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Full 5G - Fulfilling the 5G Promise

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Foreword

Peter Stuckmann,
Head of Unit Future Connectivity Systems

More than half a decade after the launch of the 5G PPP, first commercial 5G services are now available in a number of European cities. This is a first important milestone and we have played our part to make this possible. All your efforts under this fantastic partnership have surely led the way globally. We have contributed to shaping the standards ready for early 5G market needs and to establishing Europe as an important home market for our industry.

But this is just the start. Ambitious private investments are needed to meet the deployment targets of the *5G Action Plan*, to cover all European cities and major transport paths by 2025.

And we have to step up our efforts to establish 5G as a technology that can deliver the promises we are making: nothing less than enabling the digital and green transformation of our economy. For this we need to have trust in the security of 5G networks. Besides the standardisation work to make 5G technology increasingly more secure, the Commission has accelerated in recent months the work with EU Member States to contribute to a secure 5G supply chain.

The *EU coordinated risk assessment* and the subsequent *toolbox* for the cyber-security of 5G networks are an important basis to enable this trust. They inter-alia provide the way forward as regards the identification and role of high-risk suppliers in European 5G networks and the requirements for operators when they roll out and run 5G networks. In this regard the Commission also *underlined* the importance of the investment in modern "stand-alone" 5G networks in order to deliver the promise of more advanced 5G services, e.g. for vertical industries such as transport, manufacturing, energy, health care and media.

The projects of the third phase of the 5G PPP show the way for these new use cases and deliver on *Europe's 5G trial strategy*. The current portfolio can be discovered in this 2020 release of the European 5G Annual Journal. The whole 5G PPP trial project portfolio is now worth more than EUR 300 millions of EU funding, and is expected to leverage more than EUR 1 billion of private investment in 5G vertical trials, reinforcing Europe's leading position in this field.

Another wave of projects will be launched this year with projects for roughly EUR 200 million still to be launched in the last Work Programme of Horizon 2020. A second wave of 5G Corridor projects has been selected recently and other calls are either under evaluation or upcoming – from 5G innovation in hardware and software, to more forward-looking projects Beyond-5G.

This year, we are planning to launch a new European Partnership on Smart Networks and Services under Horizon Europe, the new Research and Innovation programme proposed for the next EU long-term budget starting in 2021. We are working closely with Member States and the industry including the 5G Infrastructure Association to develop this major initiative. We can expect that it will cover both R&I towards 6G as well as 5G deployment actions using the Connecting Europe Facility (CEF), in particular the coordination of programmes for 5G Corridors for Connected and Automated Mobility (CAM). We welcome the progress of the Strategic Research and Innovation Agenda (SRIA) that 5G IA produced in cooperation with Networld2020 identifying topics for beyond 5G and later 6G. As regards the CEF pillar, a major progress was achieved in October last year, when a first draft outline of the *Strategic Deployment Agenda (SDA) c*oncerning 5G for CAM was published.

But let's for now focus on the exciting third phase of the 5G PPP to further deliver on the 5G Action Plan, the 5G trial strategy, and start preparing for beyond-5G or 6G, no matter what brand you like most. We wish all of us as participants of the 5G PPP the best in our projects and activities. Our contribution will be key to a digital Europe!

Editorial

Colin Willcock, Chairman of the Board, 5G IA

Although we have faced a number of unique challenges over the past year such as, the cancellation of the MWC2020 and other events, the 5G PPP has made good overall progress with a strong set of projects creating significant results as documented in this journal. 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 make this possible.

As we approach the last project calls for 5G PPP it is worth pointing out that the development of mobile communication technology will not stop with the end of this Programme. We need to start considering what comes next and what is necessary in the future for Europe to retain its leading position in mobile communication research and innovation. Amongst these last 5G PPP project calls will be the first set of projects to consider what comes after 5G. These Beyond 5G (B5G) projects should provide the bridge to the future activities foreseen in the next Smart Networks and Services (SN&S) partnership Programme which is proposed to be part of Horizon Europe. For the future of Europe both in terms of technological leadership and commercial competitiveness it is vital that this SN&S partnership is approved with substantial long-term funding.

5G NOW LIVE IN MANY EUROPEAN COUNTRIES

Ten key results from the past 12 months

More than 233 5G tests and experiments in Europe[1]

As many as 233 5G trials have been listed so far in the 5G Observatory database[2]. The share of technical tests dropped significantly in the past year as some mobile operators have already launched 5G commercial services and others are planning 5G network deployment for 2020. On the contrary, trials involving verticals have increased. Standalone architecture is also being trialled to build 5G networks totally independent of existing 4G networks.

The most trialled verticals are related to media and entertainment (36 trials) followed by transport (31 trials) and automotive (22 trials).

The organised 233 trials were conducted in 30 countries (191 in 25 of the 28 MSs of the European Union and 42 in Russia, San Marino, Norway, Turkey and Switzerland).

Frequency bands tested are available only in selected trials (48% of all trials listed). The most used frequency band for trials is by far the 3.4-3.8 GHz (79 trials tested the 3.4-3.8 GHz frequencies out of 112 trials mentioning which band was considered). The 26 GHz band has been tested 6 times in Europe, and the 28 GHz band 12 times.

WRC-19 outcome

The 2019 World Radiocommunication Conference WRC-19 ended on November 22nd, 2019. For four weeks, many agenda items were debated, including Agenda Item 1.13 on mm-wave bands for 5G and Agenda Item 1.6 and 9.1 on the satellite sector.

Under Agenda Item 1.13, delegates agreed to make frequencies in mm-wave bands such as the 26 GHz (24.25-27.5 GHz), 40 GHz (37-43.5 GHz), 45.5-47 GHz, 47.2-48.2 GHz and 66-71 GHz available for 5G services and to protect existing radio usages. In total, 17.25 GHz of spectrum has been identified for IMT. Out of this number, 14.75 GHz of spectrum has been harmonised worldwide, reaching 85% of global harmonisation.

Long-term protection of the EESS in the frequency band 23.6-24 GHz was considered as vital for weather prediction and disaster management (resolution 750). The related European satellites are those from the Copernicus programme and those from the European Agency Eumetsat.

5G spectrum assignment 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 14 Members States plus the United Kingdom at least one spectrum auction is complete or on going as of the end of December 2019. 20% of 700 MHz spectrum, 31.7% of 3.4-3.8 spectrum and 3.6% of 26 GHz spectrum have been assigned in the EU-27 plus the UK countries as of the end of March 2020.

The 700 MHz band has been assigned in six Member States: Denmark, Germany, France, Finland, Italy, and Sweden. The 3.4-3.8 GHz band has been assigned, in accordance with 5G technical conditions, in the UK and in 10 MSs (Austria, Czech Republic, Finland, Germany, Hungary, Ireland, Italy, Latvia, Romania, and Spain). The 26 GHz band has been assigned in Italy. While it has not been formally assigned in the UK, local licences are available there.

5G commercial launches in Europe and in other regions

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

1. *in March 2020*
2. *http://5gobservatory.eu/5g-trial/major-european-5g-trials-and-pilots/*

(SA) core network is expected to start by mid-2020, enabling the provision of full 5G functionalities including network slicing.

10 commercial 5G services in EU 27 plus the United Kingdom

At the end of March 2020, 5G commercial services had been deployed in 10 (EU 27 plus the UK) countries: Austria, Finland, Germany, Hungary, Ireland, Italy, Latvia, Romania, Spain and the United Kingdom. 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, eleven MSs had published fully-fledged national 5G roadmaps including spectrum strategies (Austria, Denmark, Estonia, Finland, France, Germany, Luxembourg, Spain, Sweden, The Netherlands, and the UK).

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.

5G commercial services in China were launched by the three operators, China Mobile, China Unicom and China Telecom in November 2019.

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, is expected to offer 5G services in 2021.

5G devices available in various form factors and for multiple frequency bands

As of February 2020, Gsacom reported 208 5G devices announced by 78 different vendors and 16 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.

Most of the devices launched in 2019 have been based on Qualcomm Snapdragon 855 along with an X50 modem that was built in 2020. Most devices will be based on second generation 5G baseband and heated competition with first devices powered by Mediatek 5G solutions. While initial 5G devices often had either sub 6 GHz, or? mm-wave RF system for 5G in 2019, in early 2020 the first mm-wave + sub-6 GHz devices appeared on the market.

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

5G Global events

The 7th Global 5G Event "*Creating the Digital Future*" took place in Valencia, Spain between June 17 and 18, 2019. The event was organised by 5G IA/5G PPP and the European Commission. The 7th Global 5G Event was a unique opportunity for 5G PPP projects and European organisations involved in 5G to be exposed to 5G stakeholders from outside Europe. The 7th Global 5G Event was co-located with EuCNC 2019 (June 18-21, 2019).

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).

MoUs and cooperation agreements

In 2019 the 5G IA and the ERTICO – ITS Europe have signed a Memorandum of Understanding. More specifically, on November the 28th 2019 in Riga, Jacob Bangsgaard, CEO of ERTICO – ITS Europe, and Dr Colin Willcock, Chairman of the Board of the 5G Infrastructure Association (5G IA), co-signed a Memorandum of Understanding (MoU) to foster cooperation and synergies on 5G and Intelligent Transport Systems and Services (ITS).

As the contractual partners of the European Commission for Public-Private Partnerships on ITS and 5G, ERTICO and 5G IA aim to promote collaboration between European stakeholders from public and private sectors and sustain the implementation and development of the Digital Single Market.

Workshops organised by 5G PPP projects & white papers

Workshops

2nd Vertical Workshop

Following the first session held in Brussels on February 12-13, 2019, a second Workshop was organised in Rome, Italy, between July 9 and 10. The Workshop was included in the 3GPP SA6 meeting.

5G PPP workshop @IEEE 5G World Forum

The IEEE 5G World Forum took place between September 30th and October 2nd, 2019, in Dresden, Germany. 5G PPP projects, including 5G-Drive, 5G EVE, 5G-VINNI, 5GENESIS, and SLICENET, organised the "*2nd Workshop on 5G-Trials – From 5G Experiments to Business Validation*". It aimed at providing a forum for industry and academics to disseminate new findings on 5G trials and new business development.

White papers

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

5G PPP Test, Measurement and KPIs Validation WG White Paper (June 2019)

"*Validating 5G Technology Performance – Assessing 5G architecture and Application Scenarios*"

This paper proposes a unified vision on the Test and Measurement topics for 5G, allowing for common procedures and terminology and provides substantiated answers to more high-level relevant questions such as "does slicing help fulfilling vertical requirements for 5G?"

5G Media WG Slice Definition White Paper (September 2019)

This document is the outcome of a joined working group set up between the two European Technology Platforms, New European Media (NEM) and Networld2020. The objective was to combine expertise from the media sector which brought application requirements and the network domain which brought expertise in 5G.

Nine media & content use cases have been identified by the group that cover most of the common media & content situations from production to consumption.

From these 9 use cases, the group has identified 12 parameters that should be used to adapt the network to the application requirements, such as Latency, Reliability, Data rate, Mobility, User density, Positioning, and User equipment speed.

Looking at the 5G network capabilities and parameters that could be activated, the last section provides a description of 5G Media Slices. The choice to make "slices" plural is due to one of the main conclusions of the paper, that is that the media chain encompasses a number of functionalities and operations such as content creation, service composition, service aggregation, content distribution, devices, user interaction and interfaces, that require different slices. Additionally, 5G requirements will be different for production, which needs mostly uplink capacities, and distribution, which needs mostly downlink capacities.

For each of the 9 use cases, there is a proposal to allocate 1 or 2 slices, detailed in the paper's conclusions.

5G PPP Automotive WG White Paper: "*Business Feasibility Study for 5G V2X Deployment*" – (October 2019)

The 5G PPP Automotive Working Group issued a Paper in October 2019 on "*how 5G Strategic Deployment can support Connected and Automated Mobility (CAM) in Europe*". The paper analyses how 5G PPP projects interpret Cloud-Native design patterns and identify adoption barriers. This is an Initial Proposal for reaching out towards a broader range of potential stakeholders in the area of connected and automated mobility in Europe with the target to develop a blueprint document. This document sets out the shared view of a wide group of industry stakeholders supporting the objectives of the 5G Strategic Deployment Agenda (SDA). The common aim is to support Connected and Automated Mobility (CAM) in Europe, based on future-proof 5G infrastructure, technologies and vehicles.

SatCom WG's White Paper on "*SatCom Ressources for Smart and Sustainable Networks and Services*" (November 2019)

This white paper reports the research challenges that the Networld2020 SatCom WG considers strategic to be addressed in the next decade in order to allow full exploitation of the satellite component in support of Europe's ambition to deploy smart and sustainable networks and services for the success of the digital economy.

The paper shows how satellite communications are fundamental components to help reliably deliver ICT (Information and Communication Technologies) services, not only across the whole of Europe, but also in all regions of the world, and at an affordable cost. According to the SatCom WG, SatCom should be part of the future smart networks, where innovations are required to develop techniques/technologies to ensure also sustainable ICT: economically viable, eco-friendly and yielding social benefits.

5G PPP 5G Architecture WG White Paper – Consolidated Version – (February 2020)

The consolidated European view on 5G architecture design by the 5G PPP 5G Architecture Working Group, including the inputs from the Public Consultation phase, are presented in the Final Version 3.0.

5G PPP Software Network WG White Paper: "*Cloud-Native and 5G Verticals' services*" – (February 2020),

To highlight the value and challenges of becoming Cloud-Native, the 5G PPP Software Network WG prepared this publication titled, Cloud Native and 5G Verticals' services, depicting the three phases to evolve from Virtual Network Functions (VNFs) to Cloud-Native Functions (CNFs).

"*5G network support of vertical industries in the 5G PPP ecosystem*" Brochure – (February 2020)

The 5G PPP Verticals task force together with the ICT-17 projects 5G EVE, 5GENESIS and 5G-VINNI have prepared an overview of the extended pilot trials that are being executed to validate 5G for vertical use cases using these three research infrastructure projects. These trials are being performed in the context of the 5G Public-Private Partnership (5G PPP) programme and cover multiple domains, like autonomous driving, smart factories, healthcare, media, energy, etc.

White Paper related to the "*On Board Procedure to 5G PPP Infrastructure Projects*" – (April 2020)

Prepared by the ICT-17 projects 5G EVE, 5GENESIS and 5G-VINNI, this white paper describes the basic procedures that must be followed when vertical sector oriented projects of the 5G PPP plan to use the 5G PPP infrastructure project services. For each of the infrastructure projects this paper informs – among others – about how to interact with the infrastructure, what information is needed for running experiments, what output and how it is provided, as well as what are the future plans of each infrastructure project for the longer-term support of vertical applications.

Phase 3 key achievements

The pre-structuring Model

The Phase 3 (Part 2) Pre-structuring Model (PSM) Version 2.0 was released by the 5G Infrastructure Association (5G-IA) in July 2019.

Targeting a successful and coherent PPP Phase 3.II research and innovation programme and building on PPP Phase 1, Phase 2 and Phase 3.I experience, the 5G IA members have developed the Phase 3.II Pre-Structuring Model. The first goal is to ensure that the forthcoming set of projects (portfolio) will work together cleverly in Phase 3. It should also be straightforward between Phase 2 and Phase 3 projects. The Model is focused on Phase 3.II projects portfolio and related projects, not on proposals, and is building on the EC Work Programme 2018-2020 (final version of the WP2020 officially released on 02.07.19[3]). The Model presents features and recommendations to guarantee smooth integration of new projects in the existing coordinated Programmes. It targets system recommendations to develop future, efficient and cross-project cooperation, ensuring a comprehensive coverage of R&I (Research & Innovation) topics, with no gaps or redundancies.

The PSM Phase 3.II focuses on the following EC Strategic Objectives:

- ICT-52-2020 – Smart Connectivity beyond 5G (RIA) – Deadline for submissions on 22.04.20.

3. *http://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/main/h2020-wp1820-leit-ict_en.pdf*

- ICT-41-2020 – 5G Innovations for Verticals with Third Party Services (IA) – Deadline for submissions on 22.04.20.
- ICT-42-2020 – 5G Core Technology Innovations (IA and CSA) – Deadline for submissions on 16.01.20.
- ICT-53-2020 – 5G for Connected and Automated Mobility (CAM) (IA) – Deadline for submissions on 13.11.19.

The PSM Version 2.0 was presented during the EC Proposers Days on 19-20.09.19 in Helsinki (https://www.ideal-ist.eu/news/ict-proposers-day-2019).

The PSM Phase 3.II Version 3.0 was released in November 2019, following the start of the ICT-20-2019 projects. This version included the key topics addressed by the funded ICT-20-2019 projects, targeting an overall Portfolio-Structuring Model and providing important context for the rest of the PSM Phase 3.II TAs (Targeted Actions).

There is a public Brokerage resource for the 5G PPP calls requesting proposal submissions in 2020 specifically addressing the H2020 Strategic Objectives ICT-41, ICT-42 and ICT-52.

The ICT-41, ICT-42 and ICT-52 call texts, as prepared by the EC, and the 5G PPP Phase 3.II Pre-structuring Model as prepared by the 5G-Infrastructure-Association, will provide a context for identifying where your interests lie and give some suggestions for possible proposal delineation.

Start of the 5G PPP Phase 3, Part 4: 5G Long Term Evolution

Eight Projects (ARIADNE, 5G-CLARITY, 5G-COMPLETE, INSPIRE-5Gplus, LOCUS, MonB5G, TERAWAY, 5G ZORRO) 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 move the European 5G Vision of "*5G empowering vertical industries*" closer to deployment.

Whilst 5G early introduction targets "local" network improvements (e.g. at radio access level), the longer-term vision targets the realisation of pervasive mobile virtual services, through a network managing computer, storage, and transport connectivity functions in an integrated way. The challenge is to transform the network into a low energy distributed computer, where processes and applications are dynamically created, moved, and suppressed, depending on the information flows, customer needs, and where new terminal types such as cars, objects, appliances, and new interfaces are. The interaction between humans and the ICT systems will be based on gestures, facial expressions, sound, and haptics.

There is a public brokerage resource for the 5G PPP calls requesting proposal submissions in 2020 specifically addressing the H2020 Strategic Objectives ICT-41, ICT-42 and ICT-52.

The ICT-41, ICT-42 and ICT-52 call texts, as prepared by the EC, and the 5G PPP Phase 3.II Pre-structuring Model as prepared by the 5G-Infrastructure-Association, will provide readers with a context for identifying their areas of interests as well as suggestions for possible proposal delineation.

Covid-19 impacts on 5G

Beyond the dramatic health impact of this unprecedented crisis that affects all of us, there are many impacts on the 5G ecosystem today. Significant mobile traffic increase in sub-urban areas, delayed CAPEX, postponed spectrum auctions and standardisation are among the main ones.

- Firstly, as more countries have adopted outright quarantines or stay-at-home policies through mid-April 2020, it looks as if cellular networks are "holding". First 5G networks in Europe only have a limited number of users so congestion is not yet present. 4G networks have seen a significant increase of traffic in March and Vodafone Group CTO Indicated in early April that Vodafone has seen "*six months of forecast demand growth emerge over the past month (March)*".
- Secondly, 3GPP face-to-face meetings have been cancelled during the crisis, 3GPP Release 16 and Release 17 are currently delayed by three months. Stage 3 Release 16 specifications should now be finalised in June 2020, and the proposed date for Release 17 shifted to December 2021. The final version of Release 16 is going to provide evolutions of 5G networks' efficiency, including power consumption and mitigation of interference with enhanced MIMO, self-organising networks and enhanced Dual Connectivity. It will also specify new API

frameworks, access to unlicensed spectrum, enhancements to protocols for Vehicle-to-everything (V2X) and industrial IoT applications. Release 17 will probably deal with further Radio Access Network upgrades, update existing protocols and further new technologies.

- A short to medium term impact is that European mobile network operators will probably delay investments in 5G networks. CAPEX decrease will "benefit" from delays in spectrum auction and availability. In early April 2020, delays were already confirmed in many countries due to the outbreak of the novel coronavirus. Moreover, current shutdowns of municipal offices is slowing down permits granted to mobile operators for building new cell sites.
- Longer term trends have some positive impacts as it is likely that this crisis will give 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.

CONTRIBUTIONS FROM 5G PPP PROJECTS

This chapter presents contributions from H2020 projects for phase 2 and phase 3 projects still active in 2020. 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

21 5G PPP Projects were retained from the 101 proposals received by the EC in response to the second call of the 5G PPP. The phase 2 projects still active in 2020 are presented in this section.

5G Picture

Goals of the Project

5G-PICTURE designed and developed an integrated, scalable and open 5G transport infrastructure that relies on a converged fronthaul (FH) and backhaul (BH) solution, integrating advanced wireless access and novel optical and packet network domains. 5G-PICTURE adopts the novel concept of Disaggregated-Radio Access Networks (DA-RANs), allowing any service to flexibly mix-and-match and use compute, storage and network resources through hardware (HW) programmability. This disaggregated network approach is key for the creation of a 5G infrastructure able to support a large variety of 5G ICT and "Vertical" services.

According to the proposed solution, vertical service providers, currently relying on closed and proprietary infrastructures, will be able to deploy any service without having to own and install any HW or software (SW) component. This solution will allow end-users and third parties to access physical or virtual resources, services, and tools on demand regardless of their geographical location. This will enable the transformation of telecommunications infrastructures from closed inflexible environments into a pool of modular HW and SW components that can be combined on demand to support a large variety of vertical sectors. This solution supports any type of service ranging from best effort, to delay sensitive services and to ultra-reliable services.

Major achievements

One of the main achievements of 5G-PICTURE is the development of programmable platforms as an enabler to deploy different functionalities in the network that can be specified using certain high-level description deployed at run-time[4]. This approach permits the 5G network to support a wide set of complex network functions (NFs), which can be dynamically changed and moved among different network nodes depending on the network conditions and on the required Service Level Agreements (SLAs). We have proposed physical and virtual functions that can be executed over the aforementioned platforms and are orchestrated by the 5G-PICTURE orchestration layer referred to as 5G Operating System (5G OS)[5]. In the RAN domain we have demonstrated how Ethernet Time Sensitive Networks (TSN) based on IEEE 802.1Qbv and IEEE 802.1Qbu can be used to carry real FH traffic generated by SW Base Stations components, while protecting high-priority traffic flows even in overloaded conditions. In the transport domain we demonstrated a hierarchical control plane connecting heterogeneous transport domains. In the synchronisation domain we have presented an integrated demonstrator showcasing the capabilities of the Synchronisation Harmoniser function.

Other main achievements of the Project are the development and demonstration of the 5G OS[6], which is a lightweight OS that integrates loosely coupled domains offering compute, transport and wireless access resources to provision end-to-end services in a dynamic and autonomous manner. Following estimation

4. 5G-PICTURE deliverable D3.3, "Final report on Data Plane Programmability and infrastructure components", January 2020.

5. 5G-PICTURE deliverable D4.3, "Integration of developed functions with 5G-PICTURE orchestrator", January 2020.

6. 5G-PICTURE deliverable D5.4, "Integrated Prototype", January 2020.

of the performance achievable with the different programmable platforms it can allocate the NF that must be executed, in the most suitable node. 5G OS can provision a complete virtual Wi-Fi and LTE network service in less than two minutes, leveraging an integrated multi-domain test-bed set-up, making a significant step forward in automating the provisioning of the complex network services involved in the operation of mobile network architectures.

Description of the demos

5G-PICTURE focuses on proof of concept and real-life validation of the project technical solutions via demonstration activities in operational rail, smart city and mega event environments[7]. Three major demo sites have been used to demonstrate the outcomes of 5G-PICTURE, namely:

Railway demonstration

5G-PICTURE has developed an experimental testbed for seamless service provisioning and mobility management in a moving railway environment in Barcelona, Spain. The multiservice railways network developed in the 5G-PICTURE project reduces investment and accelerates 5G NR deployment in railways. The demonstration comprises the development and integration of:

- State of the art mm-wave technologies that beam to the trains at full speed.
- Cost efficient passive G.metro optical networks supporting multiple 10 Gbps auto tunable services along the railway track.
- Mobility server function to keep continuous connectivity along the railway track.

These technologies support less than 1 ms latency and precision time synchronisation, which is key for rail critical services. The solution provides coverage to approximately 1.5 km of track with a target of 1 Gbps throughput (see figure 1a) to a train running at 90 km/h. The final integration was shown live in the railway network from Ferrocarrils de la Generalitat de Catalunya (FGC), including development and integration of the trackside/stations infrastructure and the onboard train telecom network.

Smart city demonstration

A smart city environment has been showcased in Bristol, UK, which aimed to provide a managed platform for the development and testing of new solutions delivering reliable and high-capacity services to several applications and vertical sectors. Demonstrations related to converged FH and BH services have be demonstrated over a variety of integrated deployed optical and wireless transport and access technologies. These include the Time Shared Optical Network (TSON) solution and mm-wave technologies to support a high capacity and flexibility transport network as well as massive MIMO wireless solutions integrated with computing facilities.

The smart city demonstration was performed at the Millennium Square (figure 1b), located at the Bristol city centre, where two end-user use cases were demonstrated with the support of the underlying 5G network:

- A Virtual Reality use case, where a hologram of a music event was shown with six users participating in a synchronous interactive communication as avatars in the hologram.
- A Smart City Safety Camera use case, where a number of cameras were deployed in the square and on the roof of the MShed to generate traffic for the network. The video feed passes through an app to detect the presence of humans from all the camera feeds.

Stadium demonstration

A stadium demonstration with ultra-high user density, supporting media services has been showcased in Bristol, UK. The objective of the various demonstrations in the stadium was to address the following 5G topics: 1) Application aware network (i.e. programmable network) over heterogeneous HW, 2) Differentiated treatment of the application using slices, 3) Service resilience using slices – in a multi-connectivity link scenario (see figure 1c) for Wi-Fi, and 4) High capacity wireless access technologies: Massive MIMO.

The objective of the various demonstrations in the stadium vertical was to address the following 5G themes:

- Application aware network (i.e. programmable network) over heterogeneous HW.
- Differentiated treatment of the application that was demonstrated using slices.
- Service resilience using slices – in a multi-connectivity link scenario for Wi-Fi.
- High capacity wireless access technologies: Massive MIMO (physical).

7. 5G-PICTURE deliverable D6.3, "Final Demo and Testbed experimentation results", to appear in May 2020.

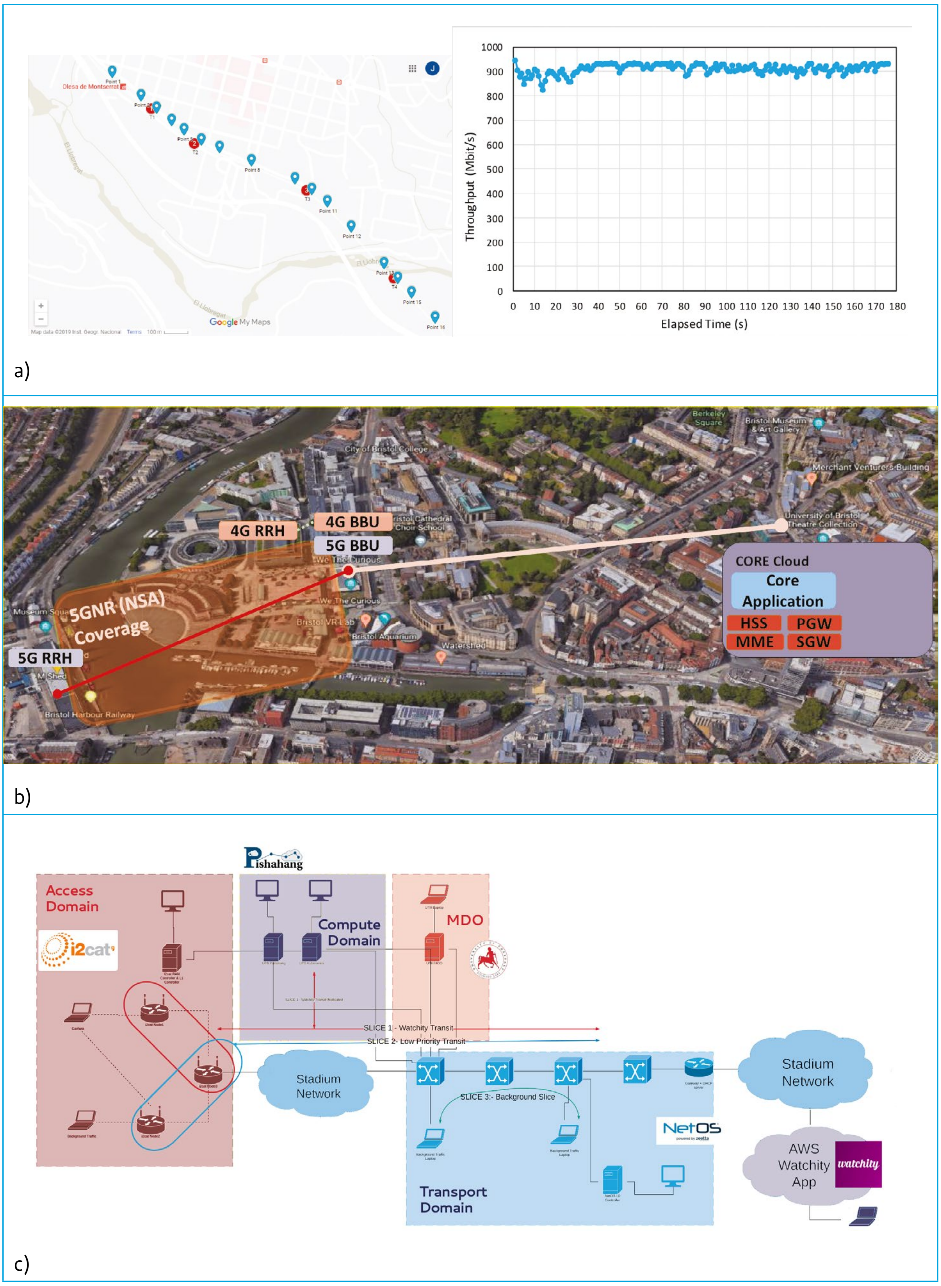


Fig. 1: 5G-PICTURE demonstration activities

Goals of the project

The main goal of the 5G-PHOS project is to create an ultra-broadband converged 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) Base Station site. In this way, 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 Networks and massive MIMO mm-wave 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 converged FiWi network. In this way 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, since it allows for flexible wireless last-mile placement of the remote equipment in the service area while maintaining compatibility with standardised eCPRI, as shown in figure 2.

Recent major achievements and innovations

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

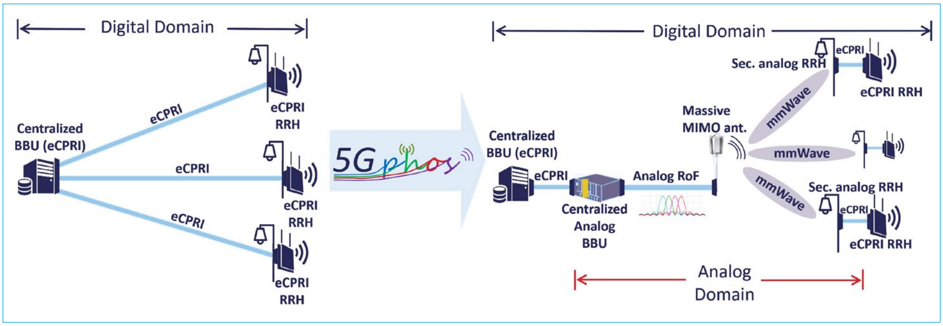


Fig. 2: 5G-PHOS transforms the PtP dedicated fibre-link Fronthaul to a converged Fibre-Wireless PtMP high capacity analogue Fronthaul.

- **Architecture, topologies, use-cases and KPIs:** The 5G-PHOS project has produced an updated architecture which provides an Ethernet-based FiWi eCPRI-compatible PtMP topology. Several architectural instantiations have been described in order to meet the main stakeholders' needs, which are the MNOs and the infrastructure owners. The consortium has also provided a fully parameterised dimensioning tool as well as an updated definition of the KPIs to be validated by the 5G-PHOS.
- **Experimental demonstrations**: The consortium has succeeded in transmitting the world's highest cumulative 5G FiWi transmission speed, by concurrently utilising 6 mm-wave channels, each carrying up to 4 Gb/s of data using highly directional 60 GHz antennas. More experiments successfully carried out include: a) the demonstration of FiWi links using the 5G-PHOS MIMO antenna, achieving 1 Gb/s user data rate with up to 120° degrees beam-steering, b) the demonstration of multi-user

FiWi environments within a 90° sector, using either Frequency Division Multiplexing or Spatial Division Multiplexing with beamsteering and c) the world's first demonstration of a 5G FiWi with 360° coverage using 4 wavelength Reconfigurable Optical Add-Drop modules and 4x-MIMO beams, as well as a two-stage optical fronthaul bus topology that can selectively reconfigure and re-allocate optical resources.

- **Resource allocation algorithms and SDN functionality**: During this year the project has defined and developed the FiWi architecture's resource allocation process over the SDN control plane, which assigns wireless sub-bands and optical wavelengths based on a series of performance factors, such as desired capacity or target latency. Detailed performance evaluation studies in terms of packet delay, which is the most critical factor in fronthaul applications, have also taken place by use of event-driven and system-level simulators.

5G-PHOS demonstrators

5G-PHOS will carry out three main demonstrators in total 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 the in-field legacy TIM PON infrastructure in Turin and it 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 over 60 Gbit/s aggregating multiple optical channels! 4QAM-OFDM and 16QAM-OFDM IF signals with ~200 MHz and 400 MHz bandwidth (considered within 3GPP NR specifications) were generated and optically multiplexed with the legacy FTTH services. After optical propagation, the Analog-RoF stream was directly fed to a directional wireless link operating at 60 GHz. Successful PON and Over-the-Air transmission well below the 3GPP (<12.5% EVM) requirements for 5G NR was obtained.

The project consortium now focuses its efforts towards the implementation of the next two demonstrators that will take place during the last months of the project's duration:

- 5G-PHOS Demo 2 will focus on ultra-dense networks and will interconnect two different sites, the "server site" located at the COSMOTE building and the "client site" located at the NTUA premises. A mixture of services will be validated over an Ethernet-over-5G-PHOS infrastructure, emulating in this way an eCPRI-over-5G-PHOS Fibre-wireless fronthaul scheme employing real MNO equipment.
- 5G-PHOS Demo 3 will focus on hot-spot scenarios, which will be installed and tested in the PAOK FC stadium, located in Thessaloniki. The setup of this demo will be validated through the delivery of WiFi services over the 5G-PHOS infrastructure.

5GTANGO

Goals of the project

5GTANGO enables the flexible programmability of 5G networks by delivering an integrated NFV Service Platform, which includes:

a) A Service Development Kit (SDK) to facilitate developers the creation of innovative Network Services (NS) and applications;

b) A Validation and Verification (V&V) Platform that facilitates the automatic testing of these NSs in "quasi-production" environments before being deployed in a real network. It targets Network Operators and/or Third-party Organisations that may provide services for the certification of these new Services.

c) A Service Platform with an innovative Management and Orchestration (MANO) solution that allows the efficient orchestration of the available infrastructure resources and the control of the whole life cycle and expected performance of the NSs. It is oriented to support Network Operators.

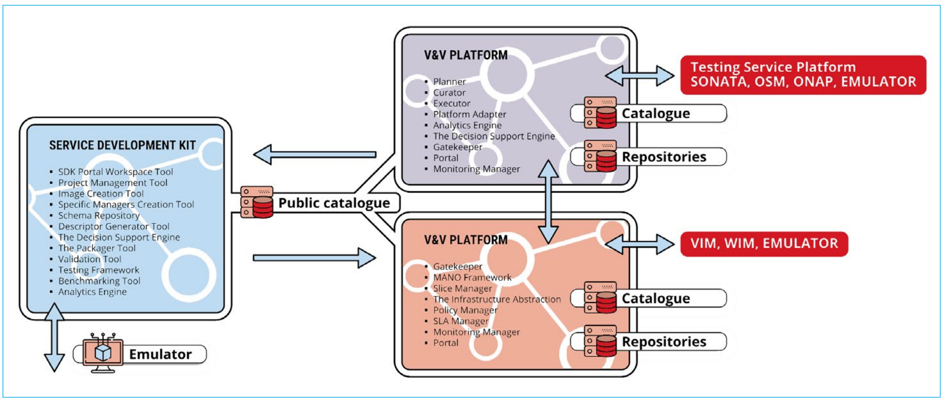


Fig. 3: SONATA High-level Architecture

Each of these modules corresponds to one of the main stages of the life cycle of a service: development, testing and operation. 5GTANGO allows the implementation of an extended DevOps (Development-Operations) model for Telecom that enables the agile management of the complete lifecycle of NS, increasing the productivity, reducing the time to market of services and allowing the creation of an ecosystem to encourage collaboration and innovation.

Major achievements

5GTANGO has delivered an Integrated NFV Platform that covers the whole lifecycle of the innovative and complex NSs to be deployed over 5G networks, from development to operations, but without forgetting the automatic validation and verification of those services, one of the main innovations introduced by the project.

Apart from the expected technical impact, 5GTANGO has followed a holistic impact strategy to ensure a true influence and footprint of the project outcomes that has mainly revolved around the project open source strategy. 5GTANGO results have been delivered under Apache 2.0 license in a public GitHub repository, freely available for download and use. The latest software release, SONATA 5.1, was delivered by the project in January 2020. SONATA 5.1 provides compelling features, such as:

- Invaluable set of tools for the creation and local testing of services.
- Automated V&V of services over different production-like environments and NFV platforms.
- Support of cloud-native deployments.
- Network Slicing.

- High level of automation though the dynamic management of runtime policies.
- Deployment flavours, QoS support and SLA management
- Service-based licensing model support.
- Advanced real-time monitoring system.

A huge effort has been made in order to facilitate adoption, which includes high quality documentation, easy installation processes, technical support, etc.

Especially fruitful has been the project contribution to Open Source communities and Standards, with the inclusion, for example, of the 5GTANGO slicing solution in OSM release FIVE, and contributions to some of the most salient standards such as ETSI NFV, ETSI ZSM or IETF/IRTF. The project activity related to 5G PPP collaboration has been also quite relevant with participation in several WG and collaboration with other projects. We can even claim the use of some 5GTANGO results by some of them like 5G-MEDIA, 5G-TRANSFORMER, 5GCroCo, 5G-VINNI, 5G-EVE, RESISTO or 5GROWTH.

Description of Pilots

- Smart manufacturing: The goal was to design a novel, agile and flexible network for a modern factory making use of NFV/SDN technologies. It also focused on the analysis of data coming from the machines in order to improve different processes in the factory. The goal, for example, can be efficiency improvement. It showcases three different cases: the first use case focuses on a new machine set-up in a smart factory, where after the physical machine is installed on site and connected to the physical network infrastructure, 5GTANGO takes care of deploying the required network services to integrate the machine into the factory network; the second use case focuses on containing a potential threat using 5GTANGO to deploy an intrusion detection system and firewall; finally, the third use case is based on maintenance based on augmented reality.
- Immersive media: It showcases how to provide advanced multimedia services making use of new technologies like 5G, vCDN, VR, 360° video cameras, image recognition, etc. It focuses on streaming a real-time video using a 360° camera at 4K resolution to users that, for example sitting at the leisure of their home, can enjoy a fully live immersive experience on a variety of devices such as VR head mounted displays (HMD), desktops or smartphones. The live stream is also enriched adding multiple secondary streams that can be selected by the user and even with social media (YouTube and Twitter) content. This enables high personalisation of the live stream creating a unique experience. Automatic QoS detection is also used to provide a seamless user experience. This means that the streaming is adaptive to the network conditions as well as to the number of different streams simultaneously accessed by the user in order to optimise the video quality on the client side.
- Real-time communications: The goal of this pilot is to deploy a commercial operator real-time unified communication platform over an NFV architecture. This includes the setup of multiple Network Slices over SONATA NFV Service Platform. Each instance of a collaboration system for real-time communications is deployed on each Network Slice, with different QoS requirements, which are enforced though a Transport network, using WAN Infrastructure Manager (WIM) interface. This demo leverages all the automatic procedures provided by 5GTANGO to instantiate an operative Network Slice including Network Services in just a few minutes with almost no effort. The final services provide advanced collaborative features such as multi-conference, screen sharing and whiteboard.

BlueSPACE

BlueSPACE Concept and Technologies: Space Division Multiplexing for 5G Fronthaul with Digitized and Analogue Radio-over-Fibre and Optical Beamforming

The core concept of BlueSPACE is to exploit the added value of optical space division multiplexing (SDM) in the radio access network (RAN) and to introduce analogue radio-over-fibre (ARoF) fronthaul with an efficient optical beamforming interface for wireless transmission in the millimetre-wave bands of 5G new radio (5G NR). Combining SDM with ARoF transport, BlueSPACE envisions a fronthaul network ideally suited to support large RF bandwidths and mm-wave carriers[8].

SDM in optical networks not only increases capacity manifold, but also allows sharing of the fibre infrastructure in multi-service or multi-operator scenarios and adds an additional degree of freedom to support increased flexibility[9]. Optical beamforming allows the concurrent and independent transmission of multiple beams for a single antenna array and thus allows an increased capacity per cell as well as a denser reuse of spectrum. The implementation of full complex beamforming networks becomes feasible with photonic integration, reducing footprint and energy consumption.

BlueSPACE demonstrates the added value of SDM for both digitized and analogue radio-over-fibre (DRoF and ARoF) fronthaul transport in a combined infrastructure, shown in figure 4, managed and orchestrated by a software defined networking (SDN) and network function virtualisation (NFV) framework[10] expanded to support SDM and optical beamforming as well as power-over-fibre delivery.

The project focuses its attention on a number of key challenges in 5G networks, addressed through the technologies introduced by BlueSPACE: first, fronthaul capacity which threatens to become a major bottleneck for the use of centralised radio access network (C-RAN) architectures is increased by the introduction of SDM in the network, while the introduction of analogue fronthaul minimises the capacity required per cell while seamlessly supporting the much larger radio bandwidths available in mm-wave 5G new radio. Second, beamforming and -steering based on optical beamforming networks allows true multi-beam transmission from a single antenna array and provides an efficient interface between fibre-based fronthaul and radio transmission. Third, ARoF with full centralisationof resources at the central office (CO) and optimum resource assignment reduces latency. Fourth, BlueSPACE extends the network control and management by means of SDN and NFV orchestration across the full fronthaul infrastructure with awareness of the SDM fibre medium, optical beamforming and the differences between DRoF and ARoF. Finally, BlueSPACE has designed all its architectures and hardware solutions with the target to maximise their facility for 5G, providing compact, cost and energy efficient solutions for integrated ARoF transceivers and optical beamforming networks.

8. BlueSPACE Consortium, "Space Division Multiplexing 5G Fronthaul with Analogue and Digital Radio-over-Fibre and Optical Beamforming – the BlueSPACE Concept," Aug. 2018, doi:10.5281/zenodo.1403140

9. S. Rommel et al., "High-Capacity 5G Fronthaul Networks Based on Optical Space Division Multiplexing," IEEE Transactions on Broadcasting, vol. 65 no. 2, pp. 434–443, Jun. 2019, doi:10.1109/TBC.2019.2901412

10. J. Brenes et al., "Network slicing architecture for SDM and analog-radio-over-Fibre-based 5G fronthaul networks,"

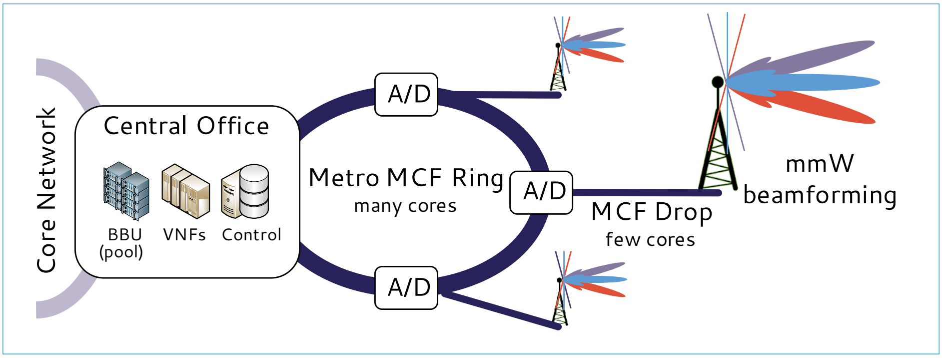


Fig. 4: BlueSPACE concept and architecture overview including optical fronthaul based on space division multiplexing fibres and multi-beam transmission based on optical beamforming networks.

BlueSPACE Demonstrations, Results and Key Achievements

Currently in its third year, BlueSPACE has successfully implemented many of its technologies and performed a number of public demonstrations at conferences and at the premises of the consortium partners[11]. The demonstrations performed included most of the key technologies introduced by BlueSPACE with the exception of optical beamforming which will be demonstrated in the upcoming months, leading up to the final project demonstration which combines all BlueSPACE technologies in order to showcase a shared optical network based on SDM, supporting both DRoF and ARoF with optical beamforming, managed via a unified SDN and NFV platform. Two BlueSPACE demonstrations based on DRoF and ARoF, both using multi-core fibre (MCF), demonstrated the capabilities of the DRoF transceivers and SDN controller of BlueSPACE and the feasibility of analogue fronthaul for large bandwidth millimetre wave 5G signals respectively.

In the DRoF demonstration, shown in figure 5, the signal processed by the pool of baseband units (BBUs) is transmitted as digitized waveform data over the WDM and SDM fronthaul network via a bank of BVTs, an optical switch and a set of passive multiplexers at the CO, allowing for fully flexible bandwidth, wavelength and spatial assignment of the signals. At the remote nodes and cell sites passive multiplexers split the signals and BVTs decode them, before they are fed to the remote radio units (RRUs).

A centralised SDN controller manages the entire fronthaul network with full control over the bandwidth, spatial and spectral resources. To enable this control, the nodes and cell sites host the SDN control agents to allow configuration of the network elements. Such programmability of the network elements across the fronthaul infrastructure is key to ensure efficient resource utilisation.

This concept has been evaluated in multiple experiments within BlueSPACE, successfully demonstrating the transport of an extended 5G NR signal with a capacity of 5.67 Gbit/s and a bandwidth of 760.32 MHz. The digitized version of this signal is framed into a 22.25 Gbit/s DRoF data stream and transmitter over the network with 100 GHz spaced WDM channels and 25.4 km of 19-core MCF. Overall this network has a capacity of up to 760 channels, showcasing the scalability of combined SDM and WDM optical networks. Analogue fronthaul avoids the large bandwidth required for the digital transport of radio signals and directly transports the target analogue waveform at baseband, at an intermediate frequency (IF) or directly at radio frequency (RF). For mm-wave 5G NR, transport at IF with subsequent optical heterodyning minimised cost and complexity, as it reduces the required bandwidth of optical components and allows centralisation of frequency sources and references.

11. blueSPACE Consortium, "blueSPACE Demonstrations," https://www.bluespace-5gppp.eu/demonstrations »

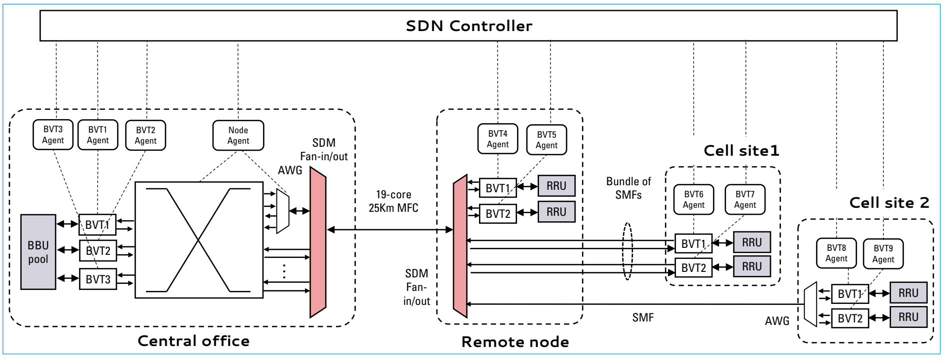


Fig. 5: DRoF fronthaul demonstration with hybrid SDM/WDM network and BVTs under centralised SDN control.

In the BlueSPACE ARoF architecture, shown in the figure 6, the BBU provides an analogue baseband signal which is upconverted to IF for ARoF fronthaul transport. The signal is carried over a MCF to the remote side, where optical heterodyning of the IF modulated two-tone signal generates the 5G NR millimetre wave signal. For full centralisation of frequency sources and to minimise complexity of the remote unit (RU), an unmodulated copy of the two-tone signal is also transported to the RU and provides a local oscillator (LO) for downconversion of the uplink millimetre wave signal to IF. The uplink IF signal is transported over the same MCF to the CO, where it is downconverted to baseband by the IF unit and digitized and processed by the ARoF BBU.

This architecture was successfully demonstrated in a BlueSPACE ARoF demo, featuring real-time processing of all signals and using extended 5G NR signals of 760.32 MHz. The demonstration included a loopback of the RF signal at the RU before downconversion with the remotely fed LO and direct input to the IF unit without return transport over MCF; this configuration allows to emulate worst-case performance. Successful transmission of the extended 5G NR signal was demonstrated with millimetre wave transport at 25.5 GHz and full real-time processing, achieving a throughput data rate of 1.4 Gbit/s.

This showcases the feasibility of ARoF fronthaul over MCF with maximum centralisation and a reduced complexity RU. BlueSPACE further plans to show ARoF fronthaul with photonic integrated transceivers and with fully integrated optical beamforming networks to show the ideal synergies between ARoF transport with optical heterodyning and optical beamforming.

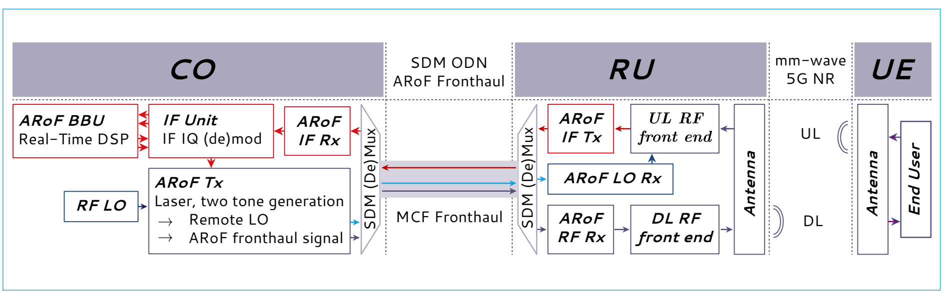


Fig. 6: ARoF fronthaul architecture with SDM network and optical heterodyning for millimetre wave 5G NR signal generation.

BlueSPACE further plans additional demonstrations to validate its technologies in relation to the KPIs identified by the project: i) the peak data rate achievable for a single user under ideal conditions, ii) the capacity of the fronthaul network over a certain area, iii) the energy efficiency of the ARoF fronthaul, iv) the service deployment time with full SDN and NFV management, v) the low latency achievable with ARoF fronthaul, and vi) the spatial efficiency of spectrum usage supported by optical beamforming and dense frequency reuse. The final demonstration will bring together parts of all BlueSPACE demonstrations in the final project demo on the premises of Eindhoven University of Technology to showcase the full potential of the project's developments and demonstrate the value of SDM and ARoF with optical beamforming for 5G fronthaul as envisioned by BlueSPACE.

IoRL

Internet of Radio Light

The Internet of Radio-Light (IoRL) project strives to develop a safer, more secure, customizable and intelligent in building network using millimetre Wave (mm-wave) and Visible Light Communications (VLC). The conceived solution reliably delivers increased throughput (greater than 10Gbps) from access points pervasively located within buildings. It does so, whilst minimizing interference and electromagnetic exposure and providing location accuracy of less than 10 cm at the same time. Thereby IoRL's ambition is to show how to solve the problem of broadband wireless access in buildings and promote 5G global standard.

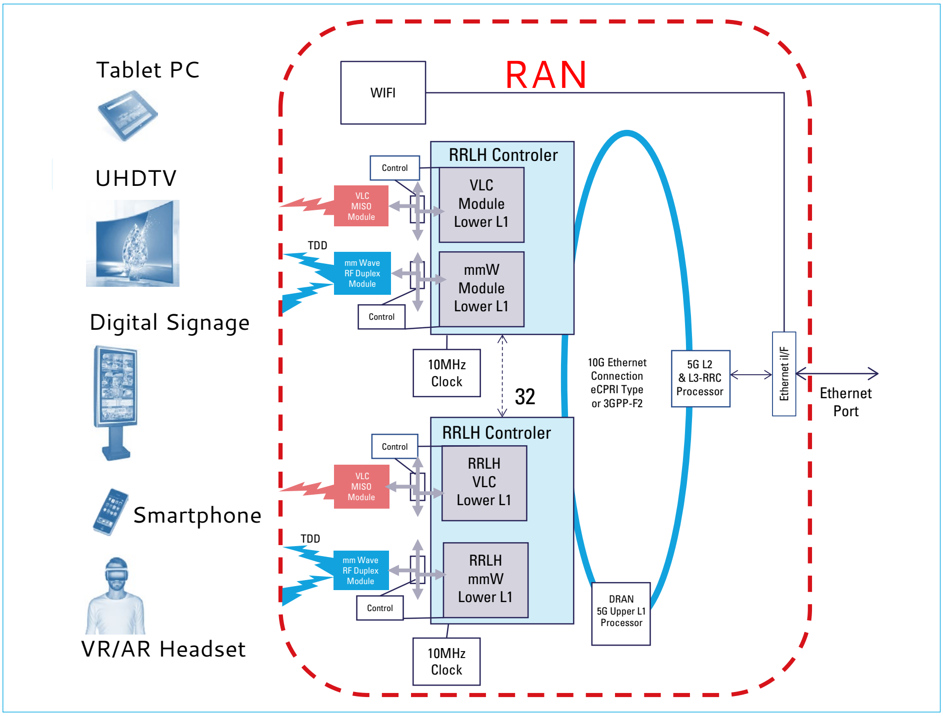


Fig. 7: RAN combining mm-wave and VLC.

After the interfaces between Layer 1 and Layer 2 systems at the Remote Radio-Light Heads (RRLH) and UE and between the Intelligent Home IP Gateway (IHIPG) and the Layer 2 systems had been resolved, much of the work in 2019 was concerned with the integration of the sub-systems to produce a complete end-to-end system that could be presented in the home, museum, train station and supermarket demonstration environments given the technical constraints of the sub-systems. The first main technical constraint was that the RRLH Controller and Distributed RAN could not simultaneously provide 10 MHz bandwidth Transport Block (TB) to the VLC Module and a 100 MHz bandwidth TB to the mm-wave module as originally designed due to the preliminary design of the DRAN. Since further constraints were imposed on the design due to the 10 MHz bandwidth limitations of communication LEDs, this meant that a decision was made to provide 10 MHz bandwidths to both the VLC and mm-wave parts of the system in order to show a proof of principle system in the demonstration environments. This system produces a total bitrate of 6 Mbps with 4 QAM and SCS=30 KHz for VLC and 10 Mbps at 4 QAM SCS=30 KHz for mm-wave using the Runel/Viavi testbed.

However, since the RRLH Controller and DRAN are FPGA sub-systems, the project has been able to achieve 70 Mbps using 100 MHz bandwidth with 4-QAM and SCS=30 KHz at mm-wave in the laboratory using the Runel testbed, which could be enhanced to 210 Mbps using 100 MHz with 64-QAM and SCS=30 KHz at mm-wave but was constrained by the low processing power of software implementation L2 processor module. Furthermore, a total bit rate of 42 Mbps was obtained on the VLC system with 10 MHz bandwidth, 4-QAM and SCS=30 KHz on the Viavi testbed and a total of 310 Mbps was obtained on the mm-wave system with 100 MHz bandwidth, 64-QAM and SCS=30 KHz on the Viavi testbed.

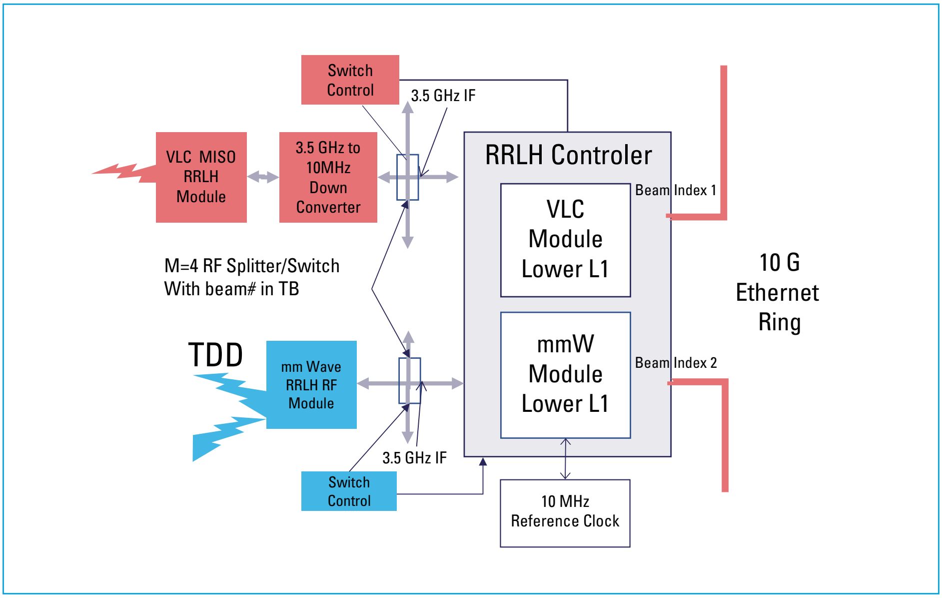


Fig. 8: RF and lower Layer 1

In principle, the RRLH Controller and DRAN designs could be enhanced to operate at 400 MHz bandwidths with 64-QAM and SCS=30 KHz at mm-wave to produce 840 Mbps per RRLH Controller in a final commercial FPGA/ASIC system. This 840 Mbps is scalable since it can be provided to each of up to 32 RRLH Controllers in rooms in a building to a total of 10 Gbps from a 10 Gbps Ethernet ring home network. Latency measurements of much less than 0.5 ms have been measured at 10 MHz bandwidth at the physical layer between the UE and the DRAN. However, at larger bandwidths this figure is expected to increase.

The second main technical constraint was that the RRLH Controller was originally designed to produce a 3.5 GHz IF signal. Modifications were thus made to it so that it could generate 15 MHz IF signal as required by the VLC driver system. A 5G compatible VLC output was produced since by imposing Hermitian symmetry on the OFDM subcarriers with a DC bias added to the bipolar OFDM time-domain signal, this renders the IF signal real and non-negative as required for VLC OFDM symbols.

In the final design the splitter/switch should be controlled from the RRLH Controller but until the principle of operation of the RSS VLC location estimation algorithms can be proved to work, an intermediate solution was designed to manually switch between RRLH VLC modules through a wireless control from a smart phone app. The project has produced an experimental test and measurement plan to validate predictions of RSS VLC location accuracies of 15cm at the centre of a room and 40cm at its edges.

Transforming a consumer light system into a VLC RRLH also proved to be a learning experience for the project. First lighting LEDs could not also be used as communication LEDs as the impedance of its complicated parallel-serial circuit was not suitable for the VLC driver system. Thus, lighting and communication LEDs circuits were separated. Second lighting LEDs were not powerful enough to act as communication LEDs so a separate communication LED design was made to produce more powerful light output. Finally, the electrical cables that are usually used to provide power for a LED light system could not be used for providing the VLC modulated power for the communication LED because it was experiencing too much interference. This was rectified by using SMA cables instead.

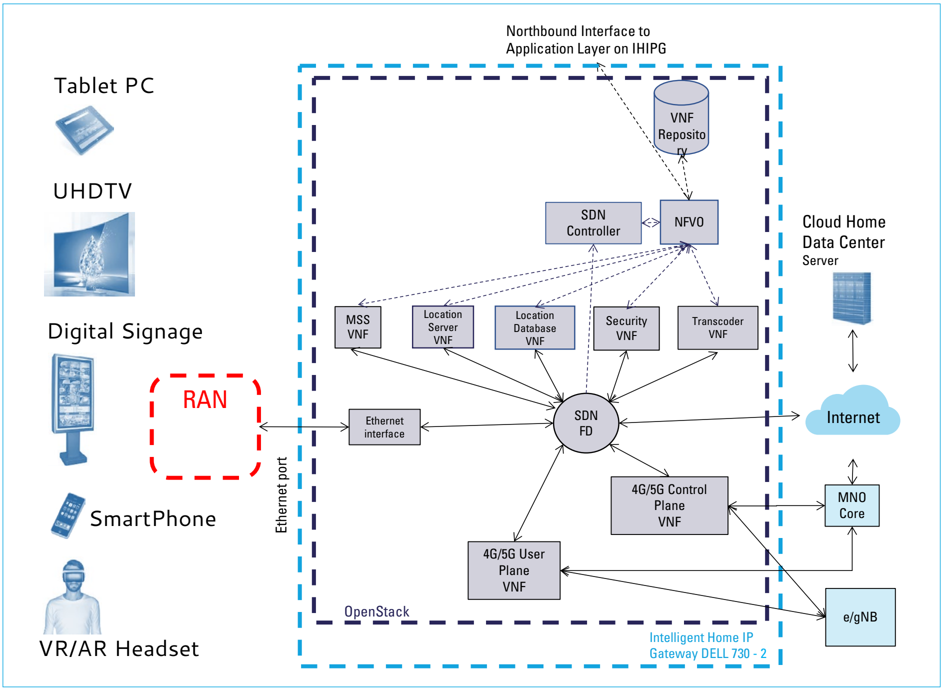


Fig. 9: Openstack Mobile Edge Cloud

An impressive set of application and network services have been developed and tested over wireless LAN Ethernet network by the IoRL project, which can be retrofitted with the 5G IoRL RAN as and when it is ready and which are being reported in the Verticals white paper being produced by 5G PPP Technology Board and 5G IA's Vertical Task Force. This ranges from streaming IP video to a 4K TV, streaming two IP videos to a picture in picture Android 4K IP TV and multiplayer gaming on VR headsets such as the HTC Vive which uses a 1080×1200 pixel resolution screen per eye and demands very low latency to avoid motion sickness. The multitude of data transactions, the number of users and the data demands for VR make latency, bandwidth and throughput critical criteria. Additionally, the project has the potential for producing a novel VR headset tracking method that requires impressive location estimation accuracy, precision and latency to meet current VR standards. Current tracking system precisions and accuracies are already sub mm, so further research is required for two orders of magnitude improvement from 10 cm which is currently what can be obtained by the to 1 mm accuracy.

An Openstack Mobile Edge Cloud (MEC) was developed on Dell 740 server, on which security, load balancing, multisource streaming, intelligent service support and location-based data access Virtual Network Functions were developed and tested over Wireless LAN, which again can be retrofitted with the 5G IoRL RAN as and when it is ready and which are being reported in the Verticals white paper being produced by 5GPPP Technical Board. The resultant system will be demonstrated at Nuevos Ministerios train station in Madrid in May 2020, at Musée de la Carte à Jouer in Paris in June 2020, at a Building research Establishment Home in September 2020 and at a Chinese supermarket in October 2020.

In summary partitioning the 5G protocol stack so that so that a 5G RAN can be provided by two or more suppliers has proved a challenge in the project even for just two manufacturers due to technical constraints of the constituent parts. Much more success has been experienced when the 5G RAN has been provided from one supplier.

The Completed MATILDA Testbed

The goal of the MATILDA Project is to deliver a holistic and innovative 5G framework to undertake the design, development and orchestration of 5G-ready vertical applications (vApps) and 5G network services over programmable infrastructures. To this goal, a telecom layer platform has been designed to realise the autonomic management of the lifecycle of 5G network slices and edge computing resources. In accordance with 3GPP, the main stakeholders actively involved in this environment are three: the vertical industry owning the vApp, the telecom service provider delivering 5G services, and the telecom infrastructure provider offering computing and communication facilities.

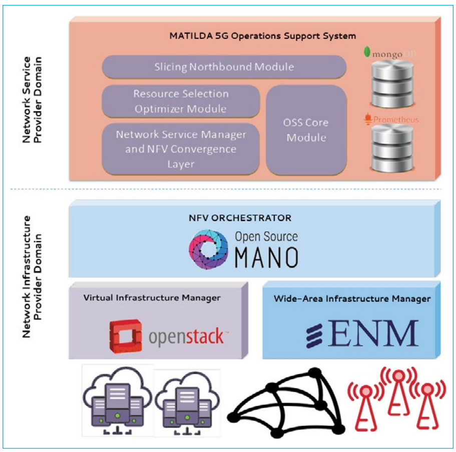


Fig. 10: Main building blocks composing the MATILDA 5G Telecom and Infrastructure Platforms

Figure 10 depicts the main functional blocks composing the telecom layer platform. The Operations Support System (OSS) is in charge of managing all functions and operations required for the placement of a vApp over a network slice, as well as maintaining the information on all the data regarding the deployed vApp, network services, available resources, and so on. The NFV Orchestrator (NFVO) is responsible for the lifecycle management of the network services, both those composing the base 4/5G services and the ones provided to slices. The Wide-area Infrastructure Manager (WIM) is devoted to manage and monitor the wide-area communication resources, to create overlay networks for vApps and base telecommunication services, as well as to provide information on the resources available in the distributed 5G infrastructure. Finally, the Virtual Infrastructure Manager (VIM – one instance per each distributed computing facility), abstracts and exposes computing, storage, and networking capabilities of datacenters within the 5G infrastructure. Vertical industries can autonomically manage the lifecycle of their application graphs by means of Vertical Application Orchestrators (VAOs). The VAO interacts with the OSS via a specific meta-model, called slice intent, which represents all requirements that should be satisfied during the creation of a slice. The VAO and OSS include most of the innovations developed within the project. In the OSS, among other functionalities, the NFV Convergence Layer (NFVCL) module provides a level of abstraction for the flexible and high-level management of the complete lifecycle orchestration of network services, Virtual Network Functions (VNFs) and Physical Network Functions (PNFs) instantiated in the 5G infrastructure.

Testbed Deployment

For the final demonstrations of the MATILDA Project, the testbed has been deployed as shown in figure 11. A wide-area network interconnects three VIMs and two e/gNodeB PNFs. VIMs 1 and 3 are supposed to be "edge" VIMs, in the sense that they are placed geographically closer to the e/gNodeBs, while VIM 2 is placed in the "core" of the Telecom infrastructure.

On top of this infrastructure, the NFVO instantiates a Public Land Mobile Network (PLMN) as base network service. The PLMN in figure 11 is composed of a number of network services, whose VNFs are highlighted with the light blue color. One service, in the core VIM 2, includes a single monolithic VNF implementing the EPC functionalities. This VNF has two main network interfaces, one towards the 4/5G network and one towards the public Internet. On each edge VIM, an additional network service is created for managing and configuring an eNB PNF and for providing S1 bypass capabilities. The S1 bypass has two main network interfaces, one towards the wide-area network to interconnect with the EPC and the eNBs, and one towards a virtual layer-2 network internal to the VIM.

An OpenStack project is fully dedicated to the vApp and directly controlled by the VAO via a connection to the public Internet. Different vApps in the same VIM will be assigned to different and isolated OpenStack projects, highlighted with a sketched purple box in the figure. vApp components might be placed on edge VIMs close to the attach point network, if they have particular performance requirements, or in other VIMs, like the ones in the infrastructure core. In that case, a further Network Service (whose VNFs are colored in red in figure 11) should be created and deployed to provide connectivity among the vApp components in the different VIMs.

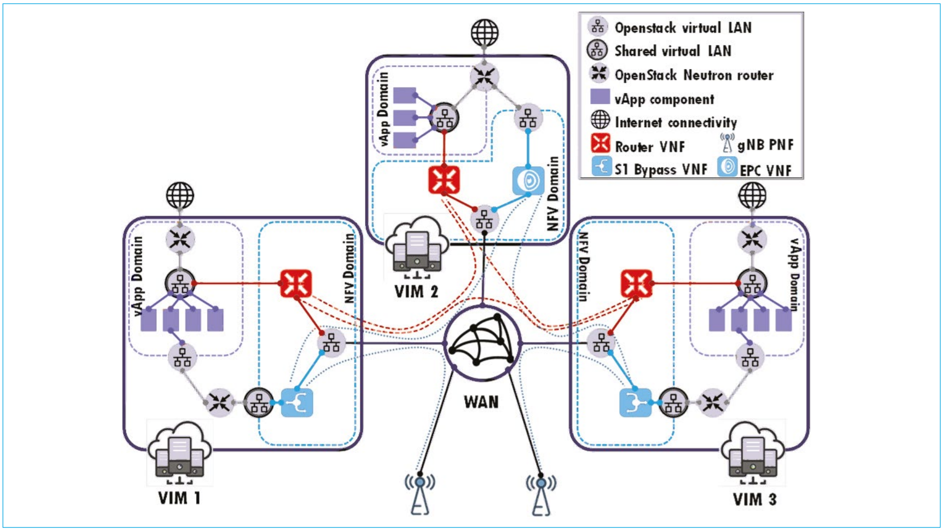


Fig. 11: Testbed deployment for the evaluation, including a base network service and a network slice, produced by the MATILDA Telecom Layer Platform.

MATILDA Use Cases and Demonstrators

High Resolution Media on Demand Vertical with Smart Retail Venues' Integration (5GPACE), offering high valued services to consumers participating in a crowded event.

5GPACE consists of two main parts, providing user management services, geo-localisation functionalities, high-quality video sharing and processing capabilities, as well as smart retail recommendations for the users.

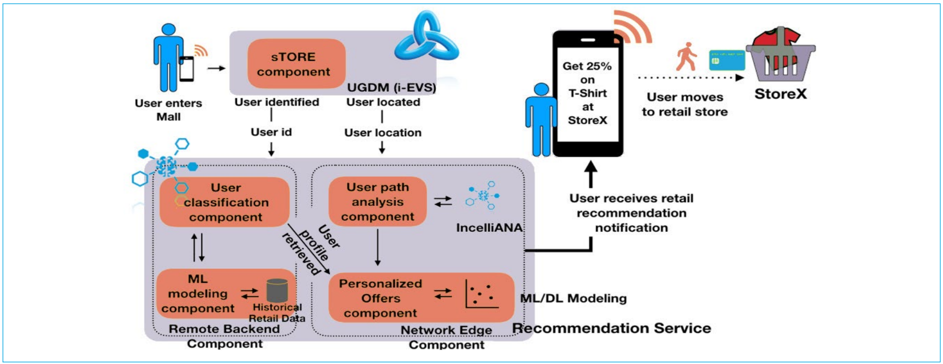


Fig. 12: High Resolution Media on Demand Vertical with Smart Retail Venues' Integration (5GPACE)

Testing 4.0 – Distributed System Testing, demonstrating the data acquisition and remote testing of Mobile System Under Test (SUT) units using the FastWAN solution by ExxpertSystems over a 5G network.

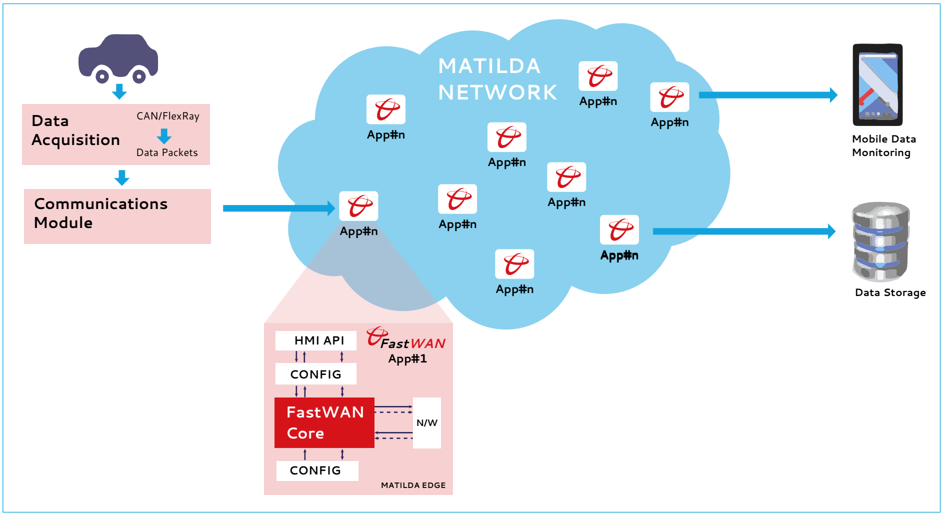


Fig. 13: Testing 4.0 - Distributed System Testing

5G Emergency Infrastructure with SLA Enforcement (5GPPRD), a 5G system for Public Protection and Disaster Relief (PPDR). It extends the capabilities of a real time intervention monitoring and critical infrastructure protection product suite (iMON), combined with a suite for performance monitoring engines to support SLAs (qMON).

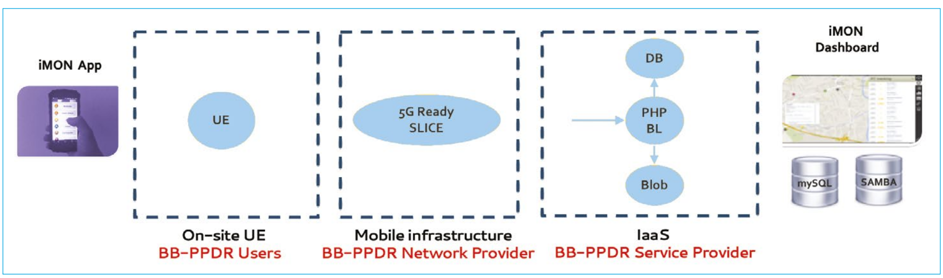


Fig. 14: 5G Emergency Infrastructure with SLA Enforcement (5GPPRD)

Industry 4.0 Smart Factory – Inter and Intra-Enterprise Integration, focusing on a logistic scenario, which offers customers the possibility to track, change and prioritise their orders, and on a production scenario, featuring both pattern detection for quality assurance and real-time distance calculation in a Human-Robot Collaborative (HRC) environment.

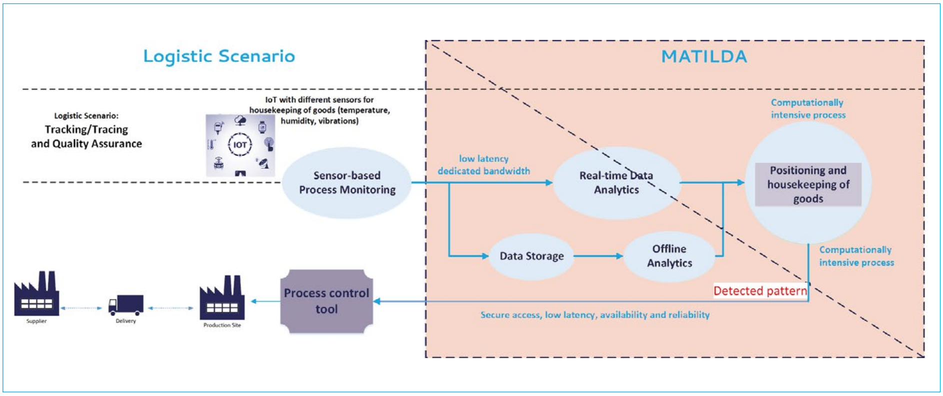


Fig. 15: Industry 4.0 Smart Factory – Inter and Intra-Enterprise Integration

Smart City Intelligent Lighting System, implementing an end-to-end operational service framework for the Smart City Intelligent Lighting solution starting from design and development to end-to-end orchestration over a 5G infrastructure assuring the end-to-end management, control and orchestration of the slice.

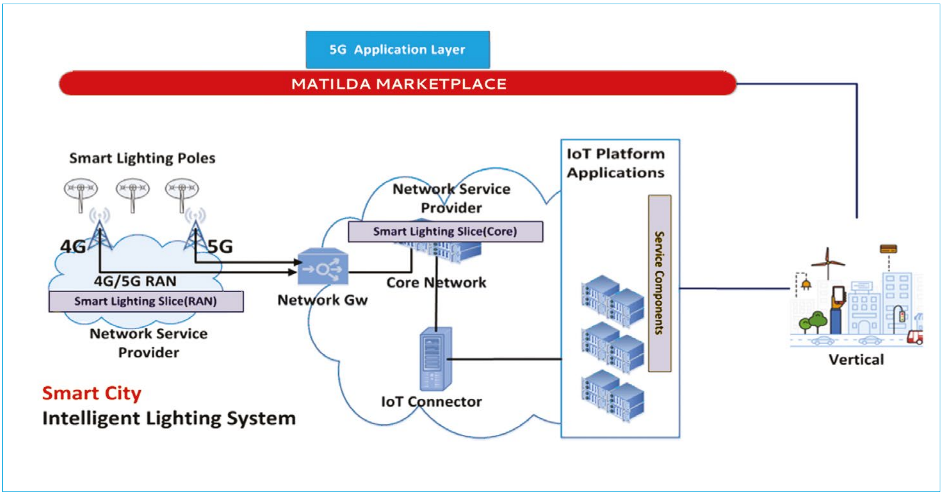


Fig. 16: Smart City Intelligent Lighting System

Metro-Haul

Introduction

In essence, our goals were to develop an intelligent, dynamic and most importantly, 5G-aware optical transport layer that can support and deliver 5G services, far faster and far more efficiently compared to existing technologies. Figure 17 below provides the scope of the project.

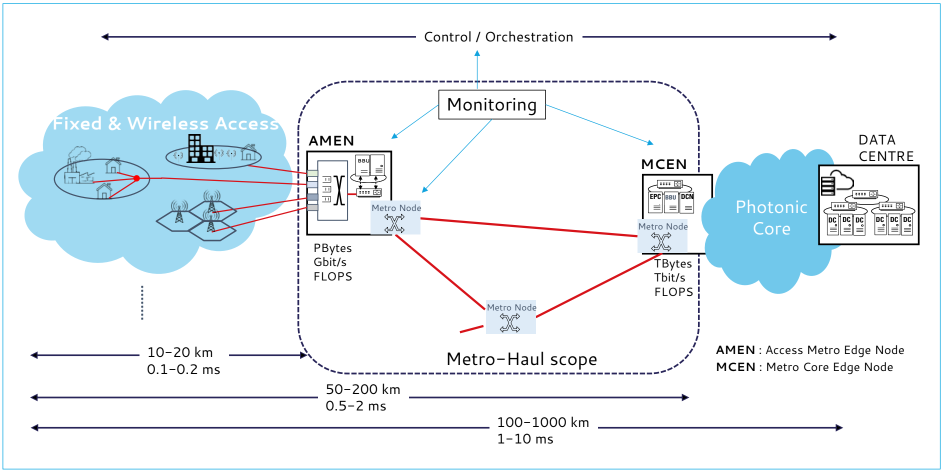


Fig. 17: Metro-Haul Reference Architecture

Early in the project, we identified several key technology innovations and principles that became the cornerstones of our technology innovation plan; these were:

- 1. Flexible metro optical network with edge computing, and an intelligent control plane;
- 2. Multi-layer disaggregated network, supporting the integration, via open interfaces, of new technologies;
- 3. Smart network telemetry platform, with real-time performance monitoring and analytics, and including an integrated open source planning and optimisation tool.

Major Achievements and Technical Contributions

Now in the last year of our project, we have been focused on implementation and testing. A key aspect of Metro-Haul is innovation collaboration and exploitation between industry and academia, as well as between network operators and equipment manufacturers. Significantly, the innovation results and testing conducted so far have justified our strategy to combine edge computing, flexible optics and network slicing, and shown it is essential in delivering 5G applications to the advantage of network operators and their customers.

Furthermore, our dissemination and standardisation activities have also been hugely successful with more than 200 publications across leading international research and industry conferences, journals, workshops, and magazine articles. The Project has been responsible for running booths and Q/A sessions at many events while demonstrating key technology innovations. In addition to the research and industrial dissemination activity, we have also led and contributed to various open and traditional Standards Development Organisations (SDOs), including ETSI, MEF, IETF, OpenROADM, CORD, ONOS, ITU-T, 3GPPP and Open Config.

Metro-Haul technical contributions at important SDOs include:

- ITU-T "Recommendation" for interfaces in 100-Gbit/s coherent transmission systems;
- ITU-T Specification for optical measurements (for example, of the relationship between the OSNR penalty and EVM for various impairments);
- ITU-T Recommendation for the theoretical background for optimum parameter choice;
- Open ROADM resource modelling;
- An IETF Enhanced VPN Framework;
- An IETF Applicability Statement of Abstraction and Control of Transport Networks to Network Slicing;
- Various open-source code contributions that will be made available for broader industry use as the project continues.

End-to-End Demonstration

Currently, we are in the process of setting up two very large end-to-end demos in the final stages of the project. These demonstrations will showcase the Metro-Haul SDN-based multi-layer metro optical network, providing connectivity between mobile-edge computing nodes supporting two Vertical Services.

We will show that to support 5G applications the optical metro network needs to provide flexibly low latency and high bandwidth connections on-demand and be capable of responding to changing real-time requirements.

Key highlights of the end-to-end demos are:

- Setup and transportation of several high-bandwidth connections over a multi-layered network.
- The metro network connectivity will be using open interfaces, with interoperable implementations from multiple vendors;
- Leverage network slicing to allocate bandwidth and facilitate connectivity of the required computational nodes to run the mobile edge computing applications;
- Demonstrate that the intelligent and automated placement of virtual network functions, which will enable efficient distribution and leverage resources more effectively;
- Monitor the connections and resource usage to manage optical and packet transport connections and resize network connections and compute resources on demand;
- Show that the Metro-Haul hierarchical orchestration framework is capable of controlling the metro network, network slicing, instantiation of compute resources, virtual network function placement, and application resources.

Our end-to-end demos will be showcased in late Spring 2020.

SliceNet

Objectives of the project

SliceNet's main objective is the design and prototyping of an innovative framework for management and control of Network Slices (NSs), leveraging Software-Defined Networking (SDN) and Network Function Virtualisation (NFV) technologies, with cognitive techniques and artificial intelligence for 5G networks.

The key drivers for SliceNet architecture design are End-to-End Network Slicing, Transversal Orchestration, and the fact that it is Data centric, Cognition Enhanced, Policy and QoE Driven, multiple domain, and Vertical oriented.

SliceNet architecture is presented in figure 18. The architecture is divided into three main planes and several sub-planes that incorporate all the software and hardware components, simplifying in this way the comprehension of the functional workflows.

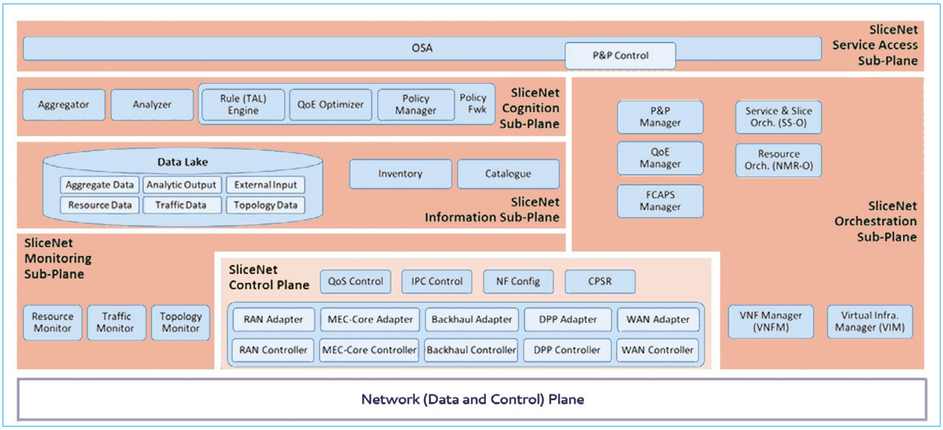


Fig. 18: SliceNet Architecture

The SliceNet Network (Data and Control) Plane comprises the sliced end-to-end network, including the 4G and/or 5G data plane and control as defined by 3GPP. The SliceNet Control Plane exposes a slice control context by means of Control Plane Services (QoS control, IPC control, NF configurations) offering per-slice run-time operations for the enforcement of the end-to-end network dynamic configuration. The SliceNet Management Plane provides all the required capabilities to manage the NSs lifecycle, including the design, on-boarding, provision, monitoring, cognition and automation loops. The Slice Management Plane is split in several sub-planes grouping the several responsibilities – SliceNet Monitoring, Information, Cognition, Service Access and Orchestration Sub-Planes.

Major achievements/innovations and performance KPIs

SliceNet project will be concluded in 2020 and therefore it is finalising its architectural developments and prototypes, including testing and validation.

The main innovations of the project are:

- The network slicing control, management and orchestration architecture implementation;
- The MEC platform and programmable infrastructure;
- The RAN slicing and data plane programmability control;
- The cognitive network management component;

- The Plug & Play Control Plane and Slicing control and the One-stop API for verticals
- The E2E multi-domain multi-tenants network slicing;
- Applying artificial Intelligence to 5G operations.

The performance of the system has been validated by experimental results, focusing on different key performance indicators. Through network slicing SliceNet guarantees a committed QoS performance throughout the End-to-End data plane, including RAN, MEC, CN and the wired connections among the different network segments. Figure 19 shows the results of an experiment on the quality of a service via slicing, by measuring latency and percentage of throughput performance of the network traffic that belongs to a slice (depicted in dark/light blue). The implementation is based on a fine-grain traffic adaptation supported by a three layer hierarchical schema (scheduling, shaping and differentiating) that is carried out by the Flow Control Agent (FCA). More details of this implementation can be found in Deliverable 4.3.

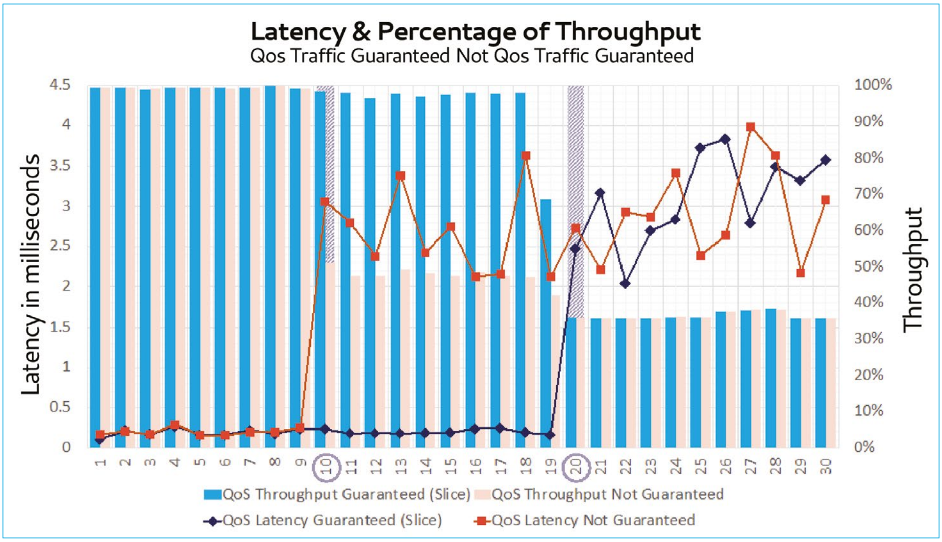


Fig. 19: Guaranteed services via slicing: empirical results [Source: Network Management -Edge and Cloud Computing-The SliceNet Case, Jan 2020, IEEE CCNC, Las Vegas, USA]

This experiment shows three different time intervals, which are divided in figure 19 by using purple columns, to showcase three possible scenarios (network conditions) that may occur when network traffic in a slice is flowing. For demonstration purposes, all interfaces throughout the experiment have been configured to allow, as maximum, a throughput of 250 Mbps. At time 0 there was no congestion in the network, therefore, both the network traffic in a slice (20 Mbps) and the traffic without a slice (20 Mbps) showed good performance results. At time 10, synthetic congestion (260 Mbps) was applied and the graph shows that the traffic without a slice dramatically decreased its performance while the traffic in the slice remained stable in terms of both sustained high throughput and low latency. At time 20 the slice was removed while the synthetic traffic of 260 Mbps was still present. Inconsequence, all traffic became unstable with downgraded fluctuating performance.

Description of demos

Slicenet is demonstrating how it facilitates vertical business added value by implementing use-cases exploiting the 3GPP defined requirements, Ultra-Reliable Low-Latency Communications (URLLC), massive Machine-Type Communication (mMTC), and enhanced Mobile BroadBand (eMBB), in three different vertical industries: smart grid, eHealth, and smart city.

The smart grid use case is implemented with ultra-Reliable Low Latency Communication 5G network slice to demonstrate a fully decentralised high-speed self-healing solution for electric power grids. These self-healing solutions rely on distributed automation and power system protection and aim at increasing energy supply Quality of Service (QoS) by reducing the number of customers affected by power outages, as well as the frequency and duration of these outages. The use case highlights the potential for 5G slicing to leverage critical systems supported by 5G network infrastructures.

The eHealth use case demonstrates how to provide support to medical emergency first responders by developing a platform that can rapidly provision dedicated end-to-end broadband 5G slices to advance the emergency ambulance services through the design of better-connected, integrated and coordinated healthcare. By providing prioritised life-critical video-streaming from inside a high-speed moving ambulance, the use case achieves "*reliable and dependable QoS and QoE with 'zero perceived' downtime*". It uses eMBB, requiring both extremely high data rates and low-latency communication in some areas, and reliable broadband access over large coverage areas.

The smart city use case demonstrates the management of a smart street lighting poles infrastructure, including lighting and power to city services, e.g. public safety surveillance, air quality monitoring, public Wi-Fi hotspots, advertising. This use case is a 5G massive machine-type communication use case in the sense of accommodating the massive number of connected actuators/controllers without impacting the QoS and QoE. Ultra-high network reliability and availability are assured, while low-power, context awareness and location awareness requirements for managing the connected actuators/controllers over the access and transport layers can further improve the solution cost efficiency.

More information about the project, technical materials, and software releases can be found on the website @ *https://slicenet.eu.*

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 are located in France, Greece, Italy and Spain (see figure) and provide both indoor and outdoor facilities. They are complemented by the Ericsson lab in Kista, Sweden. The French site is composed of a cluster of sites located in Paris, Nice, and Rennes. Each site is operated by a telecoms network operator, i.e. Orange in France, OTE in Greece, TIM in Italy, and Telefonica in Spain. 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 Release 16 compliant.

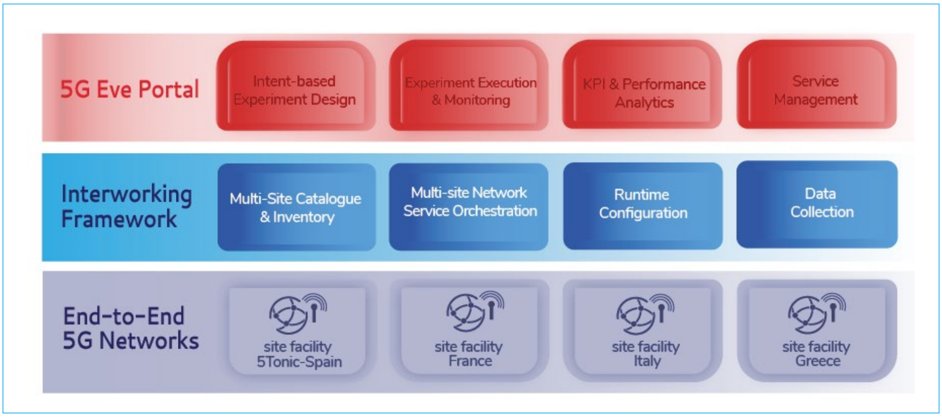


Fig. 20: 5G EVE Platform – Interworking of Multiple End-to-End 5G Site Facilities

Specifically, the technical objectives include: (i) Implementing Release 16 compatible technologies in the four sites, starting from the evolutions of current Release 15. Specific pilots validate that 5G KPIs can be achieved; (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 2019, 5G EVE achieved the following major results[12]:

At the end of 2019, 5G EVE reached an important milestone. It is related to 5G EVE's ambition to make its 5G end-to-end facility available to vertical industries for initial experimentation, including vertical industries in 5G EVE and in ICT-19 and ICT-20 projects. 5G EVE performed a systematic analysis of the key performance requirements of all use cases from verticals participating in 5G EVE as well as verticals from ICT-19 projects interested in using the 5G EVE platform (see deliverable D1.2). Furthermore, the overall 5G EVE architecture for supporting those requirements was specified (deliverable D1.3).

Each 5G EVE site facility has already deployed the required 5G capabilities (up to Rel-15), validation tools and systems, and the secure connectivity for enabling the initial experimentation of use cases on them (deliverable D2.6). 5G EVE completed and released the first development of innovative features on 5G EVE's framework for advanced and intent-based validation, KPI monitoring/analysis/validation, basic interworking and openness support (D4.1, D4.2, D5.1, D5.2, and D3.3).

Overall, 5G EVE progressed as planned in executing, validating, and supporting the pilots in 2019. The project laid the foundations for evolving the deployed 5G capabilities in all sites and for upgrading the 5G EVE framework with added-value services for the first major release of the 5G EVE platform.

12. *The 5G EVE deliverables referenced in this section are available at https://www.5g-eve.eu/deliverables/*

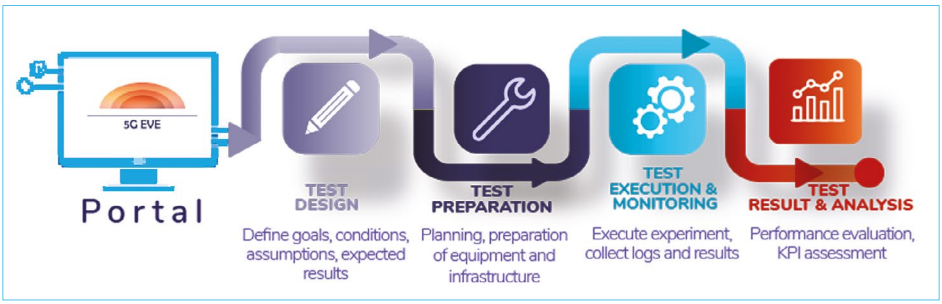


Fig. 21: 5G EVE Portal – The 4-Step Process to 5G Validation

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: (1) A 360° video virtual visit (eMBB) use case, which aims at immersing the visitor in a virtual reality scene located in a real environment. (2) 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 covering the vertical sectors of Industry 4.0, Smart Cities and Smart Energy (Utilities). Specifically, for the Industry 4.0 use case, autonomous control of an AGV vehicle via 5G connectivity has been demonstrated. In parallel, multiple smart city sub-scenarios, such as automated indoor environment adaptation, air quality monitoring and remote health monitoring have been demonstrated as well. Finally, in depth experimentation has taken place with 5G-powered management functionality for addressing outages in smart grids and for automating the network's response (power redirection) to avoid islanding, as part of the Utilities use case.

Italy – The Italian site facility is implementing four applications in three use cases: (1) Smart Transport – Urban mobility 5G data flow analysis and monitoring: the tracking and recognition services are implemented; (2) Smart Transport – UC 5G On-Board Media content provisioning: lab testing is ongoing; (3) Smart City – Public Safety: characterisation of detection of flows of people using passive smartphone probing; (4) Smart Tourism: Integration of test application and backend. The infrastructure hosts the service side and offers the VNFs, and the 5G coverage.

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, in Madrid.

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 bitrate low latency services and everything in between.

5G-VINNI adopts Network Slice as a Service (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.

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, 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 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. More information about the project, access to technical documents, details about the project releases, and information about the facility sites, can be found on the website.

Major achievements/innovations and performance KPIs

The major 5G-VINNI achievement is a 5G service model based on a consolidated slice concept, which is measurable, reproducible and repeatable. 5G-VINNI has a common schema for infrastructure description and deployment, which is flexible and verifiable. To facilitate the quick onboarding of vertical use cases onto the E2E facility, 5G-VINNI defined two structures, being:

- the 5G-VINNI Service Blueprint (5G-VINNI-SB), and
- the 5G-VINNI Service Catalogue (5G-VINNI-SC).

The 5G-VINNI Service Catalogue contains predefined 5G-VINNI-SBs which have either been pre-configured in the 5G-VINNI-SC or have been defined by previous verticals when they have conducted their tests. Over time, the number of 5G-VINNI-SBs in the 5G-VINNI-SCs will increase, as more verticals test their use cases on 5G-VINNI facilities.

A 5G-VINNI-SB is a baseline, model-based service template describing a given network slice to be provisioned using NSaaS. This service template is a structured document that provides a complete description of a given network slice, including information on service topology and expected behaviour. It is used by the Communication Services Provider (CSP) as a reference to conduct service management procedures, both at instantiation time (deployment procedures) and at run-time (operational procedures).

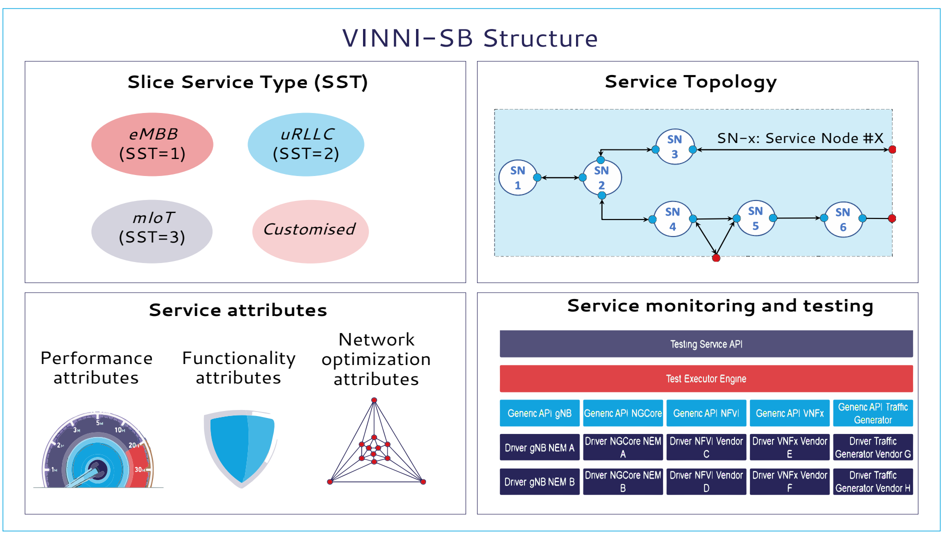


Fig. 22: 5G-VINNI Service Blueprint (SB) structure to be used by the CSPs

The 5G-VINNI facility sites infrastructure that can be used by verticals today, has undergone a rigorous validation procedure in the following areas:

- **End-to-End measurements**: have been carried out by using handsets and CPEs in order to validate which type of performance the Vertical applications might expect.
- **NFVI Network Performance**: the network fabric of the entire infrastructure has been tested to verify the solidity of performance in supporting the NFV architecture.
- **NFVI Compute Resource Performance**: these tests have been needed to verify if the NFV hardware profile was capable of supporting the NFV architecture.

Category	KPIs	Achieved Values	Description
E2E Network Performance	UL Maximum Throughput (Mbit/s)	104.27 Mbit/s	mm-wave, 27.3-27.5 GHz, 4T4R, 40 1 stream
	DL Maximum Throughput (Mbit/s)	883.69 Mbit/s	mm-wave, 27.3-27.5 GHz, 4T4R, 1 40 stream
	UL Latency (ms)	13.77 ms	3.6GHz, low foot-print traffic profile with 100Kbit/s bandwidth
	DL Latency (ms)	9.15 ms	
	UL Jitter (ms)	1.01 ms	mm-wave, 27.3-27.5 GHz, 4T4R, low foot-print traffic profile with 100Kbit/s bandwidth
	DL Jitter (ms)	0 ms	
	UL Frame Loss (%)	0.01%	3.6GHz, low foot-print traffic profile with 100Kbit/s bandwidth
	DL Frame Loss (%)	0%	
NFVI Network Performance	Maximum Throughput (0 frame loss)	4.573 Gbit/s	Two compute nodes, DPDK was configured in the test environment
	Latency between VMs	0.067 ms	
NFVI Compute Resource Performance	CPU Benchmarking Score	3,510	Yardstick CPU/Memory/Storage tests
	Memory Read Latency	7.97 ns	
	Memory r/w Bandwidth	25.641 GB/s	
	Storage r/w IOPS	5.65 k/4.21 k	
	Storage r/w Latency	188/ 621 ms	
	Storage r/w Bandwidth	1,018/425 MB/s	

Table 2: Initial KPI results from 5G-VINNI facility sites

Description of demos

A number of verticals demonstrations and experiments have been performed or are in progress. Among others remote robotic control with 360° VR-based tele-presence has been demonstrated by BT and InterDigital at the UK facility site, as well as how the process of onboarding vertical applications is working at the Univ. of Patras facility site.

Further demonstrations of 5G-VINNI's capabilities include automated Testing as a Service (TaaS) by Keysight, E2E service orchestration by Nokia, autonomous edge by Fraunhofer FOKUS and network telemetry by Telefonica among others.

The main scope of the 5GENESIS project is to allow researchers to run from remote experiments on the several testbeds that the project coordinates, thanks to the so called **5GENESIS Architecture**. In order to do so, an experimenter can access a web interface called **Portal**, or use a non-graphical **OPEN API**, as described in the video that explains how to run an experiment, available at *https://www.youtube.com/watch?v=_iuix8coh28*.

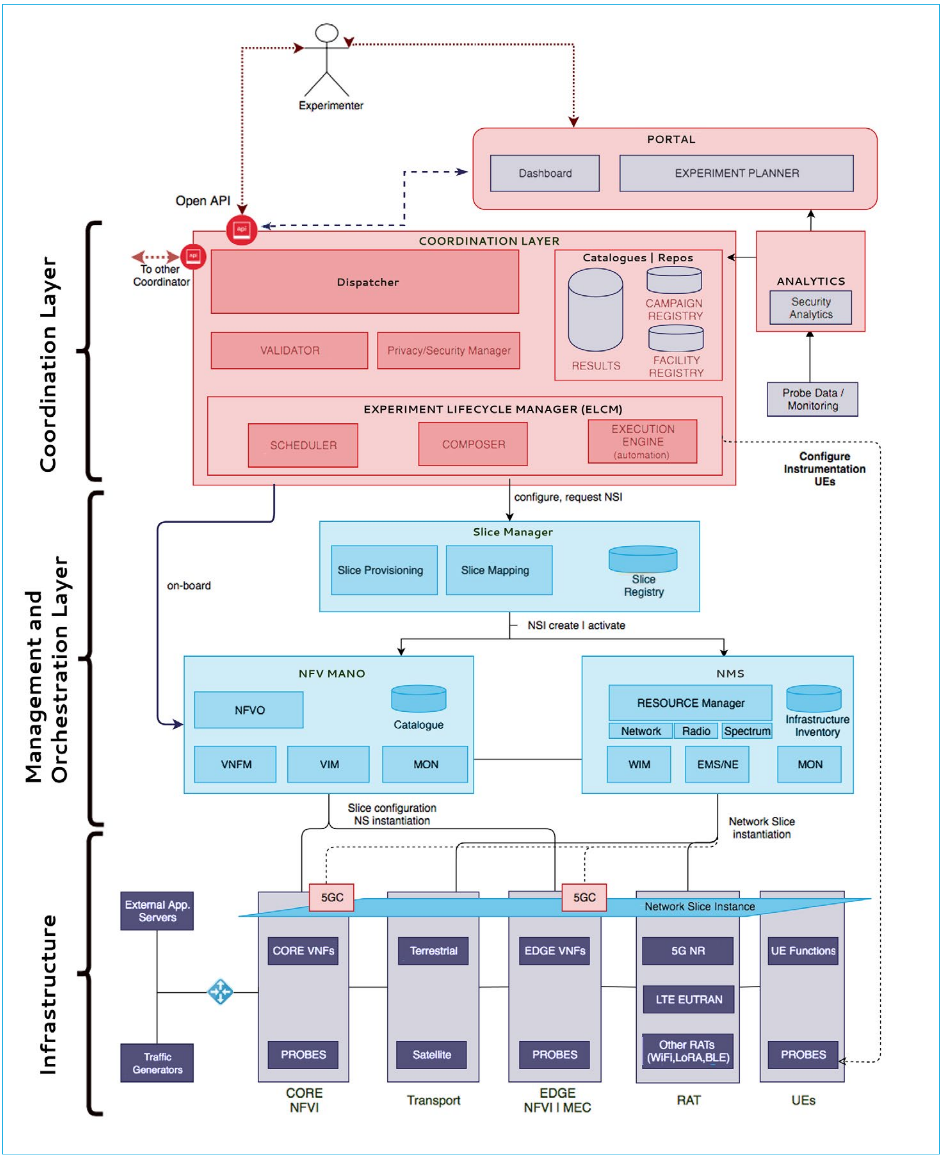


Fig. 23: The 5GENESIS Architecture and its composing blocks

Figure 23 shows the three layers, each one composed of several components that constitute the 5GENESIS Architecture: the **Coordination Layer**, the **Management and Orchestration Layer** (MANO) and the different underlying **Infrastructures**. A good overview of the 5GENESIS Architecture can be found in the public deliverable D2.2, and more details on its components in deliverables D3.1 (MANO), D3.3 (Slice Manager), D3.5 (Monitoring and Analytics), D3.7 (OPEN API), D3.15 (Experiment an Lifecycle Manager), and others, all available at *https://5genesis.eu*.

The Architecture components are continuously updated and enhanced in the **GitHub repository** available at *https://github.com/5genesis*.

Next the main characteristics of selected components of the 5GENESIS Architecture are described.

The OPEN API and the Coordination Layer

The OPEN API is the interface offered by the Coordination layer to experimenters for the definition and execution of the experiments. 5GENESIS also provides a Portal with a friendly Web Interface to facilitate the experimenters' task. Such Portal plays the role of client of the 5GENESIS open API and is able to display the execution logging output for all execution stages of the experiments (Pre-Run, Run and Post-Run). Besides, for each experiment execution, it provides a link to a Grafana-based customised experiment-specific dashboard, for easy visualisation of the data generated by the experiment. The Portal itself uses the 5GENESIS open API to communicate with the coordination layer component. Therefore, there are two ways in which the experimenters can interact with the 5GENESIS Facility, (1) via the Portal and/or (2) using the OPEN API directly in the case of more advanced users of the Platform or experienced verticals.

The Experiment Lifecycle Manager (ELCM)

The ELCM is a basic component of the Coordination Layer and is responsible for the management, orchestration, scheduling and execution of experiments. It handles the life cycle of an experiment from start to end, keeping it in an internal queue until all required resources for the experiment are available, using independent executors to run it and recovering the generated results. The ELCM has been developed from the ground up using Python, and exposes an internal web administration interface developed in Flask. The ELCM is divided in 3 main components:

- The Scheduler to manage the execution of the experiments on a higher level: An experiment execution is divided in 3 stages (Pre-Run, Run and Post-Run), and the Scheduler keeps track of the execution of each of these stages for multiple experiments in parallel.
- The Execution Engine to manage the execution of each experiment stage.
- The Composer to create Infrastructure-Specific Configurations for each experiment. The configuration generated includes the Tasks to be run by the Executors and will depend on the contents of the Facility Registry. The Facility Registry is the entity that defines the expected behaviour of the platform when specific test cases and equipment are tested.

The Slice Manager (SM)

The SM follows one of the two approaches that ETSI[13] has defined, i.e., the one realised by a standalone entity, interacting with other components of the MANO layer via defined interfaces. The SM is based on a highly modular architecture, built as a set of microservices, each of which is running on a docker container. The key advantages of this architectural approach are that it offers simplicity in building and maintaining applications, flexibility and scalability, while the containerised approach makes the applications independent of the underlying system.

13. ETSI - OSM, "Introduction to NFV and OSM," 2017. [Online]. Available: http://osm-download.etsi.org/ftp/osm-5.0-five/5th-hackfest/presentations/5th%20OSM%20Hackfest%20-%20Session%200%20-%20Introduction%20to%20NFV%20and%20OSM.pdf.

5G PPP PHASE 3, PART 2: AUTOMOTIVE PROJECTS

3 Projects have been selected from the 6 proposals received by the EC in response to the 5G PPP ICT-18-2018 call. These three projects started in November 2018 and are running for different durations implementing and testing advanced cross order 5G infrastructures in Europe.

5G-Carmen

Goals

Focusing on the Bologna to Munich corridor (600 km, over three countries), the objective of 5G-CARMEN is to leverage on the most recent 5G advances to provide a multi-tenant platform that can support the automotive sector by delivering safer, greener, and more intelligent transportation with the ultimate goal of enabling self-driving cars. The project will target automation level up to SAE L3 and L4. The key innovations proposed by 5G-CARMEN project are centred around a hybrid network, combining direct short range V2V and V2I communications, long-range V2N network communications, and back-end solutions into a single platform. The platform will employ different enabling technologies such as 5G New Radio, C-V2X, Multi-access Edge Computing and secure, multi-domain, and cross-border service orchestration to provide end-to-end network services to be tested along the corridor.

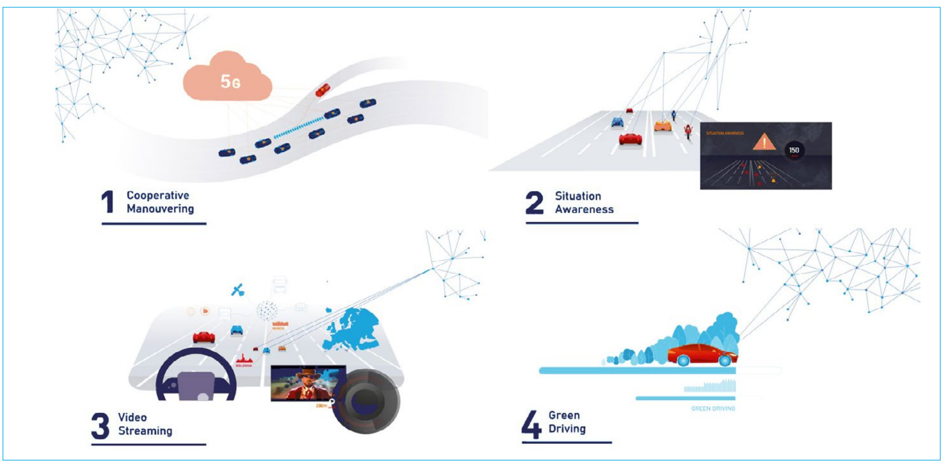


Fig. 24: 5G-CARMEN use cases overview

Current achievements

Within its first year of activity, 5G-CARMEN partners refined the project's use cases: cooperative manoeuvring, situation awareness, green driving, and video streaming. The selected use cases will allow to increase road safety, ensuring higher safety in the execution of dangerous manoeuvres (Cooperative Manoeuvring use case), and preventive knowledge of any critical issues that will be encountered along the road (Situation Awareness use case). The Green Driving use case will increase the sustainability of mobility, while the Video Streaming use case will grant a more pleasant experience to passengers, allowing higher and more stable Quality of Experience (QoE) in the fruition of multimedia content on board.

With the progress on the use cases and the CCAM platform, 5G-CARMEN System Architecture has also been refined with the aim of integrating the different solutions into an overall architecture. The system architecture and the communication interfaces have been designated and the implementation has started.

Internally, the architecture for cross-border traffic steering in the network path with the support of a MEC infrastructure has been finalised. MEC-supported applications involved in the traffic steering function which enables the necessary network interworking for range extension are envisioned to be an AMQP server and a GeoService.

Lab-based test implementations of range extension, multi-RAT dual connectivity and RNIS provisioning to MEC have been set up for research proposals, extensions to standards and a first evaluation of KPIs.

The same applies for the network Quality of Service and Precise Positioning solutions where a reference station network rollout has started, and both RTK-based positioning and cellular positioning are in evaluation.

To align with the key objectives of the targeted secure CCAM platform, the project adopted a two-layer management and orchestration scheme. In alignment with various associated standard track studies and directions, the Multi-access Edge Computing (MEC) platform represents an integral part of the designed platform.

The project is investigating the use of defined interfaces between the CCAM platform and the 5G system to support service provisioning and continuation across borders.

In alignment with the NIS Cooperation Group's 5G Risk Assessment, the project analysed security and privacy threats associated with the use cases, committing to identifying and counteracting potential risks.

In its first year of activities 5G-CARMEN has been present in a few of the most important events in its field: it won the conference's Best Booth Award at the EUCNC held in Valencia, and it participated to EUCAD 2019, ITS World Congress 2019, MobiHoc 2019, to name a few.

Planned Pilots

5G-CARMEN has defined a deployment plan for the four use cases which will start in 2020 and will continue up to the realisation of the test campaigns in 2021. 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, where issues about continuity of service in the transition from one national network to another will be addressed.

5G-CARMEN pilot will start collecting test data locally in the first half of 2020 and will focus on the use cases of Situation Awareness and Green Driving. In the meantime, a full pilot set-up plan will be finalised, including cross-border tests which represent the target scenarios. The deployment on the corridor will progress with Cooperative Manoeuvring and Video Streaming use cases. Pilot sessions in Kufstein and Innsbruck are expected to start by the end of 2020. Both in-country and cross-border tests will be carried out until summer 2021, collecting data from road scenarios for 5G-CARMEN evaluation.

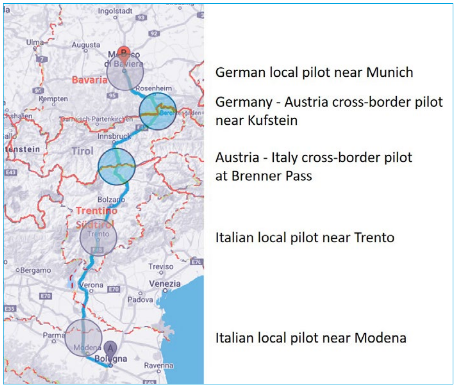


Fig. 25: 5G CARMEN Pilot locations

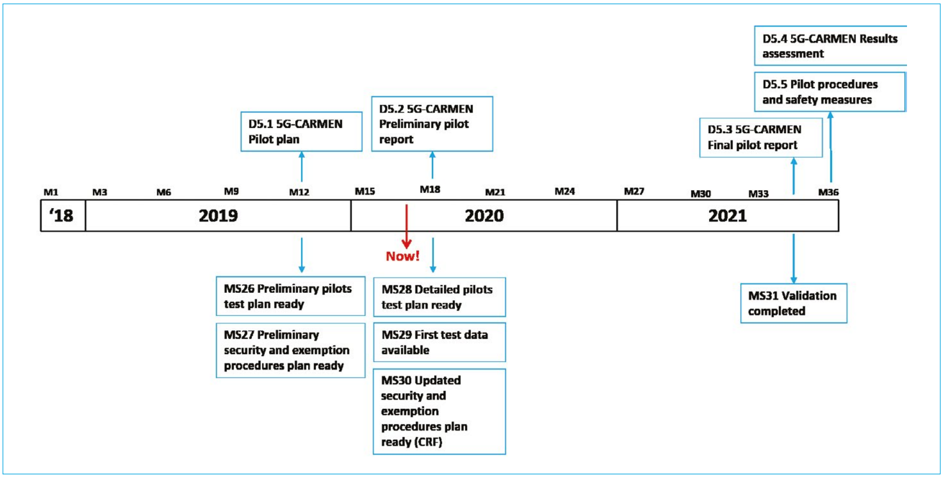


Fig. 26: *5G CARMEN timeline*

More information on the project can be found following 5G-CARMEN social profiles on Twitter (*@5g_carmen*) and Linkedin, or visiting the project's website (URL: *https://www.5gcarmen.eu*), which includes a promotional video, information on the activities being carried out, news related to the project, and the possibility to subscribe to a dedicated Newsletter to be updated on project milestones, events, and the latest developments.

5G-MOBIX

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

5G-MOBIX project is an integral EU's 5G Action Plan for Europe (5GAP) that brings together a united commitment and bold initiatives to ensure that the EU can use 5G connectivity as a strategic advantage to lead digital transformation and in particular in the area of Connected and Automated Mobility (CAM).

5G-MOBIX aims to match the benefits of the 5G technology with advanced CCAM use cases in order to enable innovative, previously unfeasible, automated driving applications with high automation levels, both from a technical and a business perspective.

5G-MOBIX is executing CCAM trials along two Cross-Border Corridors (CBC) and six urban Trial Sites. The trials allow 5G-MOBIX to conduct impact assessments, including business impact and cost/benefit analysis, particularly in sparsely populated cross-border areas with mild market failures of mobile network connectivity.

As a result of these evaluations and international consultations with the public and industry stakeholders, 5G-MOBIX will identify new business opportunities for 5G enabled CCAM and propose recommendations and options for its deployment. Through its findings on technical requirements and operational conditions, 5G-MOBIX will define deployment scenarios and is expected to actively contribute to standardisation and spectrum allocation activities.

Existing key assets such as infrastructure and vehicles will be utilised and upgraded to test the smooth operation of 5G within a heterogeneous environment that includes other concurrent technologies such as ITS-G5 and C-V2X.

5G-MOBIX 1st Year achievements

During the first year of the project's lifetime, 5G-MOBIX partners laid the foundation for the 5G enabled Cross-Border Corridor CCAM trials that will follow in the second and third year of the project. This included work on detailed specifications, cross-border issues analysis, architecture definition, deployment & trialing methodology and much more.

The main achievements of 5G-MOBIX during its first year include: i) Detailed specification of the 5G-MOBIX Use Cases / User stories to be executed at the cross-border corridors with specific contributions per UC from the 5G-MOBIX Trial Sites, ii) Detailed specification of the 5G components, vehicle, OBU and RSI infrastructure to be installed at the Trial Sites / Cross-border Corridors, iii) Definition of a common basic 5G network architecture for the interconnection of neighboring 5G networks for both CBCs and iv) Identification of the most prominent cross-border issues for cross-border CCAM functionality support, classification into four categories (Telecom, Application, Security/Privacy, Regulatory) and proposal of multiple potential solutions (to be evaluated during the trials).

Description of CBC trials

The advanced 5G-MOBIX CCAM use cases will be tested and validated in cross-border conditions in the two CBCs of the project namely in Spain – Portugal (Vigo - Porto) and in Greece – Turkey (Kipoi - Ipsala), where 5G Non-Stand Alone (NSA) networks are currently being deployed along with cutting edge Road Side Infrastructure (RSI) to assist with the more challenging use cases. Initial testing and pre-trialing is expected to take place during Q2 of 2020, while full-fledged cross-border trials are scheduled for Q3-Q4 of 2020 and all the way through 2021.

In Q1 2021 the possibility to upgrade the 5G networks at the borders to Stand Alone (SA using a 5G core) will also be evaluated, while in the meantime 5G-SA performance will be evaluated on some of the local Trial Sites participating in 5G-MOBIX. The local TSs of 5G-MOBIX also allow for early trialing (since Q2 of 2020), extreme scenario testing, additional network configurations to be evaluated as well as the examination of multiple solutions to the various cross-border issues identified.

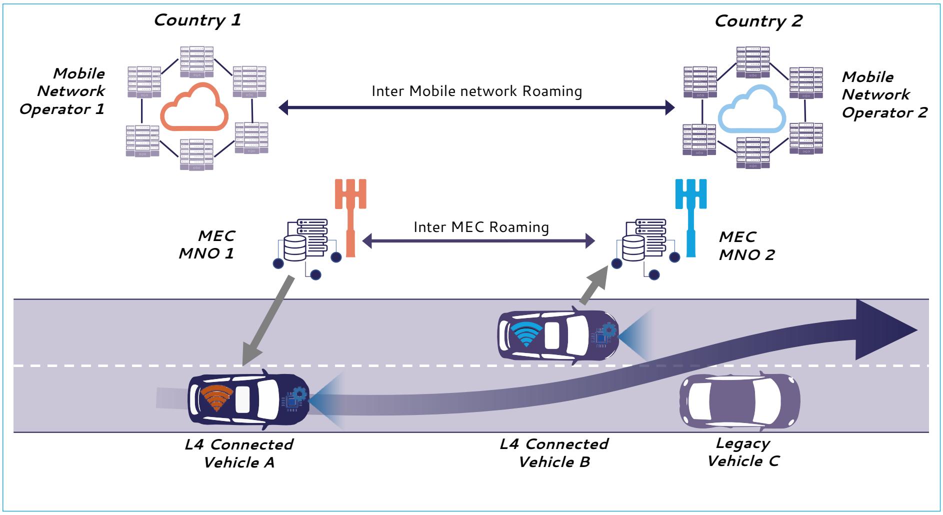


Fig. 27: 5G-MOBIX Cross-border automated overtaking use case architecture

5GCroco

Fifth Generation Cross-Border Control

Project Goals

The vision of cooperative, connected and automated mobility (CCAM) throughout Europe can only be realised when harmonised solutions that support cross-border traffic exist. The possibility of providing CCAM services throughout different countries when vehicles cross various national borders has a huge innovative business potential. However, the seamless provision of connectivity and the uninterrupted delivery of real-time services along borders also pose technical challenges which 5G technologies promise to solve. The situation is particularly challenging given the multi-country, multi-operator, multi-telco-vendor, multi-car-manufacturer, and cross-generation scenario of any cross-border layout.

Motivated by this, 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 at 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 and which pose high demands on the telecommunication network side. 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). The three use cases have been already specified in detail together with the requirements that are imposed by them[14].

Each use case consists of user stories, which stand for special variants of each use case, respectively. For each user story, a set of key performance indicators (KPIs) are identified which represent the minimum needed performance of the underlying system consisting of vehicles, communication network, and backend. In addition, D2.1[14] specifies the test cases that are identified for each User Story of each use case. The test cases are defined to demonstrate the suitability of the new features of the 5G network for automotive use cases and to prove that critical system KPIs are met. For each user story, the test cases are mapped to one or several test and trial sites.

5GCroCo Network Architecture

Network and application architectures have been developed to support the planned tests and trials of future commercial systems. The application architectures reflect the use cases as described in D2.1[14]. The network architecture, as described in D4.4[15], includes the following 5G solutions for CCAM relevant for trials:

Non-standalone 5G New Radio: 5G deployments happening right now and in the near future use 5G Radio Access Networks (RANs) with 4G Evolved Packet Cores (EPCs). This is also the baseline used for 5GCroCo. Features listed below will be added to this baseline.

Cross-Border/-Mobile Network Operator (MNO) Handover: Usual behaviour when crossing a country border is that the end-device holds on to its home network for a very long time resulting in very weak performance and eventual loss of connectivity. At this point, network selection and connection to a network in the visited country is done. It results in minutes of poor or no connectivity. Interfaces to enable handovers between MNOs across country borders are used to minimise service interruption.

14. 5GCroCo D2.1, "Test Case Definition and Trial Site Description Part 1", January 2020.

15. 5GCroCo D4.4, "Detailed Roadmap of Test Sites– Project Year Two", January 2020.

Management and Network Orchestration (MANO) and Software Defined Networking (SDN) – Single Country/MNO: Virtualisation and dynamic centrally-controlled traffic routing are key features of 5G networks. A fully virtualised packet core and application hosting will be used in the project.

MANO and SDN – Cross-border/-MNO: It is already state-of-the art for most commercially operated networks to allow the MNO to orchestrate its virtual network on its own physical infrastructure. Cross-border/-MNO orchestration allows MNOs to share infrastructure and functions among each other.

End-to-end Quality of Server (QoS) with Dedicated Bearers: Dedicated bearers are used to ensure that the QoS requirements of the use cases are met by, e.g., prioritising different traffic types and suitable configuration of RAN parameters.

QoS Prediction: Assuming that sometimes situations might occur where resources are insufficient to provide the requested QoS, the network indicates this to the application before the actual degradation happens. Furthermore, it can indicate to the application if very high throughput performance can be expected in the near future to allow to postpone transmissions.

Mobile Edge Computing/Cloud (MEC) – Computation and Hosting Close to Vehicle vs. on Public Internet: A basic feature of MEC is enabling application hosting and computation close to the end-user instead of doing this on the public Internet.

MEC – Cross-border/-MNO Inter-MEC Communication: In vehicular settings, it cannot be assumed that all vehicles use the same MNO and its MEC. Inter-MEC communication, meeting end-to-end QoS requirements, is thus applied.

5GCroCo Test Sites

5GCroCo plans to deploy 5G large-scale tests on cross-border roads at the French-German and German-Luxembourgish borders in summer 2020 and 2021. The different use cases of 5GCroCo (described in [14]) will be rolled out in this large-scale corridor. Moreover, small-scale test site deployments in France, Spain, Germany and Sweden are also planned in summer 2020 as a first step towards our large-scale tests in 2020 and 2021.

A detailed plan, roadmap and coordination of testing of 5G solutions for CCAM per test site and use case is provided in [15]. This document shows how the small-scale test sites contribute towards the large-scale test sites and testing of 5G for CCAM in cross-border scenarios and which 5G solutions for CCAM are tested per use case and test site.

Business Innovations

5GCroCo has initiated the identification of business opportunities in the new emerging and forming 5G ecosystems for cross-border CCAM. D5.1[16] contributes to identify suitable tools to conduct cost/benefit analysis, business modelling and business case generation. In addition, the stakeholders for the different use cases which are considered in 5GCroCo have been introduced and discussed. The approach in 5GCroCo will be, firstly to identify business opportunities for the use cases to be tested in the project, and then to widen the scope of the contributions to any 5G-enabled cross-border CCAM service. Automated Driving (AD) is seen as one of the key technologies and major technological advancements influencing and shaping the future of mobility. Therefore, the impact of 5G must be evaluated for private passenger cars and for the exploitation of wider shared mobility and ITS concepts. This document provides valuable discussions and insights to all identified key stakeholders, which can benefit from new possibilities facilitated by 5G-enabled CCAM:

- Telco and Automotive industries.
- Standardisation and regulation bodies.
- Local administrations (cities, countries).
- Road operators and road traffic authorities.
- Governments and policy-makers.
- Start-ups and Small and Medium Enterprises (SMEs).
- Academia and scientific community.

A gap analysis from business case perspective to steer economical examinations in an efficient way to support new AD ecosystems is provided in [16]. In a cross-border environment, new relations between existing and new players will be established in different use cases for AD. In addition, these use cases will force

16. 5GCroCo D5.1, "Description of 5GCroCo Business Potentials", September 2019.

KPI requirements and new functions for MNO's 5G networks. 5G technologies (e.g. safety, efficiency, real time solution, privacy/security etc.) are main drivers for potential business opportunities.

The general business concepts for AD use cases under consideration of new value chains (e.g. new customers, additional benefits, new markets and weakness and threats for existing players) is presented in [[16]]. The important AD stakeholders and their internal relations have been identified and analysed in the context of a new CCAM business landscape and ecosystem. This includes a gap analysis considering current technical, economic and regulatory roadblocks to the evolution of a true cross-border CCAM ecosystem. The evaluation for AD – with the focus on the given use cases - has shown the importance of data driven eco systems[16]. The data ownership spread over different actors and subsystems is a key factor for a successful business.

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

8 Projects have been retained from the 32 proposals received by the EC in response to the 5G PPP ICT-19-2019 call. These eight projects started in June 2019 and are running for about three years to get the European 5G Vision of "*5G empowering vertical industries*" closer to deployment.

5G SMART

Goals of the project

The manufacturing sector is entering a period of disruptive change and digital transformation towards what is termed Industry 4.0. Smart manufacturing is at the heart of this, enabling the transformation of today's factories into factories of the future, making the vision of highly efficient, connected and flexible factories become reality. For this, future manufacturing systems require the implementation of a reliable communication system capable of handling diverse types of information exchange that is found in a manufacturing environment and which can require low reaction times and deterministic performance. 5G is foreseen as a key enabler for this future manufacturing ecosystem.

Motivated by this, 5G-SMART[17] 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 will contribute 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 and plans

Industry field trials

5G-SMART brings 5G deployments into three real manufacturing setups. Figure 28 shows an overview of the three field trials.

These are:

- An Ericsson factory in Kista (Sweden) with a focus on 5G enhanced mobile robotics applications.
- The machine hall of the Fraunhofer Institute of Production Technology (IPT) in Aachen (Germany) with a focus on 5G enhanced industrial manufacturing processes.
- A Bosch semiconductor factory in Reutlingen (Germany) where industrial Automated Guided Vehicle (AGV) applications and industrial control communication are being explored.

17. www.5gsmart.eu

On site, the project is evaluating different 5G services (URLLC, eMBB, mMTC). In the semiconductor factory, 5G-SMART is moreover performing extensive channel measurements and undertakes the evaluation of electromagnetic compatibility. All necessary preparations for the upcoming channel measurements have been completed.

Towards the trial implementations, 5G-SMART has been working on detailing the use cases to be trialed. These use cases can be categorised into three groups, addressing the challenges related to seamless integration of 5G into manufacturing systems:

1. Use cases targeting time-critical process optimisation inside a factory.
2. Use cases targeting non-time critical in-factory communication for large number of devices.
3. Use cases targeting remote operation and massive information exchange.

In preparation for the testbed implementations, 5G-SMART has focused on characterising the communication requirements imposed by these use cases and mapping them to the communication services offered by the 5G system. This includes a thorough analysis of each of the use cases to be trialed, including the identification of various functional and non-functional requirements. The next step involves the choice and setup of the 5G infrastructure at the different trial sites. 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.

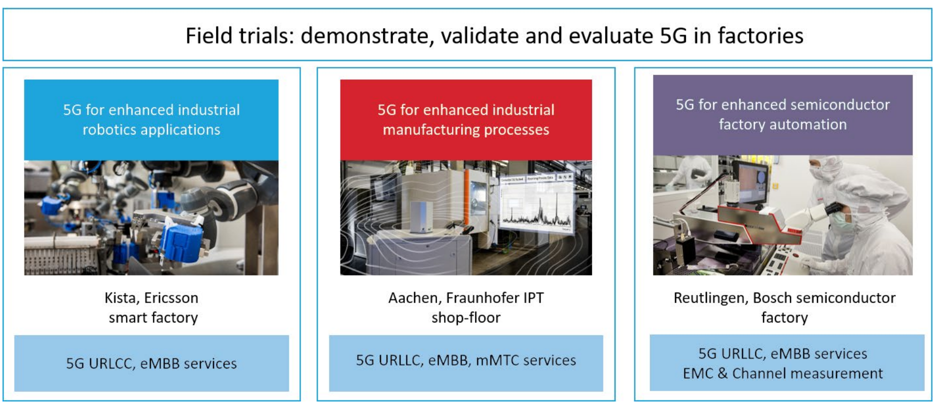


Fig. 28: 5G SMART field trials overview

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 so far focused on 5G time synchronisation for factories, 5G end-to-end technology to support verticals URLLC requirements and channel modelling concepts.

Details of the Field Trials

Kista Ericsson smart factory

At the Kista trial site a setup including both stationary robots and a mobile robot as is being built up, where connectivity is realised over the 5G network. One distinctive feature of the use cases is that the robot control logic governing the collaboration and interaction is offloaded to the edge cloud. Human-robot interaction including factory floor visualisation will also be demonstrated at the Kista trial site.

Aachen IPT Fraunhofer shop floor

At the Aachen trial site, 5G-SMART is working on the realisation of two use cases: 5G for wireless workpiece monitoring and a 5G versatile multi-sensor platform (MSP) for a digital twin. The first use case involves a wirelessly connected acoustic emission (AE) sensor that is integrated into a milling machine and used to monitor the milling process of a jet engine component. The acoustic measurements are transmitted in real-time and at high rate to the machine controller in the cloud, where they are analysed within milliseconds. A first demo of the AE system showcasing the capabilities of the system has already been built up[18]. A prototype for the MSP that will be showcased in the demo, is currently being developed.

Reutlingen Bosch semiconductor factory

At the Reutlingen trial site, 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.

18. https://www.linkedin.com/feed/update/urn:li:activity:6598515074787348481

5G Solutions

5G-SOLUTIONS is one of the seven EU-funded H2020 5G PPP projects supporting EC's 5G policy by implementing the last phase (Phase 3b) of the 5G cPPP roadmap. It addresses the challenge of the call 'H2020 ICT-19-2019: Industry heavyweights drive advanced 5G validation trials across multiple vertical industries' and the consortium from EU telecom and vertical industries and renowned research organisations, the majority of which participate in 24 out of the 43 5G PPP projects and in several 5G PPP Working Groups.

5G-SOLUTIONS aims at proving and validating that 5G provides prominent industry verticals with ubiquitous access to a wide range of forward-looking services with orders of magnitude of improvement over 4G, thus bringing the 5G vision closer to realisation.

The project is going to setup several living labs to cover the majority impact of 5G revolution. Each of said living labs will be organised in different use cases.

The primary use cases identified in the context of the **Factories of the Future** (FoF) LL are as follows:

- Use Case 1.1: Time-critical process optimisation inside digital factories;
- Use Case 1.2: Non-time-critical communication inside factories;
- Use Case 1.3: Remotely controlling digital factories;
- Use Case 1.4: Connected goods:
- Use Case 1.5: Rapid deployment, auto/reconfiguration and testing of new robots;

The used approach, involving both horizontal and vertical slicing, enables the execution of representative FoF use cases. Horizontal slicing involves computational off-loading, addressing the diverse network capacity and latency requirements e.g. 10,000x capacity at the edge with <1 ms latencies ("factory floor") due to the enormous numbers of sensors, other networked devices and time-critical applications.

The **Smart energy** living lab will target three use cases referring to the broad area of Demand Side Management (DSM). DSM refers to the changes in electricity use by consumers from their customary consumption patterns in response to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardised. In a broader sense, DSM also embeds the topic of overload avoidance and optimal self-consumption, in those scenarios where the peak power affects the energy bill, and local RES has an impact on the net power withdrawn from the grid.

The use cases to be validated in the **Smart City and Ports** LL include the following:

- Use Case 3.1: Intelligent street lighting;
- Use Case 3.2: Smart parking;
- Use Case 3.3: Smart city co-creation sounds;
- Use Case 3.4: Smart buildings – smart campus;
- Use Case 3.5: Autonomous assets & logistics for smart port;
- Use Case 3.6: Port safety: monitor & detect irregular;

Through the use of digital and telecommunication technologies, traditional networks and services become more efficient for the inhabitants, businesses and ports benefit. It is estimated that a large proportion of communications will occur between machines and not humans. In this respect, 5G supporting mMTC, eMBB, URLLC, virtualisation and slicing will be able to respond to the smart cities and ports of the future.

The main uses cases identified in the **media & entertainment** LL are the following:

- Use Case 4.1: Ultra High-Fidelity Media;
- Use Case 4.2: Multi CDN selection;
- Use Case 4.3: On-site Live Event Experience;
- Use Case 4.4: User & Machine Generated Content;
- Use Case 4.5: Immersive and Integrated Media and Gaming;
- Use Case 4.6: Cooperative Media Production.

Taking into account that the media traffic is the leading, volume-wise, traffic type being delivered by the networks, the new 5G networks will play a major role in media distribution. The solution must be transparent in different levels, from the media delivery protocol perspective to be universally adopted and from the networking efficiency to avoid overheads with extra messaging. This solution can become a reality by using content delivery analytics to measure the speed and availability of different delivery paths over the network. 5G slicing, Multi-access Edge Computing (MEC), Fog and Mist Computing architectures can make the difference in order to exploit in an isolated and scalable way geo-based network and QoS analytics with almost zero latency.

The Multi-vertical concurrent usage of eMBB, mMTC & URLLC is an additional living lab. It leverages, combines and executes in a **combined and simultaneous manner a subset of use cases previously described whose target KPI requirements** (i.e. high throughput, low latency, high density of devices) **fall under such classes of service**. In particular, each of the service classes SC5.1-SC5.3 will incorporate the parallel execution of several of the use cases in each of the LLs.

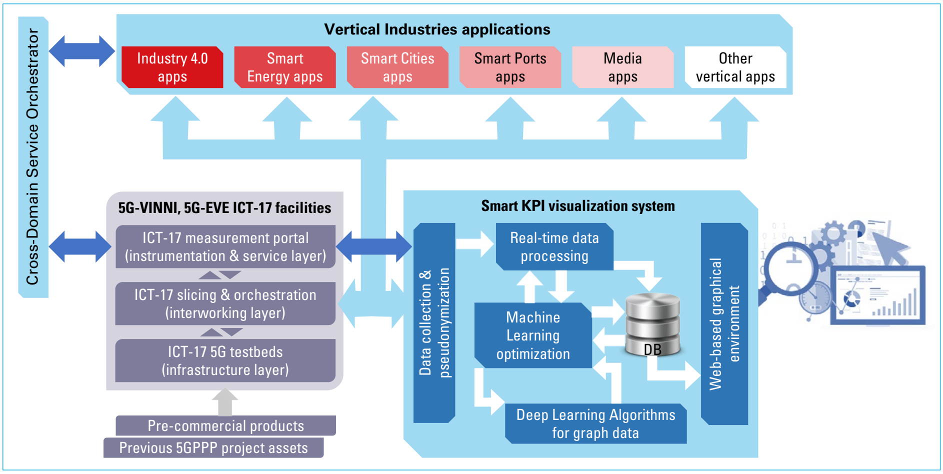


Fig. 29: 5G-SOLUTIONS architectural concept

5G-SOLUTIONS also provides validation of more than 140 KPIs for 20 innovative and heterogeneous use cases that require 5G performance capabilities and are expected to have a high future commercialisation potential. Besides, the project envisages an architectural concept, shown in figure 29, resulting in technological enablers for facilitating the execution of the field trials in an automated way, including:

- a unified cross-domain service orchestrator enabling multidomain slicing and 5G service lifecycle automation,
- an innovative smart KPI visualisation system for facilitating the near real-time analysis, presentation, benchmarking and performance validation of reference 5G network KPIs against predefined target values
- intent-based APIs for stimulating innovation and fostering the development, portability and provisioning of new innovative applications by SMEs.

5G TOURS

Challenges and the Project Objectives

As the early pioneering platforms of 5G start to mature the wireless industry will seek to enable growth in markets beyond its existing and growing mobile broadband sector. 5G-TOURS focuses on three significant economic value creation sectors for Europe; namely Tourism, Health and Transport and seeks to evidence growth potential through 5G platforms. Through a sharp focus on the trials of thirteen use cases, 5G-TOURS will demonstrate the advantages of 5G technology in pre-commercial "friendly customer" trials environments. However, with the emphasis of the value propositions of the use cases on end users like tourists, citizens and patients, the challenge for the project goes beyond proving of technology and towards establishing proof points through recognised validation techniques that point to business models that have potential to gain traction in the market.

In this project a "City" is used to provide the economic environment or context for the use cases. Rennes, (the Safe City), will focus predominantly on the demonstration of e-Health use cases. Turin (the Touristic City), will demonstrate use cases that make use of media and broadcast oriented capabilities of networks. Athens (the Mobility Efficient City), will show use cases in and around the airport that illustrate smart mobility in action.

Technical Approach to Innovations

5G-TOURS is designed to provide services that are close to commercialisation, and thus relatively high on the technology readiness scale, while addressing very different requirements on the same infrastructure. Emphasis is placed on the 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. Cognisant of the high economic value of the sectors; 5G-TOURS is deploying use cases that have been defined in such a way 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.

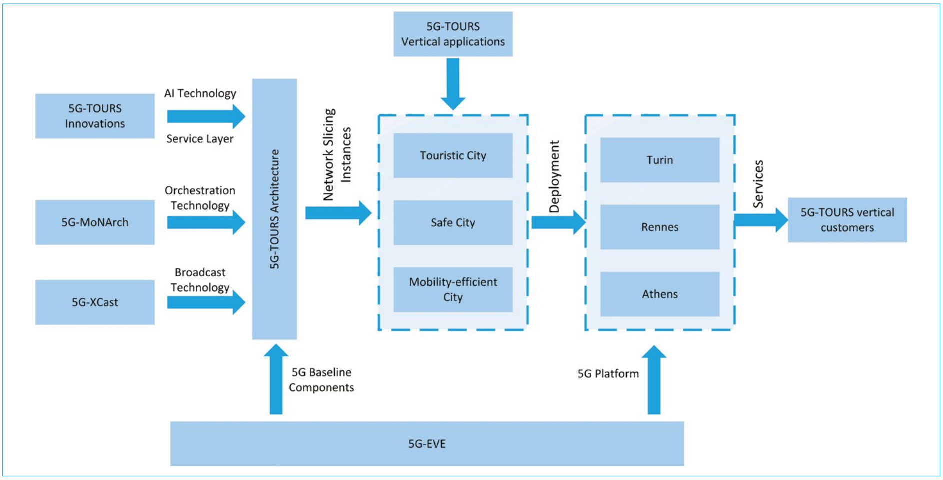


Fig. 30: 5G-TOURS architecture

5G-TOURS architecture makes use of the 5G-EVE platform. It then draws on the resource orchestration and elasticity concepts and solutions of 5G-MoNArch, along with the broadcasting innovations of 5G-XCast. The 5G-TOURS mission is to discover and evidence innovation potential in areas which are anticipated to influence the success of 5G adoption significantly. In particular, AI-based approaches and the refinement of a service layer that is easily adopted and adapted by businesses that predominantly focus their value propositions (products, services or processes) in the vertical sectors. To this end, the consortium has drawn project partners in from the vertical sectors, thus establishing a "friendly" vertical customer base within the project. This approach to the building of the consortium will lead to more effective technology and system concept knowledge transfer and translation into the vertical as various domain expertise areas are focused on the common objectives of the project.

Achievements to date and 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 that will for the end user seamlessly integrate the 5G-EVE and 5G-TOURS elements. System requirement analysis has led to the development of radar graphs that map technical KPIs for all use cases and allow for a clear refinement of the 4G vs 5G value propositions. An illustration of the approach is given in the following figure.

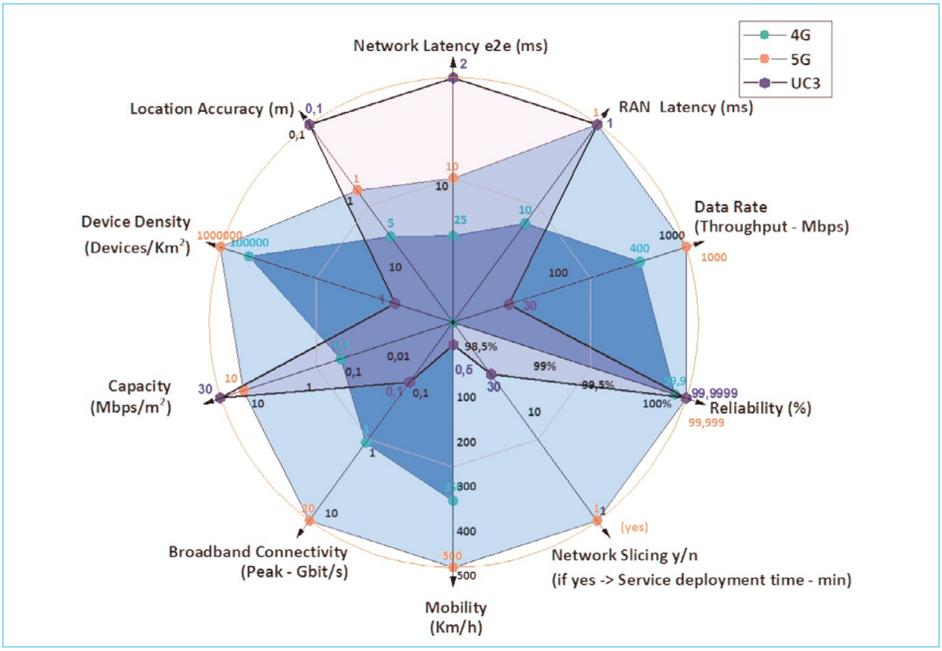


Fig. 31: 5G TOURS approach

A critical stage of the project is now underway as the trial environments become fully defined with the process including analysis of the trials' locations and refinement of network coverage and capacity specifications, together with refinement of the applications, components, and devices. Each trial site also takes care of the approach to trial user engagement and how to validate expected outcomes.

The deployment plan for all use cases employs an incremental approach. First, implementations will be tested in a laboratory environment by Q3-2020. Then, on early capability network infrastructure by Q1-2021 which will trigger further updating of the components of the network to realise full capability use cases and trials from Q4-2021. For some use cases the planned schedule is more ambitious; in particular the Touristic City with demo readiness coming within 2020, enabling trials to start in 2021. Some use cases such as "Remote and distributed video production" and "Robot assisted museum guide" use cases are being targeted for early release and demonstration by mid-2020.

A vital capability to be matured in this project will be the trialling framework. A joint PoC activity is planned with 5G-EVE to evidence the benefits of the Experiential Networked Intelligence (ENI) framework of ETSI. 5G-TOURS has already contributed to the refinement of ENI. Moreover it will go on to demonstrate the potential benefits of the adoption of the ENI principles and the integration with the ENI architecture. This is expected to bring benefits to industry as 5G-TOURS improves and standardises the approach to the building of network slices for 5G Vertical Services.

5G-HEART

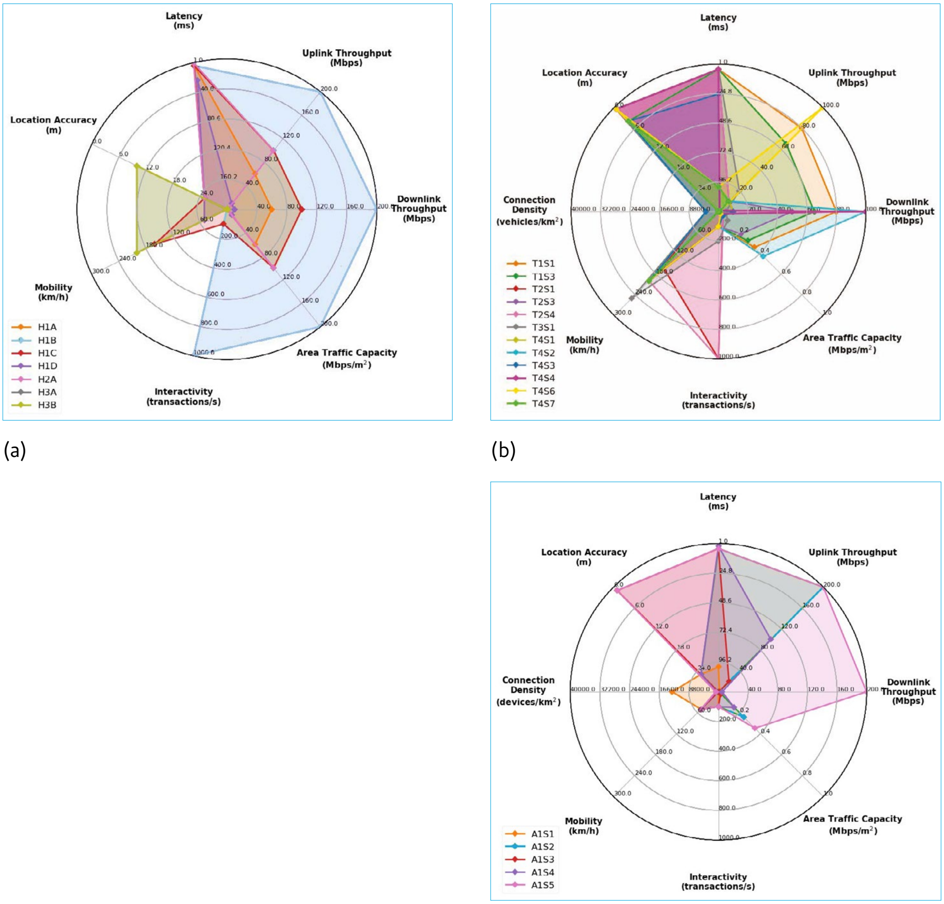
Goals of the project

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 pill cams 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.

5G-HEART use case scenarios are summarised as follows:

- H1 (H1A "*Educational surgery*", H1B "*Remote ultrasound examination*", H1C "*Paramedic support*", H1D "*Critical health event*") – "*Remote interventional support*" that explores the use of advanced, rich media communications in the context of remote monitoring, education and robotics in patient diagnostics and treatment.
- H2 (H2A "*The Pillcam*") – "*The Pillcam*", which aims to test real-time transmission with feedback control of a pill camera (capsule video endoscopy) to improve diagnosis of cancer or precancerous pathology.
- H3 (H3A "*Vital-sign patch prototype*", H3B "*Localisable tag*") – "*Vital-sign patches with advanced geo-localisation*", whose objective is to explore direct-to-cloud disposable vital-sign patches to enable continuous monitoring of ambulatory patients, anytime and anywhere.
- T1 (T1S1 & T1S2 "*High bandwidth in-vehicle situational awareness and see-through for Platooning*", T1S3 "*Dynamic channel management for traffic progression*") – "*Platooning*" that considers vehicles forming a tightly co-ordinated "train" with significantly reduced inter-vehicle distance, thus increasing road capacity and efficiency.
- T2 (T2S1 & T2S2 "*Smart junctions and network assisted & cooperative collision avoidance (CoCA)*", T2S3 "*QoS for advanced driving*", T2S4 "*Human tachograph*") – "*Autonomous/assisted driving*" which involves semi-automated or fully-automated driving in order to achieve safer travelling, collision avoidance, and improved traffic efficiency.
- T3 (T3S1 "*Tele-operated support (TeSo)*") – "Support for remote driving" that enables a remote human operator or a cloud-based application to operate a remote vehicle, and
- T4 (T4S1 "*Vehicle prognostics*", T4S2 "*over the air (OTA) updates*", T4S3 "*Smart traffic corridors*", T4S4 "*Location-based advertising*", T4S6 "*Vehicle sourced HD mapping*", T4S7 "*Environmental services*") – "*Vehicle data services*" that focuses on interconnecting the various third-party data sources and the connected automated vehicles via the available 5G infrastructure.
- A1 (A1S1 "*Sensory data monitoring*", A1S2 "*Camera data monitoring*", A1S3 "*Automation and actuation functionalities*", A1S4 "*Edge and cloud-based computing*", A1S5 "*Cage to cage – on site communication*")– "*Remote monitoring of water and fish quality*"

Figure 32 illustrates the aggregated KPIs of healthcare vertical, transport vertical and aquaculture vertical.



(c)

Fig. 32: Aggregated network requirements of healthcare vertical (a), transport vertical (b) and aquaculture vertical (c).

5G-VICTORI

Goals of the Project

The main goal of 5G-VICTORI is to conduct large-scale trials for advanced use case (UC) verification in commercially relevant 5G environments for a number of verticals. These include Transportation, Energy, Media and Factories of the Future, as well as some specific UCs involving cross-vertical interaction. The project will exploit extensively the existing ICT-17 5G Testbed Infrastructures interconnecting main sites of all ICT-17 infrastructures, namely 5G-VINNI, 5GENESIS and 5G-EVE and the 5G UK testbed in a Pan-European Network Infrastructure. Minor enhancements will be provided to these infrastructures, extending their coverage towards the integration of the 5G-VICTORI UCs.

5G-VICTORI will transform current closed, purposely developed and dedicated infrastructures into open environments, where resources and functions are exposed to the telecom and the vertical industries through common repositories that can be vertical and non-vertical specific. These functions can be accessed and shared on demand to be deployed and compose very diverse set of services. This approach offers efficient service provisioning capabilities in a large variety of ecosystems, exhibiting unprecedented levels of variability in demand granularity and volume, mobility, density, QoS, QoE, security, safety requirements, etc. In essence, this will make any 5G-VICTORI platform suitable to support any service offered by telecom operators as well as any vertical industry through a common infrastructure.

It is clear that only such future proof infrastructures will be able to address a wide range of vertical industry services, adopting flexible architectures offering converged services across heterogeneous technology domains deploying a unified software control.

Major achievements & innovations

5G-VICTORI will enable future network services and applications driven by virtualisation and software (SW) networks, fostering convergence of ICT and vertical industries in a common ecosystem. The implementation of the 5G-VICTORI architecture in any of the above mentioned sites will allow vertical stakeholders to easily deploy their services (figure 33). Adopting this approach, the platform will be able to deploy specific functions, whether they are physical or virtual network functions (PNFs/VNFs), on top of the infrastructure and reconfigure it to be used by existing services. Infrastructure sharing is achieved through virtualisation of network resources, while an extensive set of these functions will be available for sharing through the platform function repository. This approach will significantly reduce the cost and energy consumption taking advantage of its infrastructure and function sharing capabilities.

5G-VICTORI defines and implements a fully-automated and user-friendly control and management framework to enable the instantiation of vertical specific applications. These applications are complex constructs of a diverse set of functions (combination of vertical specific and vertical-independent VNF and PNFs), which can provide complex business applications. These functions will be packaged and exposed through function repositories that will be defined according to the application requirements of each specific vertical sector.

The 5G-VICTORI solution will enable interconnection and interworking of the four facilities, leveraging GÉANT for the physical connectivity between them. Furthermore, a thin inter-domain orchestration layer will be used on top of each of the orchestration solutions available at the individual facility sites to enable dynamic inter-site connectivity. The inter-domain orchestration solution will provide on-boarding of inter-domain services, end-to-end slice monitoring and management for the deployed end-to-end services.

Finally, an open data management (ODM) platform able to provide scalable data collection, aggregation and processing across the various project infrastructure sites will offer optimised vertical services, relying on advanced machine learning and artificial intelligence approaches.

Description of trials

Prior to the execution of the trials, the 5G-VICTORI infrastructures will be extended to enable integration of the vertical industry sites. This extension will involve installation of telecom equipment together with wired and wireless solutions including multi-technology access and transport links as well as compute and storage resources installed at the edge. The aim of these trials is to validate a set of Key Performance Indicators (KPIs) as they are dictated by the specific vertical UCs developed by the project and in conformance to the recommendations defined by 5G PPP. The specific trials that 5G VICTORI include:

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

The goal of this trial is to demonstrate eMBB functionality through heterogeneous access technologies for on-board network connectivity in a high mobility railway environment. Wireless transport network devices will be managed and controlled to facilitate interconnection of on-board devices with the trackside, and the trackside with the core network. Both infotainment and critical operations data (e.g. data from on board CCTV systems) will be efficiently managed from the operator's perspective in order to allow their successful and timely transmission to the edge/core network.

"*Digital Mobility*", Cross-Vertical – Transportation and Media.

5G-VICTORI will trigger the development and implementation of innovative digital mobility services and applications within the framework of the integrated Mobility as a Service (MaaS) concept. Based on the strong operational performance of applications running on 5G networks (data rates, latency, density of devices/connectivity, reliability), a driver's landscape of transport service providers can be integrated into innovative and highly personalised new digital mobility services offering seamless multimodal transport, real-time travel information as well as real-time calculation of travel alternatives.

"*Critical services for railway systems*", Vertical: Rail.

This UC aims to provide an infrastructure with enhanced throughput, safety and security features, supporting the future needs of both rail signaling systems (on-board and ground) and 3GPP Mission Critical (MC) based Future Railway Mobile Communication System (FRMCS) services for voice and data connectivity in emergency scenarios. The 5G-VICTORI solution will be compatible with the existing signaling systems and will be designed to support fast and easy deployment.

"*Smart Energy Metering*", Cross-Vertical: Energy and Rail.

5G-VICTORI will provide energy metering services in High Voltage (HV) /Low Voltage (LV) distribution grids for urban/city environments and HV distribution grids for suburban/rural areas. Infrastructure slices will be provided across heterogeneous technologies/domains to support interconnection of energy metering devices and the associated energy infrastructure with the data management platforms providing the required intelligence for smart grid operation. These services will co-exist with services offered by other verticals leading to significant cost reduction.

"*Digitization of Power Plants*", Vertical: Smart Factory.

In factories, 5G-VICTORI aims to digitize, automate and optimise factory operations exploiting 5G technologies. A 5G-VICTORI platform will enable monitoring, collection and analysis of data collected by a massive number of sensors and actuators that will be turned into actionable information. This will facilitate improved business operations costs, connection of assets and people to improve safety, minimisation of environmental impact and enhancement of decision making.

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

This UC focuses on demonstrating how 5G solutions can transform the media ecosystem and provide Ultra High Definition UHD video and immersive services (AR/VR) in challenging environments. It will provide personalised and broadcasting services in highly dense and mobile environments. These include live video and audio stream distribution in multicast/broadcast mode in crowded environments, immersive media services available over short periods of time and space to passengers arriving at stations, and infotainment services to passengers in moving trains deploying an advanced Content Delivery Platform (CDN) platform over a 5G network Infrastructure.

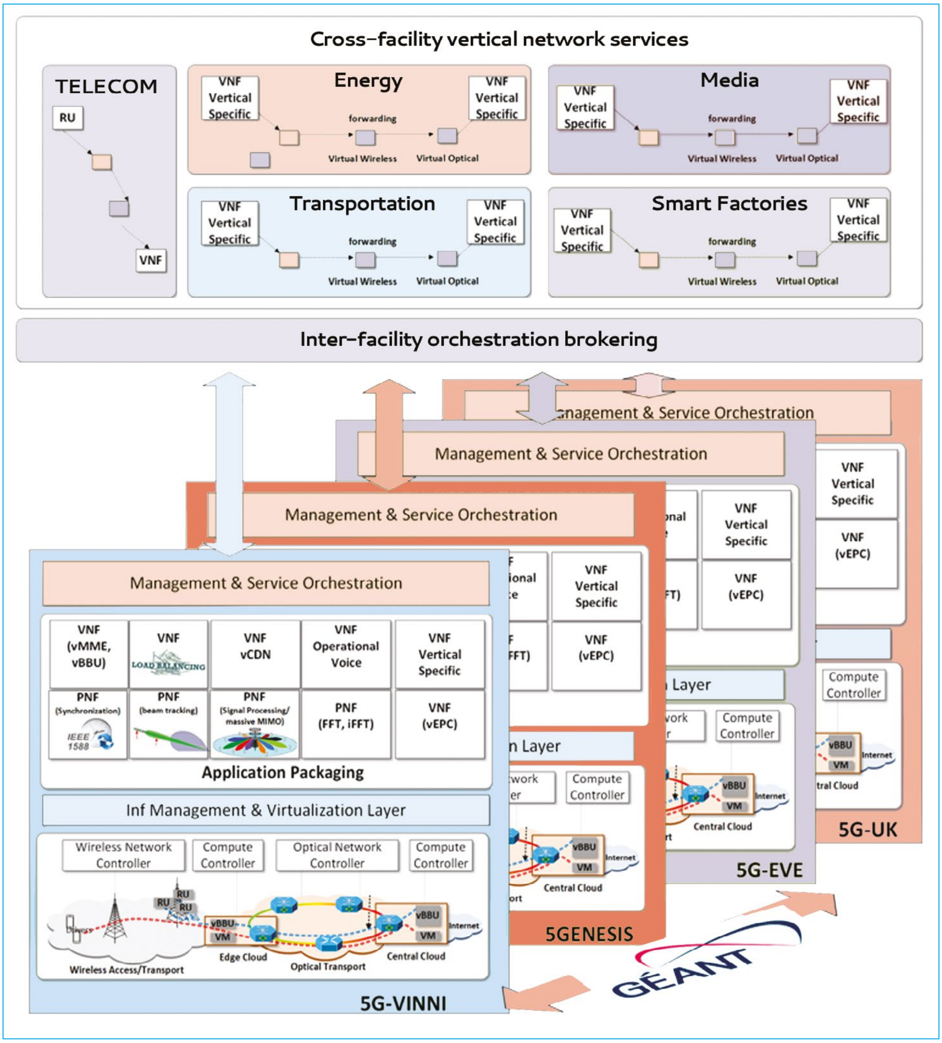


Fig. 33: 5G-VICTORI architecture enabling cross-border operation of vertical industries.

5G!Drones

Goals

The main goal of the 5G!Drones project is to enable safe and secure Beyond Visual Line of Sight (BVLOS) flights using 5G mobile networks. The project will deliver the solutions to enable better business models for the use of 5G networks in Unmanned Aerial Vehicle (UAV) operations. 5G networks leverage 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 also aims to deliver viable and sustainable business models for the use of 5G networks in the context of UAVs.

Use Cases & Scenarios

In order to truly show the capabilities of 5G networks and how the UAV ecosystem can take advantage of the 5G network, the partners in the Consortium derived four high-value use cases and KPIs specific to the use cases to measure the success of the project. Each use case covers a variety of scenarios and involves various combinations of partners and stakeholders.

Use case 1: UAV Traffic Management (UTM)

This use case covers scenarios that relate to traffic management for drones, 5G being the communications medium between the ground stations, UAVs, air traffic management systems, and other entities in the ecosystem.

The 1st scenario revolves around the UTM command and control (C2) application. The main objective is C2 being performed using 5G connectivity utilising one of the three C2 communications models defined by 3GPP standard and new functionalities offered exclusively by 5G networks, such as slicing with customised quality of service.

The 2nd scenario focuses on 3D mapping and supporting visualization/analysis software for UTM systems. This use case studies the possibilities of using VR for drone operation and real time visualization.

The 3rd scenario involves UAV logistics and demonstrates how UAVs using 5G network can provide transportation of medicines. The COVID-19 virus is the booster of drone technology and there are many use cases in China where drones help medics to deal with the pandemic COVID-19.

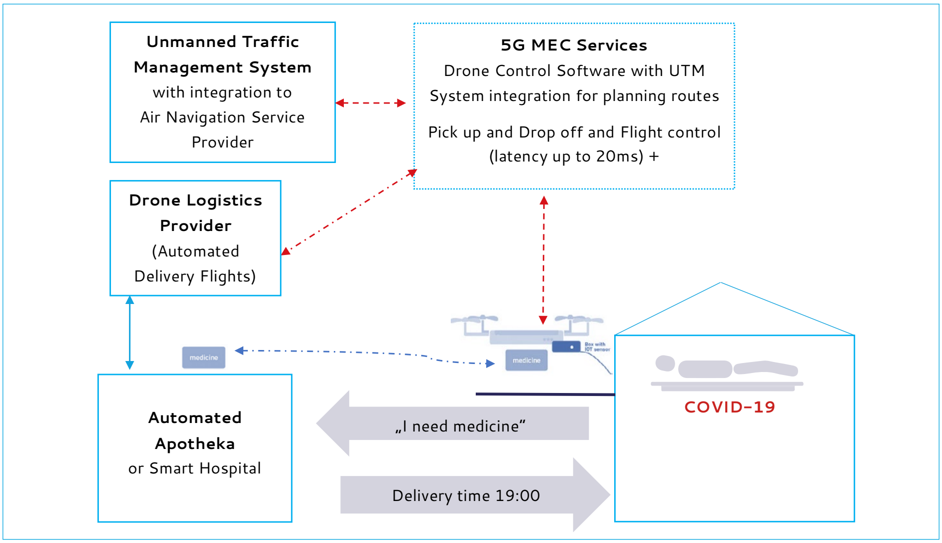


Fig. 34: Medicine delivery using 5G MEC based UAV services

Use case 2: Public Safety/Saving Lives

This use case, composed of 3 scenarios, aims at saving human life and Earth assets.

The 1st scenario is monitoring a wildfire situation. A team of fire fighters performs a coordinated operation in a forest fire scene with the aid of a fleet of drones equipped with IoT sensors/cameras. They provide the strategic aerial view to control the spread of wildfire, toxic gases, or people's movements. The communication will happen over a 5G network to enable high speed real-time data.

The 2nd scenario covers a disaster recovery situation to demonstrate how UAVs through 5G network capabilities can help first response teams during disaster situations such as fires, earthquakes, and flooding among others. In this scenario, we demonstrate disaster recovery using a swarm of three UAVs, both tethered and untethered, through 5G network.

The 3rd scenario demonstrates how remotely piloted UAVs and video analytics can be used for Police tasks, including Counter Unmanned Aircraft Systems (C-UAS) activities using 5G communication.

Use case 3: Situation Awareness

This use case involves multiple scenarios and sub-scenarios. Some of those are:

1. 3D Mapping of 5G Quality of Service (QoS),
2. Long range power line inspection,
3. Inspection and search & recovery operations in large body of water,
4. UAV-based remote IoT data collection, and
5. Location of user equipment in non-GPS environments.

All the scenarios mentioned above aim to exploit the capabilities of 5G network being used for bidirectional communications between drones, C2, ground systems, IoT devices, etc.

Use case 4: Connectivity During Crowded Events

The purpose of this scenario is to demonstrate how UAVs through 5G network capabilities can improve connectivity services in a highly crowded environment, e.g. during large events.

Challenges

1. As safety is the most important factor, we need to assure the connectivity in the air, at least up to 120m above terrain and elaborate the contingency plans in case of lost communication between drone and controller.
2. On July 1, 2020 new EU regulation will enable standard scenarios for business UAV flights without special permits.
3. Drone Service Providers need 5G MEC based services maybe only for 5% of the year. Therefore, the more important challenge for Telco Operator is who utilises the services for 95% of the time?
4. One way for telco operators is to expand their services with HPC (High Performance Computing) services. Many industrial companies need HPC services, such as Computer Vision processing and AI Deep Learning solutions, to keep them running 24/7. HPC services can be prioritised and distributed to hardware in other base stations when multiple drones in a one base station area require time-critical 5G MEC based services.

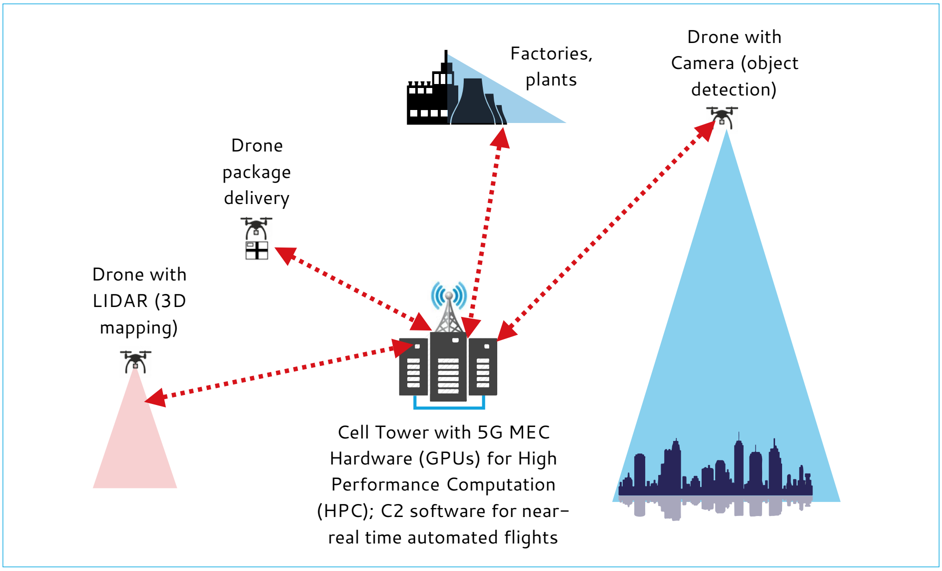


Fig. 35: 5G MEC based applications for drones

5GROWTH

5G-enabled Growth in Vertical Industries

Vision and Goal

The key objective of 5G is to provide the vertical industries with an infrastructure that is able to support more efficiently connectivity needs. At the same time 5G aims at enabling new innovative digital use cases and facilitating the creation of cross-industry partnership. The vision of the 5GROWTH project (*http://5growth.eu/*) is to **empower verticals industries**, in particular covering Industry 4.0, **Transportation, and Energy domains** with an **AI-driven Automated and Sharable 5G End-to-End Solution** that will allow these industries to simultaneously achieve their respective key performance targets.

Towards this vision, 5GROWTH will automate the process for supporting diverse industry verticals through (i) a **vertical portal** in charge of interfacing verticals with the 5G End-to-End platforms, receiving their service requests and building the respective network slices on top, (ii) **closed-loop automation and SLA control** for vertical services lifecycle management and (iii) **AI-driven end-to-end network solutions** to jointly optimise Access, Transport, Core and Cloud, Edge and Fog resources, across multiple technologies and domains.

Vertical industry involvement

The main objective of 5GROWTH is 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 (Comau S.P.A., EFACEC Engenharia e Sistemas S.A., EFACEC Energia – Maquinas e equipamentos Electricos S.A., Asociación de Empresas Tecnológicas Innovalia)** will be field-trialed on four vertical-owned sites in close collaboration with the **vendors (Ericsson España SA, Ericsson Telecomunicazioni, InterDigital Germany GMBH, NEC Laboratories Europe GMBH, Nokia Bell NV) and the operators (Altice Labs SA, Telecom Italia SPA, Telefónica Investigación y Desarrollo SA)** in the project.

The vertical partners participating in 5GROWTH from different industrial expertise in Energy, Transportation and Industry 4.0 domains have been developing the 5GROWTH project's use cases. During its first year, vertical partners are also providing valuable feedback to enhance the 5GROWTH architecture with the addition of new functionalities planned for the next code releases.

Main challenges

The main challenges of the project are (i) Design and implementation of a platform, and the related components, interfaces and algorithms, to **empower verticals to provision 5G** connectivity and services directly at the verticals' sites; (ii) **Automated multi-level, cross-domain, hierarchical service orchestration** with multi-domain management of resources with **seamless integration at vertical sites** with existing platforms; (iii) Vertical-oriented trial-based assessment, incl. 5G PPP KPIs; (iv) **Tight integration between 5Growth and ICT-17 testing facilities** with the goal of measuring KPIs and validating 5G capabilities; (v) Quantification of the **advantages** of the use of **slicing, virtualisation and orchestration**.

5GROWTH concept

Figure 36 summarizes the 5GROWTH concept, where a federated resource infrastructure is composed of End-to-End connectivity platforms (provided by the ICT-2017-18 5G EVE, 5G-VINNI projects and 5TONIC site in Madrid, Spain) and the resources locally available at the vertical premises. 5GROWTH reference architecture is based on three main building blocks:

1. The Vertical Slicer:

- **Enhanced vertical support** to process vertical service requests
- **Building and managing respective network slices** for the requested services

2. Service Orchestrator:

- **Closed-Loop automation and SLA control** for vertical service lifecycle management (create, instantiate, update/modify, terminate, ...)

3. Resource Layer:

- **AI driven end-to-end network solutions** to jointly optimise Access, Transport, Core and Cloud, Edge and Fog resources across multiple technologies and domains.

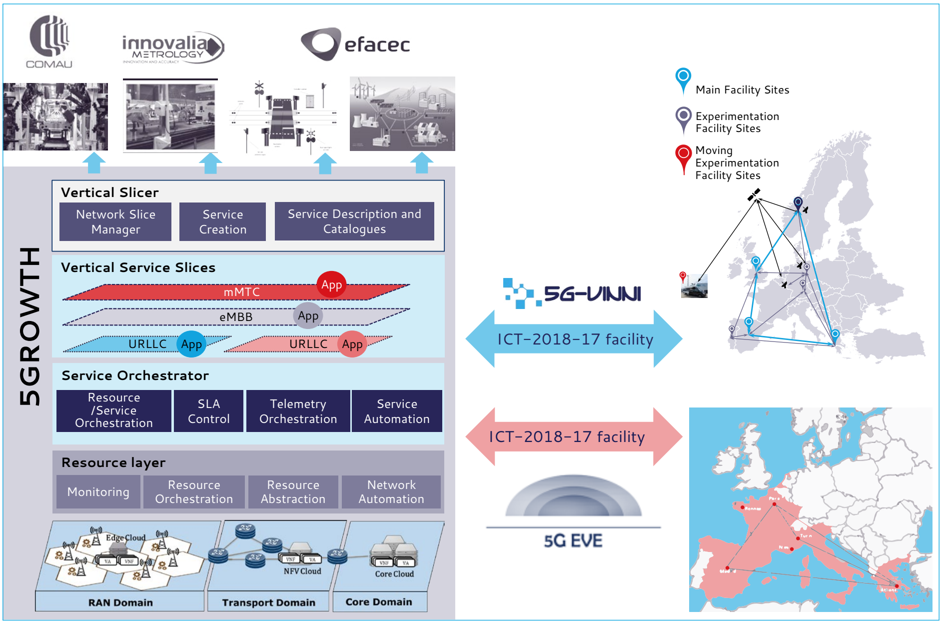


Fig. 36: *5GROWTH reference architecture*

5GROWTH will **leverage on the results of 5G PPP Phase 2 projects** where slicing, virtualisation and multi-domain solutions for the creation and provisioning of vertical services are being developed and validated, e.g., **5G-TRANSFORMER**. Two **ICT-17-2018 5G End-to-End platforms, 5G EVE and 5G-VINNI**, have been selected for the Trials to demonstrate the 5GROWTH specific vertical use cases. In addition to the impact on vertical-oriented standards (e.g., EN50126 (IEC62278) for railway signalling), the verticals in the consortium will **influence ongoing 5G standardisation** by leveraging the involvement of leading experts in the various relevant SDOs.

Communication, dissemination, and exploitation

After its official launch in June 2019, the 5GROWTH project has already been involved in several **dissemination and demonstration activities** at different relevant venues, such as EUCNC'19, ACM CoNext'19, INFOCOM'20, IEEE CloudNet'19 and ACM Mobicom '19 and has shown the description and development progress of the 5GROWTH concept. 5GROWTH has also started to contribute to relevant **standard bodies** (and groups therein), such as IETF ANIMA, IETF RAW, IETF COINRG, IETF SFC.

The code of the 5Growth MANO stack is available as **open source** at: *https://github.com/5growth*

Social media presence:

- Twitter (*@5growth_eu*)
- Youtube (*https://www.youtube.com/channel/UCfIAsV6AdEibRteQp2ftpgw*)
- LinkedIn (*https://www.linkedin.com/in/5growth-project/*)
- Instagram (*5growth_h2020)*

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 anticipated Full5G project work will be 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.

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

The 5GZORRO envisions the future 5G networks as composed of distributed heterogeneous resources by different operators across diverse geographical areas, who in turn form an end-to-end secure chain of trust in which 5G radio, spectrum, edge and core computing, storage and networking can be shared and chained thanks to efficient and flexible mechanisms to discover, broker, trade, instantiate and monitor resources and services across the different operators' domains. However, to ensure robust, reliable, and secure communications in future 5G, the industrial and research community needs to maintain a laser focus on the joint realisation of **zero-touch security & trust framework** and **fully automated network management**.

5GZORRO will develop these envisaged solutions for zero-touch service, network and security management in multi-stakeholder environments (ubiquitous), making use of Smart contracts based on Distributed Ledgers Technologies to implement required business agility.

Key Innovations

At the core of the proposed solution, there is the 5GZORRO platform, which is instantiated in each operator domain to implement the evolved 5G architecture. The 5GZORRO platform follows the principle of service-based architectures similar to the 5G Service-based architecture, and the ETSI Zero-touch Network and Service Management. Through a Blockchain based Distributed Ledgers infrastructure, the platform offers services for: 1) Smart Contracts Management, 2) Resource Discovery & Brokering; 3) Intelligent 3rd-party virtual resource selection; 4) Spectrum trading and sharing; 5) Secure SLA Monitoring.

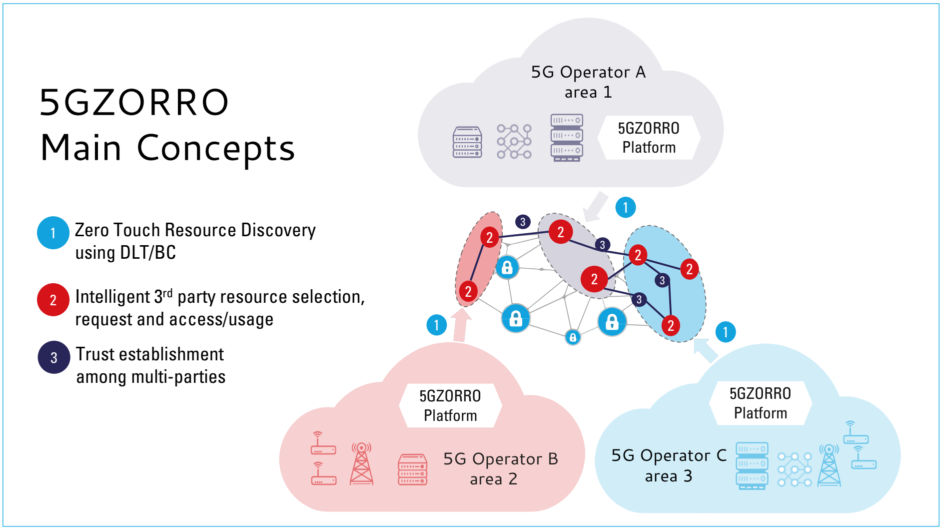


Fig. 37: 5GZORRO main concepts

Within the platform, the realisation of these services is made possible through the interaction of various functions for slice orchestration, Network Intelligence and analytics, Security & Trust, Management of Service & virtualised Resources, all executed for multi-domain and single domain scope.

To address these challenges, 5GZORRO is working towards producing the following innovations:

- **Zero-Touch Automation**: 5GZORRO vision is achieving zero-touch automation of 5G network management, along with its many operational services and goals, its multi-party and multi-layer structure, its complexity and scale. 5GZORRO approach to zero-touch automation is driven by the idea of sharing operational data across the whole system in a logically centralised data reservoir (aka Data Lake), so that multiple asynchronous management components may act upon this shared data pool towards optimising a target set of KPIs. To facilitate open data sharing, 5GZORRO will employ permissioned ledger technology for governance of and accounting for data use.
- **Multi-party Security & Trust**: Security and trust in 5GZORRO will be designed and implemented following a principle of split between coordination actions to be taken at the inter-domain layer and actions/enforcements per domain. It will be the Cross-domain Security & Trust functionality in the Inter-domain Layer of 5GZORRO the container of end-to-end security and trust parameters, policies and ML models that will help to instantiate 5G services across multiple parties ensuring the required level of security and trust. All these efforts towards a risk-free 5G multi-stakeholder scenario will also require the definition and creation of novel ML models supporting risk analysis processes as well as the detection of software vulnerabilities and compromises and the provision of a potential set of countermeasures for any of these detected vulnerabilities and its implications on the network services.
- **Distributed Ledgers with 5G**: 5GZORRO aims to integrate the distributed ledger technologies with 5G as part of its design for the evolved 5G service layer with support at the system level as well. The evolved 5G service layer envisaged by 5GZORRO sits on top of a DLT infrastructure which has at its core several permissioned consortium based Blockchain networks, built on top of open source technologies such as Ethereum and HyperLedger. The Blockchain networks act as trusted data layers for SLA enforcement, resource discovery and spectrum management.

Major achievements of the period

In the first six months of the project (Q4-2019, Q1-2020) 5GZORRO consortium has elaborated the project use cases and analysed the functional, non-functional and business requirement for the 5GZORRO architecture.

5GZORRO Use Cases

- **Smart Contracts for Ubiquitous Computing/Connectivity**: This use case originates from the consideration that the telecommunications sector at large still relies on offline, non-standard paper contracts to establish commercial interactions, including SLAs, which is inflexible and unsuitable for real-time resource supply and demand among the multiple parties involved in 5G. The 5GZORRO architecture can support smart contracts with a business logic of various multilateral agreements. This standardisation enables the automation of commercial, technical and SLA interactions between all parties by means of implementing a DLT environment that allows trustless interactions. All the parties will be able to verify the identity of participating nodes and it's the resource contribution in relation to the end-to-end provision of services to the consumer and to other entities. We foresee the inclusion of oracles, i.e. agents that verify real-world occurrences and submit the information to a blockchain to be used by smart contracts. Existing standards about the provision of ubiquitous computing and connectivity can be mapped into Oracle Smart Contracts for reference by inter-party Smart Contracts. New Oracle Smart Contracts containing commercially relevant data such as unit pricing (e.g. minute, MB, etc.) will provide a central point of reference for ad-hoc multi-party Smart Contracts.
- **Dynamic Spectrum Allocation**: 5G verticals may require licensed spectrum but only for small local areas, for example to deliver robotic automation in a factory using 5G. Given the need to avoid harmful interference, the 5G vertical cannot use unlicensed spectrum, hence it will be optimal to seek spectrum sharing mechanism including spectrum leasing from MNOs. In 5GZORRO, we intend to use the distributed trust offered by DLT infrastructures to efficiently coordinate the sharing of spectrum and implement a dynamic and efficient 5G spectrum market. Shared spectrum right holders can trade spectrum rights for a given area and time in a spectrum market, thus enhancing spectrum efficiency while allowing QoS. This will also allow many stakeholders to participate in spectrum trading. A set of business agents will obtain a spectrum license issued by the regulators. The provided license would be bound to a certain geographic area and time period, which is equivalent to a set of spectrum token (spectoken). These users would then be able to exchange spectoken with each other for spectrum rights. MNOs could also participate in this market, by offering the excess spectrum that they are not using. On the demand side, an example could be a stadium that may want nearby spectrum rights during the match time.
- **Pervasive vCDN Services**: In a 5G network using segmented and distributed virtualised resources allocated into network slices, a content service provider may need to dynamically modify the deployment of its virtual functions and services at a given place due to varying demand dynamics, typically associated with user mobility and e.g., content popularity. The possibility to leverage on 3rd-party resources from different operators can allow to flexibly extend service coverage to various locations and compose virtualised assets from various providers into a single end-to-end network slice. Through the 5GZORRO architecture a content service provider who offers virtualised content delivery network (vCDN) services can use the resource discovery process to identify usable 3rd-party resources and the candidate target infrastructures capable of maintaining trust & security for the service, and consequently select and automatically re-instantiate its vCDN elements by optimising target KPIs, security/trust properties, pricing, etc.

5G-CLARITY

5G-CLARITY is a 5GPPP Phase III project (ICT-20-2019 call: 5G Long Term Evolution), started on November 1, 2019, and is planned to be concluded on April 30, 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 specific challenges in this area, such as:

- Need to coexist with, and effectively integrate to, non-3GPPP technologies such as Wi-Fi and LiFi,
- Essentiality for novel management systems that simplify the operation and maintenance of 5G networks,
- Design of mechanisms for combining private and public 5G networks, to allow vertical users to decide the level of 5G functionality that they want to maintain on-premises, and,
- Incorporation of value-added services that have not been traditionally a priority for mobile network operators, such a cm-level positioning, that may be strategic for vertical users.

5G-CLARITY investigates how the concept of private 5G networks should evolve beyond the 3GPP Release 16, by bringing innovation in two main pillars.

The first pillar constitutes a heterogeneous wireless access network that integrates 5GNR, Wi-Fi, and LiFi, thus delivering:

1. per-UE and aggregate capacities beyond 3GPP R16, through interface aggregation and intelligent interface selection,
2. lower delays and higher reliability than 3GPP R16, through parallel access and selective packet duplication, and
3. an indoor positioning service with cm-level accuracy, through the combination of mm-wave Time-of-Flight (ToF), and Optical Camera Communications (OCC) for LiFi.

LiFi is a high data-rate technology supporting the full-duplex operation, mobility, and extremely high area capacity. The integration of LiFi in private beyond 5G networks, will be based on the upcoming IEEE 802.11bb standard, is a key component of the 5G-CLARITY vision, whereby the focalised nature of light propagation offers essential features for private networks such as increased security, as light does not propagate through walls, area capacity, and positioning accuracy. The proposed multi-connectivity framework enables an intelligent aggregation of the 5G/Wi-Fi/LiFi interfaces, resulting in eMBB and URLLC services.

The second pillar embodies a novel management plane based on the principles of Software Defined Networking (SDN) and Network Function Virtualisation (NFV), and powered by Artificial Intelligence (AI) algorithms, to enable network slicing, and autonomic network management. The envisioned management plane will feature:

1. an SDN/NFV platform exposing an Application Programming Interface (API) to drive the network configuration, to extract network state, and to manage the creation of infrastructure and service slices,
2. an AI engine that will collect data from the SDN/NFV platform and learn over time how to optimise the configuration of the network, and
3. a high-level intent-based policy language that will allow an infrastructure operator to interact with the network using business primitives, instead of low-level network configuration.

Figure 38 shows 5G-CLARITY system architecture, designed to enable the above-mentioned technologies by dynamic deployment of connectivity services inside the private venue, addressed to the venue owner as well as to the mobile network operators serving customers inside the venue.

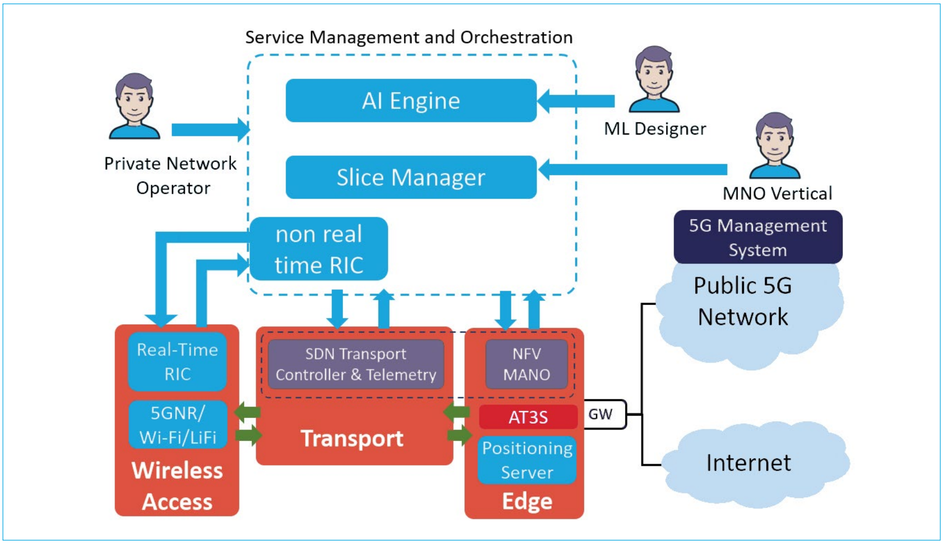


Fig. 38: 5G-CLARITY system architecture.

5G-CLARITY technologies will be demonstrated in two key private network use cases:

1. **Smart Manufacturing (Industry 4.0)**: The Industry 4.0 use case has two parts. Firstly, we will demo an enhanced network to deliver wireless multi-service support inside a lead plant of BOSCH (in Barcelona, Spain). Multiple wireless access-technology (multi-WAT) network will serve several factory-automation applications aiming at improved overall latency, and reliability by using proper wireless network slicing. The second demo is to provide enhanced positioning for Automated Guided Vehicles (AGV) used to move containers in the plant. These AGVs use advanced navigation methods fed by precise positioning information, provided by the wireless network, to move goods across the factory without a human operator/driver intervention.
2. **Smart Tourism**: This use case is an enhanced human-robot interaction application for next-generation museum visitor experiences demonstrated in M-Shed museum in Bristol. This demonstration intends to showcase how robots help to leverage tourist satisfaction in public areas, such as museums or exhibitions. The core concept is on the applications of robots powered by network intelligence, At the same time, they will be controlled remotely and guided with assistance from wirelessly networked cameras. A remote-controlled robot will perform various tasks in a complex environment, while wireless cameras will be connected to a private network and will be used to guide the brainless robot and redesign its route based on real-time information obtained from the cameras.

5G-COMPLETE

A unified network, Computational and stOrage resource Management framework targeting end-to-end Performance optimisation for secure 5G muLti-tEchnology and multi-Tenancy Environments

The Challenge

The global demand for mobile bandwidth capacity is growing at an exponential rate, due to the increasing popularity of over-the-top (OTT) media streaming services. With industry analysts predicting a 45% mobile traffic growth through 2021 and data networks continuously expanding to cover larger areas, this forecast presents real challenges for today's mobile network operators (MNOs). However, the current Distributed Radio Access Network (D-RAN) paradigm cannot pace with the economics of Access Point (AP) densification envisioned in 5G networks, which amongst other reasons, is imposed by the adoption of higher radio frequencies in the 5G New Radio (NR) standard.

The highest acclaimed solution for impairing the densification costs is the so-called RAN centralisation(C-RAN).It separates the Base Band Unit (BBU) from the Remote Radio Head (RRH), leaving the now low-cost RRH at the access site and joining it through the fronthaul network to the BBU that is placed at the Central Office (CO) of the MNO. The centralised nature of C-RAN offers a plethora of advantages, like reduced power consumption, virtual resource pooling, coordinated multipoint communications facilitation, adaptability to non-uniform traffic and future-proof upgrading, while expediting deployment and scaling, resulting in a faster time to market and considerable savings in both Capital and Operational Expenditures (CAPEX and OPEX).

However, several emerging types of applications can impose cumbersome traffic on the fronthaul. In contrast, mission critical applications, which require low latency and high reliability, are facing difficulties in being satisfied through C-RAN implementations. Multi-Access Edge Computing (MEC) was proposed, as an alternative extension for processing and storage capabilities to the edge. Nevertheless, merging MEC functionalities into next generation's 5G NR RAN solutions carries major research challenges. Firstly, optical and wireless technologies should be integrated in a flexible framework able to be adjusted to the data rate and satisfy the latency requirements of 5G services. Secondly, a synergy of novel interfaces is imperative to drive this multi-technology environment and to solve the joint RAN/Cloud/MEC optimisation problem. Thirdly, to increase network flexibility, both centralised and flexible, self-organised mesh networks need to be incorporated and concurrently operated by a centralised SDN-enabled management and operational framework. Finally, security becomes a key challenge since application execution traverses the RAN and is exposed to intruders.

The Vision

Within this highly demanding environment, 5G-COMPLETE aims to revolutionize the 5G C-RAN architecture, by combining Cloud and Edge computing functionality while placing them on top of a unified ultra-high capacity converged digital/analogue Fibre-Wireless RAN.

5G-COMPLETE's architecture combines a series of key technologies under a unique architectural proposition that brings together:

1. the high capacity of digital/analogue opticsand high-frequency radio
2. the audacity of converged FiWi fronthauling,
3. the spectral efficiency of analogue modulation and coding schemes
4. flexibility of mesh self-organised networks
5. efficiency of high-speed and time-sensitive packet-switched transport,
6. the rapid and cost-efficient service deployment through unikernel technology
7. an enhanced security framework based on post-Quantum cryptosystems and QKD.

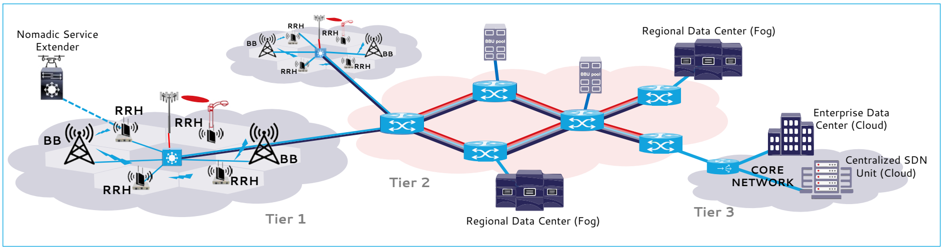


Fig. 39: 5G-COMPLETE architecture

Project Objectives

Empowered by its ambitious vision (Figure 39), 5G-Complete aims to merge the Mobile Edge Computing (MEC) and Cloud complementary forces under a common flexible, profitable and energy-efficient RAN infrastructure, being capable of synergistically exploiting Computing, Access and Storage services in order to effectively respond to the emerging mobile data deluge. More specifically, 5G-COMPLETE will:

- Develop a mm-wave point-to-multipoint (PtMP) mesh node and an integrated THz transceiver to enhance functionality and capacity at the network's edge.
- Develop a delay time-sensitive and elastic optical bandwidth framework for converged network/computational/storage architectures
- Develop an advanced DSP platform to increase the bandwidth efficiency of edge optical transport layer
- Develop and demonstrate a toolbox of hardware and software solutions
- Develop joint network, computational and storage resource allocation optimisation algorithms leveraging AI/ML techniques
- Deploy serverless computing paradigms at the edge for low latency services.
- Develop an end-to-end 5G network slicing management and orchestration framework
- Architect a low-latency, high energy efficiency, high-capacity and flexible 5G network.
- Validate its 5G network technologies in a series of scalable lab-scale and field-trial demonstrators.

5G-COMPLETE Demos

Being committed to fast validation that will allow for immediate exploitation of its 5G technologies, 5G-COMPLETE will carry out a series of scalable demonstrators across all of its targeted prototypes and network scenarios. Targeted demonstration actions include:

- Lab-scale evaluations and demonstrations hosted in ICCS/NTUA premises, Orange Labs and IASA-COSMOTE targeting the integration of the developed technologies and architectures.
- Live demonstration in Athens 5G test-bed, focusing on the integration of the deployed computing nodes for low-latency services.
- Live demonstration of the full 5G-COMPLETE solution in the 5G-UK testbed in Bristol. This demonstration will take a leap beyond technology evaluation and will also focus on end user services.

5G Complete Demos

Demo sites	Type	Purpose
ICCS	Lab scale evaluation	Integration of the developed technologies and architectures
orange	Lab scale demonstration	Software-based control of both optical/mobile
COSMOTE, IASA	Lab scale demonstration/ infrastructure slice	Energy metering applications
COSMOTE, ICCS	Live demo/edge computing test zone	Integration of the deployed computing nodes for low-latency services
University of BRISTOL	Final field trial/ Live demonstration of 5G services	Live demonstration of 5G COMPLETE concept

Fig. 40: 5G-COMPLETE targeted demonstration actions

ARIADNE

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

ARIADNE, a three year project started in November 2019, is going to enable spectral efficient, high-bandwidth, intelligent wireless communications by developing three complementary but critical new technologies for future 5G networks in an integrated and innovative way – the so-called **ARIADNE Pillars**:

1. New radio technologies for communications using the above 100 GHz D-Band frequency range,

2. Advanced connectivity based on reconfigurable intelligent surfaces (metasurfaces) becoming tunable reflectors for shaping the wireless channel in D-band, and

3. Machine Learning (ML) and Artificial Intelligence (AI) techniques for management of the high-frequency communications resources as well as reconfiguration of the metasurfaces.

The ARIADNE project proposes a novel hybrid wireless system architecture, which combines the benefits of the bandwidth-rich D-band and AI, optimised by means of:

- a novel Communication Theory framework beyond the Shannon paradigm, according to which the environment itself is made reconfigurable and can assist to establishi reliable communications,
- intelligent surfaces (metasurfaces) used to enable tunable or switchable reflections and overcome limitations resulting from obstructed links and NLOS (Non-Line of Sight) scenarios,
- propagation characterisation in the D-band for indoor/outdoor, LOS (Line of Sight) and NLOS,
- highly integrated D-band transceiver RF-frontend architectures and spectral efficient baseband processing, energy-efficient carrier aggregation, and D-band MIMO antenna design,
- waveform design, wireless access, tracking and resource allocation based on the pencil beamforming principle, and
- ML/AI-based approaches for ultra-reliable connectivity, optimal and adaptive RRM (Radio Resource Management) and End-to-End network optimisation (resource allocation, routing, etc.).

The ARIADNE Vision

The vision of ARIADNE is to investigate, theoretically analyse, design, develop, and showcase in a proof-of-concept demonstrator. It shows an innovative wireless communications concept addressing networks beyond 5G, in which ultra-high spectral efficient and reliable communications in the bandwidth-rich D-band can be dynamically established and reconfigured by ML-based design and intelligent network management.

ARIADNE targets ultra-reliable and scalable connectivity of extremely high data rates in the 100 Gbit/s regime at almost 'zero-latency'. In this respect, ARIADNE proposes to exploit frequencies between 110-170 GHz for access and backhaul links, taking advantage of breakthrough novel technology concepts, namely, the development of broadband and spectrally highly efficient RF-frontends in the D-band. The employment of metasurfaces to cope with obstructed connectivity scenarios and the design of ML-based access protocols, resource and network management techniques.

ARIADNE Concept

Sustaining a flexible and ubiquitously available 100 Gbit/s 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 the rethinking of 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 (physical and virtual) manager will be transformed into the system concept of a fully adaptive (to environmental characteristics, volatility and user requirements), power-efficient distributed computer and highly reliable connectivity provider.

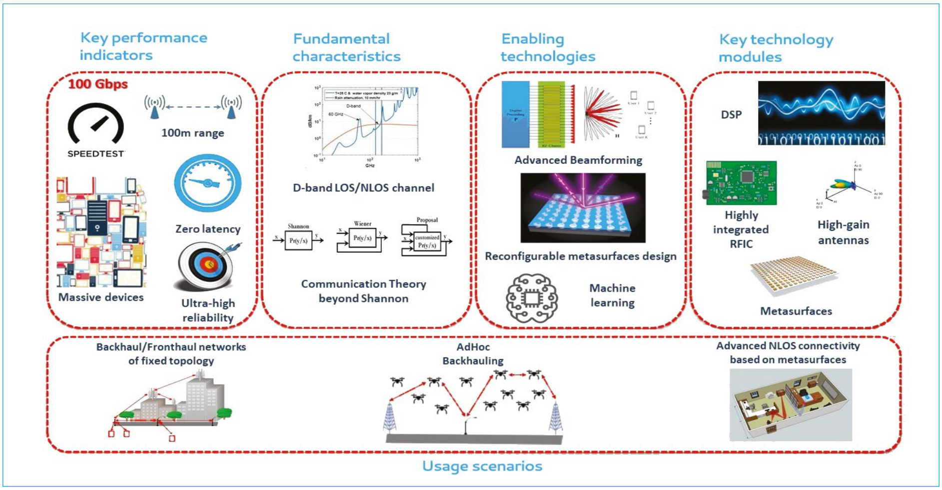


Fig. 41: ARIADNE system concept for networks beyond 5G

ARIADNE defines the following seven key performance indicators. They allow to follow up the project achievements along its three pillars:

- Aggregate throughput of wireless access for any traffic load/pattern – 100 Gbit/s
- End-to-End throughput in all relevant usage scenarios, backhaul/fronthaul, ad hoc backhaul, NLOS/obstructed – 100 Gbit/s
- End-to-End latency minimisation – 'zero' latency
- Coverage of the D-band link – 100m outdoors
- Connectivity Reliability for massive number of nodes – 'always' available
- Energy efficiency – energy consumption reduction by 10x compared to 5G
- Complexity reduction – 10x compared to 5G

A summary of ARIADNE objectives and targeted innovations leading to the achievement of the defined KPIs is presented in the next figure.

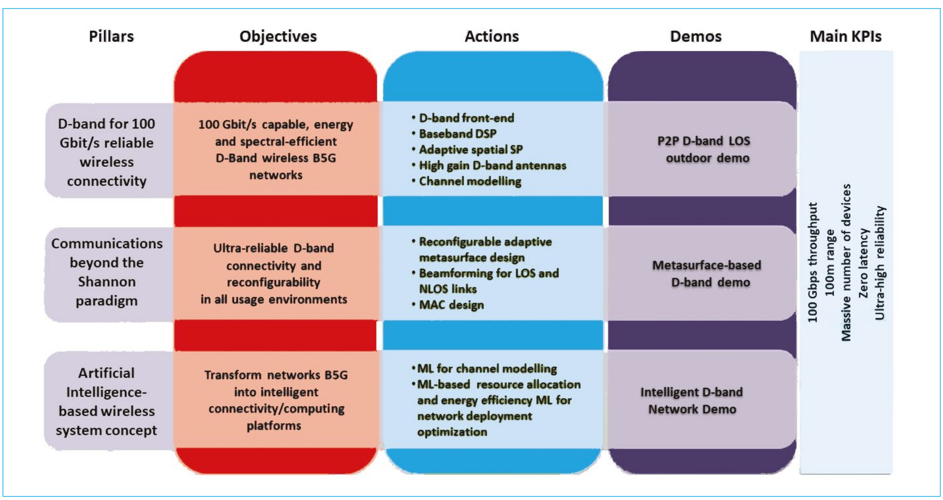


Fig. 42: ARIADNE objectives and activities

Usage Scenarios

To validate the project work and achieved results as well as to be able to showcase the project achievements in an appropriate way, ARIADNE selected the following three representative scenarios:

(a) – Backhaul/Fronthaul networks of fixed topology:

Two fundamentally different backhauling/fronthauling possibilities exist, namely, wired and wireless backhaul/fronthaul networks. Wired backhaul/fronthaul solutions include copper and fibre. However, fibre may not be available and installing new fibre for small cells may not be an acceptable solution due to the high cost. A more cost-effective and easy-to-deploy alternative is wireless backhaul/fronthaul, where small cells traffic may be carried over D-band links. In particular, the connectivity between small cells and the network aggregation point could be based on point-to-point, or mesh topologies. Fixed nodes can serve as access points and/or relays that allow the end-user to access the core network.

(b) – AdHoc Backhauling:

Moving nodes can serve as gateways (access points) offering backhauling for very high data rate connectivity, in the case of irregular traffic increase (special events), ultra-dense connectivity demands (data 'shower') and mobility environment (vehicle traffic management, etc.). Dynamic (ad hoc) backhaul nodes topology, LoS and multiple hops connectivity (mesh architectures) are the main features of this scenario.

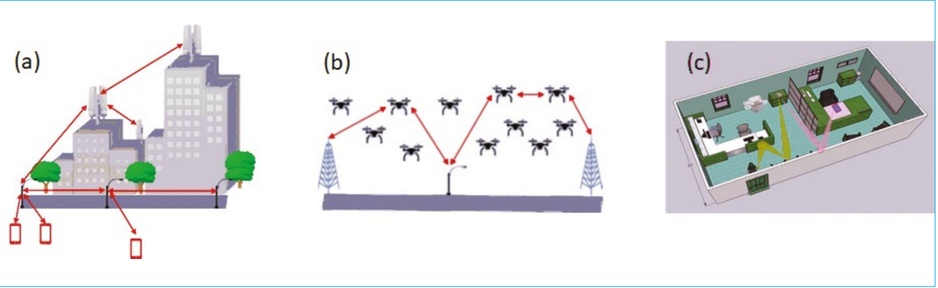


Fig. 43: ARIADNE usage scenarios

(c) - Advanced NLOS connectivity based on metasurfaces:

It is often the case that wireless communication networks operate in the high frequency bands, where the line-of-sight link is obstructed by objects and/or even by channel impairments, e.g., rain, fog, foliage, etc. Therefore, a case where the environment itself is made reconfigurable and can assist the communication between two end-points is considered. For example, randomly distributed environmental objects are coated with reconfigurable intelligent surfaces, e.g., tunable reflectors, which are able to reconfigure the system's response to the radio waves based on the available feedback information. The input and the operation of the object coated with intelligent electromagnetic material are jointly optimised and configured through a software controller.

Expected Impact

ARIADNE expectation is to impact the whole beyond 5G technology value chain and the future wireless network business. By realising its vision of bringing together D-band communications and AI in order to achieve reliable, scalable, and reconfigurable connectivity, the beyond 5G network will be transformed into a highly adaptive and powerful computing and connectivity provider. Thus revolutionising the way people communicate and catalysing future applications that go far beyond communications.

INSPIRE-5Gplus

Intelligent Security and Pervasive Trust for 5G and Beyond

Vision

INSPIRE-5Gplus makes a revolutionary shift in the 5G and beyond security vision. It is advancing 5G security and devising a smart, trustworthy and liability-aware 5G security platform for future connected systems. INSPIRE-5Gplus will enable advancing the 5G and beyond security vision by adopting a set of emerging trends and technologies, such as Zero-Touch Management (ZTM), Software-Defined Security (SD-SEC), Artificial Intelligence/Machine Learning (AI/ML) techniques and Trusted Execution Environment (TEE). A new breed of SD-SEC assets will be developed to address some known challenges, e.g. adaptive slice security, and new ones like proactive security.

INSPIRE-5Gplus will ensure that the provided security level is conformant to security requirements by legislation, verticals and standards. Trust and liability will be fostered through the integration of novel mechanisms supporting confidence between parties and compliance with the regulation. INSPIRE-5Gplus plans to deliver innovative and actionable results (methodologies, enablers, services) of interest for ongoing 5G PPP projects. INSPIRE-5Gplus results will advance technical and societal innovation and support the extension and convergence of 5G security within and beyond 5G PPP.

Key Targets

Enabling Technologies

To enforce security, trust and liability capabilities smartly and autonomously, the security management in INSPIRE-5Gplus will leverage on advanced and emerging enablers including:

- A conceptual architecture for supporting zero-touch end-to-end smart network and service security management in 5G and beyond networks, following the ETSI ZSM specification.
- Dynamic Software-Defined Security (SD-SEC) orchestration and management that enforce and control security policies in real-time and adapt to dynamic changes in threats landscape and security requirements in 5G and beyond networks.
- Smart end-to-end security management through AI/ML: INSPIRE-5Gplus will advance the state-of-the-art achievements in autonomic security management by taking advantage of new disruptive enablers for obtaining a completely new breed of security solutions in support of 5G security.
- Advanced mechanisms to foster trustworthiness of smart SD-SEC solutions in a multi-tenant/multidomain setting by empowering trust in software components (e.g. VNFs) and AI/ML techniques. Trust in software components will be based on Trusted Execution Environments (TEEs), new Digital Rights Management (DRM) approaches, novel AI-powered validation tools, and a new labelling scheme. Trust in AI/ML models will rely on interpretability, adversarial machine learning countermeasures, and distributed ledger technologies.
- New mechanisms to enforce liability of involved parties when security breaches occur and/or systems fail, including smart contracts and potentially VNF Manifest to define Trust Level Agreement (TLA), efficient mechanisms to enable AI liability, and new Root Cause Analysis (RCA) techniques.
- Optimisation of security monitoring and reactions based on distributed microservices, edge computing and P4 data plane programmability.

Architecture

INSPIRE-5Gplus will devise and implement a fully automated end-to-end smart network and service security management framework that empowers not only protection but also trustworthiness and liability in the management of 5G network infrastructures across multi-domains. INSPIRE-5Gplus will ensure that the provided security is compliant with the expected Security Service Level Agreement (SSLA) and the regulation requirements. The framework's high-level conceptual architecture (figure 44) is split into Security Management Domains (SMDs) to support the separation of security management concerns.

Each SMD is responsible for intelligent security automation of resources and services within its scope (e.g. Physical Network Functions – PNFs, virtualised network functions – VNFs). The end-to-end service SMD is a special SMD that manages security of end-to-end services (e.g. network slice) that span multiple domains. It co-ordinates different domains using orchestration.

Each SMD comprises a set of functional modules (e.g. intelligence engine, security orchestrator) that operate in an intelligent closed-loop way to provide a software-defined security orchestration and management that enforces and controls security policies of network resources and services in real-time.

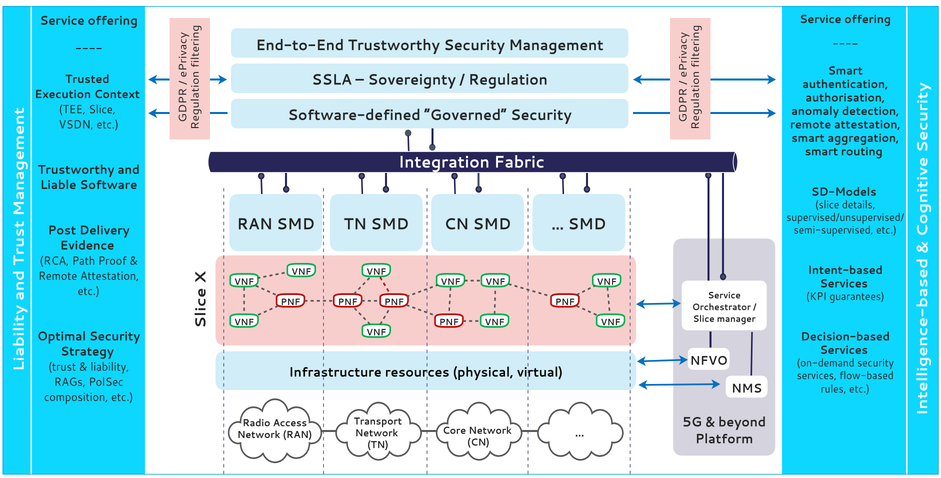


Fig. 44: INSPIRE-5Gplus high-level conceptual architecture

Main Results

The key outcomes envisioned by INSPIRE-5Gplus include:

- A comprehensive report on the current security landscape of 5G networks, and the foreseen evolution trends of this landscape regarding security threats and security requirements.
- Dynamic and adaptive secure slicing based on end-to-end security policy management and orchestration of protection, detection, and mitigation mechanisms.
- Intelligent and autonomic end-to-end cybersecurity services that can detect and mitigate existing and new threats targeting 5G networks.
- Evolved and new security assets using novel tools and techniques with a focus on trust and liability across 5G infrastructure and services.
- An integration and experimentation framework aiming to validate specific 5G security use cases.

The results obtained will be validated and tested in selected use cases, like the two depicted below. The use case in figure 45 focuses on the liable and trustable cross-border roaming of a vehicle crossing over to a different country with different regulations. The use case in figure 46 proposes a blockchain-based trusted infrastructure for detecting fraudulent information and isolating the malicious entity.

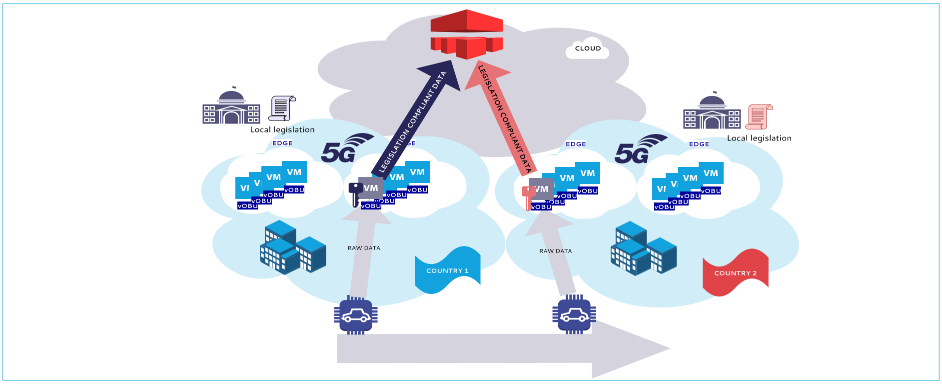


Fig. 45: Cross-border roaming use case

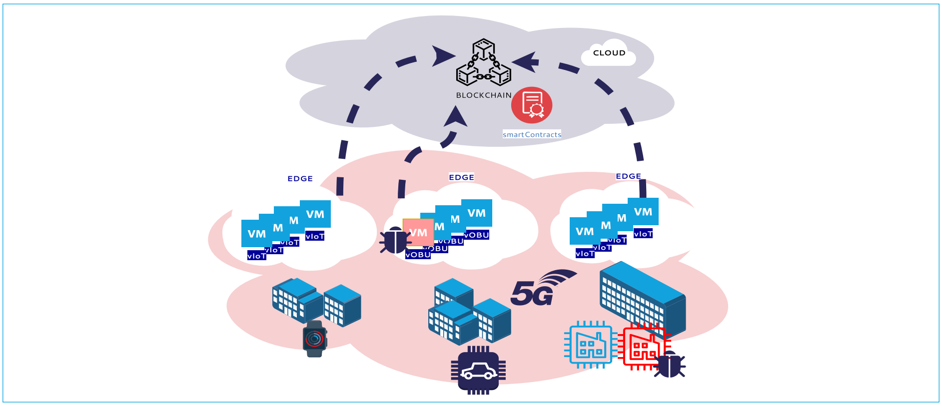


Fig. 46: Trusted infrastructure use case

Locus

Goals of the project

The goal of LOCUS is to design and develop a location management layered 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 we will build upon the work of 3GPP (Rel. 16 and Re. 17), which has started to address the cellular localisation functionality and to which some LOCUS partners are directly contributing.

In more detail, 3GPP Rel. 17 is currently extending the functionality of 5G infrastructures to enable positioning reference signals, measurements and procedure information. Building on top of these components, adequate low-complexity algorithms and scenario-dependent deployment designs can enable future versions of 5G 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 behavioral 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 user, location- and context-targeted applications. The intelligent integration of diverse technologies will open the way to a myriad of new applications, where devices, persons and things are detected, localised, and tracked with high accuracy, minimal implementation cost and maximal privacy preservation (e.g., for crowd counting and flow monitoring). Accurate localisation of terminals will also be exploited to improve network performance and to better manage and operate networks.

Technical Goals

LOCUS addresses seven main scientific and technical goals: the first one is a system architecture with built-in security and privacy, to take in due account the challenges coming from handling, analysing and providing sensitive data, such as location and behavioural analytics of people and things. The second aim is 5G Terminal Localisation, a cellular-based localisation thought of as an evolving functionality in terms of performance, which implies designing positioning algorithms and deployment solutions open to future improvements. Integration with non-3GPP localisation technologies: the third aim is to integrate cellular localisation with non-3GPP localisation technologies (GNSS, WIFI, Bluetooth, etc.) to track terminals at higher accuracy than with 3GPP radio access technology only, yet with low-complexity solutions. Device-free localisation technologies: the fourth aim is to develop solutions to use base stations and other transmitters present in the environment as "illuminators of opportunity" for passive radar, and to localise also passive targets (people and things), by exploiting such radio emissions with no additional resources and costs, which has been not explored in 3GPP yet. Analytics, Learning and Inference: the fifth aim is to analyse the behaviour of devices and targets, tracking their position and dynamics with one or more of the technologies above. Network management: the sixth aim is to use network localisation information and advanced data analytics to enhance network management. Location and analytics will enable rapid identification of network issues facilitating both network resilience and higher levels of service performance. Exemplary localisation-based services: the seventh aim is to use this rich data to empower exemplary services. Accurate, seamless indoor-outdoor localisation and tracking of 5G terminals and nodes would enable new types of service to be offered. Exemplary localisation-based services: the seventh aim is to use this rich data to empower exemplary services. Accurate, seamless indoor-outdoor localisation and tracking of 5G terminals and nodes would enable new types of service to be offered. The LOCUS architecture will be designed as cloud-native and the project research efforts will be also devoted to the devising of the supporting underlying core/edge virtualisation platforms for distributed computing, as shown in figure 47.

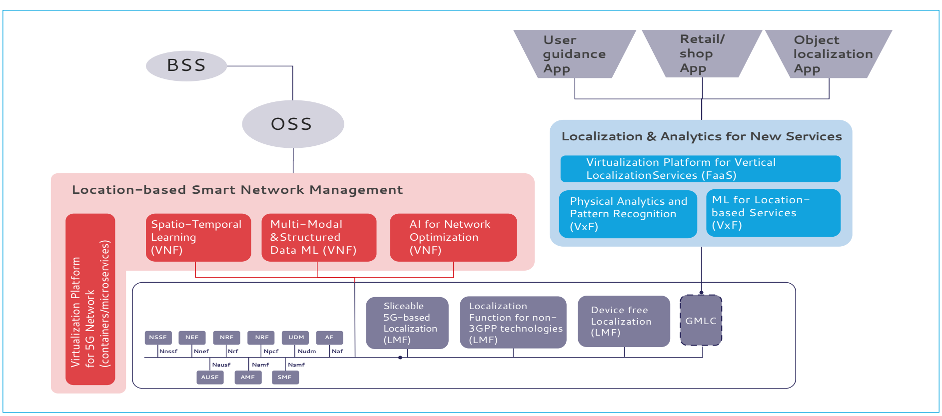


Fig. 47: LOCUS service-based architecture

Testbeds and KPIs validation

We will validate applications and services, as well as the main project technologies by means of PoCs, using real-world data collected from 4G and 5G and IoT networks by LOCUS partners.

LOCUS objectives involve the definition of use case scenarios and their targeted, measurable KPIs for performance monitoring, leading to the integration of the various LOCUS components, i.e. localisation technologies, analytics platform and algorithms, and the overall system integration. The PoCs concern: 1) Smart Network Management based on Location Information of 5G equipment and terminals; 2) Network-assisted Self-driving Objects 3) People Mobility & Flow Monitoring. The PoC evaluation capability will be underpinned by the acquisition of a data set representative of 5G deployments. There is a strong commitment within the consortium and its partners to ensure datasets from real networks relevant to the LOCUS objectives. The data sets will comprise measurements of received signal strength and quality, performance KPIs, localisation estimates (or raw data from which these may be derived), the data will be enriched to allow tracing of individual mobiles between cells. The validation will be achieved by building parametric models to relate the impact of network reconfigurations on received signal quality made by the technology or algorithm under-test to changes in KPI. A computing platform (potentially transportable) to conduct the simulation/emulation of the system based on real-world data will be provided.

MonB5G

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.

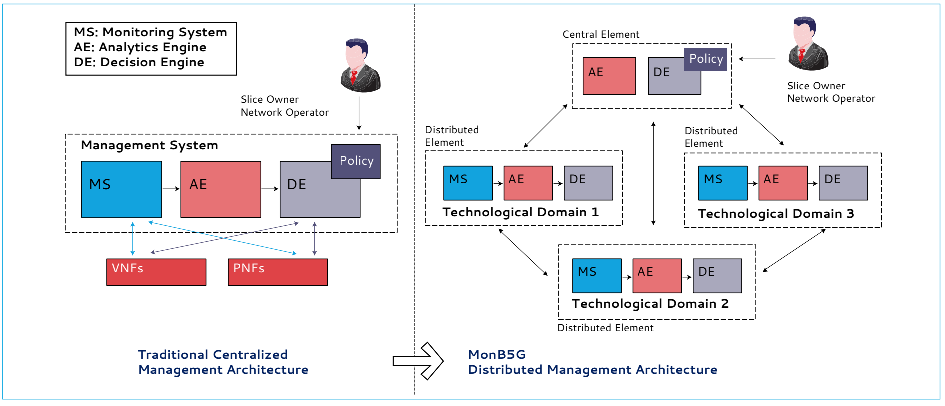


Fig. 48: MonB5G vision

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 willtarget 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

Goals of the project

TERAWAY project is designed to complement 5G vision for a fully mobile and connected society and to address the ultra-high capacity, ultra-broadband connectivity, reliability and latency requirements imposed by 5G verticals.

More specifically, TERAWAY, by leveraging optical concepts and photonic integration techniques, targets to develop a technology base that combines the generation, emission and detection of wireless signals with selectable symbol rate and high bandwidth within an ultra-wide range of carrier frequencies covering the W-band (92-114.5 GHz), D-band (130-174.8 GHz) and THz band (252-322 GHz). In parallel, aiming to get the most out of the THz technology and enable its commercial uptake, a new software defined networking (SDN) controller and an extended control hierarchy will be developed for the management of the network and the radio resources in a unified manner, capable of providing network slices to the support of diverse services.

TERAWAY started on November 2019 and by its completion will make available a set of groundbreaking transceiver modules with 4-channel modules operating from 92 up to 322 GHz, offering up to 241 Gb/s total data rate with transmission reach more than 400 m in the THz band. Four (4) independently steered wireless beams will be used to establish BH and FH connections between fixed terrestrial and moving network nodes.

Major achievements during the first months of the project

During the first four months of the project, TERAWAY has mainly focused on defining a solid set of use cases under the general description: "*Coverage of outdoor, non-recurring, mega events (cultural, social, sport events), that require ultra-broadband network resources for user communication and surveillance traffic requirements, at a designated geographical area*".

"Coverage" is translated into the provision of communication resources to the users participating in the events (communication coverage) and connectivity plus computation resources for the surveillance of these events (surveillance coverage). Since these events are either non-recurring or recurring over non-frequent intervals, the provision of permanent network resources in the form of Fibre installations is probably not the ideal proposition, cost and environment wise. In order to meet these requirements, moving nodes (MN) in the form of heavy-duty drones will be deployed to carry high-capacity gNB equipment or remote radio-head (RRH) equipment (communication) and camera (surveillance). The ultra-high capacity transceivers operating in the W/D and THz bands will be used to connect the drones with fixed network nodes (FN) on the ground.

Some examples of real life TERAWAY scenarios with both commercial and social characteristics, may be:

Mega cultural/social events: Densely crowed events e.g. New Year's Eve celebration, music concerts, or a political event at the central square of the capital city, ultra-rich in content communication needs and surveillance needs for security and control by the organisers and/or authorities.

Disaster Recovery: Safe locations designated by a national of city disaster recovery plan or picked by the people in emergency (e.g. earthquakes, flooding, fires and the likes) where surges of communication and surveillance needs are generated.

Refugee Hot Spot: Temporary shelters where migrants and refugees stay until initial registration and asylum application procedures are completed and their next destination is decided. Again, these spots are temporary and/or moving and both communication needs (journey navigation through their smartphones, exchange important information with NGOs, authorities, and more) and surveillance needs (to ensure safety and order) are of ultra-high capacity.

Description of demos

The technology that will be developed within TERAWAY will be evaluated in two stages. At the first stage, the novel TERAWAY transceivers will be characterised in terms of functionalities and performance using benchtop tests in lab settings.

At the second phase, TERAWAY will be evaluated by performing field trials at the 5G demo site of AALTO in Finland under an application scenario that emulates the above described use cases. In the field trials, TERAWAY will implement two main demonstration scenarios that involve a system (which is considered as part of a larger network system) with three TERAWAY nodes (i.e. one fixed and two moving nodes), as illustrated in figure 49.

In both scenarios, the moving nodes will be responsible for the coverage of an area of ˜10.000 m^2 of dense crowd and will carry cameras and communication equipment for the coverage of this area using <6 GHz links. The moving nodes (MN) will be connected to the fixed node (FN) over BH (first scenario) or FH links (second scenario) that will provide a total connectivity of up to 30.5 and 120.5 Gb/s, respectively, between each pair of nodes. The system will be able to establish end-to-end connections to users below the drones, perform computation tasks for the processing of the surveillance data at the fixed node and perform network management tasks like network topology reconfiguration, resource optimisation, network slicing and service prioritisation based on the type of the services and the corresponding requirements.

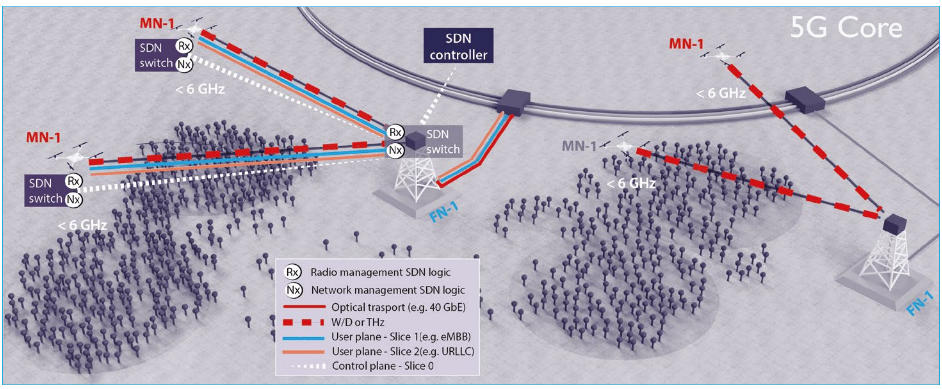


Fig. 49: TERAWAY demo system architecture

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

The following projects complementary to the 5G PPP are presented in this section: 5G ALL-STAR, 5G CONNI, 5G DIVE, 5G-Enhance Empower, PriMO-5G and Thor.

5G ALL-STAR

Leveraging 5GCHAMPION project outcomes, the 5G-ALLSTAR project aims at demonstrating multiple access comprising terrestrial and satellite links, which are key to ensuring the availability of 5G performances and worldwide continuity of services especially to support critical applications.

The 5G-ALLSTAR project receives funding from the European Union Horizon 2020 EU-Korea programme and is supported by the Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (5G AgiLe and fLexible integration of SaTellite And cellulaR).

5G Communication Networks are today at the stage of maturity of developing key enabling technologies for extended proof-of-concepts (PoC). The 5G community is now looking for translating 5G use cases, vertical industries requirements and ambitions in adopting 5G, into viable business cases. However, the support of 5G new services and seamless connectivity across various vertical industries and very diverse use cases, still requires the integration of multiple access technologies. The 5G-ALLSTAR project builds on the outcomes and the cooperation experience of 5GCHAMPION to design, develop, evaluate and trial multi-connectivity based on multiple access, combining cellular and satellite access technologies to support seamless reliable and ubiquitous broadband services. The project will develop a set of technologies and validate system interoperability to provide global connectivity and support mission critical applications of interest in both European and Korean regions. To this end, 5G-ALLSTAR will develop selected technologies targeting a set of PoCs to validate and demonstrate in heterogeneous real setup:

- 5G cellular mm-wave access system for providing broadband and low-latency 5G services,
- new radio-based feasibility of satellite access for providing broadband and reliable 5G services,
- multi-connectivity support based on cellular and satellite access,
- spectrum sharing between cellular and satellite access.

In addition, the project will actively contribute to global 5G standardisation including 3GPP and ETSI focusing on multi-RAT interoperability and New Radio based satellite access, and creation of a cross-regional lasting synergy for 5G research, innovation and commercialisation through value proposition assessment for vertical industries.

5G CONNI

Industrialised connections through 5G

The introduction of the fifth generation of mobile communication networks (5G) has been transformational. While 5G technologies such as network slicing can accommodate industrial applications in public networks, Private 5G Networks, operating locally and highly optimised towards specific applications, are a disruptive emerging approach. The EU-funded 5G CONNI project aims to provide an integrated end-to-end 5G test and demonstration network for industrial applications. They plan to set up two interconnected industrial trial sites in both Europe and Taiwan, where selected use cases will be realised and integrated into an end-to-end industrial Private 5G Network demonstrator. The project results will be used to shape the requirements for private network operations.

Objective

The fifth generation of mobile communication networks (5G) is foreseen to be a key enabling technology for the fourth stage of the industrial revolution, commonly termed as "Industry 4.0". Future Smart Factories envisioned in that context will leverage Industry 4.0 and 5G technology to increase flexibility and efficiency of the manufacturing processes, thus ensuring global competitiveness of industrial manufacturing. While 5G technologies such as network slicing may accommodate industrial applications in public networks, Private 5G Networks, operating locally and highly optimised towards specific applications, are a disruptive emerging approach to meet the specific demands of industrial use cases. Building on the premise of Private 5G Networks, the 5G CONNI project aims at providing an integrated end-to-end 5G test and demonstration network for industrial applications, leveraging current results from standardisation and related research projects. Major contributions of the project consist in the definition of new Private 5G Network architectures and operator models, measurements and tools for application specific network planning, tuning and monitoring and the development of innovative new technologies and enabling components in the context of URLLC radio communication, mobile edge computing, core network design and joint optimisation of these components. The project will set up two interconnected industrial trial sites in manufacturing facilities in both, Europe and Taiwan. At these sites, selected use cases will be realised and integrated into an end-to-end industrial Private 5G Network demonstrator. The project results will be reflected back into the relevant standardisation bodies and industry fora and used as an input for regulatory institutions in both Europe and Taiwan in order to shape the requirements for the operation of private networks.

5G-DIVE

5G-DIVE targets end-to-end 5G trials aimed at proving the technical merits and business value proposition of 5G technologies in two vertical pilots, namely (i) Industry 4.0 and (ii) Autonomous Drone Scout. These trials will put in action a bespoke end-to-end 5G design tailored to the requirements of the applications targeted in each vertical pilot, such as digital twinning and drone fleet navigation applications. 5G-DIVE's bespoke design is built around two main pillars, namely (1) end-to-end 5G connectivity including 5G New Radio, Crosshaul transport and 5G Core, and (2) distributed edge and fog computing integrating intelligence located closely to the user. The latter pillar extends significantly beyond the EU- TW-Phase-I 5G-CORAL solution framework by adding support for automation based on artificial intelligence and distributed ledger technologies. The targeted intelligent tailored design is envisioned to achieve optimised performance and thus significantly boost the business value proposition of 5G in each targeted vertical application. 5G-DIVE trials target pilots running for several weeks on the premises of the vertical applications in real-life testbeds in Europe and Taiwan, leveraging noticeably the European 5G end- to-end facilities from ICT-17 call and Taiwan's testbed facilities.

5G-DRIVE

5G-DRIVE aims to bridge current 5G developments in Europe and China through joint trials and research activities to facilitate technology convergence, spectrum harmonisation and business innovation before the large-scale commercial deployment of 5G networks occurs. 5G-DRIVE realizes this jointly with its Chinese twin-project "5G Large-scale Trial", which is running in parallel, and with both projects interacting and cooperating in order to achieve their joint objectives. 5G-DRIVE develops key 5G technologies and pre-commercial testbeds for eMBB (enhanced Mobile Broadband) and V2X (Vehicle-to-Everything) services. Specifically, 5G-DRIVE will trial and validate the interoperability between EU and China 5G networks operating for eMBB and V2X scenarios.

5G-DRIVE's specific objectives are organised into three main areas: technical, regulatory and business. The technical objectives focus on researching and developing eMBB and V2X technologies and services and trialing them based on pre-commercial end-to-end testbeds in three EU locations (Surrey, Joint Research Centre (JRC) Ispra and Espoo); analysing potential system interoperability issues in Europe and China, and provide joint reports, white papers and recommendations to address them accordingly; and submitting joint contributions to 3G PP and other 5G standardisation bodies regarding the key 5G technologies developed and evaluated in the project. The regulatory objectives focus on evaluating spectrum usage at 3.5 GHz for indoor and outdoor environments in selected trial sites, and investigating regulatory issues regarding the deployment of V2X technologies. Lastly, the business objectives focus on investigating and promoting 5G business potential; strengthening industrial 5G cooperation, and promoting early 5G market adoption.

5G-Enhance

5G Enhanced Mobile Broadband Access Networks in Crowded Environments (5G-Enhance) is a Horizon 2020 joint project composed of EU research team (VTT, FHG, UOULU and Accelleran) and Japan research team (TUAT, NICT, UEC, CATV, JCTA and RWJ). 5G-Enhance intends to develop and execute large scale trial activities on actual testbed in EU and Japan.

Objectives

A key objective for 5G-Enhance is to define and evaluate interoperable 5G eMBB and efficient network solutions in dense area. In order to fulfil this the 5G-Enhance consortium has identified a number of key project objectives; each of which is associated with a distinct set of research and innovations. These specific objectives are:

1. Develop, plan and execute large scale trial activities on actual testbeds between EU and Japan.
2. Clarify the design and specification required for the demonstration and trials based on two wireless applications with the 5G network.
3. Development of 5G enhanced mobile broadband technologies in dense area for achieving the requirements (5G KPI) of the two applications.
4. Establish long-term research collaboration between leading industry players, top research institutes and universities in Europe and Japan.

EMPOWER

EMPOWER has the ambition to accelerate the joint development between the EU and the US of advanced wireless platforms targeting the new connectivity frontiers beyond 5G. EMPOWER targets the creation of a joint EU-US advanced wireless ecosystem for (i) bridging the relevant EU-US Wireless communities and stakeholders, such as scientific researchers, platform engineers, standardisation experts, regulators, and product incubators; and (ii) developing a strategic EU-US collaboration agenda and supporting its execution ahead of worldwide competition for beyond 5G connectivity standards. EMPOWER foresees twinning with the best researchers and practitioners involved in projects funded by USA, especially with entities participating in the PAWR programme (*https://www.advancedwireless.org/*). EMPOWER will provide instruments for inducing collaboration between ongoing and forthcoming 5G and beyond initiatives targeting wireless networks experimentation on both ends of the Atlantic. Through the EMPOWER instruments we aim to create an efficient means for stimulating the mobility of ideas and people between European and similar American experimental wireless platform initiatives. We also aim at encouraging stronger collaboration between fundamental and experimental wireless researchers by making access to platform tools and data exchange simpler. EMPOWER instruments will also provide a wealth of information for global and regional standards and regulatory organisations (e.g. ITU-R, ETSI) and industry for a (e.g. NGMN). An important output of EMPOWER will also be in the form of recommendations on technologies and experimentation methodologies for future wireless experimentation objectives. This will assist in providing coordination between EU (FP9) and US NSF programmes for future individual and joint calls.

PriMO-5G

The goal of the project is to demonstrate an end-to-end 5G system providing immersive video services for moving objects. This will be done by cross-continental testbeds that integrate radio access and core networks developed by different PriMO-5G project partners.

The PriMO-5G consortium believes that a huge potential of innovative usage exists in the immersive video services for ground/aerial vehicles (e.g. cars, trucks, and UAVs/drones). Vehicles equipped with high-definition cameras can offer sights that, up till now, have not been imaginable, and thus will be able to bring benefits to various industry verticals. Application areas of the vehicles with virtual and augmented reality (VR/AR) would be enormous, ranging from police and rescue operations to entertainment and tourism.

The main envisaged scenario in PriMO-5G is the firefighting scenario, which is one of the commonly occurring scenarios in Public Protection and Disaster Relief (PPDR). The firefighting scenario considered in PriMO-5G envisions the use of fire fighting vehicles with mm-wave connectivity and a drone fleet controlled from the vehicles to enhance the efficiency and effectiveness of firefighting operations. Mobile rescue personnel can send a fleet of drones, and obtain real-time situation awareness of the fire scene though the use of drones bearing video cameras and sensors. This can be done before the crew has to come into the hazard scene. The drones will provide high-definition VR/AR video according to the control of a person in the fire engine.

The ambition of the PriMO-5G project is to interconnect the 5G testbeds in Europe and Korea so that the cross-continental testbeds can be established. Newly developed technologies will be tested in the testbeds. Finally, end-to-end operations of envisaged use cases will be demonstrated.

ThoR

ThoR (TeraHertz end-to-end wireless systems supporting ultra-high data Rate applications) is a joint EU-Japan project to provide technical solutions for the data networks beyond 5G based on 300 GHz RF wireless links.

Data traffic densities of several Tbps/km^2 are already predicted for 5G networks. To service a fully mobile and connected society networks beyond 5G (B5G) must undergo tremendous growth in connectivity, data traffic density and volume as well as the required multi-level ultra-densification. The ThoR project will provide technical solutions for the backhauling and fronthauling of this traffic at the novel spectrum range near 300 GHz, which is able to cover the data rates of 200+ Gbps required for B5G systems.

Fibre optic networks cannot provide connections to the hugely increased number of nodes due to the prohibitive costs associated with excavation and installation of accessing/installing cable and fibre-based backhaul/fronthaul infrastructure. Therefore, the use of currently unused spectrum for wireless links operating at disruptive bandwidths of 70 GHz, will be a critical key enabler for the introduction of B5G networks. ThoR will make this happen by demonstrating that such a solution is technically possible and by actively supporting the corresponding spectrum identification for land mobile and fixed services at the World Radio Conference (WRC) 2019.

Partnerships with vertical organisations

Since the end of 2018, the 5G IA signed additional partnerships with vertical organisations.

- In December 2018, the 5G IA signed two additional major partnerships. The first one is a Memorandum of Understanding (MoU) linked with the **European Cyber Security Organisation (ECSO)**. It aims at enhancing future cooperation in the field of cyber security and 5G communication networks. The second one was signed with the **Alliance for Internet of Things Innovation (AIOTI)** to explore opportunities of new combinations of IoT applications built on world-class digital infrastructures. The co-signature of a Joint Vision on Future Networks, Services and Applications followed in March 2019. In addition, 5G IA and AIOTI developed their individual positions on Horizon Europe priorities in the 5G IA position paper and AIOTI position paper. They also published a "*commons topics*" document, which summarises the combined 5G IA/AIOTI work in progress towards developing a common Strategic Research and Innovation Agenda (SRIA) together with the Networld2020 European Technology Platform, for the advancement of Horizon Europe and related programme discussions with all relevant external stakeholders.
- The **European Space Agency (ESA)** and 5G IA signed a letter of Intent in October 2018 to enable new and innovative 5G solutions and services in support of European industry and the 5G vertical markets and to further strengthen the ties between the space sector and the 5G IA, with its broad membership from the terrestrial and satellite industries, SMEs and Academia.
- **ERTICO – ITS Europe** and 5G IA signed a MoU to foster cooperation and synergies on 5G and Intelligent Transport Systems and Services (ITS) late in November 2019 during 5G Techritory.

Assessing the 5G research and development investment Leverage Factor

This section is based on the 5G PPP Progress Monitoring Report published in September 2019 and describes the methodology for the assessment of the leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems.

The calculation of this Key Performance Indicator (KPI) is based on the data extracted from the 2018 Questionnaire[19], in particular parameters under A.2 (Direct Leverage), B.1 (Follow-up of the project) and B.2 (Beyond the 5G PPP), as defined by the EC in the proposed "*Single leverage factor methodology*". A.1 was extracted from the statistics publicly available at the H2020 Qlik Sense dashboard[20].

The following specific parameters were considered

- A2.1 What, in percentage terms, was your actual average overhead rate during this 5G PPP project period?
- A2.2 What additional costs (i.e., not reimbursed) in kind contributions did you make to this project?
- B1.1 What total costs has your organisation incurred during or after this Project?
- B2.1 What total investments did your organisation make in the period 2014-2019 in the technology fields related to the 5G PPP , which you were not directly related to any of the 5G PPP projects you participated in?

The following data processing methodology was applied:

- The average values of A2.1, A2.2, B1.1, B2.1 were calculated, per legal entity type (Large Industry, SME, Academic Institution, Research Centre)
- B2.1 is given for the period 2014-2018, so its quota for 2018 was calculated by dividing the value by 5
- On the H2020 Qlik Sense dashboard, the following information has been extracted, per legal entity type, for ICT-07-2017

19. https://5g-ppp.eu/5g-ppp-progress-monitoring-report-data-collection-2019/

20. https://webgate.ec.europa.eu/dashboard/sense/app/93297a69-09fd-4ef5-889f-b83c4e21d33e/sheet/PbZJnb/state/analysis

and ICT-08-2017 Call Topics (i.e., Phase 2 projects):

- # of beneficiaries,
- Total cost and
- Total Net EU contribution
- The Total cost and Total Net EU contribution has been projected on 2018 only (assuming an average project duration of 36 months)
- Then, the following calculations have been performed, for each legal entity type:
- The average values of A2.2, B1.1 and B2.1 (2018) have been multiplied by the total number of beneficiaries
- The average Overhead (A2.1) has been applied to the Total Direct costs (= Total cost / 125%), and the difference with the flat OH 25% has been calculated
- Finally, A.1 has been calculated as the difference between the Total Net EU contribution for 2018 and the Total costs for 2018
- The sum of total A.1, A2.1, A2.2, B1.1 and B2.1 provides, for each legal entity type, the additional investment in 2018 w.r.t. the Total Net EU contribution received during the year.
- The total across a subset of legal entity types provides the overall additional investment in 2018 for that subset of beneficiaries and leads to the related Leverage Factor during the year. Two (sub)sets have been considered:
- Large Industry and SMEs; i.e. the business-oriented (and by far largest) part of private investments.
- All kinds of beneficiaries.

The result from these calculation procedures show already excellent leverage factors:

- Large Industry and SMEs in 2018 mobilised private investments that sum up to an amount **10.12 times** the public EC investment in the 5G PPP in the same period.
- All the types of stakeholders/beneficiaries invested in 2018 a total amount of money that is **7.24 times** the public investment in the same period.

This assessment demonstrates that the European ICT sector is achieving[21] the planned level of investment leverage expected in the 5G PPP Contractual Arrangement.

SME success stories and results out of the 5G PPP projects[22]

As 5G large-scale trials supported by European-wide trial infrastructures are entering their full stage within the 5G PPP , the participation of Small and Medium-sized Enterprises (SMEs) in the 5G PPP should be growing further in 2020. Thanks to an unprecedented effort of promotion of SME skills and expertise since the launch of the initiative, reflected in the annual "*SME brochure*" and the regularly updated "*Find your SME web page*", and to the request from the 5G PPP to ensure 20% participation from SMEs as mentioned in its list of Key Performance Indicators (KPIs), the participation of SMEs had already reached 19.6%[23] by end of 2019.

The past year also saw an increase by almost 30% in the number of SMEs being members of the NetWorld2020 / 5G IA SME Working Group, bringing the total number to 170+ including 140+ SMEs. After the success of the "*SME Expertise and Skills in the 5G Domain*" brochure that was released mid-2018 and disseminated in several key events including Mobile World Congress 2019, a full update was released early 2020, with contribution from about 50 European SMEs. The "*Find your SME*" web page was updated in parallel[24]. A dedicated SME

21. *The target (for the cPPP) at the end of H2020 is between 5 and 10.*

22. *The SME Working Group (WG) is gathering about 170 members including 140+ SMEs, i.e. almost 30% more than in 2019. 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 interinnov. There are five SME representatives in the NetWorld2020 Steering Board: Integrasys, interinnov, Montimage, Nextworks, and Quobis Networks. The SME WG is chaired by Jacques Magen from interinnov, and Nicola Ciulli from Nextworks is Vice-Chair. It is supported by the Full5G Coordination and Support Action. More information is available at http://networld2020.eu/sme-support/. If you wish to join the SME Working Group, please send a request to sme-wg-contact@networld2020.eu.*

23. *in EC funding.*

24. *Cf. https://www.networld2020.eu/find-the-sme-you-need-new-page/ and https://www.networld2020.eu/wp-content/uploads/2020/02/01-2020-sme-brochure-web.pdf.*

booth with demos and achievements out of the 5G PPP projects was held at EuCNC in Valencia, Spain, in July 2019.

In the 2019 edition of the 5G PPP Annual Journal, we were already providing information on success stories from SMEs. This year we are pleased to report more such success stories. Once again, those examples are illustrations of what SMEs have achieved in the 5G PPP , and do not represent an exhaustive list of results from all SMEs involved. We are looking forward to reporting more success for SMEs next year, when Phase 3 outcomes lead to actual 5G-related solutions being progressively deployed.

The Belgian SME Acceleran NV, based in Antwerp, is involved in several 5G PPP projects including Phase 2 5GCity and Phase 3 5GClarity and 5GComplete. Acceleran's participation in such projects as well as in national 5G-focused projects allowed the different consortia involved to leverage on the company's RAN/vRAN Software Solutions and Small Cell products to enable new 5G architectural paradigms (virtualisation, slicing, edge computing, etc.) and advances required in future networks. The participation of Accelleran in those projects also helped the launch of Accelleran's ORAN-aligned Cloud Native Virtualised dRAX Open Interface RAN Intelligence enabling AI/ML xApps in an open, scalable and interoperable RAN platform.

ACTA Ltd, an SME from Athens, Greece, is a partner in two 5G PPP projects, 5G-TOURS and 5G-HEART. ACTA has already supported the efforts to convert the user/vertical defined business KPIs into network KPI's, and to specify the relevant, measurable, network KPI values. When the 5G-TOURS and 5G-HEART pilot 5G networks are installed, by Ericsson and Nokia respectively, ACTA will utilise probes and the KVaP application to measure the performance of the network. The network KPI values will be compared to the required "per vertical use case", to verify that the pilot 5G networks deliver up to the expectations.

CyberEthics Lab. (CEL), an Italian SME with a holistic vision of innovation, generated by efficiency, scientific curiosity, and respect for human beings, is involved in the 5G PPP 5G-SOLUTIONS project. Together with two other SMEs i.e. Inlecom Group and Applied research to technologies, the Ethics Panel assures compliance with ethics principles during the whole lifecycle of the project. Since the beginning of the project, CEL methodology aims to create awareness about ethics and legal issues inside the consortium and to create a mindset shared among partners to prevent potential risks by applying a set of common methods and procedures for the project research process. ACTA's experience in the context of 5G-SOLUTIONS is now being applied to various market segments including Factories of the Future, Smart Energy, Smart Cities & Ports, and Media & Entertainment.

Telcaria is a Spanish SME from Madrid providing advanced services to network operators and equipment manufacturers worldwide. The company is currently working on three 5G PPP projects, 5G EVE, 5GROWTH, and 5G-DIVE. Telcaria collaborates as an expert in the Master of SDN&NFV technologies offered by another partner, University Carlos III from Madrid, and is currently actively developing and commercially distributing Alviu, its SD-WAN solution. Telcaria's participation in those projects and other 5G network-related projects including 5G-CORAL (in collaboration with Taiwanese partners), allowed the company to benefit from the technology advances generated from those projects to acquire the know-how for applying technologic achievements for rapid prototyping, design, validation, and direct deployment of Edge and Fog distributed computing platforms, advanced multi-domain monitoring platforms, innovations in orchestration mechanisms to assist offloading and roaming scenarios among others.

Ubiwhere from Aveiro, Portugal, has been participating in all three phases of the 5G PPP, in projects such as SelfNet, SONATA, 5GCity and 5GZORRO. Several company products have been created or affected by the company's participation in the 5G PPP. For example, the "Smartlamppost" product vision was born at the end of SELFNET project, leveraging on its architecture as well as on its monitoring and self-action capabilities for the edge computing and orchestration framework. Smartlamppost is a clean solution that leverages on urban furniture to elegantly provide 5G network deployment, EV-charging stations and edge computing capabilities, among other plug-and-play functionalities, targeting municipalities but also other vertical businesses (such as MNOs). The first version of the "NFVal" tool, a software tool able to allow the Network Service programmer to validate both VNF and NS packages (supporting different Orchestrators) and in case of incompatibility to allow its fast identification, was created in the context of SONATA and later expanded by Ubiwhere to support other NFV MANO orchestrators. In addition, Smartlamppost's edge orchestration framework was considerably boosted by Ubiwhere's participation in the 5GCity project and critical to Smartlamppost's path to market. This project also allowed Ubiwhere to establish important partnerships and co-creation activities with other partners of the project, with whom Ubiwhere has already performed commercial activities in the scope of Smartlamppost through trials in Portugal.

As we are entering a deployment phase for 5G solutions, it is becoming more and more important for SMEs to think beyond research and innovation and enter the emerging 5G marketplace. The SME Working Group is therefore looking into new activities to further support its members and more generally SMEs working in the 5G domain. Examples of such new activities include devising a strategy for supporting European SMEs to better reach the market, in the overall context of the new EU SME strategy highlighted by the Commission under the new Presidency of Mrs. Ursula von der Leyen, i.e. "[...] *to contribute to the new SME strategy to help them scale up and expand, including through improved access to finance*", that was released on March 10th, 2020[25]. To achieve this, the SME WG is looking at SME strategies that have already been in place in Europe and internationally, as well as establishing interactions with organisations supporting SMEs beyond research and innovation.

EC H2020 5G Infrastructure PPP

The 5G Infrastructure PPP Programme and its related projects continued their impressive work during 2019, providing key results and significant achievements for 5G networks and their evolution.

Following up on the successful completion of Phase 1 projects, the technological development provided by 5G PPP 2[26] projects has kept Europe in the leading position in the 5G race. The importance of EU funded projects to build a worldwide consensus at a pre-standardisation level, the visionary specification of futuristic use cases and the raising of public awareness about the capabilities of 5G networks is undeniable. 21 Phase 2 projects, having started in June 2017 are delivering high-value results. Although some Phase 2 projects have completed their operation in June 2019, several projects continued their work into 2020. The Phase 2 "*key achievements*" include 60 highlighted technological results[27], having prototyped, validated, tested and piloted 5G in several vertical sectors.

The recently published "*5G Infrastructure PPP – Trials & Pilots Brochure*" highlights 10 of these Phase 2 Trials & Pilots, selected by a PPP panel based on the assessment of the Trials & Pilots impact[28]. Project overviews and results, test architectures and deployment schemes to validate uses cases, as provided by vertical players participating on 5GPPP projects, have covered the most relevant European industrial sectors.

Started in 2018, three automotive projects, under the ICT-18 call have continued, throughout 2019, 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: "*Business Feasibility Study for 5G V2X Deployment*"[29], and "*Initial proposal on how 5G Strategic Deployment can support Connected and Automated Mobility (CAM) in Europe*"[30].

Furthermore, 5G Infrastructure PPP Phase-3[31] includes three platforms projects (through the ICT-17 call) that 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 infrastructure provides 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].

25. Cf. *https://ec.europa.eu/commission/sites/beta-political/files/president-elect_von_der_leyens_mission_letter_to_thierry_breton.pdf* and *https://ec.europa.eu/digital-single-market/en/news/sme-strategy-launched-european-commission*.

26. *https://5g-ppp.eu/5g-ppp-phase-2-projects/*

27. *https://5g-ppp.eu/phase-2-key-achievements/*

28. *https://5g-ppp.eu/wp-content/uploads/2019/09/5GInfraPPP_10TPs_Brochure_FINAL_low_singlepages.pdf*

29. *https://bscw.5g-ppp.eu/pub/bscw.cgi/d293672/5G%20PPP%20Automotive%20WG_White%20Paper_Feb2019.pdf*

30. *https://5g-ppp.eu/wp-content/uploads/2019/10/20191031-Initial-Proposal-5G-SDA-for-CAM-in-Europe.pdf*

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*

As 5G networks aim to support the vertical industries, another set of eight Verticals Pilot projects (through the ICT – 19 call) has started their activities in June 2019. They demonstrate advanced 5G validation trials across multiple vertical industries. These projects will take advantage of the abovementioned ICT-17 projects and interwork with them using different infrastructure exposure levels. Overall, ICT-17 and ICT-19 projects cover a wide range of vertical industries as shown in the table below. Also, they will create the necessary knowledge to smoothly integrate different verticals with the 5G network infrastructure.

	Industry 4.0	Agriculture & Agri-food	Auto-motive	Transport & logistics	Smart cities & utilities	Public Safety	Smart (Air)ports	Energy	eHealth & wellness	Media & Entertain.
5G EVE	✓		✓		✓	✓		✓	✓	✓
5Genesis				✓	✓	✓				✓
5G-VINNI	✓			✓		✓		✓		
5G!Drones				✓		✓				✓
5G Heart		✓	✓	✓					✓	
5Growth	✓			✓				✓		
5G smart	✓									
5G Solutions	✓				✓		✓	✓		✓
5G-TOURS				✓	✓		✓		✓	✓
5G Victori	✓			✓				✓		✓

Table 3: Phase III projects and their link to vertical industries

In November 2019, and under the ICT-20 call, eight new projects have started working on the longer-term vision for telecommunication networks. These projects target 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.

A detailed list of all use case experiments, that are taking place in Europe between 2018 and 2020, can be found in the verticals cartography[33]. It has been developed in the context of the Global5G CSA project. Using this cartography, 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 WG, that deals with pre-standardisation activities, has recorded 611 activities from Phase 1 and Phase 2 projects that led to standardization. 5G PPP projects have disseminated their results in several scientific journals, international conferences, book chapters and white papers. Until September 2019, Phase 2 and Phase 3 projects had produced over 800 such publications.

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

- Jointly with the Global5G project, the verticals cartography for Phase 3 projects has been created. It contains information about the experiments per project, their location, the type of the experiment, their scheduled date, their relation to network slice types and the vertical consortium partners involved.
- The "*5G Network Support of vertical industries in the 5G PPP ecosystem*" report for ICT-17 and ICT-19 projects has been produced. It provides information about the capabilities of the infrastructure platforms, the relation of their functionality to standards, their time-plan and their link to ICT-19 projects.

33. https://global5g.org/cartography

- The "*5G Infrastructure PPP – Trials & Pilots Brochure*" has been produced that highlights the key results of ten Phase 2 Trials & Pilots.
- Two face-to-face TB meetings have been organised. The first one took place in Brussels in May 2019. During the meeting, the production and update of cartographies and brochures took place. The second meeting took place in Malaga in October 2019. In this meeting, apart from the continuation of the work on the cartographies, effort was spent on the synchronisation of ICT-17 and ICT-19 projects as well as on specific technical topics like Edge Computing. As a result, two new White Papers have been initiated at a Technology Board level. The first one is related to the impact of 5G networks in the vertical industries. The second one will analyse the significance of edge computing in 5G networks and their evolution. 5G PPP was present in MWC 2019 with 13 5G PPP projects presenting their innovations and results. As a highlight, 5G-Monarch -a Phase 2 5G PPP project - received the prestigious '5G Industry Partnership Award', which is one of the Global Mobile Awards 2019, for 'first large scale industrial commercial 5G trial'.
- The 5G PPP initiative was present at the EuCNC 2019 conference participating in many sessions, workshops, tutorials, panels, special sessions, presenting 21 technical papers and showcased their results in 25 booths. In the booths, visitors could find out what projects they are working on and how to get in touch with them. Also, the 5G PPP SME booth allowed visitors to meet some of the SMEs that are participating in the initiative. The best booth award of EuCNC was awarded to the EU 5G Cross Border Corridor Projects (i.e., 5G-CARMEN, 5G CroCo and 5G-MOBIX).
- The 7th Global 5G Event "*Creating the Digital Future*" took place in Valencia, Spain in June 2019). The event was co-located with EuCNC 2019 (18-20 June 2019). Thanks to the great synergy between these two major events, besides the conference sessions, visitors enjoyed an exhibition area with over 75 stands with compelling state-of-the-art indoor and outdoor 5G demonstrations, including those from many 5G PPP projects. Over 550 participants from all over the world attended this edition of the Global 5G Event for over two days, contributing to making it a remarkable success. The 7th Global 5G Event 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.
- The Pre-Structuring Model (PSM) Phase 3.II was released by the 5G IA in Versions 1.0 and 1.1 in February 2019. The PSM Phase 3.II Version 2.0 was released in July 2019[34]. The PSM is prepared by the 5G IA Vision and Societal WG. The PSM presents features and recommendations to guarantee smooth integration of the forthcoming Phase 3 projects in the existing coordinated programme. It also targets system recommendations to develop future efficient cross-projects cooperation. Based on the PSM model, ICT-41, ICT-42, ICT-52 and ICT-53 calls were issues in 2020. These could potentially enable the funding for up to 51 new projects. Their activities will be integrated into the overall TB activities.
- 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.

34. *https://5g-ppp.eu/wp-content/uploads/2019/09/190712_5GInfraPPP_PSM-Phase3.II_V2.0_Final.pdf*

5G CHRONICLE

Past months have been rich in events and promotional activities. 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 programs 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).

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.

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 Brazil. 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 planned[35] to take place at the Shanghai International Convention Centre in Shanghai, China on July 2-3, 2020. The event will be hosted by IMT 2020 (5G) Promotion Group. The 2-day event will include a one and a half day conference and one half-day technical tour. The 2-day event will include a one and a half day conference and one half-day technical tour.

EuCNC

The 5G PPP initiative was present at the EuCNC 2019 (17-21 June 2019) with many sessions, workshops, technical papers and booths. The visibility of 5G PPP projects increased significantly compared to previous editions.

At the 5G PPP booth, the latest 5G PPP results were shared, the 5G IA international activities were discussed, and the leading demos developed by SMEs were showcased. The exhibit was well attended particularly when 5G PPP speakers were on stage. Specific PR material was available and disseminated at the event.

Eight workshops and three special sessions were organised. Twenty-six booths highlighted 5G PPP projects and programme achievements through videos, demonstrations, posters, holograms, live-streaming service.

A series of activities was organised by 5GCity in the Outdoors Exhibition Area. The Barcelona media TV Company documented outdoor events with live TV transmission on top of the 5GCity platform deployed in Valencia: camera operators equipped with a 5GCity video backpack will transmit live via 5GCity network to editors at the 5GCity booth for production and subsequent streaming on the Internet. At the outside setting, there was a focus panel with interviews of key representatives of 5G in Europe to present the "*5G deployment in EU*" report by INCITES. Invited to the panel were representatives from EC and 5G Infrastructure Association, together with 5GCity partners INCITES and i2CAT. There was a live focus panel with students from the UPV and local SMEs, Telco & verticals to discuss jobs opportunities opened by the 5G ecosystem.

The 5G PPP booth was shared with SMEs, the 5G IA and the European Commission. It also provided information and demos from SMEs. 60 Technical Papers were presented by project representatives during the conference sessions.

Due to the world COVID-19 pandemic, the Steering Committee of EuCNC 2020 has decided to change the format of the conference to an online virtual one, instead of the usual face-to-face physical one in Dubrovnik. The EuCNC 2020, supported by the European Commission will take place from June 15 to 18, 2020. This edition is 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.

The second Vertical User Workshop (9-10 July 2019)

A first workshop was held in Brussels on 12th and 13th February 2019. This 5G Vertical Users Workshop aimed at establishing a collaborative event for strategic dialogue between industries and 3GPP by exchanging on future needs and upcoming standard developments. The workshop

35. *Event postponed to next year due to the Covid-19 outbreak*

as a result, aimed at producing a report shared directly with 3GPP Project Coordination Group (PCG) as a means to stimulate and facilitate greater involvement of the 5G Vertical Users in the 3GPP process.

Following this first session, a second event with more focus on practical steps to be taken by 5G vertical industries and SDOs to improve vertical input was organised in Rome on July 9-10, 2019. This initiative, launched by 3GPP Market Representative Partners (5GAA, 5G-IA, 5G-ACIA and PSCE) was organised as a collaborative event for strategic dialogue between vertical industries (technology, automotive and transport, health and public safety) and 3GPP by exchanging on future needs and upcoming cellular standard developments. The Workshop focused on 5G vertical technical viewpoints, common requirements and common interests with lively interactive discussions. 5GAA members Huawei, Nokia and Orange supported the workshop. The 5GAA CTO, Maxime Flament, had seized the opportunity to address:

- The 5GAA vision for 3GPP rel-17 as part of C-V2X and intelligent transport systems;
- Predictive QoS, an innovative mechanism to provide in-advance QoS notifications from the network to the V2X application.

CLEEN 2019 (15 April 2019)

5G Cloud Native Workshop and Session

This workshop explored novel concepts to allow for flexibly centralised radio access networks using cloud-processing based on open IT platforms, exploiting network virtualisation and multi-access edge computing technologies that are recognised as key enablers for the definition of future 5G systems. The aim was to allow for a guaranteed high quality of experience for mobile access via efficient management of cloud resources and services, and to allow for a future network evolution focused on energy efficiency and cost-effectiveness processing.

This workshop covered technologies across PHY, MAC, and network layers, technologies which extrapolated the cloud-paradigm to the radio access and backhaul network, and analysed the network evolution from an energy efficiency perspective. It studied the requirements, constraints, and implications for mobile communication networks, and also potential relationships with the offered service, both from an academic and industrial point of view.

CLoud Technologies and Energy Efficiency

5G-Coral and 5G-Transformer organised a workshop on CLoud Technologies and Energy Efficiency in Mobile Communication Networks @CLEEN 2019. NG-PaaS organised a Workshop on Cloud Design. 5G-XCast and One5G are co-organising a workshop on Advanced 5G Radio Access Network features and performance. Sat5G and 5GENESIS are organising a workshop on Satellite-terrestrial interworking: "*a pillar of forthcoming 5G systems*".

European Research and Innovations Days 2019

European Research and Innovation Days was the first annual policy event of the European Commission, bringing together stakeholders to debate and shape the future research and innovation landscape. They took place on September 24-25-26, 2019 in Brussels.

The event was central to finding research and innovation solutions for this great transition by working across polices, setting the direction, spurring innovation and triggering investment. It was the moment for all stakeholders to meet and co-create the strategic priorities for the European Commission's investment in research and innovation.

2nd Workshop on 5G trials @IEEE 5G World Forum (30 September-2 October 2019)

The 2019 IEEE 2nd 5G World Forum (5GWF'19) took place on September 30 and October 2019.

It brought experts from industry, academia and research to exchange their vision as well as their achieved advances towards 5G, and encouraged innovative cross-domain studies, research, early deployment and large-scale pilot showcases that address the challenges of 5G.

5G-DRIVE, 5G EVE, 5G-VINNI, 5GENESIS, and SLICENET organised the "*2nd Workshop on 5G-Trials – From 5G Experiments to Business Validation*". The workshop aimed at providing a forum for industry and academics to disseminate new findings on 5G trials and new business development. The workshop focused on test results from trials as well as theoretical results based on realistic deployment schemes and new 5G business models.

Mobile World Congress 2020 (cancelled)

The 3 ICT-17 infrastructure projects 5G EVE, 5G-VINNI, 5GENESIS and the 5G IA were planning to hold the stand 7K39 in Hall 7. The 3 projects were planning to showcase amazing demos. They were planning to provide end-to-end testing capabilities to vertical industries to validate a wide variety of use cases on the new 5G network. Other 5G PPP projects were planning to be present and to show demos and results:

- 5GCity was planning to showcase a dedicated video based on the technical achievements, business impact and final results of the project. 5G City also planned to showcase the Mobile Backpack demo for live event video broadcasting from the street using a slice of 5GCity infrastructure in the city.
- 5GZORRO was planning to present a dedicated introductory video based on the technical objectives and challenges of the project.
- 5G-MOBIX, 5G CARMEN and 5GCROCO were planning to showcase demos on their trials for cooperative, connected and automated mobility along European 5G cross-border corridors.

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
Verticals Task Force Raffaele De Peppe, TIM	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

The European 5G Annual Journal/2020

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