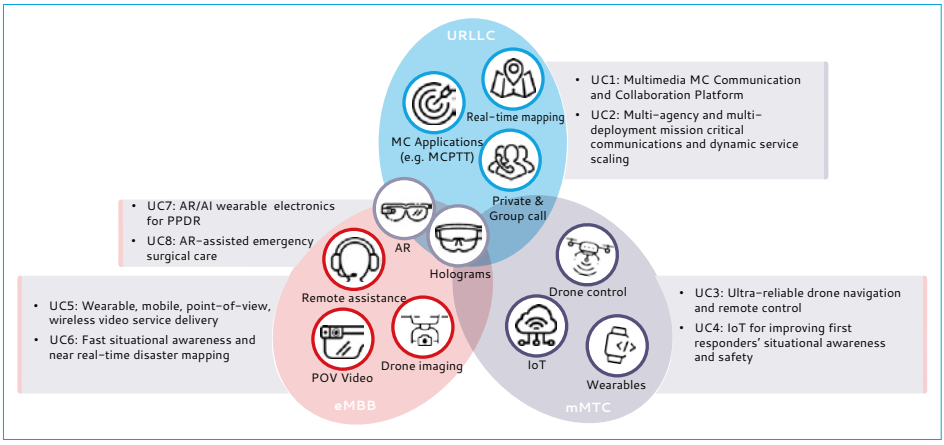

Fig. 54: 5G-EPICENTRE first-party experiments mapping to ITU's 5G enabling service types.

5GASP

In a glance

As 5G approaches a very high maturity level, the testing and validation of the innovations achieved in 5G by integrators and verticals service providers has become of utmost importance. Verticals have very different needs, as the cases of the Automotive industry and Public Protection and Disaster Relief (PPDR) readily illustrate. This will therefore require different levels of support in taking their applications and services from concepts, to prototypes and finally to products. However, it is also more and more frequent that services in different verticals need to exchange data, particularly mobility services such as those found in connected automobiles and PPDR.

5GASP, which started in January 2021, aims at shortening the idea-to-market process through the creation of a European testbed for SMEs that is fully automated and self-serviced, in order to foster rapid development and testing of new and innovative NetApps built using the 5G NFV based reference architecture. Building on top of existing physical infrastructures, 5GASP intends to focus on innovations related to the operation of experiments and tests across several domains, providing software support tools for Continuous Integration and Continuous Deployment (CI/CD) of VNFs in a secure & trusted environment for European SMEs capitalising in the 5G market. 5GASP targets the creation of an Open Source Software (OSS) repository and of a VNF marketplace targeting SMEs with OSS examples and building blocks, as well as the incubation of a community of NetApp developers assisted with tools and services that can enable an early validation and/or certification of products and services for 5G. The project is focused on inter-domain use-cases, development of operational tools and procedures (supporting day-to-day testing and validation activities) and security/trust of 3rd party IPR running in our testbeds.

Objectives

1. Acceleration of the development, testing and certification of NetApps, through the creation of a common platform, aligned DevOps tools and a certification roadmap.
2. Provide state-of-the-art testbeds where applications for relevant verticals can be tested and validated in a cost-effective way.
3. Innovate technically by addressing inter-domain use-cases, security and trust aspects associated with NetApp deployment and Operation.
4. Automate the process of testing and validation, lowering cost associated with testing and certification of NetApps in telecommunication environment.
5. Provide all the community with state-of-the-art tools for test deployment, test automation, continuous integration and monitoring of testbeds, mainly through Open Source Software tools.
6. Create a practice community, where developers can share knowledge about 5G NetApps
7. Create a business model around a marketplace of NetApps, by which all stakeholders can share revenue.

Architecture

5GASP approach is based on the DevOps set of practices that combines software development and, in our case, 5G Network Operations. This approach relies heavily in the software automation of several processes and on the creation of a virtuous cycle of Onboarding new Network Applications/Services (NetApps), Automation of tests performed by the testbeds, Validation of tests and certification of the NetApps and finally Feedback to the developer, in order to produce fixes and improvements to the NetApp. In 5GASP we intend to reach out to developers through the creation of a community of practice for 5G Applications and Services. This community will be anchored around a web portal with community building tools such as Discussion Groups, Documentation, Tutorials and other Multimedia Content. In addition, we intend to promote NetApps that have gone through the 5GASP approach through a NetApp Store.

Bootstrapping

5GASP consortium includes 7 innovative SME's, which provide several NetApps targeting challenging uses-cases in Automotive and Public Protection and Disaster Relief (PPDR). These NetApps will constitute the initial clients/users of the 5GASP platform and will assist in the validation and testing of our approach.

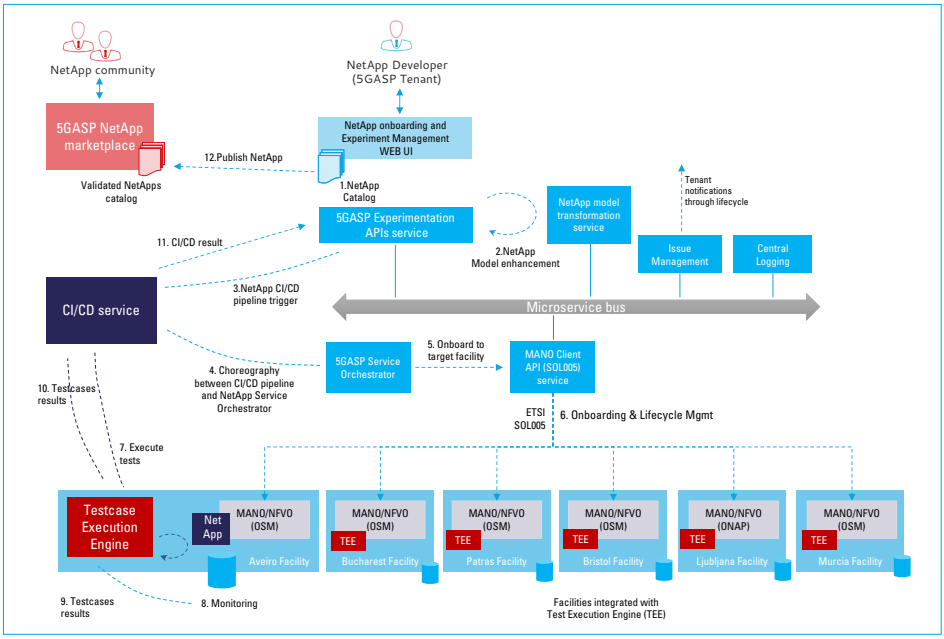

Fig. 55: 5GASP approach on DevOps experimentation and certification readiness Lifecyle

The initial NetApps are the Virtual On-Board Unit provisioning NetApp (vOBU), the Virtual RoadSide Unit provisioning NetApp (vRSU), the ITS station NetApp, Multi-domain Migration NetApp, the Vehicle-to-Cloud (V2C) Real-Time Communication NetApp, the Remote Human Driving NetApp - Teleoperation for assisting vehicles in complex situations, the Efficient MEC handover NetApp, the Privacy Analyser NetApp, the 5G Isolated Operation for Public Safety NetApp (5G IOPS NetApp), the Vehicle Route Optimiser NetApp and the Fire detection and ground assistance using drones (FIDEGAD).

Next Steps

We will soon have the 5GASP community portal online together with an initial version of our CI/CD platform, which we invite all 5G stakeholders to join.

6G BRAINS

Objectives of the project

Ubiquitous smart wireless connectivity is critical for future large-scale industrial tasks, services, assets and devices. Very significantly improved connectivity needs to be unlocked through novel spectrum combinations and the fully autonomous management of the underlying network resources by applying online Artificial Intelligence (AI) at multiple decision layers.

6G BRAINS aims to bring AI-driven multi-agent deep reinforcement learning (DRL) to perform resource allocation over and beyond massive machine-type communications with new spectrum links including THz and optical wireless communications to enhance the performance with regard to capacity, reliability and latency for future industrial networks.

6G BRAINS will deliver a novel comprehensive cross-layer DRL driven resource allocation solution to support the massive connections over device-to-device (D2D) assisted highly dynamic cell-free network enabled by Sub-6 GHz /mmWave/THz/OWC and high resolution 3D Simultaneous Localisation And Mapping (SLAM) of up to 1 mm accuracy. The enabling technologies in 6G BRAINS focus on four major aspects:

- Enhanced new spectrum links: OWC and THz
- AI-driven D2D cell free network architecture for highly dynamic and ultra-dense connectivity
- AI-based end-to-end directional network slicing with guaranteed QoS over highly dynamic networks
- AI-driven data fusion for 3D indoor position mapping through heterogeneous location methods enabling 1 mm location position accuracy and 1° orientation accuracy.

The proposed solution will be validated by proof-of-concept trials. The primary and secondary applications of THz and OWC technologies for a very broad spectrum of scenarios will be evaluated at BOSCH's self-contained smart factory. The developed technologies will be widely applicable to various vertical sectors such as Industry 4.0, intelligent transportation, eHealth and others. In particular, new business opportunities emerging in 6G BRAINS will be identified for follow-up exploitation activities. The results of 6G BRAINS are expected to create a solid basis for future projects and global standardisation for B5G and 6G technologies in areas relevant to industrial environments.

Major achievements/innovations and performance KPIs

Towards that vision, 6G BRAINS aims to bring AI-driven multi-agent DRL to perform the resource allocation over the high dynamic ultra-dense D2D cell free network with new spectrum links including THz and OWC to achieve up to 100 devices per m^3 network density, up to 99.999% reliability and up to 0.1 ms air interface latency for the future industrial network. 6G BRAINS project is the first project to propose a comprehensive cross-layer AI driven resource allocation solution to support the massive connections over D2D assisted high dynamic cell free network enabled by THz/OWC and high resolution 3D SLAM of up to 1 mm accuracy. In order to achieve this, the enabling technologies in 6G BRAINS have been divided into four major parts including the disruptive new spectrum links, the high dynamic D2D cell free network modelling, the intelligent end-to-end network architecture integrating the multi-agent DRL scheme and AI-enhanced high resolution radio-light 3D SLAM data fusion.

BOSCH has set out a vision for a B5G-enabled industrial network where every part of the production environment is fluid, except for the walls and ceilings. Industrial machines, devices, and vehicles will be made mobile by 5G or B5G and made intelligent by edge and cloud based analytics, enabling factory owners to change their production lines according to demand in a short period of time. The massive connected IoT solution is envisioned to be one of the most promising drivers for many of the emerging use cases, including industrial automation as a means to deploy reconfigurable production systems, which can be torn up and down according to real-time demand. 6G BRAINS solution will have very few fixed elements, and even these elements will be intelligent. The building will be static, but flexible. Every piece of equipment in these new plants can be wireless, and mapped as a digital twin with the high resolution radio-light 3D SLAM. AI enabled Non-Public Network (NPN) slicing for 6G BRAINS networks will liberate factories from their fixed production lines. The MEC (multi-access edge computing) of 6G BRAINS will organise retrofitted connectivity and enable analytical applications like predictive maintenance even in old machines. The multi-agent DRL framework of this project will bring real-time intelligence and orchestration capabilities to help humans handle more changeable production routines. The AI-enabled massive D2D clusters' modelling, enhanced by the multi-band channel models for the 200 GHz and 300 GHz as well as OWC band in 6G BRAINS over the high dynamic ultra-dense D2D industrial network is essential to open the path to 6G in industrial environment for THz and optical spectrum to bring the real scenarios into the controllable platform. The innovative disruptive technologies in 6G BRAINS like the Grant-free Non-Orthogonal Multiple Access (GF-NOMA) over cell free massive MIMO with underlaid D2D clusters, optimising content placement in edge caches aiming at low delay and traffic offloading, user-centric interfaces enabling intent-based networking, new radio waveform for THz and OWC and evolved E2E directional network slicing management and orchestration (DNS MANO) allow a higher capacity and zero-perceived latency to meet massive

URLLC connectivity requirements. The mobile robots use case demands very high requirements on latency, communication service availability, and determinism. This application can involve simultaneous transmission of non-real time data, real-time streaming data (video) and highly critical, real-time control data. The latter involves very high requirements in terms of latency and communication service availability over the same link and to the same mobile robot. Enhanced coverage in indoor (from basement to roof), outdoor (plant/ factory wide) and indoor/ outdoor environment is needed due to mobility of the robots. 6G BRAINS will support seamless mobility such that there is no impairment of the application in case of movements of a mobile robot within a factory or plant.

Description of demos

A so called "factory of the future" represents one the most challenging applications of the future mobile communication systems. A large number of specific use cases representing this scenario have been described in different bodies including 3GPP and 5G-ACIA (see also Figure 56). From the vast list of specific "factory of the future" use cases, 6G BRAINS identified the following ones, which require further improvement of the current 5G technology. The first use case represents the offloading of the control logic from the industrial controller running as part of a production cell on the shop floor to a more centralised computing area called "factory edge" in a virtualised form as a virtual machine or a container. A more centralised approach, where all controllers (real or virtualised) are placed in the same area will significantly increase the flexibility of the production process and reduce the cost. Connecting the production cells through the 6G BRAINS communication system to the "factory edge" shall enable the ease of reconfiguration of hardware and software components on demand. This use case sets very high expectations on the guaranteed latency and deterministic communication that should support low industrial application cycle times and very precise synchronicity. Another use case is represented by wireless video cameras that are easily deployed in every factory production cell at different locations to send high quality and high frame rate video to an image analysing system located at the "factory edge". By this, a new level of production monitoring is unleashed enabling a long list of new features such as anomaly detection, improved safety, process tracking and logging, remote control and predictive maintenance. This use case has high requirements on the data rate consuming up to 3 Gbps per camera in case of state-of-the-art industrial camera systems. Finally, the combination of these two use cases represents a very challenging approach for a system that is required to provide a precise QoS differentiation by, e.g., creating individual slices for each of the required services.

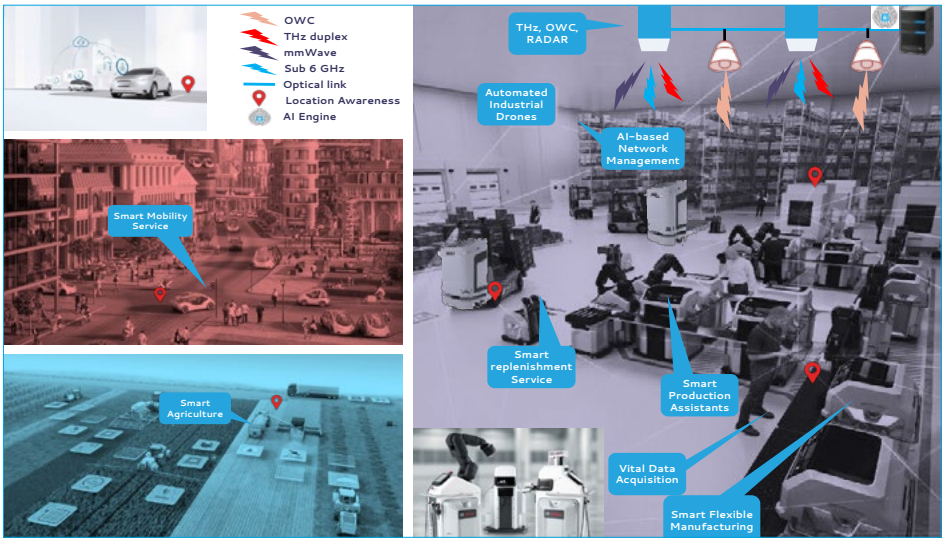

Fig. 56: 6G BRAINS Concept Vision (images: Bosch)

Goals of the project

Artificial Intelligence has become a major innovative force, and it is one of the pillars of the fourth industrial revolution. While significant progress has been made during the last years concerning AI-enabled platforms' accuracy and performance, their integration in potentially autonomous decision-making systems or even critical infrastructures requires assuring end-to-end quality. The goal of AI@EDGE is to achieve an EU-wide impact on industry-relevant aspects of the AI-for-networks and networks-for-AI paradigms in beyond 5G systems. To this aim, AI@EDGE targets significant breakthroughs in two fields:

(i) **general-purpose frameworks for closed-loop network automation** capable of supporting flexible and programmable pipelines for the creation, utilisation, and adaptation of the secure, reusable, and trustworthy AI/ML models; and

(ii) definition of a **converged Connect Compute platform** for creating and managing resilient, elastic, and secure end-to-end slices capable of supporting a diverse range of AI-enabled network applications (Fig. 57).

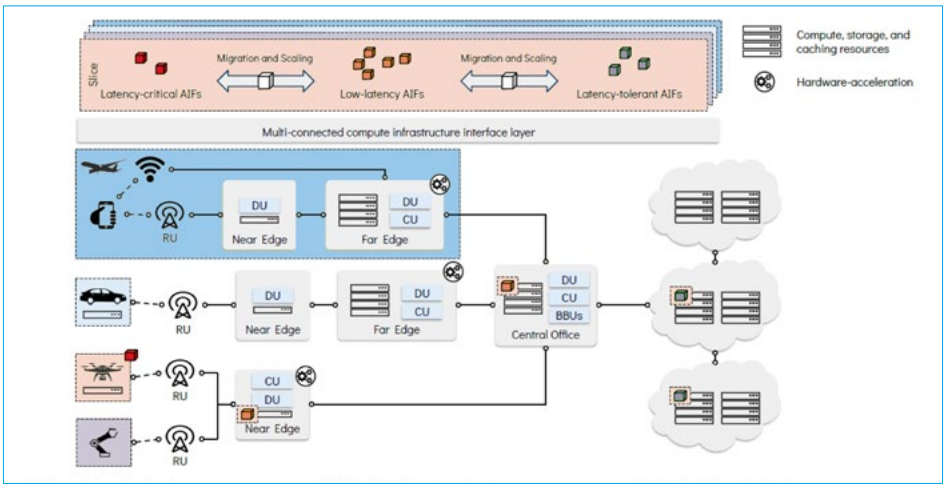

Fig. 57: AI@EDGE Connect Compute Platform

Envisioned achievements/innovations

The introduction of AI and Machine Learning (ML) technologies in the cloud-network convergence process will be crucial and help operators achieve a higher level of automation, increase network performance, and decrease the time-to-market of new features. AI@EDGE will leverage the concept of reusable, secure, and trustworthy AI for network automation to achieve an EU-wide impact on industry-relevant aspects of the multi-stakeholders environments. It cannot be expected that each and every subsystem of future access, edge, core, and cloud segments will employ distinct and separated AI tools and datasets: such an approach would lead to AI-silos slowing down advances vital to achieving sustainable networking and ultra-scale complex services relying on distributed compute-connect fabrics. AI@EDGE approach to answering the above-mentioned challenges has two lines of action:

First, we will design, prototype, and validate a network and service automation platform capable of supporting flexible and programmable pipelines for the creation, utilisation, and adaptation of secure and privacy-aware AI/ML models.

Second, we will use this network and service automation platform to orchestrate AI-enabled end-to-end applications. Here, we introduce the novel concept of Artificial Intelligence Functions (AIFs) to refer to the AI-enabled end-to-end applications sub-components that can be deployed across the AI@EDGE platform.

In particular, the AI@EDGE project will focus on six main breakthroughs:

1. AI/ML for closed-loop automation;
2. Privacy-preserving, machine learning for multi-stakeholder environments;
3. Distributed and decentralised connect-compute platform;
4. Provisioning of AI-enabled applications;
5. Hardware-accelerated serverless platform for AI/ML;
6. Cross-layer, multi-connectivity and disaggregated radio access

Based on them, AI@EDGE will develop a connect-compute fabric – specifically leveraging the serverless paradigm – for creating and managing resilient, elastic, and secure end-to-end slices capable of supporting a diverse range of AI-enabled applications.

Description of Use Cases

The AI@EDGE platform will be validated using four Use Cases with specific requirements that cannot be satisfied by current 5G networks according to the 3GPP Rel15 and 3GPP R16 standards, in particular in terms of support for latency-sensitive and highly dynamic AI-enabled applications (Figure 58).

- **Use Case 1: Virtual validation of vehicle cooperative perception:** this Use Case recreates the network-level data exchange between the simulated vehicles, the edge and the vehicle on-board unit through interconnecting a hardware-in-the-Loop 5G network emulator, a dynamic driving simulator operated by a real human driver and a traffic simulator. A Cooperative Perception AI-based application deployed in the AI@EDGE platform will be used to demonstrate how the resource orchestration features like closed-loop network automation can be used to support an industry 4.0 digital twinning use case.
- **Use Case 2: Secure and resilient orchestration of large (I)IoT networks:** this Use Case addresses two challenges: (i) the deployment of AI for network security (intrusion detection) for device level and 5G-level segments and (ii) the secure deployment of AI (adversarial machine learning). Several edge devices will be equipped with intrusion detection capabilities, and attacks will be performed against the automation system. A commercial 5G system will be used and extended to demonstrate the security capabilities of the AI@EDGE platform in the deployment of (I)IoT networks.
- **Use Case 3: Edge AI assisted monitoring of linear infrastructures using drones in BVLOS operation:** this Use Case pursues the following objectives: (i) short term use of advanced edge capabilities combined with AI algorithms while drone scan is performed, (ii) combined use of powerful computing solutions (GPUs) at both drone embedded compute units, edge dedicated devices and cloud, (iii) dynamic scaling of on-demand drone video content distribution, (iv) fast slice creation to support exceptional incidents.
- **Use Case 4: Smart content & data curation for in-flight entertainment services:** this Use Case aims at (i) delivering curated content to airline passengers, (ii) develop an edge cloud infrastructure on-board aircraft and (iii) deploy 5G connectivity in the aircraft cabin for content delivery. The AI@EDGE platform will enable a sliceable, lightweight, container-based system wherein artificial intelligence ensures the automation of the infrastructure and services lifecycle, relying on monitoring tools and network optimisations.

More information on the project can be found following AI@EDGE social profiles on Twitter (@AIatEdgeH2020) and Linkedin (https://www.linkedin.com/company/aiatedge) or visiting the project's website (URL: https://aiatedge.eu/).

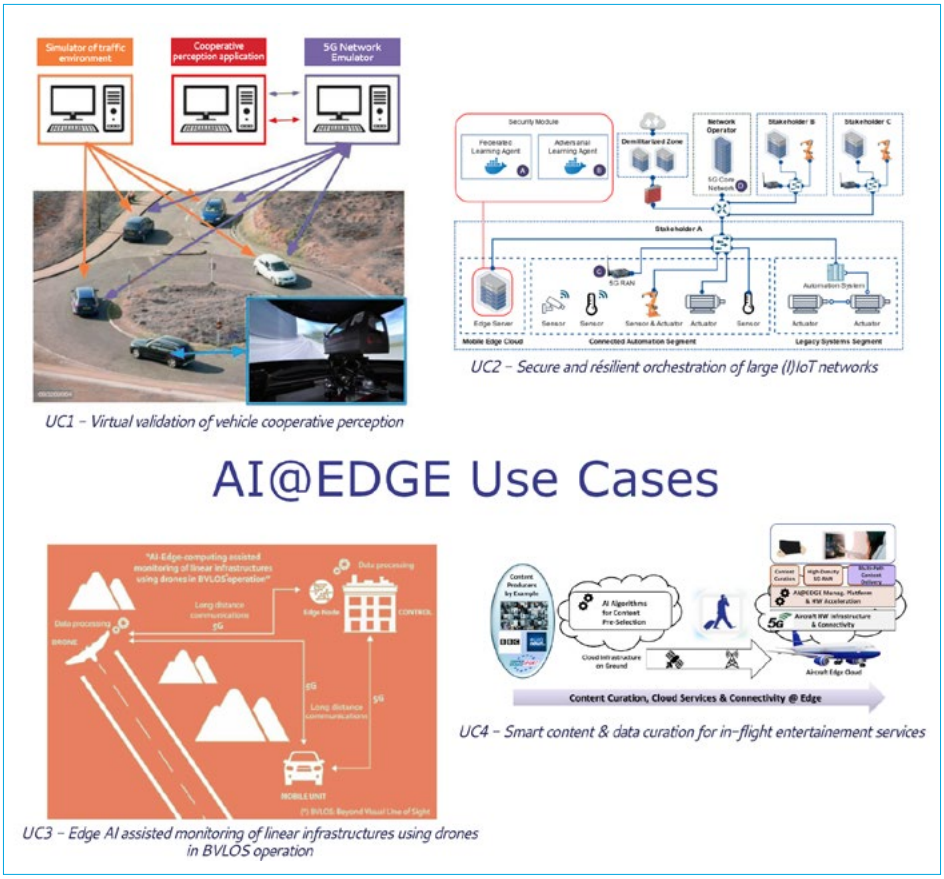

Fig. 58: AI@EDGE Use Cases

Daemon

Goals of the project

DAEMON aims at realising a pragmatic and systematic integration of Network Intelligence (NI) in mobile networks, with the aim of ensuring that the NI drives zero-touch 6G systems towards meeting their very high expectations in terms of performance, sustainability and reliability. Achieving this goal requires updating the network architecture so that it can best accommodate NI, as well as re-thinking the design and deployment of machine learning solutions, tailoring them to increasingly complex and diversified mobile networking environments.

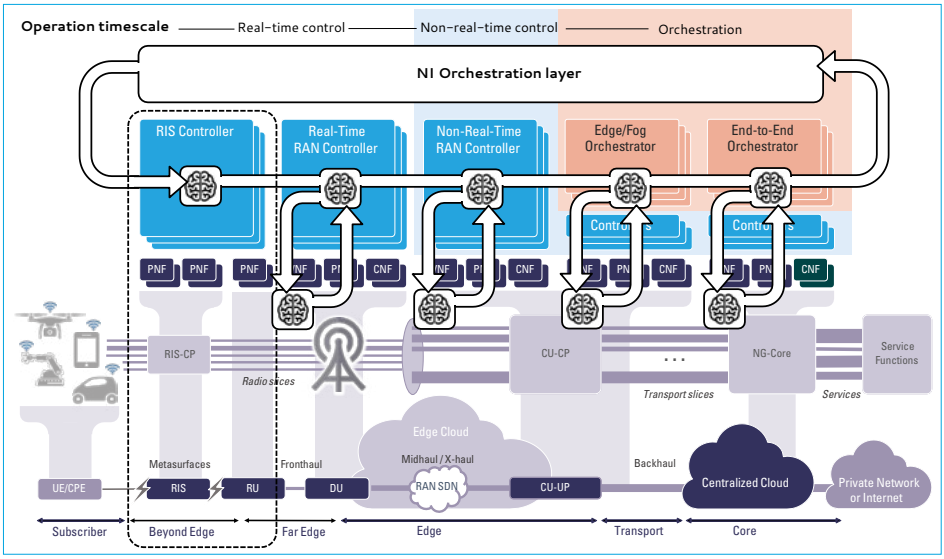

Fig. 59: Concept of the DAEMON NI-native architecture, enabling coordination of NI across all network domains, and integration of NI at individual VNFs. Here, a global NI Orchestration layer harmonises NI actions across three levels of NI operation timescales (real-time control, non-real-time control, and orchestration).

The overarching goal above is is broken down into three technical objectives.

1. **Designing a "NI-native architecture" for B5G systems.** While present efforts for integrating NI in mobile networks aim at tweaking machine learning solutions so that they fit networking environments, DAEMON upends the approach, and seeks to update the network architecture so that it natively supports NI operations. This objective stands on two pillars: (i) enhancing the current architectural vision of standardisation bodies so that it enables a comprehensive coordination across the many NI instances that operate in the network infrastructure; and, (ii) fostering a deeper and tighter incorporation of NI into the network infrastructure, by developing and demonstrating novel coordinated NI solutions that operate at the VNF level and are implemented in the user plane. An initial architectural concept abiding by the pillars outlined above is in Figure 59.

2. **Establishing fundamental guidelines for a pragmatic design of NI.** DAEMON challenges current practices in machine learning for network automation, which slightly adapt solutions developed in other computer science communities (e.g., in machine learning, or image processing) to the networking context. This conventional approach only yields a superficial integration of AI in the network architecture, hence falls short of DAEMON's vision of a NI-native B5G network. To ensure that NI can benefit to a maximum extent of recent advances in AI, DAEMON adopts a structured strategy for the definition of original AI models that are specifically tailored to NI tasks, by: (i) assessing when powerful but non-interpretable Deep Learning (DL) models are appropriate, and when statistical, analytical or hybrid models should be preferred; (ii) devising custom and/or self-learned loss functions that overcome the largely unexplored "loss-metric mismatch" problem in NI design; and, (iii) designing AI models that can adaptively trade off accuracy for network-critical metrics like computational complexity and execution times.

3. **Developing specialised NI-assisted network functionalities for 6G systems.** DAEMON designates a concrete list of key network functionalities for which it will devise and implement NI algorithms capable of taking full advantage of the proposed NI-native architecture, and spanning varied planes, domains and operation timescales. Specifically,

the project targets zero-touch operation of eight critical 6G network functionalities: (i) Reconfigurable Intelligent Surfaces (RIS) control, (ii) multi-timescale edge resource management, (iii) in-backhaul support for service intelligence, (iv) compute-aware radio scheduling, (v) energy-aware VNF placement, (vi) self-learning MANO, (vii) capacity forecasting, and (viii) automated anomaly response. These are critical functionalities that span control and user planes in diverse network domains, and run at timescales from milliseconds to hours: tackling them jointly will allow assessing the NI coordination capabilities of the DAEMON architecture, and demonstrating its advantages in terms of network performance, sustainability, and reliability.

Early achievements/innovations

DAEMON has started on January 1, 2020. The partners are currently working towards the first contributions planned for the project:

- defining the functional and non-functional requirements of NI entailed by the wide range of network functionalities targeted by the project, and ways to verify them
- identifying limitations that prevent a systematic NI integration and coordination in the current architectural models set out by standardisation initiatives, including the likes of ETSI MEC, ETSI NVF MANO, O-RAN, ONAP, or OSM.

Meanwhile, the project has already started dissemination and communication activities, by:

- establishing a presence on the web and social media (e.g., *https://h2020daemon.eu/*)
- attracting attention from the press (e.g., *https://www.6gworld.com/exclusives/daemon-eyes-greater-network-intelligence-in-6g-systems/*)
- participating in the activities of standard-defining organisations, such as the ITU-T Focus Group on "Autonomous Networks" (FG-AN)
- contributing to the 5G Infrastructure Association white paper on 6G
- organising a scientific workshop held in conjunction with ACM MobiSys 2021.

DEDICAT 6G

Dynamic coverage Extension and Distributed Intelligence for human Centric Applications with assured security, privacy, and trust: from 5G to 6G

In future 6G wireless networks, it is imperative to support more dynamic resourcing and connectivity to improve adaptability, performance, and trustworthiness in the presence of emerging human-centric services with heterogeneous computation needs. The aim of DEDICAT 6G is to develop a smart connectivity platform based on the following enablers: i) Enablers for the dynamic distribution of intelligence, the dynamic/aggregate management of communication, computing and storage resources, in conjunction with predictive caching; ii) Enablers for the dynamic coverage and connectivity extension through the exploitation of any type of device (e.g., drones, robots, connected cars, other mobile assets like fork-lifts in a warehouse, etc.); iii) Security, privacy and trust assurance especially for mobile edge services. iv) Enablers for novel interaction between humans and digital systems through innovative interfaces and devices. The overall goal is to reach higher utilisation of resources; reduction of end-to-end delay and energy consumption; reduction of operational expenditures (OPEX) and capital expenditures (CAPEX).

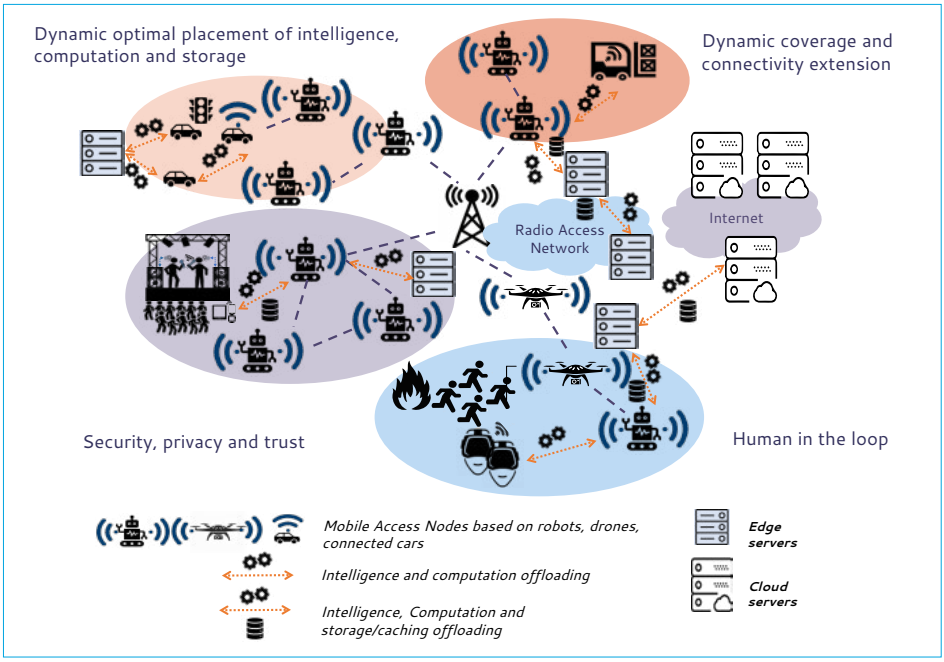

Fig. 60: DEDICAT 6G concept

Figure 60 provides an overview of the project concept while Figure 61 depicts a preliminary DEDICAT 6G baseline functional architecture. In this functional architecture, the functional entity for Goals, objectives, and policies includes information on application, service and network goals and objectives to be achieved, as well as potential policies. The functional entity on Capabilities of network elements, Mobile Access Points (MAPs) and edge devices includes information on the capabilities of these entities in terms of communication networking (e.g., radio access technologies (RATs) and spectrum, capacity, and coverage), physical movement, the type of the MAP, computation capabilities, storage capabilities and available power. The functional entity for Context and situation awareness provides information and knowledge on the context that has to be addressed in terms of computation tasks, power consumption requirements, a set of mobile nodes that need coverage, mobility and traffic profiles of the different nodes, radio quality experienced by client nodes, options for connecting to wide area networks, the locations of docking and charging stations for drone and robot MAPs and the current locations of the terminals and MAPs elements. These three functional entities provide input to the key enablers of DEDICAT 6G. The outputs of the DEDICAT 6G key enablers are logged by the Knowledge functional entity along with corresponding contexts and situations encountered (triggering those decisions), the effectiveness of the decisions and actions taken in terms of achieved power consumption, latency, QoS, cost, etc. Other information stored by the Knowledge entity is related to security, privacy and trust issues identified and corresponding actions taken. Knowledge can be developed autonomously (e.g., by each MAP or edge node) and in a centralised, aggregated manner (in the "global" cloud). Knowledge can then also be exploited by the different key enablers providing insights on actions that have proven valuable and thus speeding up the decision-making process. Actions on (i) optimal placement of intelligence, computation, and storage, (ii) coverage and connectivity extension and (iii) security, privacy and trust are then enforced on the Cloud and Edge resources and the Radio Access Network by utilising existing radio access network management and orchestration tools (e.g., ETSI OSM MANO).

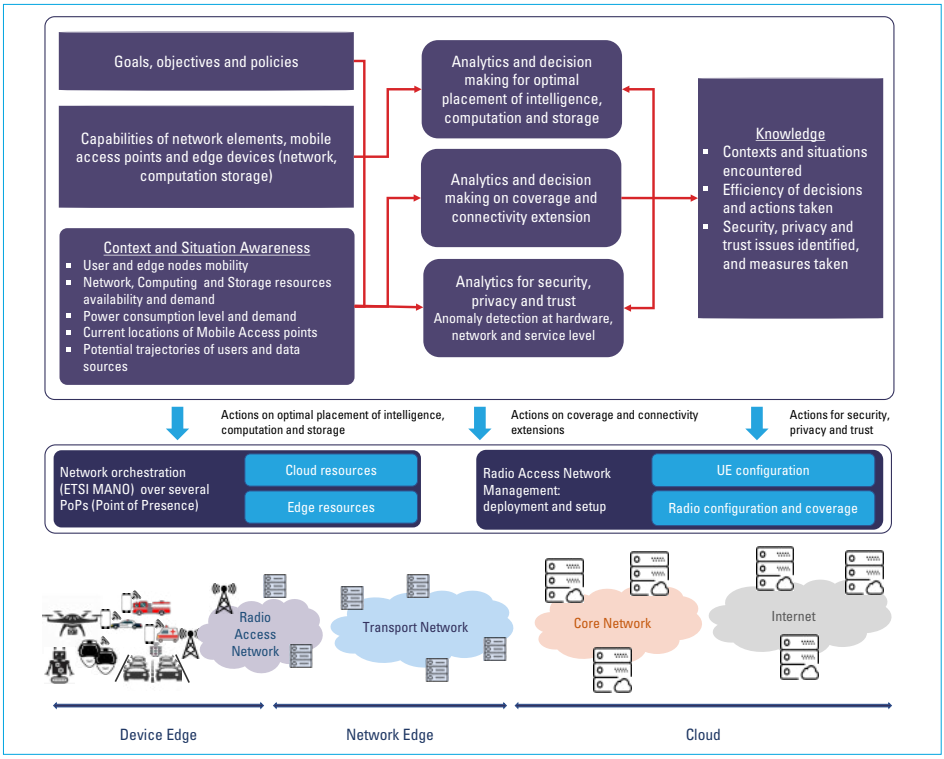

Fig. 61: DEDICAT 6G functional architecture

DEDICAT 6G focuses on four representative 6G use cases: Smart Warehousing, Enhanced Experience, Public Safety and Smart Highway. The pilots will demonstrate the pillars of the project vision for a smart and flexible connectivity platform, facilitating the integration of the developed technology and innovative interfaces and running-up the demonstration of human-centric applications. The pilots will define a set of measurable key performance indicators (KPIs) that will permit the testing of the integrated platform, both in terms of technical performance but also from the perspective of end users/stakeholders' acceptance and non-technical validation (usability, smart and reliable services, relevance, and other pertinent features of the developed solutions in each pilot). The Smart Warehousing pilot will take place at Diakinisis, Greece, led by Fondacia Vizlore Labs. It aims to demonstrate improved latency, reduced energy consumption and improved quality of experience. The Enhanced Experience pilot will take place at University of Surrey, UK and Public events in Oulu, Finland, led by VTT. It will be on demonstrating the throughput to individual users, service availability and reliability (packet losses) and end-to-end latency. The Public Safety pilot will take place in Elancourt, France, led by Airbus DS SLC, and will focus validation on improved latency, improved availability, reliability, and response time. The Smart Highway pilot will take place in E313 highway, Wommelgem, Belgium and B101, Ore Mountains, Germany, led by Interuniversitair Micro-Electronica Centrum. This pilot will pay attention to the end-to-end latency, reliability (packet delivery rate), throughput and processing time. The use cases leaders will facilitate the integration and run-up of the demonstration of the technologies developed during the project. Feedback from the participation of relevant stakeholders, not only within the scientific but also in the relevant business fields, will play a key role in the validation of the technology and business cases, smoothing the market uptake after the project end.

EVOLVED 5G

EVOLVED 5G vision and concept

With Non-Public 5G Networks (NPN) already emerged, the existing experimentation platforms around Europe should increase the development pace to incorporate realistic business cases for the use of 5G by vertical industries. In this endeavor, the directions provided by 3GPP (mainly in SA6) are considered as an effort to provide verticals with a common ground for upgrading their applications.

A central concept that has emerged is the composition of NetApps (Network Application) i.e., services that consume 3GPP APIs (native APIs) as well as other telco assets (referring to business support system – BSS APIs, e.g., service orchestration APIs) to support the vertical application with network-related capabilities. For example, a NetApp could consume APIs that provide monitoring events and network slice configuration analysis to compose a service that guarantees quality of experience for latency-sensitive applications.

EVOLVED 5G embraces the potential of the emerging NetApp ecosystem under a twofold scope: i) to build an open experimentation facility for NetApp creation, validation, and certification, and ii) to provide the means and the tools for long term evolution of 5G-enabled vertical industries.

Irrefutably, the NetApp ecosystem will be beneficial for multiple and heterogeneous vertical industries. However, at project level, a single industry approach allows for clear contributions and deeper analysis of the expected impact. In view of this, EVOLVED 5G has strategically selected the vertical industry of smart manufacturing in the context of the Factory of the Future (FoF).

EVOLVED 5G objectives

The objectives of the EVOLVED 5G project are summarised below:

- Upgrade the 5G experimentation potential in Europe, through the design, development, and release of an open 5G experimentation facility that will materialise network programmability and will expose standard 3GPP APIs (currently studied by 3GPP SA6) to enable automated NetApp validation tests.
- Materialize the openness of 5G to vertical industries by creating a NetApp development and verification environment, i.e., a workspace/SDK for third-parties, which will embrace the principles of continuous integration and continuous delivery (CI/CD) and adopt the software architecture used for microservices.
- Provide the means for enabling the digital market around the NetApps by designing, developing, releasing and maintain an active marketplace/App store that will incorporate vertical data space interaction (through IDS broker) and store NetApps that are certified by operator-driven certification tools.
- Provide a clear and quantified contribution towards the 5G penetration in smart manufacturing by designing, developing, validating, and publishing innovative NetApps and multiple applications on top of them that will cover major business use cases for the factories of the future.
- Quantify the performance and the flexibility that 5G provides to verticals, though a set of vertical-driven measurement campaigns, which will use standard reference points (e.g., the NWDAF), target critical network metrics and feed data a technoeconomic analysis.
- Maximise the technological fingerprint and the business potential expected from the integration of 5G in manufacturing, through targeted actions (trainings, workshops, and hackathons) for building an active community around NeApps development, as well as through an ambitious SME acceleration and engagement program (open access to the facility, mentoring events and business conferences).

EVOLVED 5G FoF applications

The EVOLVED 5G NetApp ecosystem will be the ground for the development of 11 FoF-related business applications based on the expertise that 11 SMEs[25] will bring to the project. The development of FoF applications will be organised around 4 major pillars of the manufacturing sector in the Industry 4.0 era, as explained in the table below.

25. GMI AERO, INTERNET INSTITUTE, COMMUNICATIONS SOLUTIONS AND CONSULTING LTD, CAFA TECH OU, INQBIT INNOVATIONS SRL, FOGUS INNOVATIONS & SERVICES P.C., INFOLYSIS P.C., EIGHT BELLS LTD, PAL ROBOTICS SL, QUCOMM IDIOTIKI KEFALAIOUXIKI ETAIREIA, IMMERSION, UNMANNED SYSTEMS OU.

Pillar	Target FoF Application Intent-driven Chatbots for precise maintenance
Innovation in the interaction of employees and machines though AR features and remote-control capabilities	Haptic-driven console for industrial surface repairing (hot bonding)
	Mixed Reality (MR) assisted manufacturing
Efficiency in FoF operations with novel predictive maintenance applied on digital factory twin	IoT/M2M-based remote monitoring platform
	AI based video analyser for industrial and robotics safety
	ML-driven anomaly detection system for Industrial Processes
Security guarantees and risk analysis for the FoF communication and management systems	L7-aware Whitebox Switch with Dynamic SFC and TSN Support
	SIEM (Security information and event management) system
	Blockchain Data Brokerage Engine
Agility in the production line infrastructure through automation and robotic parts	AI-driven Humanoid robots
	AI-driven logistics robotic fleets

Table 6: the four major pillars of the manufacturing sector in the Industry 4.0 era

An abstract representation of the EVOLVED 5G Approach can be found in Figure 62.

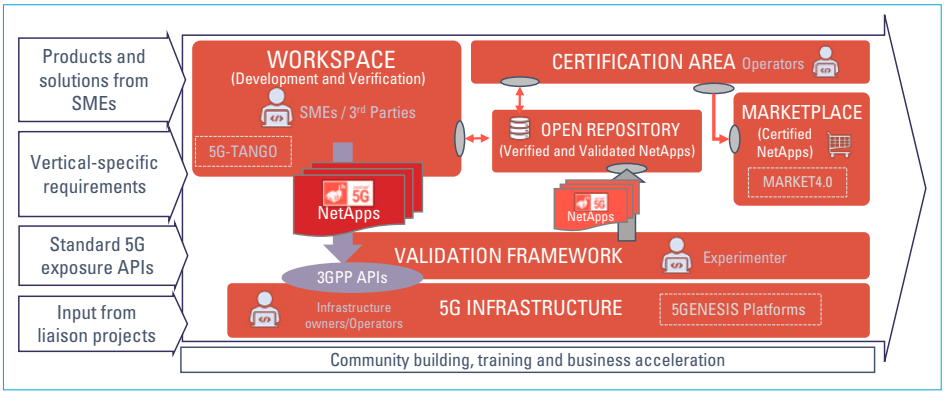

Fig. 62: EVOLVED 5G Approac

EVOLVED 5G has just started

EVOLVED 5G project started on January 1, 2021 and it is currently working on the definition of the reference architecture that will serve as the implementation blueprint of the EVOLVED 5G facility. In the next coming months, the EVOLVED 5G team will work intensively around the overall design of the reference architecture, the process definition and first steps in the actual production of the workspace (SDK) for the NetApp development and the validation framework and methodology needed for the integration between the NetApps workspace and Athens and Málaga 5G experimental facilities.

Hexa-X

A flagship for 6G vision and intelligent fabric of technology enablers connecting human, physical, and digital worlds

Project goals

The main goal of the Hexa-X project is to define a 6G vision for the world of 2030 which tightly interlinks the human world of our senses, bodies, intelligence and values; the digital world of information, communication and computing; and the physical world of objects, organisms and processes as can be seen in Figure 63. This will be done by addressing the key research challenges: **Connecting intelligence**, both human and artificial; **Network of networks**, integrating resources such as communication, data- and AI- processing, and localisation and sensing optimally connecting at different scales; **Sustainability**, addressing the critical challenges of our modern world both in terms of direct impact, but also leveraging on 6G networks to enable sustainable development both in terms of environmental and societal impact; **Global service coverage**, where digital inclusion will be a top priority and encompass efficient and affordable solutions; **Extreme experiences**, pushing the boundaries of what can be done with mobile wireless connectivity in terms of bit rate, latency, capacity, and localisation and sensing; **Trustworthiness**, ensuring that any 6G network design will be reliable, available, and resilient to be able to handle the critical service expected from the society of 2030.

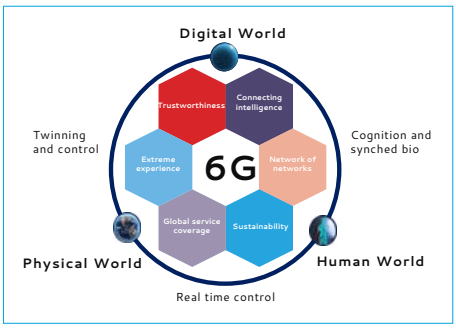

Fig. 63: Hexa-X 6G vision and key research challenges

To address the 6G research challenges, the Hexa-X project will design, develop, and evaluate technological enablers including a) *radio performance* including advances in radio access technologies towards Tbps and high resolution localisation and sensing by exploring GHz and sub-THz frequencies; b) *connecting intelligence* including native integration of artificial intelligence for e.g. network orchestration and service management as well as dynamic data-driven air-interface design; and c) *network evolution and expansion* to increase the flexibility and efficiency of networks, including specific verticals as well as facilitating the application of intelligent agents in the network by identifying and addressing roadblock in the design.

These technological enablers will be tied together in a framework — the *x-enabler fabric* — which will act as a solution space for the technical work in the Hexa-X project and will be translated into a roadmap for the future a 6G end-to-end system that will take into account intangible yet important human and societal needs and values such as sustainability, trustworthiness and inclusion.

Major achievements

The Hexa-X project started on January 1st, 2021. The project kicked-off by exploring prospective 6G use cases which will be defining the 2030 era. These use cases were grouped into five use case families in terms of their intended application as shown in Figure 64. **Sustainable development** encompasses use cases which focuses particularly on the UN SDGs of reducing inequalities by providing global access to digital services as well as the objective of climate action by energy-optimised infrastructures and services; **Massive twinning** expands on the use of digital twins by fully representing the human and physical world in the digital world allowing close monitoring and control, through sensors and actuators, of every facet of the world of 2030; **Telepresence**, expands the use of virtual, augmented and extended reality (VR, AR, XR) to allow blurring the line between the real and the virtual world, through visual, auditory, olfactory, and haptic interactions, effectively removing distance as a barrier; **Robots to cobots** leverages on the realisation and deployment of ubiquitous robots, AI agents, and autonomous systems inundating the world of 2030 as an integral part

of the society requiring close collaboration between different machines and between machines and humans; **Local trust zones** encompasses use cases which requires extreme reliability, availability, and resilience on a local scale from microscale in-body networks e.g. for health monitoring to wide are deployment of sensor networks that should be as trustworthy as local embedded sensor systems.

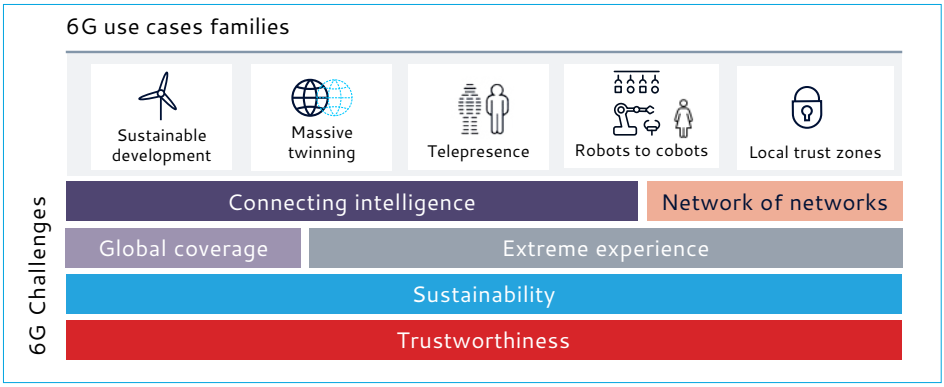

Fig. 64: Families of use cases for the 6G era mapped to 6G key challenges of research

Description of demos

The project proposes five different demos during the lifetime of the project.

- **Demo #1: 6G OTA – Waveforms in action**: verify selected 6G candidate waveforms design in Hexa-X in real environments with non-ideal RF and radio channels and evaluating the joint communication and sensing performance.
- **Demo #2: FED-XAI – Federated XAI demo**: demonstrate the developed framework for federated learning of explainable AI (XAI) models where end-user AI agents can collectively train an XAI model without exposing their data to other agents.
- **Demo #3: Flexible topologies (FLEX-TOP) for efficient network expansion**: explore the efficiency of flexible topologies, leveraging on mesh/ad hoc/D2D networking, disaggregated devices with the ability to flexibly allocate functionality (management of computing resources), ultra-high spectrum, and on coordination with the infrastructure, e.g., in terms of resources to use.
- **Demo #4: Extreme performance in handling unexpected situations in industrial contexts**: a set of robots cooperating on a task will experience an unexpected fault in the networks, devices or functionality which will be mitigated by utilising a) flexible topology and predictive orchestration; b) extreme performance to deliver high bit-rate, low latency and high performance; c) using advanced radio and positioning to address impairments.
- **Demo #5: Algorithms for data-driven device-edge-cloud continuum management**: evaluate a set of algorithms to support zero-perceived latency, through predictive state handling and service self-adaptation.

Further information is available on the Hexa-X website at *hexa-x.eu*

MARSAL

Goals of the Project

The MARSAL Project will develop and evaluate a complete framework for the management and orchestration of network resources in 5G and beyond (B5G), by utilising a converged optical-wireless network infrastructure in the access and fronthaul/midhaul segments. MARSAL breaks the barriers of the traditional cellular networks paradigm by proposing breakthrough distributed processing cell-free massive MIMO architectures, which will be integrated with existing virtualised Radio Access Network (vRAN) elements, while being in-line with the Open RAN (O-RAN) concept. It also proposes a new paradigm of elastic virtual infrastructures that integrate in a transparent manner optical-wireless convergence architectures, networking, management and security technologies, in order to deliver end-to-end transfer, processing and storage services in an efficient and secured way.

MARSAL's evolved architecture towards B5G offers unprecedented degrees of flexibility and closed-loop autonomy at all tiers of the infrastructure, and significantly improves spectral efficiency via cell-free networking. The overall concept and architecture of MARSAL is depicted in Figure 65. An evolved 3GPP NG-RAN is adopted and extended with emerging cell-free technologies for network densification. Moreover, MARSAL significantly evolves the Multi-access Edge Computing (MEC) system towards fully elastic edge computing and deploys a distributed edge infrastructure with Data Centres (DCs) structured in 2 tiers, featuring Regional Edge and Radio Edge nodes.

To achieve its goals, MARSAL focuses on three pillars to enable a new generation of ultra-dense, cost-efficient, flexible and secure networks: network design pillar, virtual elastic infrastructure pillar, and network security pillar.

At the network design pillar, MARSAL develops novel cell-free-based network and mmWave dense fronthaul solution approaches that will allow the significant scaling up of Access Point (AP) deployment in a cost-effective manner, while cell-free support will be added in O-RAN's architecture for the first time; these network architectures will achieve unprecedented spectral efficiency and increased performance due to the significant reduction of inter-cell interference, thus enabling MARSAL to address ultra-dense traffic requirements.

The elastic edge infrastructure pillar supports a fully elastic edge cloud and dynamic slicing support for the wireless and optical domains, offering zero perceived latency to MEC applications. MARSAL will implement a novel, hierarchical network control plane approach, as well as a novel ML-driven elastic edge cloud infrastructure, targeting to maximise the utilisation of network, computation, and storage resources, and achieve zero-perceived latency to smart connectivity applications.

The Network security pillar focuses on the security and privacy implications of multi-tenant infrastructures, offering a holistic framework for end-users and tenants. Novel ML-based mechanisms will be developed for the provision of data protection, integrity assurance and malicious traffic detection in multi-tenancy environments, along with a novel blockchain-based platform that targets to maximise network's flexibility in a secured approach.

MARSAL Proofs of Concept (PoCs)

MARSAL will carry out a series of demonstrations as an outcome of the proof-of-concept phase to demonstrate the practical viability of all of its targeted network, management and security technologies, to cover MARSAL's technical objective, with strong market potentials. Two PoCs will be demonstrated to highlight the novelty of MARSAL, namely:

- **PoC1: Cell-free networking in dense and ultra-dense hotspot areas**

  This PoC will showcase cell-free networking, which can offer seemingly infinite capacity and mitigate cell edge challenges in hotspot areas. The PoC will explore two deployment scenarios for MARSAL's cell-free NG-RAN:

  - *Experimental scenario 1 - Dense user-generated content distribution with mmWave fronthauling*

    This scenario will demonstrate and evaluate MARSAL's distributed cell-free NG-RAN in terms of increased capacity and spectral efficiency gains, and the adaptivity of dynamic

clustering and radio resource management mechanisms in managing connectivity resources in a dynamic environment with varying hotspots areas. Furthermore, this scenario will evaluate the ability of Hybrid MIMO Fronthaul to offer a dynamic AP topology.

- *Experimental scenario 2 – Ultra-dense video traffic delivery in a converged fixed-mobile network*

  This scenario will showcase MARSAL's solution towards fixed-mobile convergence in an ultra-dense indoors scenario. Mobile clients served by a distributed cell-free RAN will share the optical midhaul with fiber-to-the-home (FTTH) clients. The scenario will evaluate the spectral efficiency and channel capacity gains of the distributed cell-free RAN in a serial fronthaul topology, along with the load balancing and end-to-end slice reconfiguration mechanisms of the converged infrastructure.

· **PoC2: Cognitive assistance and its security and privacy implications in 5G and beyond**

This PoC will demonstrate MARSAL's multi-tenant elastic edge infrastructure for cognitive assistance (AR/VR) applications and will also address security and privacy implications in applications that process personal data and Personally Identifiable Information (PII) as per the GDPR. Two scenarios will be considered for this PoC:

- *Experimental scenario 1 – Cognitive assistance and smart connectivity for next-generation sightseeing:*

  This scenario will demonstrate MARSAL's virtual elastic infrastructure, showcasing its ability to ensure high reliability and quality of experience for next-generation human-centred applications with new terminal types, while sharing resources with high-priority 5G network functions.

- *Experimental scenario 2 – Data security and privacy in multi-tenant infrastructures*

- This scenario will demonstrate MARSAL's privacy and security mechanisms that guarantee the isolation of slices and ensure collaboration of participants in multi-tenant B5G infrastructures without assuming trust. These mechanisms will also be evaluated in terms of their ability to mitigate the increased privacy risks of next-generation internet applications that process PII.

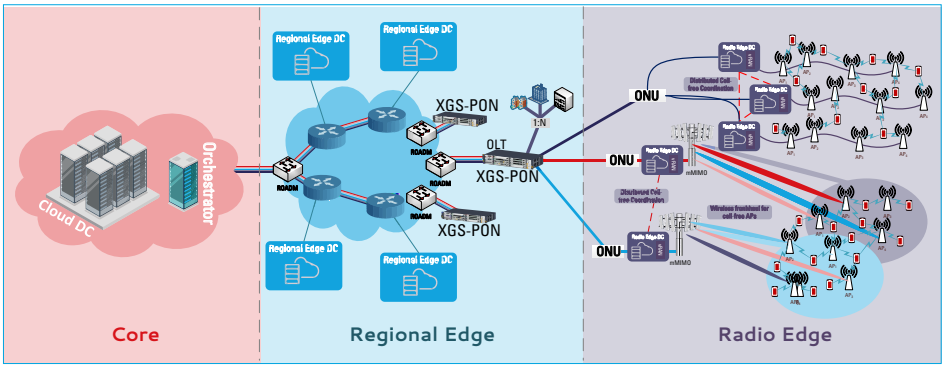

Fig. 65: Main concept of MARSAL project describing a complete 5G system set-up from access to the core networks

REINDEER

The next generation of multi-antenna connectivity

Goals of the project

The REINDEER project will develop a new smart connect-compute platform with a capacity that is scalable and offers perceived zero latency while interacting with an extremely high number of embedded devices. This is made possible through the development of RadioWeaves technology: a new wireless access infrastructure consisting of a fabric of distributed radio, computing, and storage resources which function as a massive, distributed antenna array.

Many future applications will rely heavily on wireless connectivity to offer interaction in real time with imperceptible latency and unnoticeable dislocation between virtual and real elements. Applications could include a remote medical expert wearing lightweight augmented reality (AR) glasses with a built-in camera, which can monitor the patient health data and control medical equipment. The glasses operate as an energy-neutral device, which are charged wirelessly via signals transmitted from the REINDEER platform. They receive HD video streams for the displays, but all processing is off-loaded to the infrastructure. Likewise, in manufacturing areas, people and machines will cooperate, with an increasing number of robots and autonomous vehicles and drones. By 2030, one could expect merged realities where physical and virtual realities will be interchangeable. These applications will require unperceivable latency and high reliability. No retransmissions can be tolerated, and zero outage is required in their operational environment. This will furthermore require precise positioning technology that offers a high accuracy in any point in the coverage zone.

Innovations and KPIs

The REINDEER project will bring essential innovation to progress both the platform architectures and the protocols and algorithms to realise the great potential in actual deployments and to establish future interactive applications. **A transformational RadioWeaves smart connectivity platform** will be developed as energy-efficient, smart, scalable and secure connectivity infrastructure, and topologies for zero-outage and efficient and secure deployment. REINDEER works on scalable protocols and algorithms for **cell-free operation**, and signal processing solutions for **resilient interactive applications and cooperation** with (100x higher density) 'energy-neutral' devices through pro-active diversity, location learning, and distributed intelligence – accomplishing imperceptible latency and with a service probability exceeding 99,9999%. An experimental **validation** and **demonstration** of the **RadioWeaves smart connectivity platform** and the REINDEER algorithms for robust applications and interaction with energy-neutral devices will be performed. The REINDEER results will be shared with a broad group of stakeholders and the scientific community to promote the technological vision in pre-standardisation activities and to ensure **interoperability**.

Description of application areas

REINDEER will focus on the analysis and specification of technical requirements for future **interactive applications** in industrial, entertainment and care use cases:

1. **Adaptive robotised factories, warehouses, and logistics:**

   In future factories, warehouses, and logistics, applications will **critically rely** on wireless connectivity, and requiring zero-outage and imperceptible latency communication. Moreover, high quality localisation is needed for robots, autonomous vehicles and instruments to cooperate. Cooperation of people and machines in the same space will require many simultaneous broadband links. Ultimately, one wants to track all goods, based on energy-neutral devices. Manufacturing and industrial settings are typically highly reflective and feature many blocking objects. Future interactive applications in these environments will hence face combined challenging requirements.

2. **Immersive entertainment for crowds of people:**

   Crowds of people will want to enjoy immersive entertainment, realised through augmented experiences and mixed-reality support. Besides a high-throughput link, this also

requires very low latency. The future connectivity infrastructure needs to offer a capacity than can be scaled up to support a **very high number of individual video services and enhanced user experiences** to be offered in places where crowds gather, far beyond the capabilities current and emerging wireless networks. This occurs in large and typically relatively open spaces such as a stadium, on a festival ground, in big halls or auditoriums.

3. **Natural human-machine interaction in care environments, hospitals, and assisted living:**

   Future human-oriented applications will need to provide intuitive experiences for people interacting with robots and objects in their environment. The **people-friendliness** of the experiences is thereby extremely important. The latter applies to both the reliability of the application, people may need help from robots, and the esthetical integration of the electronics in the environment.

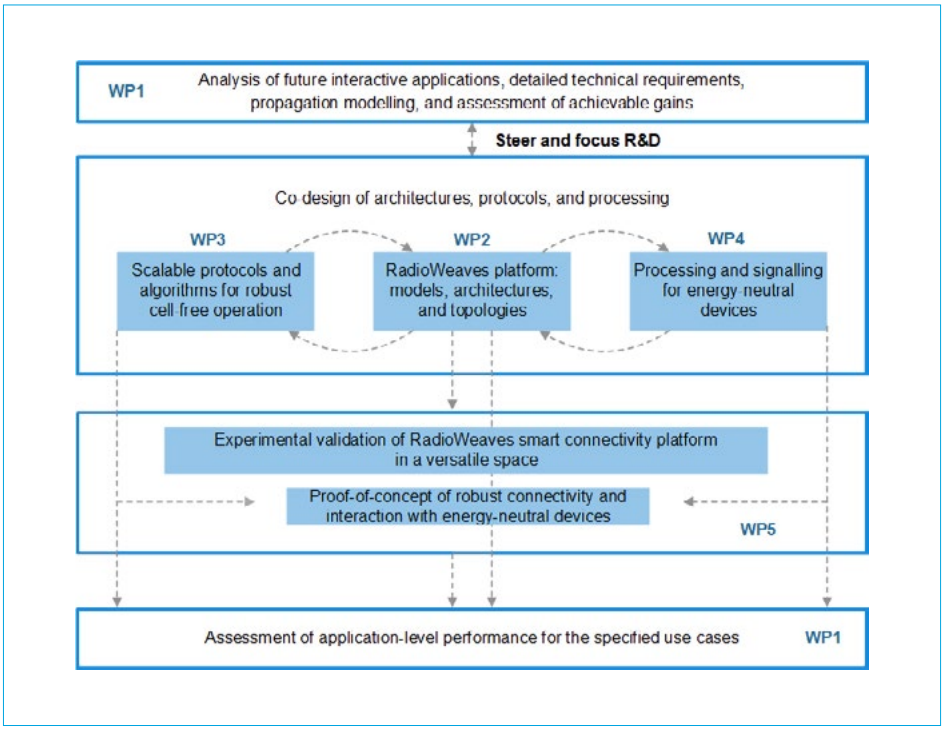

Fig. 66: Methodology to advance innovation driven by use cases

Reconfigurable Intelligent Sustainable Environments for 6G Wireless Networks

The RISE-6G project is focused on the design and operational management of Reconfigurable Intelligent Surfaces (RISs) to create and shape on demand smart radio environments, where the wireless propagation conditions are co-engineered with the physical-layer signaling and infrastructure, and to investigate how to utilise this new design dimension.

The project's ambition is to go well beyond the current state-of-the-art on the RIS technology and to build a novel wireless connectivity paradigm empowered by this pioneering hardware with a two-fold advantage: i) to enable highly concentrated in time and space service delivery to intended end users; and ii) to remove energy from indoor/outdoor regions, where non-intended users are present.

The RISE-6G vision is indeed to enable a wireless environment as a service (see Figure 67), by smart use of RISs, going beyond the current vision that the wireless communication environment is uncontrollable and that the communication system has to adapt to it. The project will focus on the exploration of the potential of artificially controlling and shaping the wireless communication channel to support dynamic adaptation to future stringent and highly varying 6G service requirements, in terms of Electro-Magnetic Field (EMF) Emissions, localisation accuracy, Energy Efficiency (EE), secrecy guarantees, as well as legislation and regulation changes, while incurring minimal connect-compute network redesign and reconfiguration costs. This approach is opposed to the up-to-date trend, where propagation environments are seen as uncontrollable and imposed by the communication context. It's the RISE-6G vision to promote the dynamical trade-off of the latter key performance indicators under multi-objective design optimisation frameworks, enabling performance-boosted geographical areas.

To this end, the RISE-6G project focuses on: i) the realistic modelling of RIS-assisted signal propagation; ii) the investigation of the fundamental limits of RIS-empowered wireless communications and sensing; and iii) the design of efficient algorithms for orchestrating networking RISs, in order to implement intelligent, sustainable, and dynamically programmable wireless environments, enabling diverse services that go well beyond the 5G capabilities.

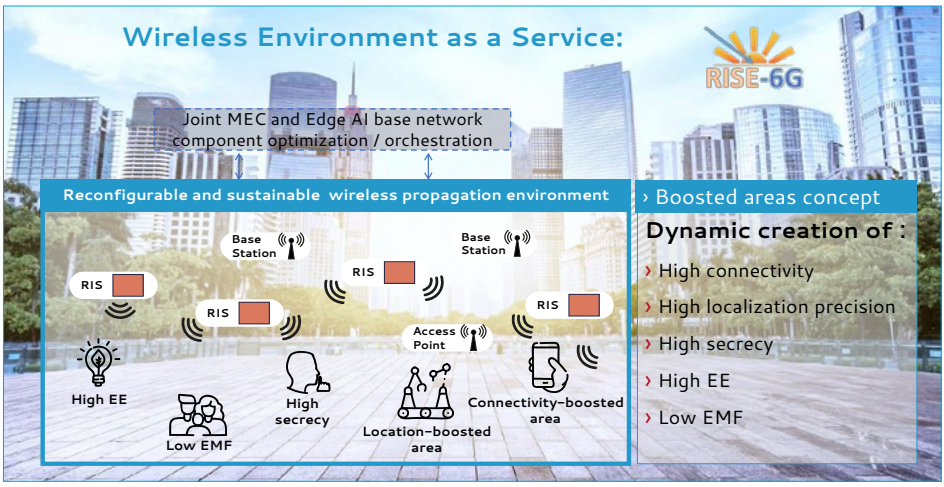

Fig. 67: The RISE-6G wireless environment as a service enabled by the RIS technology, offering highly concentrated in time and space performance-boosted areas.

Scenarios and Use cases.

The RISE-6G project will investigate both sub-6GHz and millimeter-Wave (mmWave) frequency bands. Among the scenarios that are likely to benefit from the adoption of RISs, the following will be prioritised:

Enhanced Connectivity and Reliability: If the quality of experience / service of a wireless network is below expectation, an RIS is applied to improve the radio coverage both in outdoor and indoor. RIS-empowered wireless connectivity needs to be implemented in compliance with regulations and EMFE limits;

Localisation and Sensing: The RIS technology is expected to enable advanced sensing and localisation techniques for environment mapping, motion detection, opportunistic channel sounding, and passive radar capabilities applied to various environments: industrial, high user-density and indoor.

Sustainability and Security: RIS-empowered networks are expected to enable the reduction of the energy spent to radiate the wireless signals, to improve the EE, reduce the EMFE, and increase the security due to highly directive and location-dependent communications.

Proof of concepts.

RISE-6G will offer two unprecedented proof-of-concepts for realising controlled wireless environments in near-future use cases. The goal is to substantiate the attainable performance of RIS-empowered wireless propagation environments, while pursuing different objectives, such as overall performance optimisation and localisation accuracy maximisation. More specifically, two exemplary scenarios have been selected for RIS-based performance boosted proof of concepts: a train station and a vertical Industry 4.0 setup, respectively (see Figure 68).

- **The Train Station Scenario for Proof of Concept**

  An RIS-empowered solution will be properly and carefully set up in the train station located in Rennes, France. To facilitate the deployment of such proof-of-concept, generic distribution control networks will be developed to centrally control all RIS-based equipment considered in the scenario.

- **The Connected Factory Scenario for Proof of Concept**

  The RISE-6G project will deploy RISs within a smartly connected factory scenario. In particular, it will focus on the industrial operations in an automotive plant of Fiat-Chrysler Automobiles (FCA). Inside the plant, a variety of processes (logistics, for example, for sub-assembly, preparation, and transport of components or group of components (called kits) from logistics areas to lineside) require precise positioning of their moving assets: components, containers, racks, kit handlers, Autonomous Guided Vehicles (AGV), unmanned aerial vehicles, and robots. Moreover, this proof of concept will enable the validation of the proposed solution aiming at minimising the number of installed RISs required to seamlessly cover entire working areas, as well as at identifying the best localisation algorithms offering resolution/refresh rate trade-offs.

Fig. 68: RISE-6G Proof of concepts scenarios: Train station (left) and vertical Industry 4.0 at FCA premises (right).

Smart5Grid

Goals

Smart5Grid aims to revolutionise the Energy Vertical industry through the successful establishment of four fundamental functions of modern smart grids: (i) automatic power distribution grid fault detection, (ii) remote inspection of automatically delimited working areas at distribution level, (iii) millisecond level precise demand- respond monitoring control, and (iv) real-time wide area monitoring in a creative cross-border scenario.

Since underpinning experimentation with a fully softwarised 5G platform for the energy vertical industry is one of the key targets of the project, Smart5Grid also proposes an open 5G experimental facility supporting integration, testing and validation of 5G services and NetApps from third parties. Moreover, to supply start-ups and newcomers with the opportunity to accelerate their growth in the energy industry, Smart5Grid provides an open access NetApp repository, provisioning support and assistance to third parties through a clear and trustworthy experimentation roadmap.

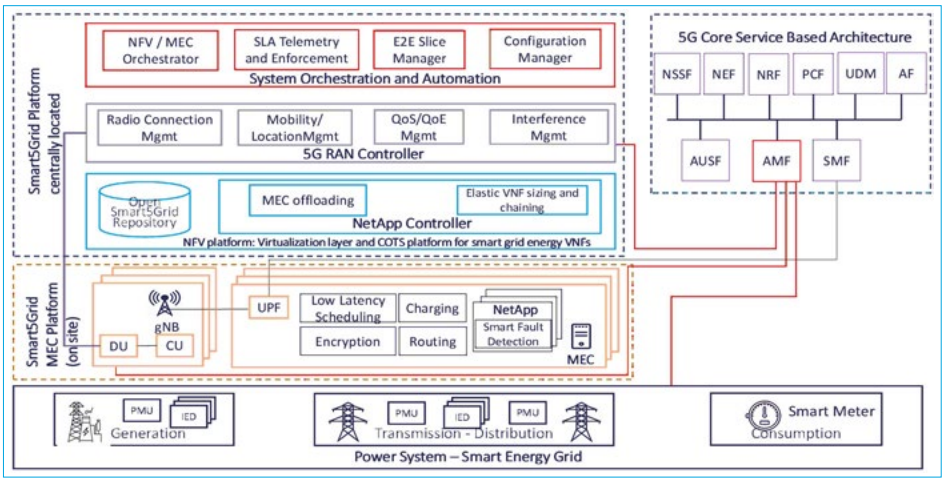

Fig. 69: Smart5Grid high level functional architecture

Main innovations

- Open experimental 5G network platform customised for Smart Power Grids.
- Open Service Repository to develop and accommodate NetApps, providing rapid access and execution environment to developers from the energy vertical sector.
- Validation and Verification framework for NetApp automatic testing, certification, and integration.
- High-performance NetApps supporting the ambitious Smart5Grid energy-oriented use cases.

Description of demos

Four use cases tailored to the requirements of existing real operational issues faced by the modern smart energy grids will be implemented.

- **Automatic Power Distribution Grid Fault Detection:** The goal is to minimise the System Average Interruption Duration (SAID) and Customer Average Interruption Duration (CAID) Indexes by the detection and isolation of failures in milliseconds, allowing the normal function of the rest of the network. ***Demonstration setup:*** Installation of Remote Terminal Units in Primary and

Secondary Substations of ENEL grid in Olbia (Italy) for transmitting energy telemetry data to the Supervisory Control and Data Acquisition (SCADA) system of the operational centre. Public WI3 5G network will be used.

- **Remote Inspection of Automatically Delimited Working Areas at Distribution Level:** The goals will be: (i) generating a detailed 3D volumetric model of the power grid assets where the work will be carried out, (ii) automatically delimitating in a volumetric way the working areas (safety areas) and tracking the authorised personnel, (iii) permitting the real-time communication of big data generated from the fixed infrastructure sensors, worker sensors and cameras within the working area, (iv) allowing the real-time remote monitoring of the work and capture the movements of the different technicians, and (v) processing collected big data and providing real-time warning signals and alerts. ***Demonstration setup:*** Primary substation with open-air busbars (Garraf Natural Park, Barcelona, Spain). Private 5G network with edge-computing capabilities to be deployed.

Fig. 70: Garraf Natural Park Primary substation

- **Millisecond Level Precise Distribution Generation Control:** This use case aims at developing a monitoring and telemetry platform under real operational conditions that will (i) facilitate energy generation/consumption forecast for balancing purposes and (ii) enable energy cost optimising and visualization of end user behaviour to optimally manage the energy profile, operational availability and flexibility services through respective markets (intraday and balancing markets) in millisecond-level information exchange. The platform will be designed for Hydro, Solar and Wind Power Plants, providing all the real-time operational information of the renewable energy sources plants to the system operators and plant owners, allowing flexible plant management for procuring accurate and secure demand-respond services by the Distribution and Transmission System Operators (DSO/TSO) as well as visibility to plant owners for optimal plant management. ***Demonstration setup:*** Various power electronic devices (i.e: sensors, inverters, control units) of grid-connected, decentralised wind power plant in South East Bulgaria – Sliven region will be connected to the Smart5Grid platform. The main innovation in this use case is to find, test and concept-proof an IoT solution working over 5G connectivity to provide grid flexibility services. Public 5G network operated by Vivacom will be used to provide the connectivity.

- **Real-time Wide Area Monitoring:** The goal is to develop a 5G virtual Phasor Data Concentrator (PDC) enabling: i) the comparison of different measured variables from various monitoring Phasor Measurement units (PMU) for both real-time and historical data, ii) the real-time monitoring of triggered events detected by PMU devices, as well as snapshots of the events in various levels of detail, iii) the real-time displacement of the rate of change of frequency across the entire monitored network, and iv) configuration of the voltage magnitude and angle difference state measurements across the distribution and transmission grid segments in real-time. It will be also applicable for TSO-DSO PMU configurations to maintain the stability of the overall power grid at national level. It will provide a more reliable TSO-DSO PMU communication link, at both national levels (Greece and Bulgaria individually), but also a TSO PMU configuration for interconnected cross-border smart grids. ***Demonstration setup:*** Existing PMU devices of the cross-border area of Northern Greece and Southern Bulgaria. Public 5G network operated by Vivacom and OTE will be used for the collection and propagation of PMU measurements in Bulgaria and Greece respectively. In case of lack of 5G coverage at any desired location, alternative solutions will be investigated.

TeraFlow

Goals

TeraFlow will create a new type of secure cloud-native SDN controller that will radically advance the state-of-the-art in beyond 5G networks. This new SDN controller shall be able to integrate with the current NFV and MEC frameworks as well as to provide revolutionary features for both flow management (service layer) and optical/microwave network equipment integration (infrastructure layer), while incorporating security using Machine Learning (ML) and forensic evidence for multi-tenancy based on Distributed Ledgers.

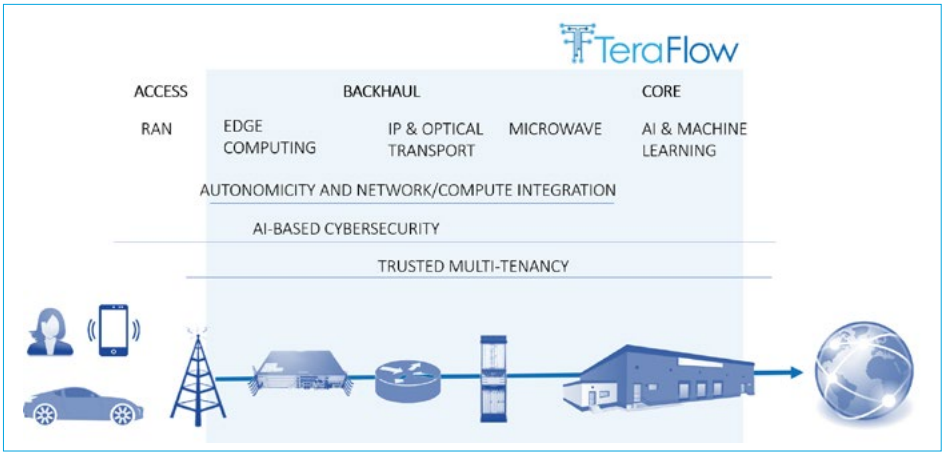

Fig. 71: TeraFlow SDN controller applicability scenario

Main achievements

The novel TeraFlow architecture will be validated through the implementation of the TeraFlow OS with the following innovations: a) Cloud-Native Architecture; b) Transport Network Integration; c) Unification of Network and Cloud Resource Management; d) Machine Learning based security; and e) Distributed Ledger Technologies.

The target pool of stakeholders expands beyond the traditional telecom operators towards edge and hyperscale cloud providers. These actors will benefit from TeraFlow by a) exploiting a new type of secure SDN controller based on cloud-native solutions while, b) achieving substantial business agility with novel and highly dynamic network services with zero-touch automation features. During the course of the TeraFlow project, experimental implementation and demonstration of prototypes will also play an important role in the project, including communication and dissemination activities and strong collaboration with Standard Defining Organisations (ETSI NFV, ZSM, ENI, PDL, IETF, ONF), and open source software community with dedicated focus on ONF ONOS and ETSI OpenSourceMANO. TeraFlow will also foster strong relationships with other 5G PPP projects through multiple collaboration activities. A concrete plan for TeraFlow results adoption will be implemented as well.

Demos

In the context of TeraFlow several use cases will be examined focusing on a variety of telecom and vertical industry services. More specifically, TeraFlow will demonstrate: (a) Autonomous Networks Beyond 5G, with focus on transport network infrastructure for B5G, (b) Automotive scenario, where vehicles are becoming autonomous and wirelessly connected to cooperate with each other for safer and more efficient driving, and (c) Cybersecurity scenario that includes threat analysis and protection.

- **Autonomous Networks Beyond 5G**

  The advent of 5G networks brings the opportunity to deploy new services in the network. Each service and/or network slice may require specific resources from the network. When moving towards scenarios B5G, we expect that the network will deliver any service that end users or applications request with certain guarantees by consuming network resources. This means that the network must be able to provide such adaptation capabilities, relating the requested services to the specific underlying network resources that are offered. These network resources need to be orchestrated in order to provide multi-layer multi-domain services.

- **Automotive**

  The automotive industry is evolving towards a vision where cars are becoming autonomous and wirelessly connected to cooperate with each other for safer and more efficient driving. Today, the majority of safety and efficiency features in vehicles are supported by the on-board sensors, which are limited to visual line-of-sight. Connectivity offers a good complement to the on-board sensors by extending vision and detection range even when visual line-of-sight is not available, while deploying cooperative, connected, and automated mobility (CCAM) services.

- **Cybersecurity**

  Cyberthreat analysis and protection is one of the most significant TeraFlow objectives, including the design and development of a scalable ML-based Intrusion Detection System (IDS) for protecting the TeraFlow network and infrastructure against advanced network threats at multiple transport layers. Moreover, the use of distributed ledger technologies is also important and this use case will help to demonstrate relevant TeraFlow capabilities.

VITAL5G

Project Concept and Goals

The strategic objective of VITAL5G[26] is to create an open, virtualised and flexible experimentation facility comprised of an intelligent virtual platform, three distributed European 5G-testbeds (Antwerp, Athens and Galati (Danube)) and associated vertical infrastructure, to enable the testing and validation of Network Applications (NetApps) for Transport and Logistics (T&L) services in real-life conditions, utilising 5G connectivity. To that end, VITAL5G engages significant logistics stakeholders (Sea/River port authorities, road logistics operators, warehouse/hub logistic operators), Mobile Network Operators (MNOs), as well as innovative SME experimenters, thus prioritising a multi-modal focus and addressing challenges of the entire 5G-enabled T&L ecosystem.

VITAL5G's concept of NetApps is defined as virtual applications that are built and distributed through self-contained packages comprising their virtual images and metadata, descriptors and scripts that simplify their composition in service chains formed by virtualised and physical functions. Multiple NetApps will be developed, enhanced and validated over the complementary facilities offered by VITAL5G infrastructure, while the invitation towards 3rd party experimenters will allow for external SMEs to build and validate their T&L solutions and services utilising the VITAL5G NetApps and experimentation facilities.

26. https://www.vital5g.eu/

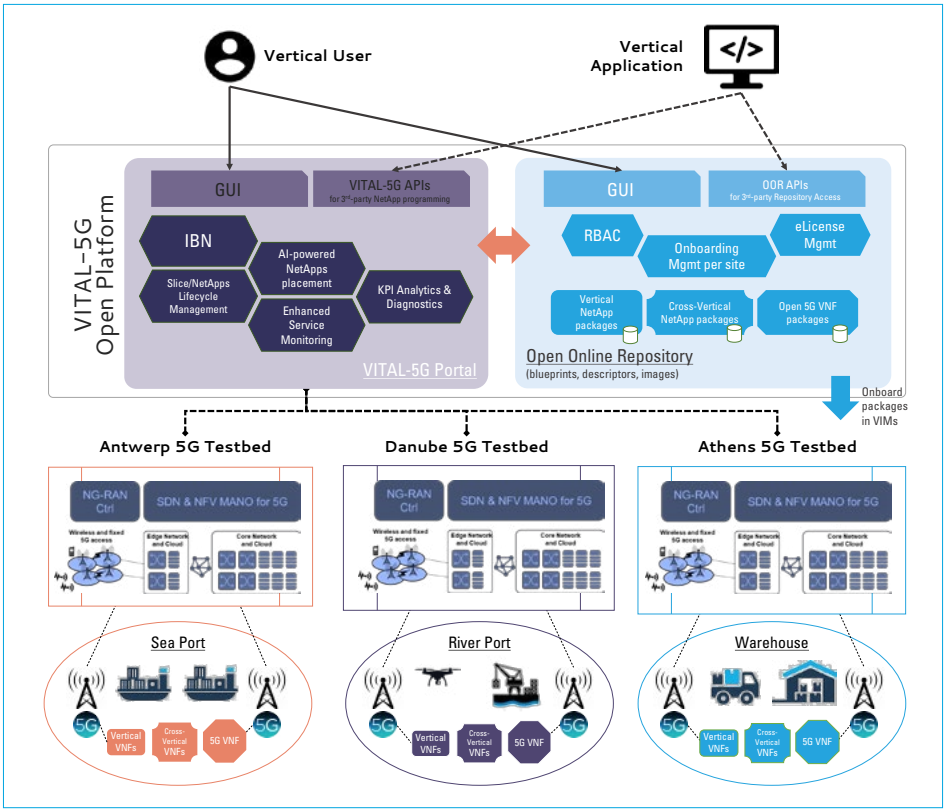

Fig. 72: VITAL5G System Architecture

The VITAL5G conceptual architecture, shown in Figure 72, is structured in two layers: i) the VITAL5G Open Platform implementing all tools and services for design, on-boarding, deployment, orchestration, monitoring, validation and diagnostics applied to T&L vertical services and ii) the three 5G-enabled T&L testbeds.

The VITAL5G platform will consist of a Service Portal for T&L services lifecycle management and an Open Online Repository to share NetApps from different software developers. The coordinated actions of these two functional blocks will allow VITAL5G's vertical stakeholders to design, onboard, instantiate, manage and benchmark their T&L NetApps. The platform will support a multitude of experimentation tools, such as Intent-Based interfaces (IBN), programmatic APIs, Machine Learning (ML) algorithms, analytics dashboards and more, to facilitate and enhance the experimentation experience.

Experimentation Infrastructure and Targeted Trials

Three industry-driven use cases (UCs) have been selected for trials over the VITAL5G experimentation facilities.

- **Use Case 1: Automated vessel transport – Antwerp facility**

  In the Port of Antwerp UC, 5G connectivity and slicing will be used to control semi-autonomous vessels. A real-time digital twin will be built around the vessel to support the remotely controlled vessels. In parallel, real-time route planning will be foreseen to optimise the port operations and to avoid idle times, it will be based on berthing time slots provided by the port authorities and terminal operators, the optimisation will be performed based on ML/AI methodologies.

The Antwerp 5G-testbed is based on i) infrastructure of Telenet's (MNO) Innovation Centre, ii) connectivity, infrastructure and system built for the 5G BLUEPRINT project[27] and iii) connectivity and supporting infrastructure built for Telenet's 5G commercial launch in Flanders. The complete system will provide a fully standalone (SA) 5G network supporting 3GPP Rel.16 and will further comprise a virtualised 5G Core, MEC nodes and multiple end devices, supporting end-to-end slicing.

- **Use Case 2: Warehouse/freight logistics – Athens facility**

  The Athens based UC targets the automation and remote operation of freight logistics, effectively instantiating the concept of a Smart Warehouse. The target is to facilitate and optimise day-to-day warehousing operations, through an integrated state-of-the-art operational system based on Automated Guided Vehicles (AGVs) and the easy deployment and control/operation of such services via NetApps. To that end, the UC will investigate concepts such as lean warehousing (elimination of time waste), in-warehouse route optimisation with obstacle avoidance, remote surveillance and control, human-AGV collaboration, intelligent product inspection and more.

  The Athens experimentation facility is comprised of the 5G-testbed owned by OTE (MNO), created in the context of the 5G-EVE project[28], and the state-of-the-art logistic-hub of DIAKINISIS, the largest 3rd Party Logistics Greek operator. The 5G-testbed will be upgraded from its current Non-Stand Alone (NSA) version to 3GPP Rel.16 compliant SA and will provide indoor and outdoor connectivity over fiber backbone.

- **Use Case 3: Data-enabled assisted navigation – Galati (Danube) facility**

  This UC is focused on the implementation of a data-enabled assisted navigation application using IoT sensing system and video cameras installed in Galati river port, on a ship and barges. The UC will leverage on IoT, data fusion, ingestion, post-processing, fraud detection and sanity checks applied on the sensor data for ship insurance purposes based on AI/ML mechanisms over 5G connectivity. The UC application will allow a safer port operation and more secure navigation, even in severe weather and water conditions.

  The Romanian 5G-testbed is based on the Orange Romania (MNO) testbed platform, using parts of the commercial 5G network and experimental opensource components, created by the 5G-EVE project2. The testbed, which is currently a Rel.15 compatible NSA network, will be progressively upgraded to a Rel.16 SA network, supporting various orchestrators (ONAP/OSM), VNF onboarding and network slicing.

Targeted Innovations

VITAL5G aims to minimise the knowledge/expertise gap between telecom providers, vertical industries and application developers through the promotion and validation of NetApps. To that end specific innovative results, stemming from three innovation areas, will be delivered by the project, as depicted in Figure 73.

27. https://www.5gblueprint.eu/

28. https://www.5g-eve.eu/

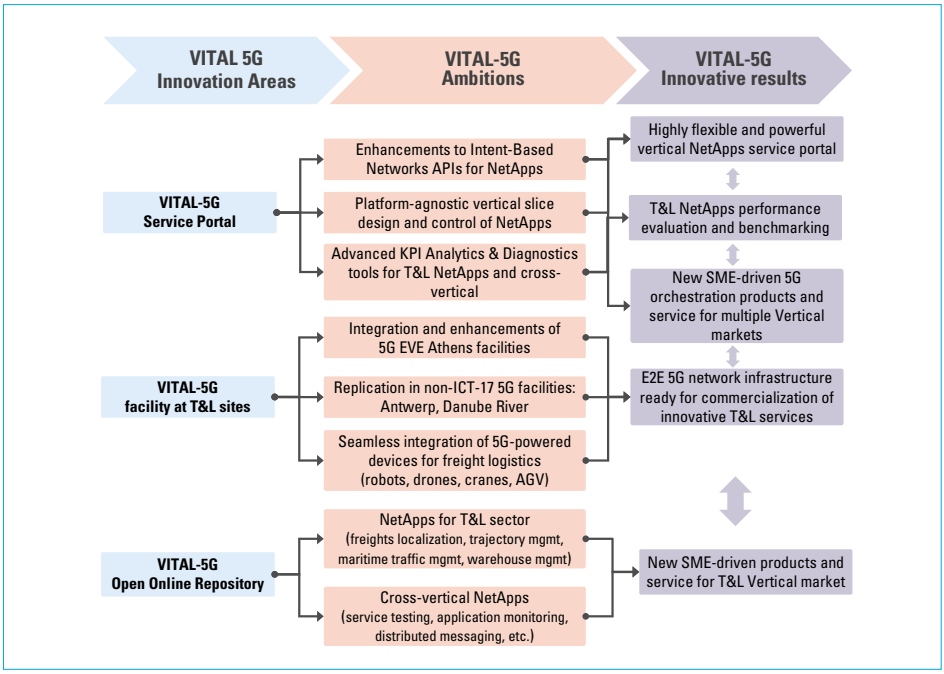

Fig. 73: VITAL5G's innovation map

SME success stories and results out of the 5G PPP projects

The 5G has entered its final stage, with the latest calls for proposals being held in 2020. At the same time, the number of running projects has never reached such a high level. This shows very well that developing and implementing 5G products still requires a lot of effort, in parallel with testing the 5G-based solutions in various contexts and vertical sectors, to ensure that the deployment will run smoothly, as well as the acceptance of the users to those innovative applications.

In this environment, the participation of Small and Medium-sized Enterprises (SMEs) in the 5G PPP is also higher than ever. The effort of promotion of SME skills and expertise has been increased throughout 2020, with not only annual but bi-annual revisions of the "SME brochure" and the "Find your SME" web page. In addition, the most recent 5G PPP ICT-41-2020 call for proposals entitled "5G PPP 5G innovations for verticals with third party services" recommended a strong participation from SMEs.

Now that all 5G PPP calls for proposals have been completed, **SME participation in the 5G PPP has reached 22%**, exceeding the original targeted Key Performance Indicator (KPI) of 20%. This represents a total EC funding for SMEs of 156.3 million euros. **The budget for the participation of SMEs in the "5G PPP 5G innovations for verticals with third party services" projects is 49%, showing the high interest and relevance of SMEs to contribute to 5G innovations for vertical sectors**.

55% of the SMEs contributing to the ICT-41 projects are participating in their first 5G PPP projects. In the 5G PPP as a whole, 2/3 of the SMEs participate(d) in one project. SMEs represent 24.5% of the 5G PPP contributors, in number of participants.

The number of members of the NetWorld2020 SME Working Group has again increased regularly, reaching almost 200 members, including 170 SMEs. This represents an increase of more than 20% in the SME membership in the Working Group in 2020.

All of this shows that despite the current pandemic crisis, that also led to cancelling major events for SMEs such as the Mobile World Congress 2019, and other major events e.g., EuCNC, being converted to online events, the presence and contribution of SMEs to innovation in 5G and beyond, is still strong.

As we are moving along throughout the life of the 5G PPP, SMEs have more and more success stories to report.

The participation of Azcom Technology from Milan, Italy, in a couple of 5G PPP projects, helped them improve their suite of software IPRs and hardware platforms, to build and deploy commercial and special purpose solutions for cellular communications, automotive, aerospace, home automation and mobile applications, both in terms of products and services.

The knowledge and innovation gained from the involvement of the Cypriot company eBos Technologies in several 5G PPP projects have been fused into their solutions and services, allowing them to strengthen their expertise in 5G and apply it to different vertical domains such as Factories of the Future, Smart Energy, Smart Cities and Ports, Media & Entertainment, Transport & Logistics, and Autonomous Mobility.

Incelligent from Athens, Greece, has been involved in three 5G PPP projects, offering its personnel the opportunity to enhance their competencies with respect to the 5G ecosystem. The company aims to enhance its engagements in the telecommunications sector and expand its portfolio of solutions, adding new enhanced software modules/ functionalities. The new functionalities and insights yielded will be exploitable by current products and for enabling other vertical/ 3rd party services.

Within the 5G-PHOS project, Iquadrat Informatica from Barcelona, Spain, has developed a software that enables SDN-based dynamic network resource management for 5G fronthaul configurations that optimises the fronthaul's grade of service and power consumption by adjusting the functional splitting according to the fronthaul load levels.

Through activities in 5G PPP, the Greek company WINGS ICT Solutions conceived vertical solutions that leverage on advanced wireless technologies, while contributions were made for the development and validation of various technology components, addressing vertical areas such as utilities, food security, smart city applications, and industry / logistics.

SMEs also address specific aspects of 5G. In the context of 5G Solutions, the Italian SME from Naples CyberEthics Lab's approach helped to create awareness among consortium partners of ethical and legal risks. EANTC from Berlin, Germany, provides benchmarking methodology, state-of-the-art testing expertise, and certification guidelines, in several H2020 projects focused on 5G networks and applications.

SMEs are also preparing for the upcoming Smart Networks and Services (SNS) Partnership within Horizon Europe. Many discussions have been held within the SME Working Group, leading to recommendations for the implementation of the Partnership, and proposed contributions to the 1st SNS work programme, that is still being drafted at the time this article is written. **This shows that while SMEs are still spending much effort in the development and deployment of innovative 5G solutions, they are also starting to think about what lies beyond**.

The SME Working Group (WG) is gathering about 200 members including 170 SMEs. 350+ SMEs are members of NetWorld2020, the European Technology Platform for telecommunications and related services and applications. The SME WG is jointly supported by NetWorld2020 and the 5G Infrastructure Association (5G IA). The current SME representatives in the 5G IA Board are Nicola Ciulli from Nextworks and Jacques Magen from Australo. There are four SME representatives in the NetWorld2020 Steering Board: Australo, Montimage, Nextworks, and Quobis Networks. The SME WG is chaired by Jacques Magen from Australo, and Nicola Ciulli from Nextworks is Vice-Chair. It is supported by the Full5G Coordination and Support Action. More information is available at *https://www.networld2020.eu/sme-wg/*. The "Find your SME" web page is available at *https://www.networld2020.eu/find-the-sme-you-need-new-page/*. The SME brochure may be downloaded from *https://bscw.5g-ppp.eu/pub/bscw.cgi/d391067/2021-01_5G_SME_Brochure.pdf*.

EC H2020 5G Infrastructure PPP

The 5G Infrastructure PPP Initiative kept its momentum during 2020. 5G PPP funded projects kept on building a worldwide consensus at a pre-standardisation level, specified, developed and tested advanced use cases related to a significant number of vertical use cases and were actively engaged to raise public awareness about the capabilities of 5G networks. Active projects have produced significant results and have contributed on the further evolution of the 5G networks.

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 the remaining additional projects were finalised during 2020. Following up on the successful completion of Phase 1[29] all Phase 2[30] projects have now been completed, during 2020. As 5G PPP has entered its last Phase 3, 34 projects were active during 2020. Moreover, the last group of 18 projects has been selected and will start their activities in 2021. Figure 74 illustrates the projects of Phases 3.1, 3.2, 3.3 and 3.4.

More specifically, 5G PPP Phase 3.1[31] includes three infrastructure related projects (through the ICT-17 call) that have started their work in July 2018. The projects are providing large-scale end-to-end 5G validation network infrastructures. They cover about 20 EU sites and nodes on a pan-EU basis and will be operational until 2021. Their infrastructures provide an adequate level of openness to make it possible for vertical industries to test their innovative 5G business cases. A summary of their activities can be found in the "5G Network Support of vertical industries in the 5G PPP ecosystem"[32]. Additionally, these projects have provided a detailed on-board procedure for other projects that were planned to use their platforms and infrastructures[33].

As part of 5G PPP's Phase 3.3, a set of eight Verticals Pilot projects (through the ICT – 19 call) have started their activities in June 2019. They are demonstrating advanced 5G validation trials across multiple vertical industries.

29. *https://5g-ppp.eu/5g-ppp-phase-1-projects/*
30. *https://5g-ppp.eu/5g-ppp-phase-1-projects/*
31. *https://5g-ppp.eu/5g-ppp-phase-3-projects/*
32. *https://5g-ppp.eu/wp-content/uploads/2020/02/Vertical-industries-in-the-5G PPP.pdf*
33. *https://5g-ppp.eu/wp-content/uploads/2020/04/On-Board-Procedure-to-5G PPP-Infrastructure-Projects-1.pdf*

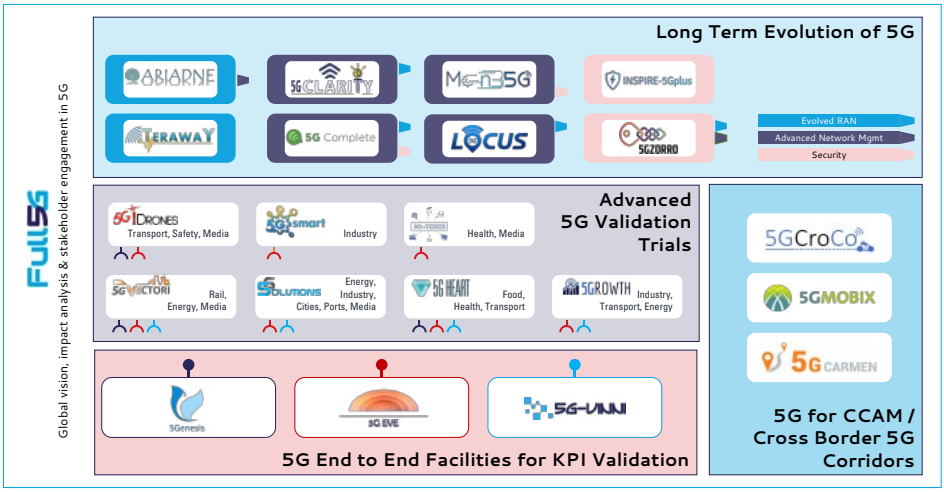

Fig. 74: 5G PPP Phase 3.1-3.4 Reference Figure

These projects are taking advantage of the abovementioned ICT-17 projects and interwork with them using different infrastructure exposure levels as shown in Table 7. Overall, ICT-17 and ICT-19 projects are covering functionalities of approximately 10 different vertical industries and are producing several vertical services. Also, they are creating the necessary knowledge to smoothly integrate different verticals with the 5G network infrastructure.

	5G EVE	5Genesis	5G-VINNI
5G!DRONES	✓	✓	
5G HEART	✓	✓	✓
5GROWTH	✓		✓
5G SMART	✓		
5G Solutions	✓		✓
5G Tours	✓		
5G-VICTORI	✓	✓	✓

Table 7: Collaboration among ICT-17 and ICT-19 projects

As part of Phase 3.2, three automotive projects, under the ICT-18 call have continued, throughout 2020, to test advanced cross border scenarios for autonomous driving. Apart from their independent tests and achievements, these projects, under the umbrella of the 5G automotive working group, have provided collective results with two white papers, namely: "5G Strategic Deployment Agenda for Connected and Automated Mobility in Europe"[34], and "5G Trials for Cooperative, Connected and Automated Mobility (CCAM) along European Cross-border Corridors"[35].

In November 2019, and under the ICT-20 call for 5G PPP Phase 3.4, 8 new projects have started working on the longer-term vision for telecommunication networks. These projects are providing innovative solutions to transform the network into a low energy distributed computer. In such a system, processes and applications will be dynamically created, moved and suppressed, depending on the information flows and customer needs. In the evolved networks, new terminal types based on gestures, facial expressions, sound and haptics may also form the basis of the interaction between humans and infosystems. Figure 75 illustrates the main area of impact for these projects.

Moreover, in continuation of the 5G PPP Phase II key achievements[36], Figure 76 presents the "Key achievements v 3.0" from 27, Phase 2[37] and Phase 3[38], 5G PPP Projects. Approximately

34. https://5g-ppp.eu/wp-content/uploads/2020/10/20201002_5G_SDA_for_CAM_Final.pdf
35. https://5g-ppp.eu/wp-content/uploads/2020/10/5G-for-CCAM-in-Cross-Border-Corridors_5G PPP-White-Paper-Final2.pdf
36. https://5g-ppp.eu/phase-2-key-achievements/
37. https://5g-ppp.eu/5g-ppp-phase-2-projects/
38. https://5g-ppp.eu/5g-ppp-phase-3-projects/

80 achievements have been reported that have been grouped in 11 different categories. Contrary to the Phase II key achievements, were these were mainly related to technological breakthroughs, the current list identifies the progress of 5G PPP according to overall plan that is related to gradual shifting from concepts to trials. Thus, as shown in the Figure 76, most of the reported achievements are related to a number of trials related to 10 different vertical sectors. Also, many projects have further continued their work in the 5G architecture and in network management and orchestration of the services. These extensions are needed to further support their trials. Some of the projects will further offer additional technological breakthroughs the number of which is expected to grow as the ICT-20 project will be in full speed during 2021. A list with the most recent technical documents has also been compiled[39].

39. https://5g-ppp.eu/top-ten-papers/

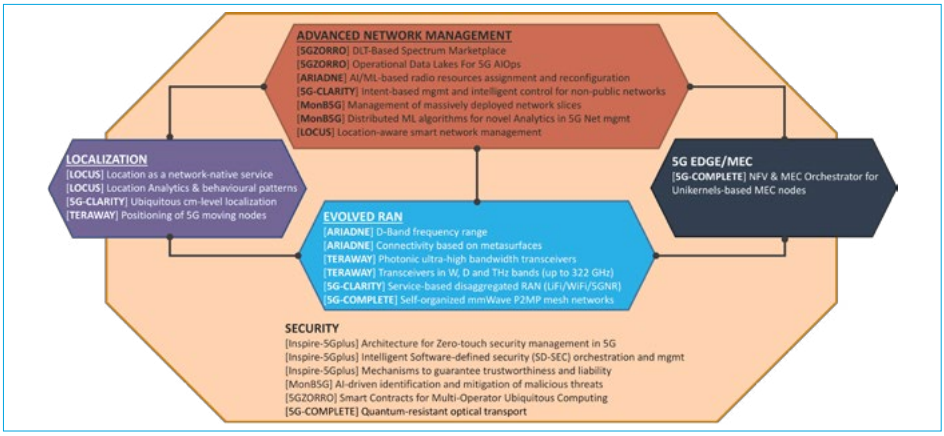

Fig. 75: ICT-20 projects main areas of impact

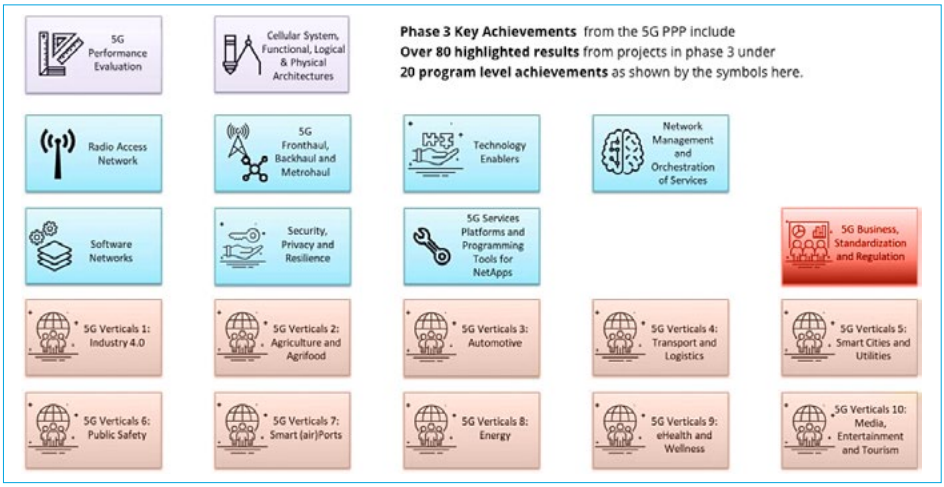

Fig. 76: 5G PPP Key achievements v3.0

During 2020 a major effort was performed to collect results from test and trials in order to identify what are the key 5G features that could be used to boost the operation of Verticals. The results have been collected and presented in the "Empowering Vertical Industries through 5G networks"[40] white paper and a related webinar. A key lesson learned from the trials performed in the context of 5G PPP projects, is that 5G networks do not only offer faster and more reliable networks. 5G is introducing a level of flexibility in the deployment of new services that have a diverse set of characteristics, which 4G networks would not be able to support. This has enabled researchers to create novel services, parts of which can be implemented over different network slices. 5G networks have been designed to be fully modular and allow the dynamic chaining of virtual functions and allocation of resources. These characteristics are the catalyst for the creation of an innovation ecosystem that is expected to shape the full digitization of vertical industries.

Moreover, the recently published "5G Infrastructure PPP – Trials & Pilots Brochure" highlights 10 of these Phase 2 and Phase 3 Trials & Pilots, selected by a PPP panel based on the assessment of the Trials & Pilots impact[41] Project overviews and results, test architectures and deployment schemes to validate uses cases, as provided by vertical players participating on 5G PPP projects, have covered the most relevant European industrial sectors.

A detailed list of all use case experiments, that took place in Europe between 2018 and 2020, can be found in the verticals' cartography. Over 180 use-case experiments have been tracked and analysed through the blueprints for phases 2 and 3, and are being fed into the online Verticals Cartography tool. Updates are an on-going effort to ensure the community is kept up to speed on progress towards the targeted ITU-defined 5G functionalities, the diverse experiments taking place across Europe and overall benefits for the verticals. Interested parties can find information on a sector, country, and ITU functionality basis.

5G PPP has played a key role in achieving pre-standardisation consensus among key stakeholders. The 5G-IA Pre-Standardisation WG is tasked with facilitating impact creation by supporting 5G PPP projects in reporting and disseminating their work to standards organisations, e.g. 3GPP, ETSI, IETF/IRTF; pre-standardisation bodies, e.g. NGMN Alliance; industry forums, associations or consortia, e.g. 5GAA, 5G-ACIA, PSCE, IALA, EBU/5G-MAG, ESOA. 3GPP has been a major target since Phase 1. This is an important achievement given its commercial focus. In Phase 1, in fact over two-thirds of the over 300 inputs were made to 3GPP, mostly to the RAN subgroup. In Phase to, the high contribution rate continued, but a shift could be noted, from RAN to SA. More precisely, the SA inputs were mostly to SA2 followed by SA4 (Codec) and SA5 (Telecom Management). The shift toward moving the contributions to SA continues in Phase 3.

- Phase 1: 317 inputs with 204 to 3GPP (mostly to RAN).
- Phase 2: 295 inputs, with 138 to 3GPP, mostly to SA2 followed by SA4 (Codec) and SA5 (Telecom Management).
- Phase 3: 139 inputs, with 74 to 3GPP, mostly to SA2 and SA1 (data analysed in June 2020).

The 5G PPP projects have disseminated their results in a number of scientific journals, international conferences, book chapters and white papers. Phase 2 projects produced approximately 1120 publications until now (25% was published in scientific journals), whereas Phase 3 projects have produced 208 publications (31% was published in scientific journals) until August 2020.

The list below highlights some of the major achievements at Programme and Technology Board level.

- Jointly with the Full5G project, the verticals cartography for Phase 3 projects has been created. It contains information about the experiments per project, their location, the type of experiment, their scheduled date, their relation to network slice types and the vertical consortium partners involved.
- The "5G Infrastructure PPP – Trials & Pilots Brochure 2.0" has been produced that highlights the key results of ten Phase 2 and Phase 3 Trials & Pilots.

40. https://5g-ppp.eu/wp-content/uploads/2020/09/5G PPP-VerticalsWhitePaper-2020-Final.pdf

41. https://5g-ppp.eu/wp-content/uploads/2020/12/5GInfraPPP_10TPs_Brochure2.pdf

- The 5G PPP "Heritage figure" has been produced. It illustrates the links between the projects during the different phases, demonstrating the continuity of research activities in the context of 5G PPP
- In relation to the analysis of the performance KPIs, TB has assisted the Test, Measurements and Validation WG to record and analyse the measured network KPIs in the PPP platforms and the providing a comprehensive mapping on how vertical services KPIs are mapped into network KPIs. This activity is expected to complete its first phase during the first half of 2021.
- The key achievement list v3.0 has been produced and disseminated, illustrating the impact 5G PPP projects are having in the evolution of 5G networks
- The TB has actively assisted in the interactions with other international activities (e.g., EMPOWER action US NSF / PAWR and PPP / ICT-17/19 Platforms)
- Preparation of two white papers in relation to services provided by ICT-17 projects and the n-board procedure to them have also been produced
- Preparation, in collaboration with 5GIA's Vertical Task Force of a white paper for the empowerment of verticals through 5G networks and dissemination of the key findings via a dedicated webinar
- Creation and update of a number of cartographies including the trials and pilots' summary table that captures the planned tests from each project
- Organised the collective work between projects for white papers in different technical areas (i.e., Edge Computing, AI & ML in 5G networks, and Indoor 5G networks) that are expected to be delivered in 2021
- Two face-to-face TB meetings have been organised. Due to the covid pandemic both workshops were electronic ones. The first one took place in May 2020. During the meeting, it was discussed how to further coordinate activities for the interworking of ICT-17 and ICT-19 projects, how to capture and analyse the network KPIs, setup the work on white papers, the impact of 5G on business validation, and further work was done on the preparation of Key achievements v3.0. Also, one session was dedicated in the progress of the Automotive projects. The second workshop, that took place in December 2020, focused on the progress of the ongoing white papers, on the activities undertaken mainly from ICT-20 projects for the evolved RAN and the use of AI-ML solutions. Moreover, special emphasis was given on the progress in the area of vertical industries where a whole working day was dedicated to it.
- All working groups have been very active and produced several White Papers, Positions Papers and workshops. During 2019, and the beginning of 2020 seven white papers have been produced covering different aspects for 5G networks.

5G CHRONICLE

Past months have been rich in events and promotional activities despite the pandemic. This section provides a global overview and reports on major past events.

In particular, Memorandum of Understandings (MoUs) paved the way to a global harmonised 5G promotion through workshops allowing a close and smooth cooperation among the various 5G PPP projects and effective dissemination actions. 5G Americas (Americas), The Fifth Generation Mobile Communications Promotion Forum (5GMF) (Japan), 5G Forum (Republic of Korea), IMT-2020 Promotion Group (5G) (non-profit organisation, China), Telebrasil (Brazil), TSDSI (India) and obviously the 5G Infrastructure Association Public Private Partnership (5G IA/5G PPP) (Europe) all acknowledged the need of a global and common 5G promotion as 5G has already been commercially launched.

5G initiatives to date

The European Commission strongly supports international cooperation and seeks a global consensus on 5G for the development of globally accepted standards and spectrum requirements. Agreements have already been signed with all regions in the world.

In 2015, the 5G Infrastructure Public Private Partnership, 5G PPP, established partnerships with similar 5G programmes outside Europe. From June 2014 to April 2018, MoUs were signed between 5G PPP and peer organisations throughout the world (respectively with the 5G Forum in South Korea in June 2014, 5G Americas in the US and the 5GMF in Japan in March 2015, the IMT-2020 (5G) Promotion Group in China in September 2015, Telebrasil in Brazil in March 2017 and TSDSI in India in April 2018).

In October 2020, the 5G-IA Pre Standardisation Working Group published the results of its 3-month analysis on 5G PPP projects impacts on Standard Development Organisations (SDOs). The survey aims at documenting the most notable achieved impacts of research projects on the relevant 5G standards and at identifying areas of improvement to maximise technology transfer "from research to standards" for future research frameworks (e.g. Horizon Europe). ETSI and 3GPP appeared to be the privilege targets. The common success factors identified were i) participation to the project of researchers with strong experience in standardisation, ii) relevance of the project objectives to standardisation bodies scope iii) good understanding of existing standardisation roadmaps.

Global 5G events

In October 2015, the 5G Infrastructure Association – Public Private Partnership (5G PPP) and partner organisations (5G Americas, 5GMF, 5G Forum, IMT-2020 (5G) Promotion Group) decided to jointly organise "Global 5G Events" twice a year to globally promote 5G. These "Global 5G Events" are intended to support multi-lateral collaboration on 5G systems across continents and countries. In September 2020, Telecommunications Standards Development Society, India (TSDSI) joined the "Global 5G Events" organisation as a party to the Multilateral Memorandum of Understanding (MMoU) for the "Global 5G Event" with 5G Forum (South Korea), 5G Americas (Americas), IMT-2020 (5G) Promotion Group (China, the 5G infrastructure Association (5G-IA, Europe) the Fifth Generation Mobile Communications Promotion Forum (5GMF, Japan) and Telebrasil – Projecto Pro Brasil (Brazil).

To date, six "*Global 5G Events*" have been held. The "*Global 5G Events*" intend to support multilateral collaboration on 5G systems across continents and countries. Basic areas of interest for the "*Global 5G Events*" include, but are not limited to:

- Vision and requirements of 5G systems and networks
- Basic system concepts
- Spectrum bands to support the global regulatory process
- Future 5G global standards
- Promotion of 5G ecosystem growth

During these two-day events, government representatives, high representatives from 5G programmes and other 5G supporting organisations, association leaders, many industry experts as well as leading universities and research centres

participated and shared the latest Research and Development achievements.

- The First Global 5G Event took place in Beijing, China on May 31st and June 1st, 2016. It was hosted by IMT-2020 (5G) Promotion Group in China with the theme of "*Building 5G Technology Ecosystem*".
- The Second Global 5G Event was held in Rome, Italy on November 9th and 10th, 2016 under the responsibility of the 5G-IA/5G PPP. It dealt with "*Enabling the 5G EcoSphere*". On this special occasion, the final version of the first 5G Annual Journal was distributed.
- After the successful events of 2016, the Third Global 5G Event was held on May 24th and 25th, 2017 in Tokyo, Japan, just one year after the First Global 5G Event. It focused on the practical use of 5G from 2020 and beyond and provided news regarding "*the 5G Filed Trial Project in Japan*" that began in 2017.
- The Fourth Global 5G Event was held in Seoul, South Korea on November 22-24, 2017. It was organised by 5G Forum.
- The Fifth Global 5G Event took place in Austin, TX and was organised by 5G Americas on May 16-17, 2018. The 5G-IA was represented by eight speakers and moderators. The 5G New Horizons Wireless Symposium discussed the status and progress of 5G.
- The Sixth Global 5G Event was held in Rio de Janeiro, Brazil on November 28-30, 2018. The event was hosted by 5G Brasil. 5G IA and 5G PPP projects were present with six speakers.
- The Seventh Global 5G Event was hosted by the 5G IA and the European Commission in Valencia, Spain on 17-18 June 2019. It was collocated with EuCNC 2019 – European Conference on Networks and Communications and featured six sessions with 49 top class international presenters from business, research, European Commission and governments across the globe covering key aspects of 5G technology and providing excellent insights and perspectives from different regions of the world. A highlight of the event was the keynote speech by Tomás Alonso (Orange, Spain), which demonstrated an impressive live 5G holographic videocall.
- The 8th Global 5G Event "*5G Empowers the Digital Economy*" was initially planned to take place at the Shanghai International Convention Centre in Shanghai, China on July 2-3, 2020. The event was postponed by one year due to the pandemic. It is now expected to be held in 2021.

EuCNC

Due to the world COVID-19 pandemic, the Steering Committee of EuCNC 2020 decided to change the format of the conference to an on-line virtual one, instead of the usual face-to-face physical one in Dubrovnik. The EuCNC 2020, supported by the European Commission took place from June 15 to 18, 2020. This edition was the 29th edition of a successful series of conferences in the field of telecommunications, sponsored by the IEEE Communications Society and the European Association for Signal Processing, and supported by the European Commission.

There will be no Workshops, Tutorials and Special Sessions. On the other hand, papers submitted to Regular Sessions that were accepted were invited to be presented in an on-line mode, and then submitted to IEEE Xplore as usual; accepted posters were also presented on-line.

Follow-up in 5G Vertical User Webinar series

To date, four webinars in the 5G Vertical User series have been organised. The latest one was held on 30 November 2020.

2nd webinar on "Spectrum for Industry Verticals" (18 June 2020)

A first workshop on "5G for Industry Verticals, standardisation and deployment challenges" was held earlier.

Following this first session, a second event was co-hosted with the European 5G Observatory and a sub-set of 3GPP MRPs. It looked at spectrum sharing, service continuity and private networks from the perspective of diverse verticals, including automotive (5GAA), manufacturing (5G-ACIA), broadcasting and media (5G-MAG) and public safety (PSCE).

3rd webinar on "5G for Healthcare, Social Care and Public Safety" (15 July 2020)

The webinar on 15 July 2020 was the third in a series organised by a sub-set of 3GPP Market Representation Partners: 5G Automotive Association (5GAA), 5G Alliance for Connected Industry and Automation (5G-ACIA),

5G-Infrastructure Association (5G-IA), Public Safety Communication Europe (PSCE). This webinar was co-hosted with the European Technology Platform, NetWorld2020. It attracted participants from 14 EU27 countries and 9 Non-EU27/global countries.

Key takeaways include the 5 following major items:

- #1: Pressing need for a common, global standard for eHealth/mHealth
- #2: Bringing together awareness, collaboration, evidence and regulation
- #3: 5G health risks and the global infodemic
- #4: New 5G Health Association and Funding are key to filling the white spots in the sector
- #5: Forthcoming White Paper to shed new light on 5G for healthcare

4th webinar on "Opportunity for Industry Verticals" (30 November 2020)

This webinar looked beyond these releases to define new requirements for Release 18 across automotive, broadcasting and media, energy, manufacturing and healthcare. Experts gave practical insights on how industry verticals can contribute to 5G standardisation over the next few years through a member, consensus-building approach.

5G end-to-end experimentation by verticals in EU projects (9 June 2020)

5Growth, 5G-DIVE, 5G-EVE, 5G-VINNI and 5G-Tours joined forces to organise an online workshop with demonstrations and presentations on 5G verticals validation.

CLEEN 2020 (11 June 2020)

This edition raised special topics.

The 5G-Croco keynote focused on 5G network functions optimised for automotive use cases based on the pilot realisation in France-Luxembourg-Germany corridor.

One of the discussants presented results and takeaways from joint trials of Toyota, Vodafone and Ericsson at the Aldenhoven Testing Centre raising the issues of "Automotive trials for Make-Before-Break 5G Edge Cloud Handover".

2nd European Observatory stakeholder Workshop: 5G for Growth and Recovery (25 September 2020)

The European Round Table for Industry published an Assessment Paper about the 5G deployment status in Europe, which revealed slow progress of 5G roll-out in terms of commercialisation and infrastructure at that time.

Tracking 5G deployment is key to best monitoring the progress but is difficult. Several global indicators or combinations of indicators emerged as being consensual appropriate tools. They should reflect discrepancies between use cases dedicated to the general public and vertical use cases and between bands to highlight band combinations (as KPI can be tracked by pioneer frequency band).

"Empowering Vertical Industries through 5G networks – the 5G PPP experience" Webinar (9 September 2020)

On September 9th 2020, the 5G Public Private Partnership (5G PPP) and the 5G Infrastructure Association (5G IA) held a webinar to present the key findings of the latest white paper on "Empowering Vertical Industries through 5G Network – Current Status and Future Trends". The white paper summarises the progress and results produced by 5G PPP projects, while developing some innovative 5G network services and solutions for vertical industries. It also provides information about requirements and addressed business cases, discusses in detail several exemplary use cases from eleven different vertical sectors and identifies key 5G features that have been used to meet the specified requirements.

European Research and Innovations Days 2020 (22-24 September 2020)

The 2020 European Research and Innovation Days 2020 took place virtually from September 22 to 24.

The policy conference formed the core of the European Research and Innovation Days.

Divided into ambitious plenary sessions spanning the depth and breadth of research and innovation in Europe, and specialised hubs covering 10 pivotal themes, it brought cutting-edge scientific research to concrete global problems. Participants were able to choose from 10 hubs and engage with sessions that interested them. These sessions gave the opportunity to listen as

experts shared their insights, and get involved in game-changing conversations about shaping the future. Each hub had a virtual front desk providing information on hub-specific topics, breakout rooms for dedicated discussions and meetings and a virtual meeting room for policy sessions.

The Science is Wonderful! Session featured an array of fun, educational online activities that introduced visitors to the latest cutting-edge research taking place throughout Europe and the rest of the world.

5G-IA/NetWorld2020 co-workshop (22 October 2020)

5G-IA and NetWorld2020 hosted the webinar "Driving innovation in Healthcare with 5G and Smart Networks" to help define short and mid-term priorities for the adoption of 5G and smart networks in healthcare. Taking stock of the benefits and expected impacts from early pilots, the panellists engaged in a discussion on future priorities with a view to fostering further public and private investments in the sector, defining future research and innovation focus, with end-user validation.

5G PPP Webinar on 5G Cooperative, Connected and Automated Mobility (6 November 2020)

The webinar was run in two parts with a short introduction from the European Commission. The first part showed the CCAM work and the white paper produced by the three H2020- ICT-18-201 5G PPP corridor projects: 5G-MOBIX, 5G-Carmen and 5GCroco. The second part introduced the new CAM related Projects under the 5G PPP ICT-53-2020 call: 5GBlueprint, 5GMED, 5GROUTES and 5GRail.

5G Techritory – 3rd Baltic Sea Region 5G ecosystem forum (11-12 November 2020)

The 5G Techritory Forum 2020 was the third-annual event bringing together the leading minds in 5G deployment in the Baltic Sea Region. This third gathering was parti

The 5G Techritory platform is an initiative to bring together every aspect of 5G for a faster and more swift implementation and commercialisation of 5G to increase the pace of economic development in the Baltic Sea Region.

Other joint initiatives will follow in 2021

EuCNC 2021

The 2021 edition of the EuCNC, supported by the European Commission will take place in Porto, Portugal from 8 to 11 June 2021. This edition is the 30th of a successful series of conferences in the field of telecommunications, sponsored by the IEEE Communications Society and the European Association for Signal Processing.

MWC Barcelona 2021

MWC Barcelona 2020 was cancelled after health concerns in the wake of the coronavirus. MWC Barcelona 2021 initially scheduled at the end of February 2021 has been rescheduled from 28 June to 1 July 2021.

8th Global 5G Event

The 8th Global 5G Event initially scheduled for July 2-3 2020 at the Shanghai International Convention Centre in China was cancelled. It is rescheduled in 2021.

Appendix 1: working groups

Working Groups and Leaders	Origin
Pre-Standardisation WG Olav Queseth, Ericsson Riccardo Trivisonno, Huawei Stephanie Parker, Trust-IT	5G Infrastructure Association
Spectrum WG Giovanna d'Aria, TIM	5G Infrastructure Association
5G Architecture WG Simone Redana, Nokia Oemer Bulakci, Nokia	5G PPP Projects
Software Networks WG Bessem Sayadi, Nokia Cristian Patachia, Orange	5G PPP Projects
Network Management & QoS WG Kieran Sullivan, Waterford Institute of Technology Anastasius Gavras, Eurescom	5G PPP Projects
Vision and Societal Challenges WG Arturo Azcorra, IMDEA Håkon Lønsethagen, Telenor	5G Infrastructure Association
Security WG Jean-Philippe Wary, Orange Pascal Bisson, Thales	5G Infrastructure Association
SME WG Jacques Magen, Interinnov	Networld2020
Trials WG Didier Bourse, Nokia Carles Anton, CTTC	5G Infrastructure Association
5G Automotive WG Mikael Fallgren, Ericsson Konstantinos Manolakis, Huawei Michele Paolino, Virtual Open Systems Jesus Alonsos-Zarate, CTTC Apostolos Kousaridas, Huawei	5G PPP Projects
IMT-2020 Evaluation Group Werner Mohr, Nokia	5G Infrastructure Association
Test, Measurement and KPIs Validation Andrea F. Cattoni, Keysight Technologies Evangelos Kosmatos, WINGS ICT	5G PPP Projects
International Cooperation	5G Infrastructure Association

Appendix 2: acronyms

3GPP	3rd Generation Partnership Project
5GAA	5G Automotive Association
5G-IA	5G Infrastructure Association
5G PPP	5G Infrastructure Public Private Partnership
AI	Artificial Intelligence
AR	Augmented Reality
BBU	Baseband Unit
C-RAN	Centralised RAN
CBC	Cross-Border Corridors
CCAM	Cross-border corridors for Connected and Automated Mobility
CDN	Content Delivery Network
CPRI	Common Public Radio Interface
eCPRI	Enhanced CPRI
eMBB	Enhanced Mobile Broadband
eNB	ENode B
E2E	End-To-End
FRMCS	Future Railway Mobile Communication System
HW	Hardware
ITS	Intelligent Transport Systems and Services
KPI	Key Performance Indicator
LoS	Line of Sight
MaaS	Mobility as a Service
MCF	Multi Core Fiber
MoU	Memorandum of Understandings
mMTC	Massive Machine Type Communications
mm-wave	Millimeter waves
NFV	Network Function Virtualisation
NSaaS	Cloud Network Security as a Service
ODM	open data management
PNF	Physical Network Functions
PoC	Proof of Concept
PtMP	Point to MultiPoint
PtP	Point to Point
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RSI	Road Side Infrastructure
RRH	Remote Radio Head
RRLH	Remote Radio-Light Head
SDK	Service Development Kit
SDN	Software-Defined Networking
SW	Software
TA	Targeted Actions
UE	User Equipment
UrLLC	Ultra-Reliable Low-Latency Communication
V2X	Vehicle-to-everything
VLC	Visible Light Communication
VR	Virtual Reality
WDM	Wavelength Division Multiplexing

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5G PPP

More information at https://5g-ppp.eu