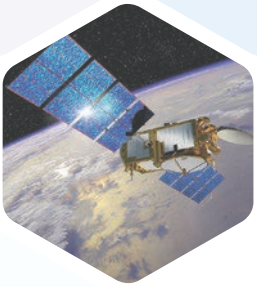
5G PPP

5G IA



The European 5G Annual Journal 2019

Supported by the

European Commission

THE EUROPEAN 5G ANNUAL JOURNAL/2019

Grant Agreement N°: 761338
Coordination and support action
Call Identifier: H2020-ICT-2016-2

To-Euro-5G – Supporting the European 5G Initiative

THE EUROPEAN 5G ANNUAL JOURNAL/2019

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5G PPP: AN INNOVATIVE INITIATIVE TO FOSTER R&D

The 5G Infrastructure PPP is a unique opportunity for the European ICT industry to compete on the global market for 5G infrastructure deployment, operation and services.

The 5G Infrastructure PPP, in short 5G PPP, is a joint initiative between the European Commission and the European ICT industry. The Commission is investing 700 million € and the industry will leverage this investment by a factor of 5, bringing the total investment in the 5G PPP to more than 4 billion €, to rethink the infrastructure and to create the next generation of communication networks and services. The 5G PPP is aiming at securing Europe's leadership in the areas where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment & media. The 5G PPP initiative reinforces the European industry to successfully compete on global markets and open new innovation opportunities. The 5G PPP delivers solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade.

The goal of 5G PPP is to maintain and enhance the competitiveness of the European ICT industry and to ensure that the European society can enjoy the economic and societal benefits these future networks will bring.

"THE AIM OF THIS FOURTH EDITION OF THE EUROPEAN 5G ANNUAL JOURNAL IS TO PRESENT AN ANALYSIS OF THE 5G ECOSYSTEM EVOLUTION OVER THE PAST YEAR. IT PRESENTS THE ACHIEVEMENTS OF PHASE 2 5G PPP PROJECTS ENDING IN 2019 AND AUGUST 2020 AND PHASE 3 5G PPP PROJECTS, WHICH STARTED IN 2018.

Foreword

Peter Stuckmann,
Head of Unit Future Connectivity Systems

5G is here – this was a slogan that we could see at the booths of the technology suppliers at Mobile World Congress 2019 in Barcelona. And indeed, 5G networks – based on the first versions of the standard – are now being deployed and launched worldwide, also in Europe. The first commercial 5G handsets are expected within the next few months.

But this is just the start. Ambitious private investments are needed to meet the deployment targets of the 5G Action Plan[1], to cover all European cities and major transport paths by 2025. Further work in 3GPP is required to meet the promise of 5G enabling industrial use cases. 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 also started to work with EU Member States to contribute to a secure 5G supply chain[2].

Cooperation is key to developing the 5G ecosystems, especially in partnership with the vertical industries. Europe is leading this process, also thanks to all projects of the 5G PPP. The current portfolio can be discovered in this 2019 release of the European 5G Annual Journal.

The latest report[3] from the European 5G Observatory[4] shows that Europe is indeed well positioned in 5G trial activities, with 147 major trials developing new 5G business opportunities. To illustrate this, at MWC19 in Barcelona earlier

1. *https://ec.europa.eu/digital-single-market/en/news/communication-5g-europe-action-plan-and-accompanying-staff-working-document*
2. *http://europa.eu/rapid/press-release_IP-19-1832_en.htm*
3. *http://5gobservatory.eu/wp-content/uploads/2019/04/80082-5G-Observatory-Quarterly-report-3.pdf*
4. *https://ec.europa.eu/digital-single-market/en/news/eye-future-european-5g-observatory*

this year, the global mobile industry association GSMA awarded all three 5G Global Mobile Awards (GLOMO)[5] to European companies, acknowledging the importance of European players in preparing and promoting the deployment and take-up of 5G technologies. One GLOMO was won by a 5G PPP project: 5G-MoNArch. Congratulations to the whole team!

The 5G PPP has now fully entered into its 3rd and final phase and has started delivering on Europe's 5G trial strategy[6]. Including the most recent call and the projects that we launched at EUCNC'18 in Ljubljana and at ICT'18 in Vienna the whole 5G PPP trial project portfolio is now worth more than EUR 300 million 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 next year with projects for roughly EUR 200 million still to be selected in WP2020, which will be published very soon following the consultation with EU Member States. Plenty of opportunities ahead – from 5G innovation in hardware and software, a second call for 5G Corridors, to more forward looking projects towards Beyond 5G.

This year, we will also start preparing the programmes under Horizon Europe, the new Research and Innovation programme proposed for the next EU long-term budget starting in 2021. We are happy to see that the 5G Infrastructure Association has developed a first concept[7] for a new partnership on Smart Networks and Services under Horizon Europe. Partnerships involving a broad range of stakeholders, including Member States and industry, will play an important role under Horizon Europe, as they did under Horizon 2020. We welcome the progress of the Strategic Research and Innovation Agenda (SRIA)[8] that 5G IA produced in cooperation with Networld2020 identifying topics for beyond 5G and later 6G.

As regards the Connecting Europe Facility Digital Programme, we are glad to see that the 5G PPP has taken up preparatory steps to foresee a coordinating role in the area of 5G Corridors for Connected and Automated Mobility under the possible new partnership. The draft outline of the Strategic Deployment Agenda (SDA)[9], which is supported by a broad range of stakeholders, can indeed be instrumental to pre-structure CEF Digital projects and make a first network of pan-EU 5G corridors a reality.

But let's for now focus on the exciting third phase of the 5G PPP to further deliver on the 5G Action Plan and the 5G trial strategy. We wish all of us as participants of the 5G PPP the best in our projects and activities. Our contribution will be key to make 5G a success for Europe!

5. https://ec.europa.eu/digital-single-market/en/news/european-companies-win-all-three-5g-glomo-awards-mwc19-barcelona

6. https://5g-ppp.eu/5g-trials-roadmap/

7. (https:/5g-ppp.eu/wp-content/uploads/2019/02/5G-IA-Position-Paper-Smart-Networks-and-Services_Horizon-Europe.pdf

8. https://www.networld2020.eu/wp-content/uploads/2018/11/networld2020-5gia-sria-version-2.0.pdf

9. https://ec.europa.eu/digital-single-market/en/news/5g-strategic-deployment-agenda-sda-connected-and-automated-mobility-cam-stakeholder-workshop

Editorials

Colin Willcock, Chairman of the Board, 5G IA

We have achieved some memorable results and achievements in the last year, highlighting the value of the 5G PPP for Europe. The strong presence at MWC19 with thirteen 5G project demonstrations and a GLOMO award associated with the 5G-MoNArch project typified the success and visibility that the programme has achieved. Such success is not a result of chance, but rather the reward for the hard work and dedication from the entire 5G PPP / 5G IA community and I would like to thank everyone for their efforts.

The success of the 5G PPP is also an excellent example of the European Commission (EC) working with European industry to create the critical technological research framework necessary for leadership. The courage of the EC to commit substantial resources to this area at an early stage should be applauded. Looking to the future, as the next multi-year framework programme 'Horizon Europe' takes shape, it is important these lessons are not forgotten. The evolution of mobile communication technology will not stop in 2020 and in an uncertain world it is vital that Europe continues to invest in research in this area to ensure that technological leadership is retained.

Jean-Pierre Bienaimé – Secretary General, 5G IA

The 5G PPP and the 5G Infrastructure Association (5G IA) accelerated the pace in their communication and visibility during the period between June 2018 and March 2019, on the European and worldwide scenes. Among over 30 events, let's highlight:

The EuCNC Conference, in June 2018 in Ljubljana, gave the European Commission the opportunity to launch 5G PPP Phase 3 with three ICT-17 new projects, and also 5G IA to present notably their "What does 5G PPP do for Europe?" brochure, while encouraging the next ICT-19 projects on 5G validation trials across multiple vertical industries.

At the first IEEE 5G World Forum, in July 2018 in Santa Clara, 5G IA and IEEE 5G Initiative organised a successful Worldwide Industry Fora conference, focusing on 5G Regional Visions and Inter-Regional Cooperation Activities.

The sixth Global 5G Event "5G Technology Changing Paradigms of a New Society", organised by 5G Brazil, took place in November 2018 in Rio de Janeiro, where EC and 5G IA/5G PPP were represented by 10 speakers presenting at an extensive set of panels, and notably their 5G Pan-European Trials Roadmap version 4, highlighting the key EU cities that are targeted for 5G early deployments.

At the ICT-2018 conference "Imagine Digital, Connect Europe", organised by EC in December 2018 in Vienna, the 5G IA had the opportunity to sign an MoU with ECSO on security cooperation, as well as with the AIOTI Association, aiming at exploring the opportunities for new combinations of IoT applications built on world-class digital infrastructures.

International cooperation was illustrated by the first India-EU Stakeholders' Workshop on 5G Technology Landscape, organised by 5G IA, TSDSI and BIF early February 2019 in Delhi, with the support of the Delegation of the European Union to India, and with presentations from five 5G PPP Projects. Significant takeaways were obtained there, notably the willingness from India to join the 5G Multilateral MoU (organiser of the Global 5G Events), the target of interoperability events leveraging the 5G Test Beds programme of India, and the aim of a continuous dialogue between experts for sharing of experiences from trials, implementations and alignments in view of globally harmonised 5G standards.

The first 5G Verticals Workshop, organised by 5G IA, 5GAA, 5G-ACIA and PSCE mid-February 2019 in Brussels, provided a much-needed and unique opportunity for key representatives from 3GPP, 5G Verticals Associations and 5G PPP Projects to exchange on how to engage 5G Verticals in the 3GPP standardisation process, and notably how to accelerate the creation of 5G vertical platforms and consolidate the 5G vertical requirements. On the example of the existing inputs from the 5G IA Pre-standardisation WG and 5G PPP Projects to 3GPP, it was emphasized for Verticals to identify gaps in 3GPP specifications, and to push consolidated requirements and solutions into Rel-17 by December 2019...

In terms of cooperation with Verticals and International Organisations, let's also mention the MoUs signed in 2018 with ESA, ENCQOR (Canada) and 5GAA, that will be followed by several others in 2019-2020, targeting sectors such as industry, health, energy and media.

As for the 5G PPP Contractual Arrangement and Impacts, the first Progress Monitoring Report based on the new common set of KPIs fixed by the European Commission – Mobilise private investments, New skills and job profiles, Impact on SMEs, Significant innovations – was judged as quite satisfactory and posted on the 5G PPP web site in September 2018. The same exercise is being done for measuring the 5G PPP impacts in the past year, to be published in June 2019.

This edition of the European 5G Annual Journal 2019 illustrates these 5G IA/5G PPP actions & impacts.

5G DEVELOPMENTS

Ten key results from the past 12 months

After standardisation of 3GPP Release 15 NSA in December 2017, tests and the first pre-commercial launch of 5G services took place in 2018. The first commercial launches took place at the end of 2018 and early 2019. We selected ten key topics concerning 5G development in Europe between mid-2018 and early-2019, as outlined below.

First 5G commercial launches

First 5G networks launches were reported in 2018 but generally with reduced coverage and a very limited number of devices only supporting fixed wireless access and hotspot functions:

- Elisa reported its 5G network carried a 5G phone call on June 27th, 2018 between the Estonian minister of Economy and her Finnish colleague in Finland.
- Verizon 5G Home service was launched on October 1st, 2018 in limited areas of four US cities (Houston, Sacramento, Indianapolis, Los Angeles). This is a fixed wireless service not using the 3GPP standard but a proprietary one. Verizon announced its plans to deploy 5G for mobile services in 30 markets starting mid-2019. Verizon announced that it intends to launch its 5G Ultra Wideband network for mobile services in more than 30 U.S. cities in 2019.
- AT&T announced the launch of a commercial standard-based mobile 5G network on 21st December 2018. 5G hotspots will be deployed in the dense urban areas of 12 cities.
- SK Telecom, LGU+ and KT launched their 5G service in a number of cities on December 1st, 2018. The launches came earlier than previously announced and thus expected. In fact, in July 2018, all MNOs announced their intention to jointly launch 5G in April 2019.

5G handsets appear in 2019

The first 5G devices appeared at the end of 2018 with the fixed wireless access terminal for Verizon and a WiFi hotspot for AT&T. At Mobile World Congress in February 2019, many manufacturers announced 5G smartphones (Samsung, Huawei, LG, Xiaomi, OnePlus, Oppo and ZTE).

In December 2018, NetGear was among the first device manufacturers to launch a WIFi router, the NETGEAR Nighthawk® 5G Mobile Hotspot. Previously, Motorola had presented a 5G extension module for its Z3 smartphone call 5G mod designed for use on Verizon's 5G network.

More than 180 5G tests and experiments in Europe in early 2019

At the end of March 2019, as many as 180 trials had been listed so far (in EU 28, Russia, San Marino, Norway, Turkey and Switzerland). A little more than a third of the trials are technical tests. There were 147 5G trials in the 28 MSs of the European Union. Trials are the most numerous in Spain, France, Germany and Italy. These top four countries are totalling 40% of trials.

The most trialled verticals are media and entertainment (32 trials) followed by transport (25 trials) and automotive (18 trials). The most used frequency band for trials is by far the 3.4-3.8 GHz.

Major trials in Europe are referenced in the 5GObservatory (*http://5gobservatory.eu/5g-trial/major-european-5g-trials-and-pilots/*)

5G trials roadmap 4.0

The 5G Pan-European Trials Roadmap Version 3.0 has been elaborated and is supported by the Trials Working Group (WG) Members organisations. It is coordinated by the 5G Infrastructure Association (5G IA), expanding the work initiated by the Industry and the European Commission (EC) in the context of the 5G Manifesto and of the 5G Action Plan (5GAP). It was presented at the 5th Global 5G event in Austin, USA in May 2018.

The 5G Pan-European Trials Roadmap Version 4.0, released in November 2018, has been elaborated and is supported by the Trials Working Group (WG) Members organisations. It is coordinated by the 5G Infrastructure Association (5G IA), expanding the work initiated by the Industry and the European Commission (EC) in

the context of the 5G Manifesto and of the 5G Action Plan (5GAP)..

This Roadmap Version 4.0 highlights the key EU cities that are targeted for 5G early deployments, already engaged in 5G pre-commercial/commercial trials and pilots, engaged in 5G R&I trials and pilots and also making available 5G R&I platforms. A description of the major EU cities engaged in the 5G UEFA EURO 2020 Flagship event is also provided.

5G Global events

5G Americas organised the 5th Global 5G Event also known as 5G New Horizons Wireless Symposium in May 2018. The Symposium focused on worldwide progress of the 5th Generation of wireless technologies. The event was co-located with both 5G North America and BCE at the Austin Convention Centre in Austin, Texas.

5G Brazil hosted the 6th Global 5G Event – 5G Technology Changing Paradigms of a New Society – with other leading 5G organisations from China, European Union, Japan, Republic of Korea and United States of America on November 28-30, 2018 in Rio de Janeiro, Brazil.

The 7th Global 5G Event "Creating the digital Future" will take place in Valencia, Spain in June 2019. The event will be co-located with EuCNC 2019 (18-20 June 2019).

Spectrum for 5G

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 was adopted in January 2019. The European Commission is about to adopt a harmonisation decision for the 26 GHz band in Q1 2019[10].

Member States have adopted a common deadline for the effective usability of pioneer spectrum in the European Electronic Communications Code, namely the 3.6 GHz band and at least 1 GHz within the 26 GHz band have to be assigned in all Member States by end of 2020.

All Member States have recognised the need for significant harmonised spectrum for 5G. Work is ongoing. The review of progress towards making spectrum available to 5G shows various stages.

10. ECC PT1 issued two CEPT reports (Report 67 on 3.6 GHz and Report 68 on 26 GHz) on '5G-ready' technical harmonisation measures in July 2018 in response to a Commission mandate of 2016. EC regulations will be based on these two reports.

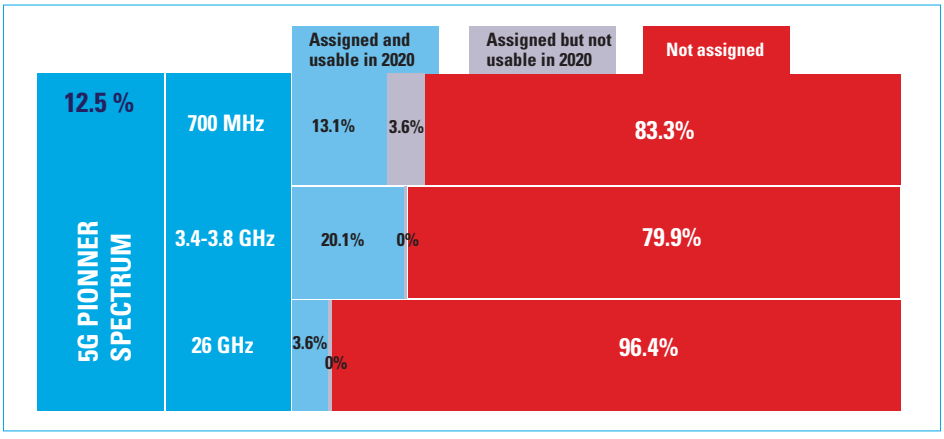

Fig. 1: 5G pioneer spectrum assignment in EU-28 (March 2019)
Source: 5G Observatory

In nine Member States at least one spectrum auction is complete or ongoing as at March 2019.

The 700 MHz band has been assigned in five Member States: Germany, France, Finland, Italy and Sweden and the 3.4–3.8 GHz band has been assigned in accordance with 5G technical conditions in 5 MSs: Austria, Finland, Ireland, Italy, Latvia, Spain and United Kingdom. Italy was the first Member State to auction 1 GHz of the 26 GHz band.

Other countries

South Korea awarded 2,400 MHz spectrum at 28 GHz and 280 MHz in the 3.6 GHz band in June 2018.

In the USA, the 600 MHz (T-Mobile), 2.5 GHz (Sprint), 28 GHz (Verizon and AT&T) and 39 GHz (AT&T) bands are going to be used for 5G commercial services.

In Asia-Pacific, China has authorised mobile operators to use the 2.6 GHz, 3.5 GHz and 4.8 GHz bands for 5G whereas in Japan, the 3.6–3.8 GHz, 4.4–4.9 GHz and 28 GHz are under consideration.

5G and verticals

The 5G IA together with industry associations are involved in promoting 5G usage by vertical players. 5G aims for industrial communications to help digitise the economy and contribute towards global digital transformation. Vertical sectors such as media and entertainment, transport, public safety and manufacturing will likely be the leading adopters.

The 5G Infrastructure Association (5G IA), representing the private side in 5G PPP, includes verticals engagement as a main objective. The 5G PPP Vertical Engagement Task Force (VTF) was therefore established to coordinate and monitor activities related to working with vertical sectors. Specifically, it has the following objectives:

- Enhance verticals engagement in 5G PPP
- Promote relevant funding Calls within verticals industries
- Gather verticals feedback on 5G needs and potential barriers for adoption
- Raise awareness of 5G potential

In the automotive sector, the 5GAA (Automotive Association) already gathers more than 110 members working together on all aspects of C-V2X including technology, standards, spectrum, policy, regulations, testing, business models and go-to-market.

5G ACIA (5G Alliance for Automated Industries and Automation) is involved in defining 5G use cases for Industry 4.0. Its mission is to "Ensure the best possible applicability of 5G technology and 5G networks for the manufacturing and process industry by addressing, discussing and evaluating relevant technical, regulatory and business aspects".

MoUs and cooperation agreements

The 5G Infrastructure Association has been very active in the past twelve months with the signature of many Memorandums of Understanding (MoUs) and cooperative agreements:

- 5G IA and ECSO co-signed a MoU in December 2018 with the aim of enhancing future cooperation in the field of cyber security and 5G communication networks. ECSO and 5G IA have a shared objective of establishing a common and coordinated strategy for a secure and trustworthy 5G communication network, as its application will have an impact on many sectors, including e-health, industry 4.0, intelligent transport, entertainment & media, just to mention a few.
- 5G IA and the Alliance for Internet of Things Innovation (AIOTI) signed a MoU in December 2018, at the ICT-2018 conference in Vienna. This partnership will set the scene for exploring the opportunities for new combinations of IoT applications built on world-class digital infrastructures.
- 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.
- Telecommunications Standards Development Society, India (TSDSI) and the 5G IA signed a MoU in May 2018 to foster collaboration on Research, Standards, Regulations and Policies over the next 3 years. TSDSI and 5G IA will seek

to develop and deploy mechanisms to promote 5G-related R&D initiatives based on the aligned opportunities identified by both parties.

- Public Safety Communication Europe (PSCE), the European public safety Association, and 5G IA, signed a Cooperation agreement in May 2018 to foster collaboration on 5G development. The objective is to make sure that 5G will bring the necessary developments to the security and safety communications for improving the activities of the PPDR community.

Phase 2 key achievements and launch of H2020 phase 3

Phase 2 key achievements from the 5G PPP include 60 highlighted results from the phase 2 projects categorised under 14 programme level achievements:

- 5G performance evaluation framework
- 5G system, functional, logical & physical architectures
- 5G flexible RAN
- Novel 5G radio systems and air interface
- Technology enablers for 5G RAN platforms (HW & SW)
- 5G fronthaul, backhaul and metrohaul
- 5G autonomous network control and management
- 5G multi-domains multi-tenants plug & play control plane and slicing control
- 5G flexible and agile service development
- End-to-end orchestration across optical, packet, wireless virtualized networks
- 5G resilience and availability
- 5G service platforms and programming tools for NetApps
- 5G verticals experimentation, trials and pilots
- 5G business, standardisation and regulation

In June 2018, the 5G PPP Initiative launched Phase 3 at the EuCNC conference, announcing three new projects that will come on stream from 1 July 2018. The projects represent an investment by the European Commission of more than 50 million Euros plus a commitment by the ICT industry of several times that amount.

The three projects – 5G EVE, 5G-VINNI and 5GENESIS – started on 1 July 2018 and address the challenge of H2020 EC 5G PPP ICT-17-2018: "5G End to End Facility". These three projects were selected on merit from 16 proposals received and will run for 3 years.

- Three Automotive Projects under 5G PPP Phase 3, Part 2 started in November 2018: 5G CroCo, 5G Carmen and 5G Mobix and will implement and test advanced 5G infrastructures in Europe.

Workshops organised by 5G PPP projects & white papers

Workshops

- The EU-INDIA Workshop organised by 5G IA, Telecommunications Standards Development Society, India (TSDSI) and Broadband India Forum (BIF) on 5-6 February 2018 in Delhi brought together technology experts from the EU and India geographies to share their experiences and explored areas of mutual collaboration.
- Workshop on 3GPP submission towards IMT-2020 (Brussels - October 2018). 3GPP held a Workshop aimed at informing the ITU sanctioned Evaluation Groups, policy makers and interested experts on the progress of the 3GPP work to meet and exceed the performance requirements for IMT-2020 radio interface technologies. This event was in addition to the evaluation material being sent to the ITU, using the IMT-2020 'submission templates' detailing the service, spectrum and technical performance results achieved by 3GPP Radio Interface Technologies (RITs) or Set of Radio Interface Technologies (SRITs).
- The PPP Technical Workshop (Kista - 20-22.11.18) enabled significant progress in defining 5G Infrastructure PPP Performance KPIs for how the KPIs themselves will be evaluated, as well as qualifying and quantifying projects' innovation/enablers on these KPIs.
- The 5G Vertical User Workshop (Brussels – February 2019) was a collaborative event for strategic dialogue between industries and 3GPP by exchanging on future needs and upcoming standard developments. The workshop as a result, produced 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.

- Architecture Working Group Workshop (Munich – March 2019).

White papers

- **5G PPP Software Network White Paper**: *'From Webscale to Telco, the Cloud Native Journey'* (July 2018). The paper highlights what must be done in order to design a cloud-native 5G system.
- **5G PPP Automotive White Paper**: A study on 5G V2X Deployment. – (Version 1.0 Feb 2018). This paper provides first insights into the deployment models for 5G Vehicle to Anything (V2X). The second white paper was released during Mobile World Congress 2019.

5G PPP PROJECTS - PHASE 2

5GCAR

5GCAR has developed technical concepts for advanced driving use cases (lane merge, see-through, network-assisted vulnerable pedestrian protection, high-definition map, and remote parking) and is conducting their evaluation by trials whose final results are expected for mid-2019. These technical concepts have also been exploited in e.g. 3GPP standardisation process. The major topic for 5G vehicle-to-anything (V2X) is to improve communication reliability, latency, and other mission-critical quality of service related key performance indicators (KPIs) for advanced driving as depicted on all V2X links in figure 1.

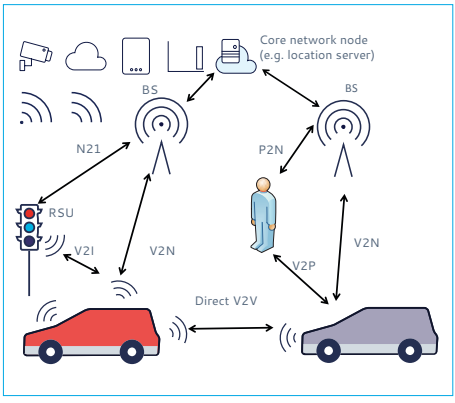

Fig. 1: KPIs for advanced driving

Automotive service KPIs for advanced driving use cases (also known as service requirements in telecom world) were derived. Automotive KPIs are related to driving maneuver performance, e.g. time to complete a lane merging process. Based on these service KPIs, we derived the communication network KPIs to support vehicle maneuvers required by cooperative and automated vehicles. Each use case analyses the respective functionality or operation in a different context (i.e., road conditions, road environment, level of automation etc.). For each of them, a study based on KPI has been made focusing on three categories: automotive requirements, network requirements and qualitative requirements. The developed technical concepts must be able to fulfil these service requirements.

For all V2X links we have developed technical concepts and a functional architecture as shown in the figure 2. Reliable communication is key for radio-based assisted, fully automated mobility. The defined use cases are supported by novel 5GCAR technical concepts working on radio links, network architecture and network functions. 5GCAR has been the major driver and contributor to the first and second published 5G PPP working group Automotive white papers (Automotive WP[11]) which have reached high global visibility, for instance in 5G Mobile Forum South Korea. In these publications, a 5G-V2X business proposal and calculations for advanced driving are proposed and they have achieved a high resonance and visibility in the public for stimulating public funding of 5G-V2X road infrastructure. Based on 5GCAR KPIs defined for the use cases, KPIs were selected that will be evaluated in 5GCAR demonstration systems, implementing some of the use cases (lane merge, see-through, vulnerable road user protection).

Another novelty is the 5GCAR V2X sidelink channel models in 3GPP release 16 New Radio

11. (https://5g-ppp.eu/white-papers/) 5G PPP Automotive Working Group, "Business feasibility study for 5G V2X deployment", White Paper v2.0, February 2019.and 5G PPP Automotive Working Group, "A study on 5G V2X deployment", White Paper v1.0, February 2018.

(NR) V2X. With this we now have a consistent scenario of V2X channel models. For NR, 5GCAR has achieved integrated network and sidelink design for comfort driving use cases, i.e. non-safety V2X use cases. The vehicle-to-network, vehicle-to-infrastructure, vehicle-to-pedestrian, vehicle-to-vehicle, links are addressed by this integrated design. Definition and evaluation of advanced antenna concepts and techniques was carried out for vehicular car terminals.

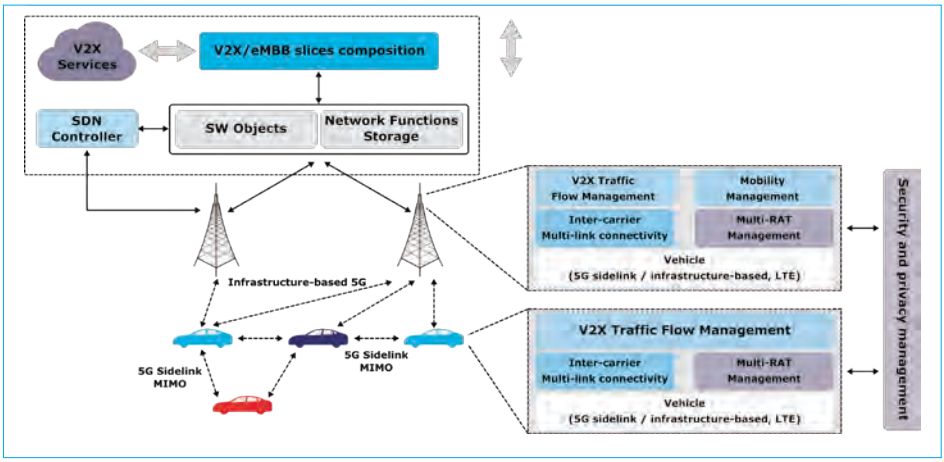

Fig. 2: End-to-end specification and design of VX 5G architecture

Novel V2X technical concepts covering both physical layer and medium access control were developed for in-coverage, out-of-coverage network situations, safety and non-safety related services. In the following, the technical concept areas are briefly described: multi-antenna techniques (including e.g. V2X beam management and predictor antenna), radio resource allocation and management covering both Uu interface (i.e. between base station and terminal) and sidelink interface (i.e. between terminals), efficient multiplexing between various services, enhanced hybrid automatic repeat request, link adaption, power control for high mobility, reliability enhancements on radio links e.g. via diversity gain by taking full advantage of sidelink and Uu link, physical signal design for sidelink synchronisation and pilot signals, full duplex link support, 5G positioning for e.g. vulnerable road user protections. Positioning is one of the key solutions for connected automated mobility and we have focused on the following sub-solutions like Trajectory prediction with channel bias compensation and tracking, beam-based V2X positioning, tracking of a vehicle's position and orientation with a single base station in the downlink, harnessing data communication for low latency positioning, enhanced assistance messaging scheme to support network assisted positioning.

Slicing and network architecture for V2X have been defined in the 5GCAR project, with major emphasis on specification and integration of 5G-V2X technical concepts into the existing 3GPP 5G architecture, which is considered as a baseline. The goal of a 5G-V2X architecture is to enhance availability, improve reliability and reduce latency for V2X mission critical applications, while ensuring the system is secure and designed to maintain users' privacy. 5G-V2X architecture considers infrastructure as a service and network slicing to deploy specific vehicular-oriented solutions to meet V2X requirements. For the network related parts we can outline the following concepts and methods: road side unit-enabled smart zone, fast application-aware setup of unicast sidelink, sidelink and Uu multi-connectivity, location aware scheduling, redundant mode jointly exploiting sidelink and Uu, infrastructure-based communication for localised V2X traffic, use case aware multi-radio access technology and multi-link connectivity, multi operator solutions for V2X communications, V2X

service negotiation, edge computing in millimetre wave cellular V2X networks, dynamic selection of sidelink and Uu communication modes, and 5G core network evolution for edge computing-based mobility.

V2X and automated driving needs more continuous research, standardisation, and innovation activities to ensure future development in the field. The work will for instance continue in the recently started V2X phase 3 projects focusing on cross border challenges and in the 5G PPP Automotive working group.

5G-City

Goals of the project

The 5GCity project is working on design, development and deployment of a distributed cloud and radio platform for municipalities and infrastructure owners acting as **5G neutral hosts.**

The main goal of 5GCity is to build and deploy a common, multi-tenant, open platform that extends the centralised cloud model to the extreme edge of the network, with live demonstrations and trials to be run in three different cities: Barcelona (ES), Bristol (UK) and Lucca (IT).

5GCity has main stakeholders in the municipalities: these entities quite often own and manage the best urban spaces to host 5G Small Cells and are undergoing a digital transformation towards Smart Cities. 5GCity works to generate most of its impact in the cities, unleashing the power of new value-added 5G services for the benefit of the citizens.

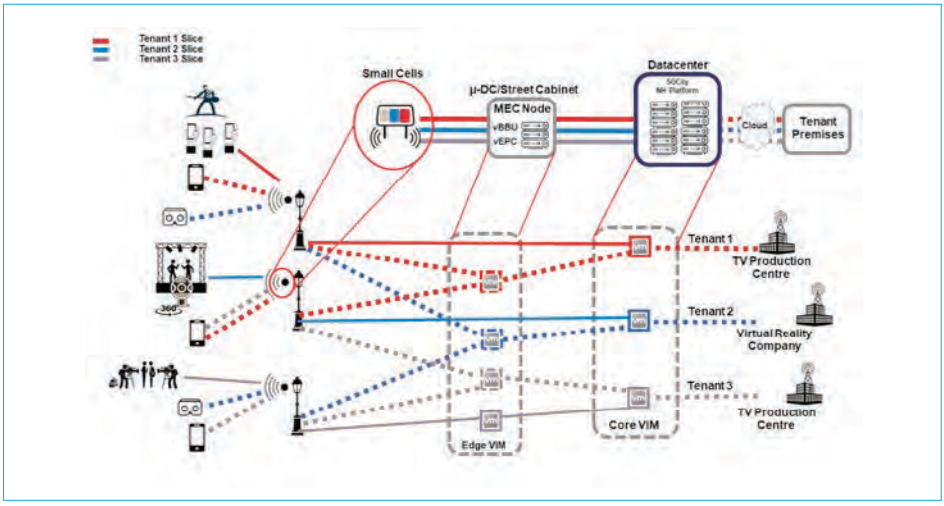

Fig. 3: 5GCity Neutral Host concept

Key Innovations and progresses of the period

5GCity is designing a completely de-centralised 3-tier architecture where compute, storage and networking are allocated between core and edge segments of the 5G network infrastructure. Key challenges to address in this context are: i) availability of a unified control and orchestration framework for the orchestration of all 5G-based edge services and capable also of controlling the underlying city infrastructure; ii) availability of powerful APIs through which it is possible to access, define and programme the different edge services and the orchestrator functionalities; and , iii) offering access via a service SDK to a rich set of primitive functions for network and vertical application services (e.g. programmable connectivity with QoS, media acquisition and transcoding, traffic monitoring).

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

- **5G Neutral Host business model**. 5GCity is elaborating the Neutral Host business model, which can ease addressing the practical difficulties in terms of space, power and backhauling stemming from the increased number of sites required in 5G. The 5GCity Neutral Host (i.e. the municipality and any other party with virtualization infrastructure in the City) develops and provides "network slices" (i.e. wholesale access) to different tenants each with a set of virtualized resources on top of the shared physical infrastructure. The 5GCity Neutral Host business model offers incentives to all players of the ecosystem from operators (cost and complexity reduction) and vertical industries (guaranteed performance, private networks) to service providers (operator agnostic value proposal, ease of service creation) and function developers (ease of function and services development). Municipalities can be assumed as the most benefitted player and can have different roles: in fact, they can be an active part of the infrastructure management by taking over the network resources, thus becoming a Neutral Host operator; alternatively, they can have a passive role by leasing their infrastructure to private operators who will in turn act as the Neutral Host. Also in this case, the municipalities can still benefit from the business operation of the Neutral Host infrastructure, getting paid with a fixed amount per available asset and at the same time having some kind of revenue sharing model per additional customer/service engaged in the service. Finally, municipalities can also cover the role of Vertical, above all in scenarios where public services are implemented for the citizens (e.g. signalling and managing car parking areas, public advertisements, free Internet areas, public transit management, controlling waste dumping, video surveillance, emergency communications, etc.).
- **MEC Node Virtualization Platform and Guest Optimizations**. 5GCity also aims to provide virtualization extensions for city wide infrastructures. In particular, the aspects of security, connectivity and performance are covered by 5GCity research:
  - *Security through Trusted Computing*: EdgeVIM is a Virtualized Infrastrucure Manager completely designed and developed in 5GCity, which offers Trusted Computing features in OpenStack through a thin safety certified virtualization solution, the VOSYSmonitor. EdgeVIM relies on ARM TrustZone and is particularly suited for embedded and smart city deployments. A prototype of the EdgeVIM is available today with compute nodes authentication, system security monitoring, asset-tagging, and geo-tagging features. Next steps will go in the direction of the development of virtualized Trusted Platform Module for VNFs.
  - *Connectivity through Multi-PoP support and Wireless Virtualization*: RAN provisioning in dense edge deployments requires the instantiation of multiple virtual functions and virtual networks over a shared infrastructure. 5GCity tackles this virtualization challenge with support for Multi-PoP in OpenStack and virtualization of LTE and Wi-Fi wireless devices. The 5GCity wireless virtualization solution consists in defining a configuration and management plane between the physical devices and the 5GCity platform, in order to enable sharing of physical wireless interfaces among a set of tenants in the form of wireless slices. A prototype has been developed which uses NETCONF Yang to configure Wi-Fi and Small Cells. Next steps will focus on supporting additional wireless technologies, as well as mobility and self-healing mechanisms.

- *Performance through Unikernels*: 5GCity is enhancing the open source project Unikraft, a toolkit designed to build unikernels targeted at specific applications. In the recent release v0.3, 5GCity contributions to Unikraft were added to support Virtual File Systems (VFS) and ARM (32 and 64 bits) devices support, as well network stack improvements (virtio paravirtualized driver and the lightweight network stack lwip). Next activities will focus on improving the maturity and the stability of these features.

- **Flexible Orchestration & Control layer and SDK**. 5GCity is also developing a platform for managing network slice lifecycle management, network service design and orchestration, optimized resource and monitoring. Although the platform covers a wide palette of management functionalities, the core and most innovative achievements of the past year were:
  - *SDK toolkit for designing slicing- and SLA-aware network services*: The 5G Neutral Hosting models calls for a decoupling of network service design from network service and network slice operation. These points have been addressed through the 5GCity SDK, which consists of functionalities to allow service designers to specify their virtualized functions in an abstracted way ("Editor" mode) and graphically declared the intended service function chain ("Composer" mode) with slice-related deployment preferences and KPIs. The service and functions defined in 5GCity SDK are Vertical-oriented, i.e. they do not bring in the complexity of ETSI NFV descriptors: an internal translation module automatically generates ETSI NFV-compatible descriptors for the subsequent network service lifecycle management.
  - *Multi-access slices and multi-layer orchestration*: The 5GCity platform is built around a Slice Manager component, which offers an API that fully supports slice lifecycle management, including slice creation and termination, service deployment on slices, and more. However, the 5GCity Slice Manager goes beyond typical solutions in the domain in that it homogeneously supports a variety of "sliceable" access resources (e.g., LTE/5G-NR, WiFi) in addition to sliceable compute resources (currently OpenStack-supported but designed in a VIM-agnostic way), abstracting technology details from slice users. Further, it brings NFV- and MEC-orchestration under the same hut, thus partly decoupling slices from the Network Service concept and making them more Cloud-native and edge-aware, while still fitting within the NFV context. This is all integrated with state-of-the-art NFV monitoring solutions and already being tested in the project pilot cities of Barcelona, Lucca, and Bristol.

- **City-wide pilots for validation**. 5GCity is the only 5G PPP Phase 2 project which is validating its innovations in three different cities with live trials: Barcelona (ES), Bristol (UK) and Lucca (IT).

Major achievements of the period and future plans

In its 2nd year, the 5GCity consortium has achieved the following achievements:

- **Interim release of 5GCity Platform**. The 5GCity platform interim release were made at the end of Nov 2018. It included basic features including compute and network slicing along with rapid service provisioning on these slices using NFV-MANO.

- **Deployment of City infrastructures**. In all three cities, Barcelona, Bristol, and Lucca, we have completed the deployment of Metro DC, MEC node (street cabinet) and wireless network. In Barcelona, we have used a small cell operating live in the commercial LTE 3.5GHz spectrum to stream contents from a local edge server towards LTE 3.5GHz smartphones

- **Demonstrations** of the 5GCity platform interim release was successfully demonstrated in the ICT18 event in Vienna along with three 5GCity use cases including Waste dump detection in cities, Video acquisition & production and 360° immersive services for museums. The updated 5GCity platform was also demonstrated in the Mobile World Congress 2019 along with the Video acquisition and production use case. A demo of the RAN virtualization solution with a lamppost mock-up was presented at the Smart City Expo World Congress 2018 in Nov 2018 (18,000 visitors from 700 different cities).

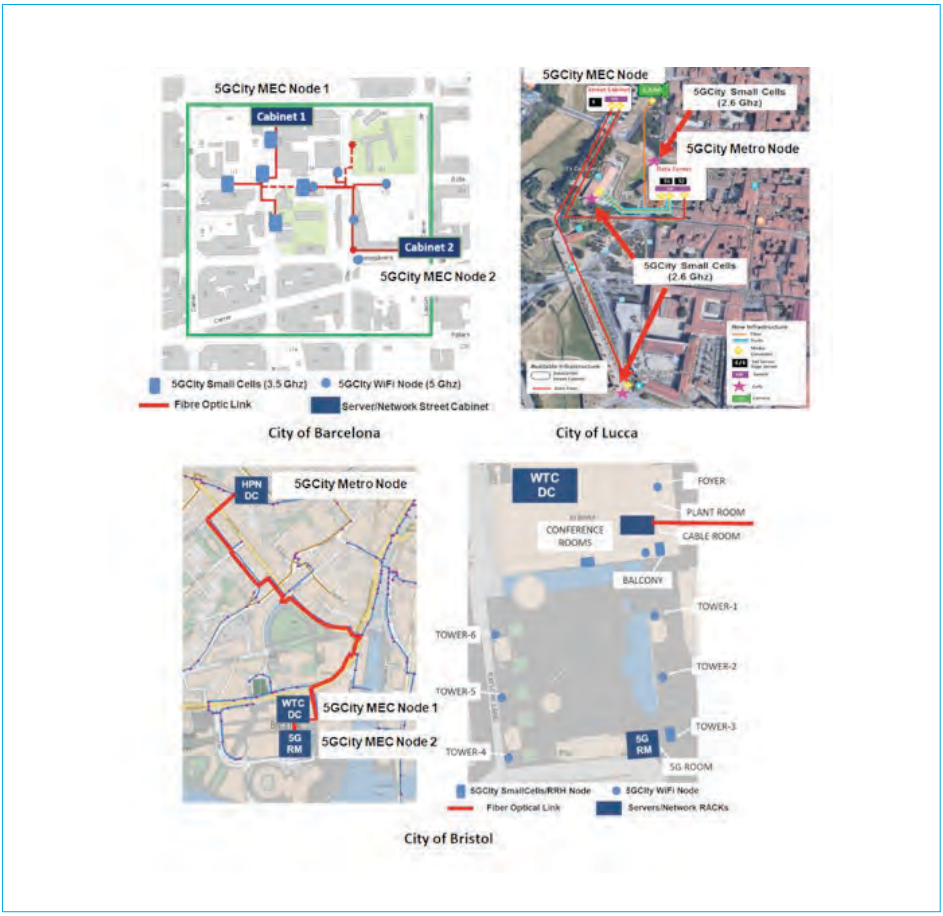

Fig. 4: City-wide pilots for validation

The next milestones planned by the consortium include:

- **Final release of the 5GCity platform with full featured SDK**, planned by end of May 2019. This last platform release will be used to validate the six use cases of the project in the three cities.
- **Validation of the six use cases in the three 5GCities**, planned to assess the performance of the media use cases, public safety and connected mobility in the cities of Barcelona, Bristol and Lucca.
- **Promotion of the 5GCity platform and SDK with two hackathons**, planned to validate and finetune the platform and SDK with external developers from the industry and academia challenged to define their new services for the 5G City with the project tools.
- **Demonstrations** of 5GCity platform, SDK and use cases are planned for EUCNC2019 in Valencia (ES), and Smart City Expo World Congress 2019 in Barcelona (ES).

5G Essence

Objectives

The 5G ESSENCE project is a research and innovation action that "addresses" the paradigms of Edge Cloud computing and Small Cell as-a-Service (SCaaS) by fueling the drivers and removing the barriers in the Small Cell (SC) market, forecasted to grow at an impressive pace up to 2020 and beyond and to play a "key role" in the 5G ecosystem.

The 5G ESSENCE aims to offer a highly flexible and scalable platform, able to support new business models and revenue streams by creating a neutral host market and reducing operational costs, via the provision of new opportunities for ownership, deployment, operation and amortization. The main measurable objectives of the 5G ESSENCE include:

- Full specification of critical architectural enhancements (with reference to the original context of the proposed 5G PPP reference architecture).
- Definition of the baseline system architecture and interfaces for the provisioning of a cloud-integrated multi-tenant Small Cell network and a programmable radio resources management (RRM) controller.
- Development of the centralised software-defined radio access network (SD-RAN) controller to programme the radio resources usage in a unified way for all CESCs (Cloud-Enabled Small Cells).
- Development of orchestrator's enhancements for the distributed service management, in a multi-tier architecture.

To a certain extent, the 5G ESSENCE framework leverages knowledge, SW modules and prototypes from previous 5G PPP projects of Phase 1. However, the 5G ESSENCE goes a step further with the aim of accommodating a range of use cases in terms of reduced latency, increased network resilience and less service creation time. One of its major innovations is the provision of an end-to-end (E2E) network and cloud infrastructure slices over the same physical infrastructure, so as to fulfill vertical-specific requirements as well as mobile broadband services, in parallel.

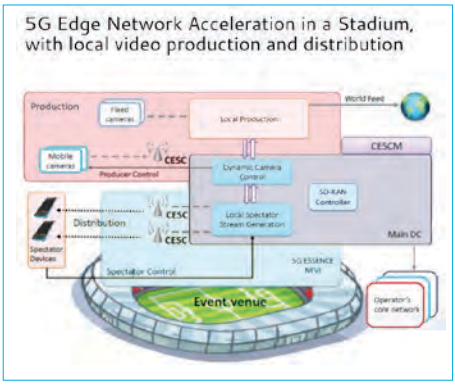

Fig. 5: 5G Essence Use Case 1

Building upon these foundations, ambitious objectives are targeted, culminating with the prototyping and demonstration of the 5G ESSENCE system in three real-life use cases associated to vertical industries, that is: 5G edge network acceleration for a crowded event (e.g., in a stadium) with local video production and distribution; Mission Critical (MC) applications for Public Safety (PS) communications providers, and; In-Flight Entertainment and Connectivity (IFEC) communications services for passengers.

Major achievements/innovations

5G ESSENCE project introduces innovations in the fields of network softwarisation, virtualization and cognitive network management. More specifically, the use of end-to-end network slicing mechanisms allows to share the 5G ESSENCE infrastructure among multiple operators/vertical industries and customizing its capabilities on a per-tenant basis. This approach allows new stakeholders to "dynamically enter the network value chain" and offers on-demand access to "evolved" Small Cell platforms with enhanced Mobile Edge Computing (MEC) capabilities to Small Cell operators, network operators and other OTT players. The 5G ESSENCE "addresses" a variety of use cases, being critical for the vertical industries. These are deployed and validated in real life conditions aiming to demonstrate how the proposed project solution is important for the realization of 5G, per case.

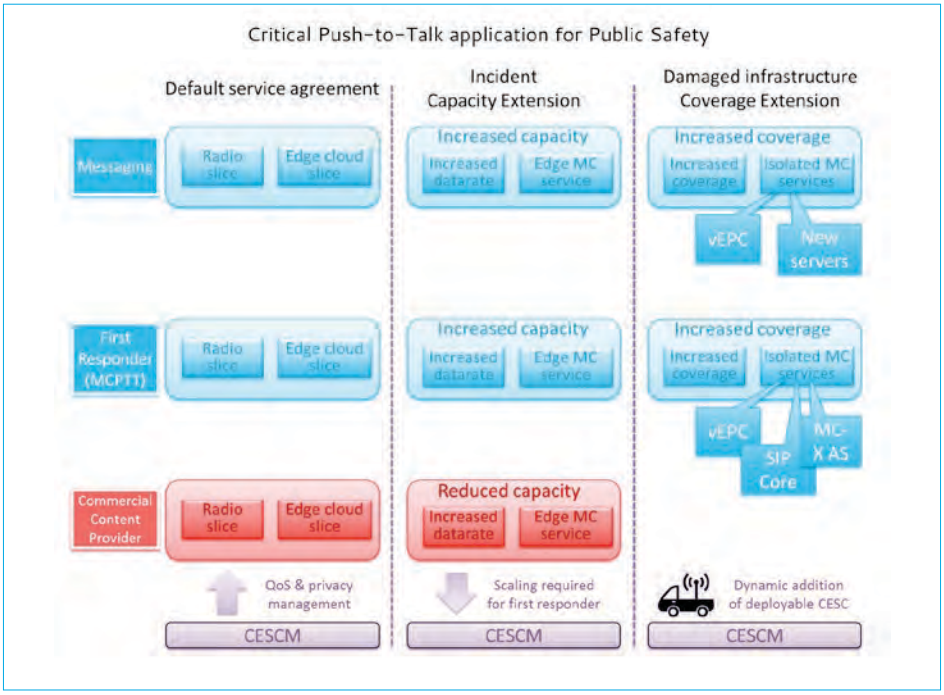

Fig. 6: 5G Essence Use Case 2a

The implementations will leverage well-known and accepted standards, as well as open-source SW, when available. Every use case is a very important context in which the target is to verify new capabilities coming from the 5G systems in terms of reduced latency, increased network resilience and less service creation time, with respect to existing systems for many verticals. Importantly, this enables and fosters the creation of a novel ecosystem where new business models can be envisioned and where actors (such as neutral host providers and vertical industries) can efficiently enter the value-chain.

Some elements about the performance KPIs

The different demonstration scenarios are sharing providing the same KPIs for MEC service and categorization:

- 5G Edge network for a stadium
- Mission Critical applications for public safety
- Next Generation integrated in-flight connectivity and entertainment systems

5GESSENCE is targeting providing results on a selected set of Performance KPIs such as Mobile data volume per geographical area, Network Management OPEX, Service deployment time and Service reliability.

The project is focused on providing an optimized solution for deploying Edge Clouds in distributed datacenters, empowering MobileEdge Computing and smallcell RAN virtualization taking advantage of MRDC capabilities of 4G, 5G and WiFi RATs. Besides the classical RAN KPIs, the KPI work is extended to consider Virtual Infrastructure specific KPIs as a new set of KPIs related with the Service Creation and Service Reliability but also for Resource Utilization. 5GESSENCE is targeting collecting Performance KPIs from different sources depending on the feasibility of each KPI like as Virtual Infrastructure Performance counters, Ran Infrastructure Performance counters, Simulation. We can also consider the aspects correlated to the service reliability

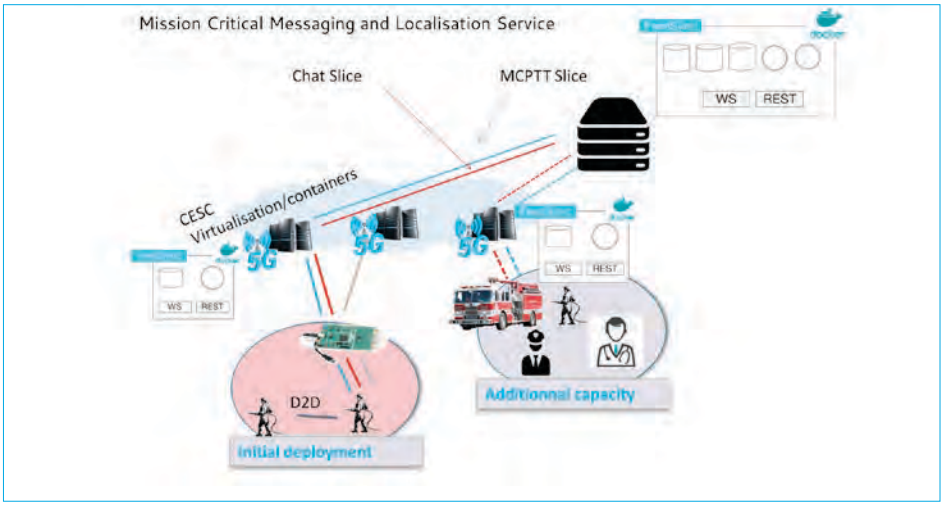

Fig. 7: 5G Essence Use Case 2b

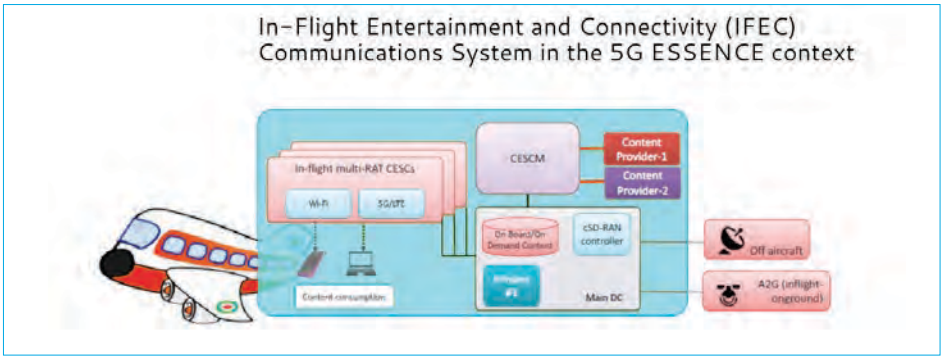

Fig. 8: 5G Essence Use Case 3

Demo

We are going to finalize three demos to demonstrate that in use case 1 "massive data traffic" in big-event scenarios will not affect nor overload the backhaul connection as it will be produced, processed and consumed just locally. In the case of use case 2, chat and localization application for public safety use capabilities will be demonstrated to underline the improvements coming from the 5GESSENCE solution. Finally we validate the multitenancy-enabled network solution for passenger connectivity and wireless broadband experience for the use case 3.

Future work covers a full realization of demo of the proposed solution at management and orchestration levels, as well as at the level of single functional components (e.g. control and monitoring).

Particular focus is on the virtualized video transcoding and video catching for demonstrating the VNF caching service. Besides, our goal is to demonstrate the flexibility of 5GESSENCE for delivering media rich services in in-flight entertainment and connectivity systems and in crowded real contexts, both in UK and in Greece.

5G-MEDIA - Programmable edge-to-cloud virtualization fabric for the 5G Media industry

Goals of the project

Media-based applications are amongst the most demanding services in terms of bandwidth and latency to enable high audio-visual quality and interactivity. The goal of the 5G-MEDIA project is to develop an integrated programmable platform consisting of a Service Development Kit (SDK) facilitating the development, testing and emulation of media services and a Service Virtualization Platform (SVP), enabling the deployment and operation of media services on 5G networks by leveraging the principles of Network Function Virtualization (NFV) and Software Defined Network (SDN). The platform offers an advanced cognitive management environment for the provisioning of network services and media-related applications, which directly link their lifecycle management with user experience as well as optimization of infrastructure resource utilization. Another innovation of the 5G-MEDIA project is the integration of serverless computing with media intensive applications in 5G networks, increasing cost effectiveness of operations and simplifying development and deployment time. The platform is being validated using three media use cases: immersive Virtual Reality 3D gaming application, remote production of broadcast content incorporating user generated contents, and dynamically adaptive CDNs for the intelligent distribution of Ultra-High Definition (UHD) content.

Major achievements and innovation

During the second year of the project the consortium has worked mostly on the implementation of the different components of the 5G-MEDIA platform and on the realization of the use cases.

The 5G-MEDIA Service Virtualization Platform (SVP) is built upon the Open Source MANO (OSM) NFV-MANO and, within the project work, two new Virtualized Infrastructure Manager (VIMs) are provided, in addition to those supported by OSM, i.e. the Function as a Service (FaaS) VIM, which enables the use of the so-called FaaS concept and the OpenNebula VIM, which enables the connection of OSM to OnLife NFVI provided by Telefonica. A refinement of the architecture has been released and it includes, among other refinements, a more detailed specification of the SDK and the 5G App and Service Catalogue and the Media Service MAPE (Monitoring-Analyze-Planning-Execute) is provided.

The 5G-MEDIA Service Development Kit (SDK) supports the development of new media applications and services assisting the function, application and service development, emulation, testing and validation process, prior to the deployment phase and allows the use of lightweight virtualization through Docker and unikernels; it provides an all-in-one environment to validate Network Service Descriptors, to emulate network services, to onboard NS in the NFV catalogue and finally instantiate it on a specific NFVI/VIM through the SVP. In addition, the 5G-MEDIA SDK allows FaaS Emulation using Lean OpenWhisk (Lean OW) and FaaS CLI Tools allow media application developers (NS developers) to leverage the FaaS programming model and quickly develop and evaluate value added code while relieving them from the infrastructure management concerns. It also offers CLI tools for unikernels, to enable unikernel development, providing improved security, smaller footprint and consequent faster boot time. Finally, it provides a VNF/NS Emulation toolkit including service profiling and monitoring tools that enable load testing on a media application (profiling) and provides visualization of predefined performance metrics (monitoring). This allows media application developers to test and verify their applications functionality, debug and fine-tune them before deploying to a production environment. The 5G App and Service Catalogue is placed between the SDK and the MANO components. The catalogue is designed to be NFV MANO platform-agnostic in terms of formats and syntax for NS descriptors and VNF Package information model. The catalogue uses a novel generalized and extendible format for representing NSs and VNFs, and it is capable to onboard NFV service elements as well as Mobile Edge Cloud (MEC) media applications and services and other virtual applications such as SDN applications, and functions implementing the FaaS paradigm. Another key component of the SVP is the Media Service MAPE mechanism, which is responsible for the optimized media services

orchestration. The Media Service MAPE loop leverages monitoring of application level metrics, machine learning techniques and cognitive control principles and aims to accommodate QoS/QoE by executing specific actions to reconfigure VNF across the network service or update the live VNF Forwarding Graphs (VNFFGs).

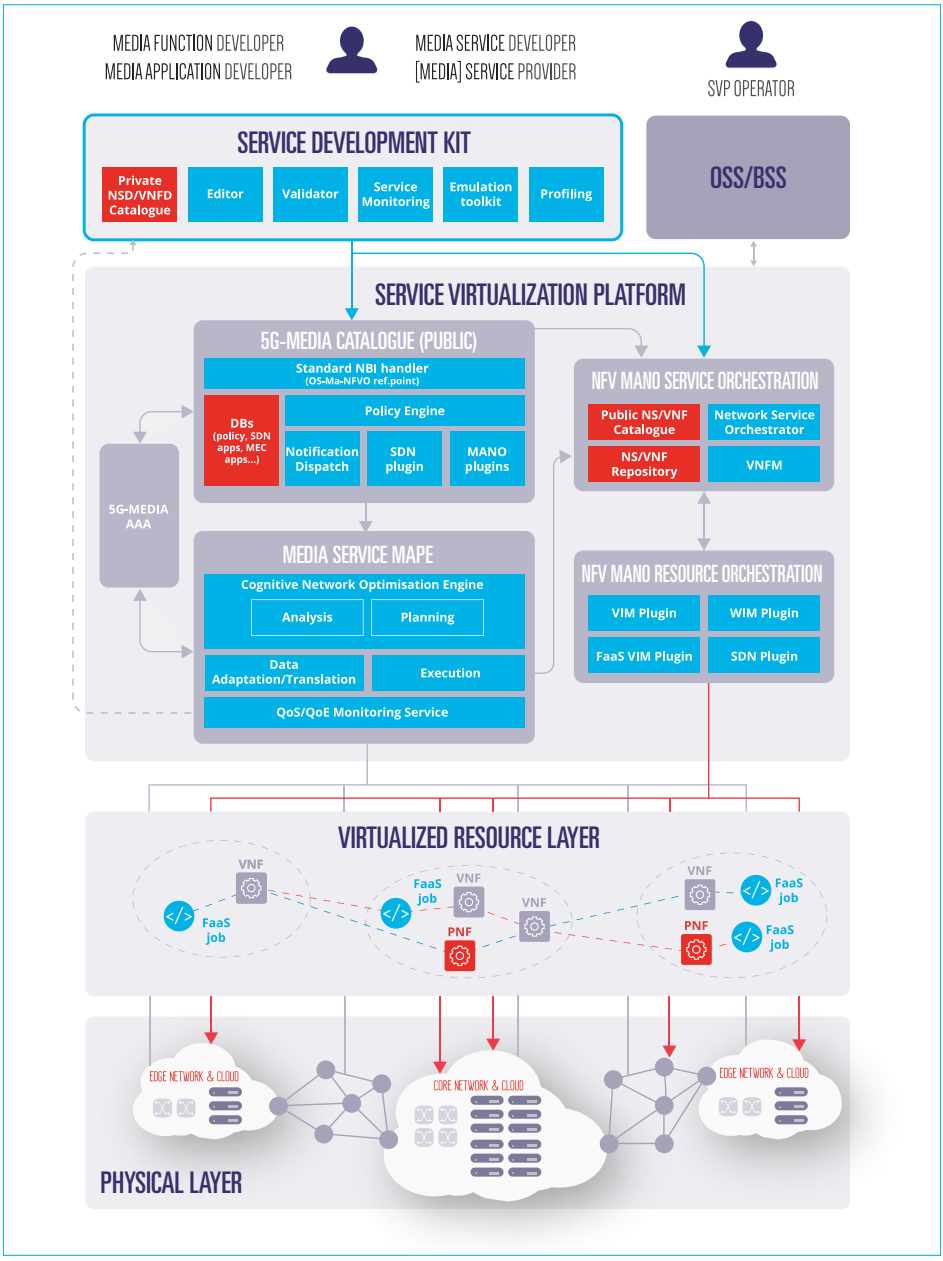

Fig. 9: High level architecture

The innovative components of the 5G-MEDIA platform have been demonstrated in three use cases on different infrastructures provided by the 5G-MEDIA consortium partners.

Use case 1 – Immersive media and Virtual Reality: Tele-Immersive (TI) applications are immersive media network based applications that enable the multi-party real-time interaction of users located in different parts of the globe, by placing them inside a shared virtual world. TI applications produce a large volume of heterogeneous data, thus, creating a challenging networking scenario. This use case requires high bandwidth (next-gen immersive 3D media), low latency streams between the players (establish the needed interaction) and smooth playback for the spectators. In this context, two users are remotely interacting with each other in a gaming context via their real-time 3D reconstructed replicas which are transferred as 3D multimedia streams over the network, allowing for unrestricted free viewpoint rendering. In addition, their interactive session can be spectated by an arbitrary group of users. The project delivers a demo showcasing the tele-immersive game scenario through the deployment of the media specific VNF, vTranscoder, enabling the real-time 3D reconstructed replicas of the players. The deployment of the vTranscoder is triggered by the user on an event-driven manner following the FaaS model.

Use case 2 – Smart Production and User-generated Content: Due to the steadily rising cost pressure, broadcasters are looking for new, low-cost and time-saving production methods, which include participatory and user-generated media archives in the production, also known under the term smart production. This use case aims to demonstrate the benefits that the advancements in 5G technology, bring to professional remote broadcast productions. In this domain, when the production of a live event needs to be done, a 5G-MEDIA Gateway (GW) is set up in order to convert the video signal from SDI to IP. In this demo, the 5G-MEDIA platform is used to deploy different media-specific VNFs, i.e., a virtual Media Process Engine (MPE), virtual Compression Engines (vCE) and a Speech-to-Text Engine (S2T). The virtualization of these media services allows the broadcaster to perform the remote production, saving personal and technical costs thus reducing the complexity for the user and ensuring operational reliability (QoS, QoE).

Use case 3 – Ultra High Definition over Content Delivery Network: This use cases targets the UHD media delivery over virtualized content distribution networks. Leveraging on 5G technologies, 5G-MEDIA has developed a vCDN solution capable of meeting the needs of the media industry, where there is a high demand for services capable of distributing different types of media contents, with a high volume of data depending on the media quality, to a heterogenous set of end-devices (e.g. phones, pads and TV screens) connected to the network. For offering a proper QoE to the end-user, with a zero-perceived interruption of the streaming service, the instantiated vCDN adapts its vCaches hierarchy. This demo showcases the scaling out of vCaches on the edge computing node as a response to the rising number of active sessions. The most recent demo of this use case has been presented at Mobile World Congress 2019.

The most impactful events where the 5G-MEDIA progress and use cases have been presented and demonstrated are: the workshop "Media delivery innovations using flexible network models in 5G" at IEEE Broadband Multimedia Systems and Broadcasting (BMSB) 2018, four different workshops organised within the EuCNC 2018 - European Conference on Networks and Communications 2018, the Mobile World Congress 2019 where the 5G-MEDIA project has been hosted in the 5G IA booth. Next major events will be EuCNC 2019 and Global5G conferences, co-located in Valencia and planned for June 2019.

5G-Monarch

Challenges and objectives

A flexible, adaptable and programmable architecture is key to satisfy the large diversity of requirements and services of 5G mobile networks. 5G-MoNArch designs and develops such a 5G fully-fledged mobile network architecture[12] together with two functional innovations: 1) resilience and security, targeting a vertical industry use case with strong requirements on reliable, resilient and secure communication; 2) resource elasticity, targeting a media & entertainment use case where the network needs to quickly adapt to changing application and usage characteristics. These use cases are implemented into two real-world testbeds: The Smart Sea Port in Hamburg and the Touristic City in Turin. The ultimate goal is to provide a novel 5G network architecture that can reach out to new economic sectors and verticals with the corresponding societal and economic impact.

Major technical achievements

To realise end-to-end (E2E) network slicing, the **5G-MoNArch overall architecture**[13] provides 1) native slicing support in all domains of the architecture enabling intra-slice and cross-slice control and management, 2) unified service-based architecture and service-based interface, and 3) integrated data analytics framework comprising standardised management data analytics function, enhancements on core network (CN) analytics as well as radio access network (RAN) analytics[14]. Included are functional extensions for resilient and secure network slices and resource elasticity principles.

5G-MoNArch developed a **slice blueprint design** with specific examples showcasing the transition from tenant requirements into generic slice templates, functional architecture and finally the testbed implementations.

To meet the stringent requirements of vertical industries, 5G-MoNArch developed an approach enabling increased levels of RAN reliability[15] using the concept of **dual connectivity**, where the connection of terminals to the network is realised via multiple simultaneous physical links (that is, to multiple base stations). Particularly proposed and analysed were algorithms that allow duplication of the transmitted data, increasing the probability that such critical data are successfully delivered to the respective terminals. In this context, the developed algorithm involves a proper coordination of the duplicated packets to minimise the overhead introduced by duplicate transmissions.

To handle the management complexity coming with resource multi-tenancy through network slicing, 5G-MoNArch introduced Artificial Intelligence (AI) and Machine Learning (ML) **algorithms for efficient resource orchestration** to relieve human operators and scale to large scenarios composed by thousands of slices in heterogeneous environments. These solutions fit very well with the concept of network elasticity[16]. The work included architectural contributions to relevant standardisation bodies (ETSI ENI).

Testbeds and kpi validation

5G-MoNArch implements the designed architecture and a selection of the developed functions on resilience and security, and resource elasticity, into two testbeds.

The **Hamburg Smart Sea Port testbed** implements a full E2E slicing-enabled mobile macro network including the developed mechanisms on dual connectivity and fault mitigation. The three implemented applications represent typical industrial use cases (cf. Figure 10) with strong requirements on network reliability, resilience and security. The radio base station – installed at the Hamburg TV tower – covers the central part of the Hamburg sea port and connects via optical link to a local control and data plane (edge cloud) at a commercial data centre in Hamburg, and to a central data plane (central cloud) at a commercial data centre in Nuremberg. A local data centre at the premises of HPA hosts the applications to operate the actual use cases (e.g., the traffic light control and sensor monitoring). The testbed includes a full slice lifecycle management

12. M. Shariat et. al, "A Flexible Network Architecture for 5G Systems," Hindawi Journal of Wireless Communications and Mobile Computing, Vol. 2019

13. 5G-MoNArch D2.3, "Final overall architecture," April 2019

14. E. Pateromichelakis, et. al, "End-to-End Data Analytics Framework for 5G Architecture," IEEE Access, March 2019

15. 5G-MoNArch D3.2, "Final resilience and security report," March 2019

16. 5G-MoNArch D4.2, "Final design and evaluation of resource elasticity framework," March 2019

which allows to design, deploy and remove slices in the live testbed within minutes, showcasing the impact of different slice designs and corresponding allocation of network functions to the different data centres on the performance of the implemented use cases. Furthermore, it can be demonstrated that through the network slice isolation, potential performance issues in one slice do not impact the performance on another slice even though they both use the same physical and virtualized infrastructure.

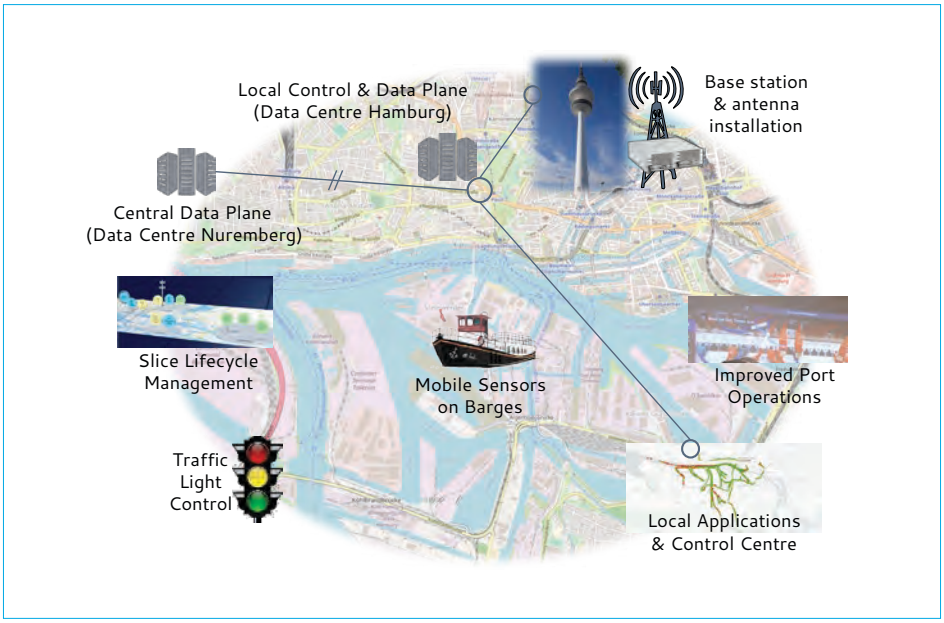

Fig. 10: Smart Sea Port testbed setup

The **Turin Touristic City testbed** demonstrates the benefits of the 5G-MoNArch solutions with a focus on network slicing, mobile edge computing and resource elasticity. The implemented applications represent advanced multimedia and entertainment services for digital tourism services, in particular, an interactive virtual reality visit of a representative room of Palazzo Madama in Turin. The Touristic City testbed consists of several hardware and software modules (cf. Figure 11) designed to provide a flexible and scalable solution, implementing a standard compliant 5G radio interface based on a software-defined radio for physical layer and medium access control, and a slicing-capable implementation of higher layers in the protocol stack. Resource elasticity is achieved through an orchestration module that takes advantage of the network function virtualization over a central and edge clouds. Based on such architecture, the users interact through a virtual reality application that relies on the instantiation of two slices to manage a 360° video stream (enhanced mobile broadband slice with high throughput requirement) and the haptic/voice communication (ultra-reliable low latency communication slice with particular low latency requirement).

To proof the feasibility and benefit of 5G-MoNArch concepts and innovations, a project-wide **verification & validation framework** has been established that defines a set of KPI groups to be evaluated, including system, service, and use-case related as well as techno-economic and application-specific KPIs. The evaluation is based on testbed output as well as specific software tools. Within that framework, network roll-outs in a Hamburg study area based on so-called evaluation cases are handled, to **quantitatively verify** that envisaged

innovations are technically and economically feasible, demonstrate cost reduction potentials with 5G-MoNArch's architecture features, and to identify opportunities leveraging novel services and revenue streams. The evaluation cases[17] include scenarios on resilient network slices for industrial applications, elastic network slices enabling local peak performance, and the integration of resilient and elastic slices into smart city environments.

17. 5G-MoNArch D6.3, "Final report on architectural verification and validation," to be published in June 2019

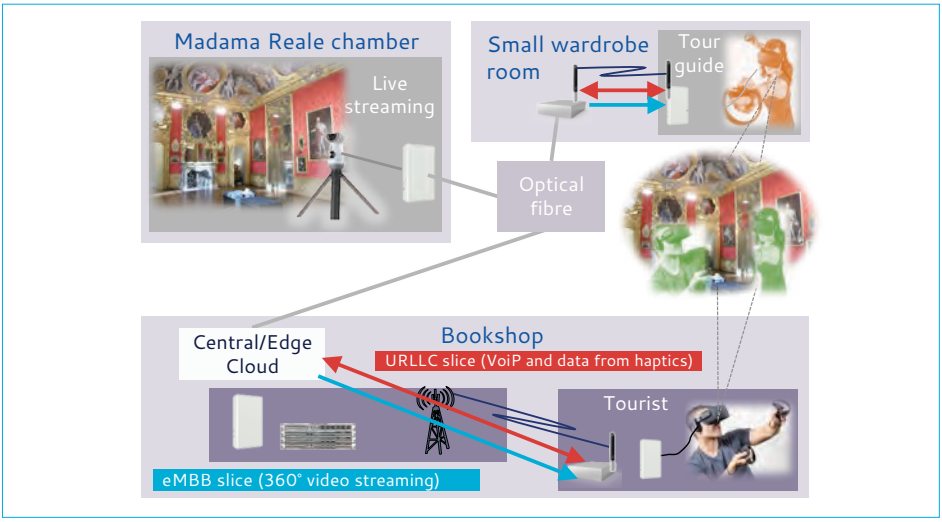

Fig. 11: Touristic City testbed setup

Achieved impact

5G-MoNArch was one of the few projects showcasing its results at the Mobile World Congress both in 2018 and 2019. The project's strong footprint was reflected through winning the 2019 GSMA GLOMO award on 5G Industry Partnership for the Smart Sea Port cooperation partners. The project has been present at EuCNC 2018 and 2019 and at the 2018 EU ICT event, with exhibitions and technical and networking sessions. Well-visited dissemination events in Turin and Hamburg were organised.

A strong focus has always been put on stakeholder interaction (e.g. vertical industries, mobile operators, service providers and equipment vendors, regulatory bodies) – already at an early stage of the project – to gather feedback and validate the achieved results, promote the advantages and features of 5G network slicing in general and the 5G-MoNArch innovations in particular, and to give insights to the testbed implementation and operation. Besides the dissemination at many research conferences and in journals, 5G-MoNArch partners have contributed with multiple project results to standards, in particular 3GPP and ETSI.

With the implementation and the operation of the two testbeds it can be demonstrated that 5G network slicing fulfils the verticals' requirements on service availability, reliability and flexibility in particular, and that new services can be easily and quickly created and deployed. This provides the opportunity for verticals to quickly adapt their communication infrastructure to changing business, and to easily create new business. In summary, with its various activities and strong partner commitment, 5G-MoNArch had a clearly visible impact on the development and socio-economic acceptance of 5G.

5G-PHOS

Goals of the project

5G-PHOS addresses the challenging ultra-dense mm-wave 5G networks encompassing a range of environments with different traffic density and coverage needs. To this end, 5G-PHOS meets the following technical and research challenges: 1) It provides a cost-effective converged Fibre-Wireless Point-to-Multipoint fronthaul specification for 5G mm-wave access networks with immediately commercially exploitable perspectives, 2) Meets the respective 5G User Experience and System Performance Key Performance Indicator (KPI) metrics, 3) Synergizes mm-wave wireless radio and mMIMO antennas to provide increased capacity and link reliability and 4) Demarcates from CPRI-based schemes towards bandwidth efficient Ethernet-based enhanced CPRI fronthaul solutions.

5G-PHOS shapes new network concepts that will be validated in a range of scalable lab- and field-trial demonstrators and introduces new business models and opportunities converting them into tangible market outcomes by its industrial Consortium partners. 5G-PHOS' outcomes will be demonstrated through different network use cases that have the highest probability to enter first the 5G era, tailored to serve the 5G network requirements both in performance as well as in business models and economic viability. 5G-PHOS is also expected to achieve a significant impact on various relevant standardisation groups by virtue of its substantial technological outputs and time-alignment with 5G standardisation and deployment roadmaps. Finally, 5G-PHOS makes a major step forward towards increasing the economic and social wellbeing of European citizens by providing its cost-effective, energy-efficient 5G network solutions for high-density use cases.

Recent major achievements and innovations

During the last year, the 5G-PHOS project has met major milestones in the following tasks:

- **5G-PHOS architectures, topologies, use cases, and KPIs**: The 5G-PHOS architecture and network layouts/topologies for the three use cases under study have been designed, while an innovative methodology for UCs description and traffic modeling has been proposed. The end-user and system KPIs have also been identified.
- **5G-PHOS centralised unit and remote radio head (RRH) prototypes**: The integration process flow for the assembly of the Flexbox and RRH prototypes has been set. The specifications and functionalities of each prototype have been redefined according to the revised demonstration concepts that are targeted in 5G-PHOS.
- **5G-PHOS optical components**: The first generation of TriPleX chips has been designed and manufactured. Mini-ROADMs in TriPleX have been also manufactured and packaged.
- **First evaluation of the 5G-PHOS fronthaul link**: 5G-PHOS has carried out a first evaluation of a high-capacity analogue (Intermediate Frequency over Fibre - IFoF) Fibre- Wireless V-band link relying on the linear high-power Externally Modulated laser.
- **resource allocation algorithms and SDN**: the DSP-enabled IFoF FiWi mechanism has been experimentally evaluated; a novel QoS based medium transparent MAC has been designed; a Coordinated MultiPoint Cooperative Beamforming algorithm has been constructed; a very efficient gated service MT-DBA protocol has been proposed. The first release of the SDN controller the Network Planning and Operation tool have been produced;
- **Demonstration experiments**: Three main demonstrators have been defined, focusing to better showcase the capability of the 5G-PHOS architecture to abide by the 5G capacity and latency specifications in three modern and critical 5G use cases, i.e., Dense, Ultradense and Hot-Spot. The intermediate steps have been carefully decided and agreed upon among the partners so as to ensure the successful outcome of the final demos.
- **5G-PHOS** had its mid-term review meeting on 24-25 January 2019, at the premises of Fraunhofer in Berlin, Germany, where the consortium had the opportunity to display the progress of the work and display a live demo displaying the converged Fibre-Wireless

fronthaul transmission over mm-wave spectrum employing a 32-element beamsteered antenna made by SIKLU and a linear EML made by III-V Lab. You can see the video of the demonstrator here: *https://www.youtube.com/watch?v=tpHWH9FevoM* .

Description of demos

5G-PHOS will carry out three main demonstrators for three modern and critical 5G use cases, i.e., Dense, Ultradense and Hot-Spot:

- **Demo 1**: a PON-overlaid demo for dense area networks, which will be installed over the deployed fibre infrastructure of the Italian telecom operator TIM and will validate the 5G-PHOS CRAN aRoF infrastructure via the delivery of mobile services.
- **Demo 2**: a demo focusing on ultra-dense networks that exploit Spatial Division Multiplexing (SDM), which interconnects 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.
- **Demo 3**: a demo focusing 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 802.11ad 60 GHz WiFi services over 5G-PHOS WDM CRAN infrastructure.

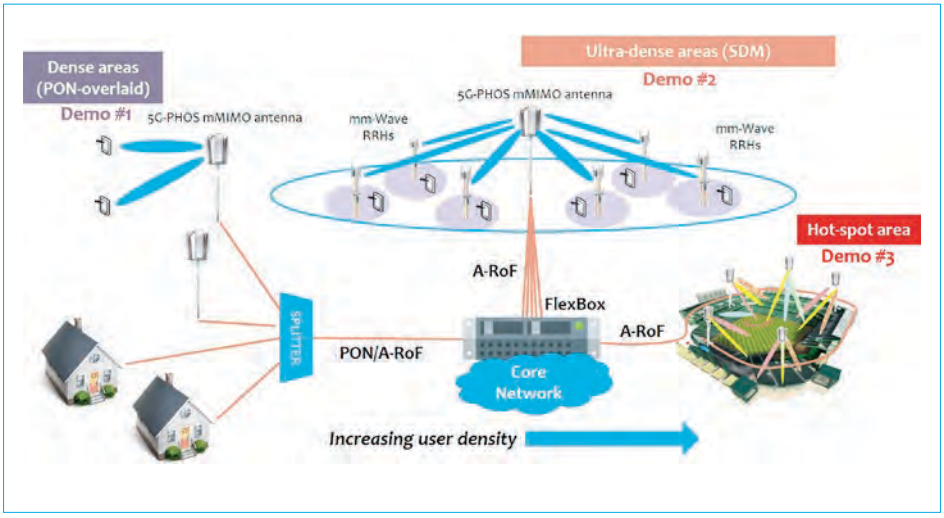

Fig. 12: Schematic representation of the three 5G-PHOS demos

5G-Picture

Goals of the Project

5G-PICTURE designs and develops 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. To address the limitations of current solutions, 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. The 5G-PICTURE solution will allow end-users and third parties to access real or virtual equipment, services, systems and tools on demand regardless of their geographical location. This solution is expected to support any type of service ranging from delay sensitive services (e.g. Virtual Reality services), to from best effort to ultra-reliable applications. This will enable 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.

Major achievements

5G Integrated Transport Networks (FH/BH)

Significant attention has been paid to the development of heterogeneous transport technologies, including wireless, optical and packet solutions, for joint support of BH and FH services. 5G-PICTURE proposes integration of network with compute resources adopting a hybrid model combining compute resources hosted at centralised Data Centres (DCs) and the network edge in accordance to the Mobile Edge computing (MEC) paradigm.

In terms of wireless transport, millimetre wave (mm-wave) solutions are being developed, considering advanced technologies for the access such as massive MIMO. In terms of optical technologies, both passive WDM and active (Time Shared Optical Network - TSON) solutions are being extended to more efficiently support the demanding requirements of transport in converged FH and BH environments. These technologies aim to offer the increased capacity levels combined with the elasticity needed to support service requirements in a scalable and efficient manner.

A dynamic and efficient support of flexible functional split options is one of the key targets of 5G-PICTURE. A novel software API (FlexRAN) and an associated controller have been developed. They allow a Distributed Unit (DU) and a Centralised Unit (CU) to dynamically negotiate the RAN functional split to be used under specific network conditions.

Evaluation studies have been carried out to analyse and benchmark the performance of the proposed architecture. In view of this, mathematical models and simulation tools have been purposely developed and are currently being extended, analysed and tested. The first part of the architecture evaluation has focused on the scalability analysis of the data and control planes. This analysis concentrated on the following topics: scalability analysis of the BBU processing chain, data plane analysis: DA-RAN over elastic optical networks, data plane analysis: integration of WDM-PON and mm-wave, Scalable Service Chaining in MEC-assisted 5G Networks, Scalable Optimization based on Artificial Intelligence and scalable multi-service placement. The second part of the evaluation focused on some initially defined rail vertical use cases. These include: 5G communications to trains and the adoption of Sub-6 GHz LTE Massive MIMO technologies, analysis of the benefits of multi-technology access network solutions in railway systems, Internet of Things in Disaggregated 5G Networks for a rail use case and an initial control plane scalability analysis for the rail environment.

Programmable Hardware

5G-PICTURE tackles an improved portability of HW programming languages via the specification and design of language/target-independent "intermediate representations". The project has identified two types of network functionalities that require different intermediate

representations: stateless and stateful network functions. For the former, these activities include: 1) design of a P4 compiler that will be used to programme high-end ASIC based switches, and 2) development of a design workflow that will allow to include P4 programmable pipelines into FPGA based network devices. For stateful network functions, a domain specific language is being defined for programming that use an Extended Finite State Machines (XFSMs) abstraction to model network functions. Moreover, this allows a platform agnostic description, which gives to the programmer the ability of having a "code-once port-everywhere" code. For the RAN, 5G-PICTURE is developing an extension of the OpenAirInterface (OAI) platform, referred to FlexRAN+, to bring the SDN separation between the control plane and the dataplane in the RAN. The radio data plane can be controlled through a central controller to which every base station (BS) connects through its agent.

Virtual & Physical Functions for: dynamic 5G RAN deployments, transport slicing and synchronisation

The work of 5G-PICTURE in this area involves a multi-tenant compute and transport network infrastructure able to provision RAN functions from different Mobile Network Operators (MNOs), and to deliver synchronisation on demand. 5G-PICTURE is currently developing physical and virtual functions, including support of the RAN protocol stack, virtualization and synchronisation.

5G-PICTURE implements RAN functional splits executed on programmable x86 hardware, based on the OAI framework, including 3GPP splits 8, 7-1, and 6. In addition, a control plane solution has been developed (FlexRAN) that allows to dynamically negotiate the functional split to be used between a Distributed Unit (DU) and a Centralised Unit (CU).

Another part of the work carried out within this topic is the development of slicing capabilities on a set of transport technologies, which include: TSON in the optical domain, Flex-E, X-Ethernet, in the packet domain, and Sub-6 IEEE 802.11 radios in the wireless domain. Several data plane and control plane enhancements have been proposed to deliver slicing for these technologies.

To achieve synchronisation as a service, control plane aspects have been identified as well as suitable synchronisation functions covering specific network technologies, e.g. 802.11ad mm-wave and Sub-6. These have set the basis to ensure that multiple technology domains feature on-path support for frequency and time distribution on a subset of their nodes. The network itself will be able to track the specific component capabilities across the network assuring successful provision of timing distribution services.

E2E Orchestration in Single and Multi-domain 5G Virtualized Networks

In 5G-PICTURE we tackle the problem of interoperating NFV, SDN, and slice management systems for management and orchestration of services and slices on large-scale heterogeneous 5G infrastructures. One of the objectives is related to the integration between control (SDN), NFV and orchestration, enabling service chains in support of different platforms to deploy network functions (such as FPGAs), network slicing and creation of programmable networks exploiting heterogeneous HW.

In view of these, services have been described in the context of network slices, formed from connectivity and network functions, running over heterogeneous networks divided into one or more domains (technology-based or administrative). In addition, the components and interfaces between orchestrators and controllers have been described. Some important interfaces are these between Orchestrator – Controller and Controller – MANO.

5G-PICTURE focuses on the development of an auto-adaptive and cross-concept orchestration, with use of scalable SDN control referred to as the 5G Operating System (OS). The architectural framework of the 5G OS captures possible relationships between three major areas of interest, namely, slicing systems, network controllers, and NFV management and orchestration systems. This framework allows infrastructure providers and operators to extract and deploy the desired operating system to control the heterogeneous, multi-technology and multi-domain infrastructure and manage slices and services on top of the infrastructure.

The project has designed and developed prototypes that enable the multi-domain orchestration, using state-of-the-art NFV orchestrators, VIMs and SDN controllers, such as the OSM, OpenStack and OpenDayLight (ODL) platforms. In particular, open proxies for the communication between OSM and OpenStack have been

developed, as well as between OpenStack and ODL, to extend the functionality of the aforementioned platforms to the multi-domain and cross-concept notions. Different ongoing and planned prototyping scenarios have been described, which are designed as proof of different concepts covered by the 5G OS. These concepts include orchestration of 1) multi-version network services, 2) connectivity and function in fixed and wireless networks, 3) multiple controllers and NFV MANO systems, 4) RAN, CN, and edge domain controllers, and 5) TSON in the optical transport network.

Results focusing on the controller placement problem, providing a scalable network control solution have been produced. We have investigated how many controllers need to be placed in different parts of a network, considering the control traffic among different controller instances as well as the control traffic between controllers and switches.

Description of the demos

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

- A **smart city** environment available in the 5GUK testbed in Bristol, UK. This testbed aims 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 fronthaul and backhaul services as well as Public Safety and Virtual Reality applications will be demonstrated over a variety of optical and wireless transport technologies as well as computing facilities (see Figure 13).
- A 5G **railway** experimental testbed showcasing seamless service provisioning and mobility management in high-speed moving environments in Barcelona, Spain. The combination of mm-wave radio links (as a channel for high quality mobile broadband) and passive WDM (which provides point-to-point logical connections through a physical point-to-multipoint network topology) results in the most appropriate technology for building a new communications infrastructure for railway infrastructures. The Train Access Network (TAN), targets to offer a broadband transparent connection between the railway track and the trains passing through it. This new network solves the traditional limitations in performance (throughput, latency) related to train mobility (see Figure 14).
- A **stadium** with ultra-high user density, supporting media services Bristol, UK. The objective of the various demonstrations in the mega-event/stadium is 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 for WiFi, and 4) High capacity wireless access technologies: Massive MIMO (see Figure 15).

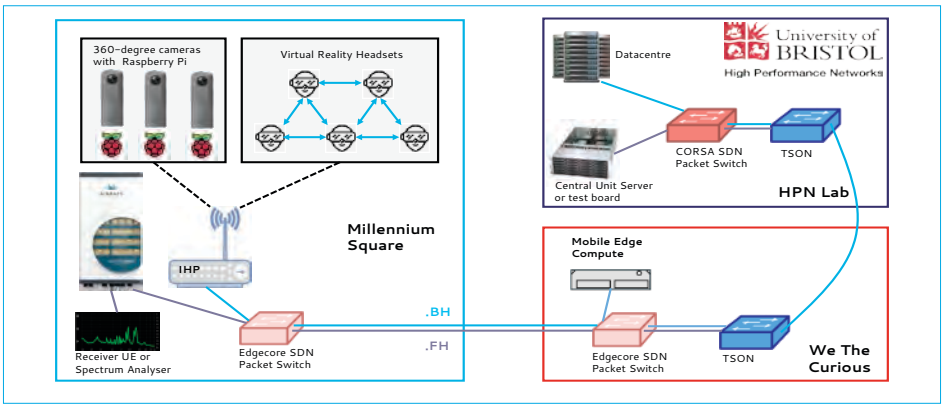

Figure 13: 5G-PICTURE Vertical Demonstration Activities.

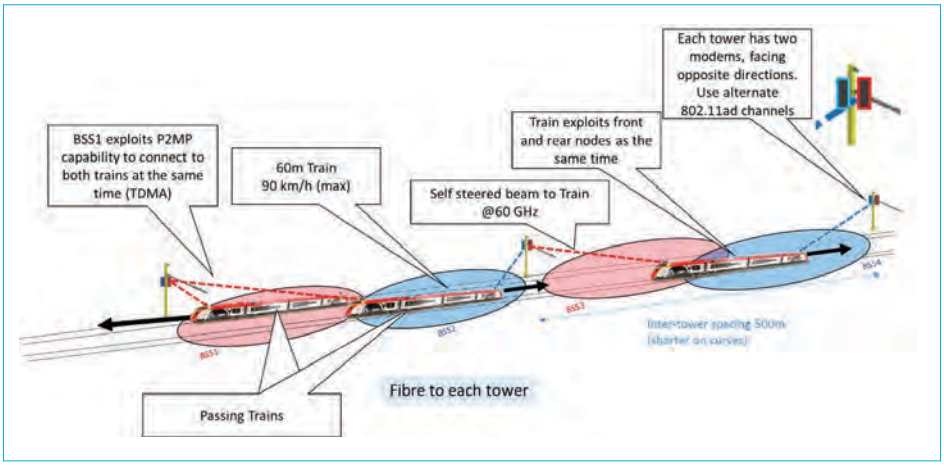

Figure 14: 5G-PICTURE Vertical Demonstration Activities.

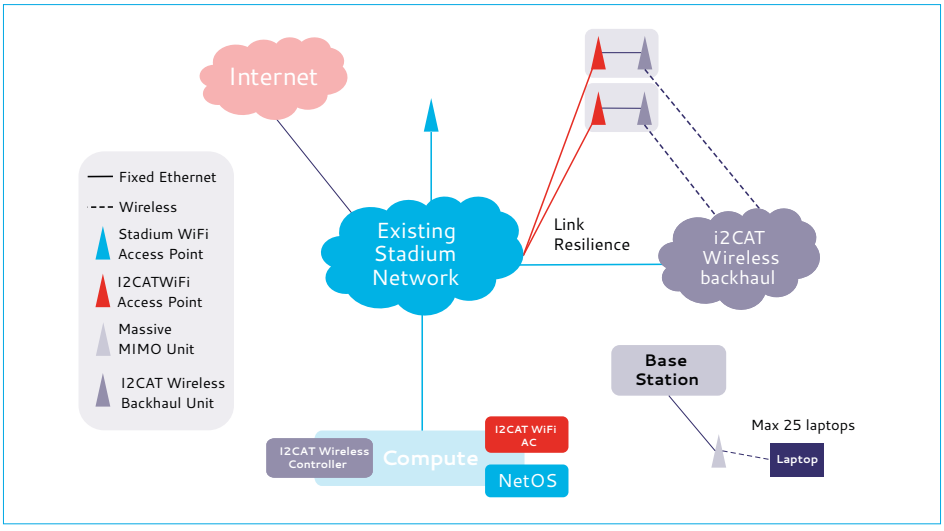

Fig. 15: 5G-PICTURE Vertical Demonstration Activities.

5GTANGO

Goals of the project

5GTANGO is a 5GPPP Phase2 Innovation Action that enables the flexible programmability of 5G networks by delivering an integrated NFV Service Platform (SONATA), which includes: a) an NFV-enabled Service Development Kit (SDK) to facilitate for developers the creation of innovative Network Services (NS) and applications; b) a Validation and Verification (V&V) Platform with advanced qualification mechanisms for VNFs/NSs, including 3rd party contributions); and, c) a modular Service Platform with an innovative orchestrator to bridge the gap between business needs and network operational management systems. 5GTANGO implements a DevOps (Development-Operations) model for Telecom that enables the agile management of the complete lifecycle of NSs, increasing the productivity, reducing the time to market of services and allowing the creation of an ecosystem to encourage collaboration and innovation.

Major achievements

During EuCnC 2018, 5GTANGO presented the first demo of the novel V&V Platform running a first set of automated tests on top of a network service being deployed with SONATA Service Platform. First project results were also presented as regular papers.

In September 2018, 5GTANGO project announced the release 4.0 of SONATA NFV platform. 5GTANGO has taken over the work of its predecessor SONATA project and keeps upgrading and extending the SONATA NFV Platform´s capabilities. This was the first major release since the finalization of SONATA project. As its main novelty, the V&V Platform is a key element to support the DevOps model in NFV. Other new features of this release include network slicing, policy and SLA management support.

In December 2018, Open Source MANO (OSM) presented its release FIVE, which included three 5GTANGO main contributions:

- VIM Emulator (vim-emu): 5GTANGO vision is to create an easy-to-use and easy-to-deploy NFV prototyping platform. The main feature that has been incorporated in the scope of 5GTANGO is the emulation of large multi-PoP (Point of Presence) NFVI scenarios. In Release FIVE, integration with OSM has been improved.
- Advanced NFV package format and tools: Extensions to ETSI NFV SOL004 where suggested where needed.
- Network Slicing Network: Slicing has been proposed to improve the existing network infrastructure resources usage and management. This is a key element in the future 5G networks, and it has been contributed from 5GTANGO to OSM.

Finally, during MWC19, 5GTANGO showed pilot functionalities in the Mobile World Capital booth with demos of two of its pilots, the communication suite and the immersive media ones.

Description of demos

The communications demo shows all the steps needed to deploy a collaboration system for real-time communications over 5GTANGO NFV Platform. 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. 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.

The immersive media demo showcases how 5G networks will enhance the experience of end users regarding media services by improving their immersiveness into multiple 360° and non-360° video streams and even the integration of their social media channels. This will allow, for example, end users to enjoy sports events in a new dimension. The SONATA Platform hosts the VNFs required to run these services with minimal hardware requirements from the end user devices. The demo leverages the automatic deployment and management of the Network Service components for a seamless experience maintaining a low latency at the same time.

The smart-factory pilot focuses on three use cases related to industry, each highlighting different aspects and benefits introduced by the use of 5GTANGO. A user story is used to introduce the use cases and roles involved. It is focused on creating a novel network design for a factory.

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.

5G-Transformer

5G-TRANSFORMER (5G Mobile Transport Platform for Verticals)

The telco ecosystem is living a revolution driven by the needs and the requirements of vertical industries, such as automotive, e-Health, media, and Industry 4.0. Supporting the use cases proposed by these new players is opening unprecedented new business opportunities.

To satisfy this challenge, 5G-TRANSFORMER (*http://5g-transformer.eu/*) has proposed an innovative architecture based on **SDN/NFV as foundations to provide dynamicity, automation and programmability capabilities to today's rigid mobile network**. Furthermore, 5G-TRANSFORMER uses **network slicing, multi-access edge computing (MEC), and service federation** concepts as key enablers to manage networking and computing resources tailored to the specific services of vertical industries.

Figure 16 shows the architecture defined by 5G-TRANSFORMER, which is based on three main building blocks:

- The **Vertical Slicer** (5GT-VS), as the entry point for the vertical to request a service, while performing network slice management.
- The **Service Orchestrator** (5GT-SO), responsible for end-to-end orchestration of services across multiple heterogeneous domains.
- **The Mobile Transport and Computing Platform** (5GT-MTP), acting as the manager of the underlying integrated fronthaul and backhaul transport network consisting of storage, computing and networking resources.

Furthermore, a transversal **Monitoring platform** is in charge of handling performance monitoring jobs, as requested by the services, and triggers real-time adaptation actions (e.g., scaling in case of resource shortage).

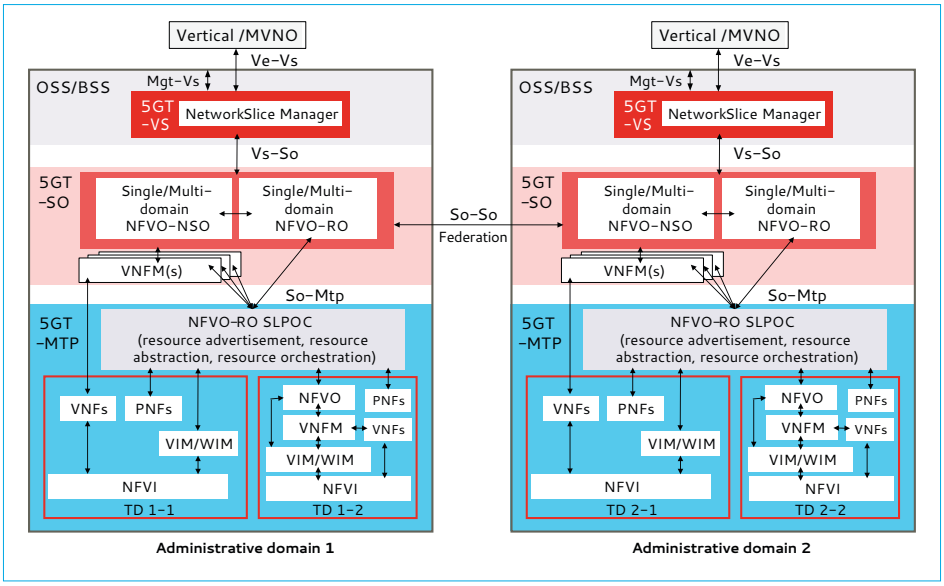

Fig. 16: 5G-TRANSFORMER reference architecture

After the initial definition of the architecture depicted in Figure 8, the work developed during the second year of the project has been focused on the development and refinement of such architecture. 5G-TRANSFORMER partners have followed the suitable procedures and recommendations of the ETSI NFV working group to define intra-block workflows and inter-block interfaces while using open source solutions to increase the scope and the interoperability of the 5G-TRANSFORMER system. It is worth mentioning that the 5G-TRANSFORMER project has proposed extensions to also cover the interaction with WAN infrastructure managers (WIMs), thus introducing a set of messages for the advertisement of network topology and the request of network paths to interconnect Points-of-Presence (PoPs) with a given Quality of Service.

Each building block presents a number of **technological innovations**. In particular, the 5GT-VS defines Vertical Service blueprints and descriptors and contains a network slicing management sub-module which has attracted the interest of other 5G PPP projects. The 5GT-SO building block presents a flexible architecture allowing the interaction with multiple open source NFV Management and Orchestration (MANO) platforms (e.g., OSM and Cloudify), the integration and selection of multiple external placement algorithms, and the easy addition of new features. The 5GT-MTP building block provides a powerful plugin system to integrate different kinds of Virtualized Infrastructure Managers (VIMs) and Wide Area Network Infrastructure Managers (WIMs) while providing appropriate resource abstraction to facilitate network service orchestration operations. Thanks to this, the work carried out in 5G PPP Phase 1 project 5G-Crosshaul on network resource orchestration of multi-technology deployments is integrated.

Several **demonstrations** at different relevant venues, such as EUCNC'18, SIGCOMM'18, ECOC'18, IEEE NFV_SDN'18, ICT'18, OFC'19 has shown the progress of the development task. (Videos of the demonstrations are available at *http://5g-transformer.eu/index.php/dissemination/video-gallery/*) These demonstrations were done in collaboration with the vertical partners present in the consortium. They showed different aspects of the 5G-TRANSFORMER architecture, such as the creation of network slices or the orchestration of network services in hybrid clouds. Especially relevant is the demonstration performed during the ICT'18 congress. In this demonstration, 5G-TRANSFORMER partners showed the first integration of the

proposed architectural stack to deploy a slice where a network media service was instantiated. Measurements confirm that the coordinated operation of the 5G-TRANSFORMER building blocks contributes in reducing service creation time to the order of minutes.

Concurrently to the development tasks, the **vertical** partners participating in 5G-TRANSFORMER have been developing its **use cases** to define and to plan the different trials to verify the innovative concepts that have been put forward by 5G-TRANSFORMER. In particular, 5G-TRANSFORMER covers the following vertical industries: **automotive, e-Health, Media Provider, Industry 4.0 and Mobile Virtual Network Operator (MVNO)**. Vertical partners are also providing valuable feedback to enhance the proposed architecture with the addition of new functionalities planned for the next code release. The most advanced and relevant new functionalities that are being developed for the next release are dynamic service composition, multi-domain service federation, and manual and automated scaling.

5G-TRANSFORMER has contributed to relevant **standard bodies** (and groups therein), such as IETF DMM, IETF DetNet, IETF SFC, IRTF NFVRG, IETF CCAMP, ETSI NFV IFA, ETSI MEC (including the creation of MEC 024). Furthermore, 5G-TRANSFORMER has participated in the ETSI white paper "MEC in 5G networks", where the deployment and integration of MEC in the 5G system is illustrated.

5G-TRANSFORMER source code has been released under Apache 2.0 licence and it is publicly available at *https://github.com/5g-transformer*. It has tight integration with open source projects like OSM, Cloudify, or Openstack.

5G-Xcast

Project goals

5G-Xcast is a 5G PPP Phase 2 Horizon 2020 European project focused on devising, assessing and demonstrating a conceptually novel and forward-looking 5G network architecture for large scale immersive media delivery. The project goals are:

- To develop broadcast and multicast point to multipoint (PTM) capabilities for 5G considering Media and Entertainment (M&E), automotive, Internet of Things (IoT), and Public Warning System (PWS) use cases.
- To design a dynamically adaptable 5G network to dynamically and seamlessly switch between unicast, multicast and broadcast modes or use them in parallel and exploit built-in caching capabilities.
- To experimentally demonstrate the 5G key innovation developed in the project for the M&E and PWS verticals.

Project achievements

Leveraging on the comprehensive Radio Access Network (RAN) benchmarking of state-of-the-art PTM technologies including 3GPP Release 14 eMBMS (evolved Multimedia Broadcast/Multicast Service) and ATSC 3.0, WP3 has proposed a holistic 5G Broadcast PTM RAN solution, including the radio interface, RAN architecture and radio access technology (RAT) protocols. WP3 has investigated the 3GPP Release 15 New Radio (NR) and extended the air interface to PTM communications. Two specific 5G PTM technologies, namely Mixed Mode and Terrestrial Broadcast Mode, are proposed in order to fulfil the different 3GPP requirements needed for broadcast and multicast. WP3 has designed a logical architecture to deploy flexible multicast RAN that can support the same services as the existing broadcast networks as well as to remove limitations concerning the specifications in LTE. WP3 has been carrying out investigations on the 5G-Xcast RAT protocol and Radio Resource Management (RRM) design which targets resolving RAT protocol limitations of the LTE eMBMS that impose constraints on the RAT technical requirements and fulfilling the NR RRM functional requirements. WP3 has also been working on prototyping the selected 5G-Xcast radio access techniques for demonstration and proof-of-concept (PoC).

WP4 describes the key drivers, benefits and use cases for full network convergence. After analysing the limitations of the LTE eMBMS technology and identifying the additional building blocks in 5G architecture, WP4 has proposed architectural alternatives and their supporting call flows to enable multicast and broadcast capabilities based on 5G architecture specified in 3GPP release 15. WP4 has also discussed an evaluation of current methodologies for providing partial network convergence, as well as highlighting some of their limitations. Based on 5G-Xcast architectural alternatives in mobile core network, WP4 has also proposed different alternatives for converged fixed-mobile 5G core network with different convergence points applied for different deployment options. WP4 has defined the work flows aligned with the 3GPP specification in release 15 to enable the use cases and fulfil the requirements defined within the project. WP4 has identified an enhancement of PDU session modification to enable the multicast delivery inside the 5G network. In parallel, WP4 has also defined the multicast/broadcast session using PTM services. WP4 has been working on the PoC where the public warning message including multimedia content can be delivered to mobile devices using two bonded channels whereby one channel is dynamically allocated through multilink.

5G-Xcast is involved in the 5G IA IMT-2020 Evaluation Group for the ITU-R evaluation process for Radio Interface Technologies (RITs). Different radio interface aspects are being analysed with respect to different Key Performance Indicators (KPIs): peak data rate, peak spectral efficiency, user experienced data rate, 5th percentile user spectral efficiency, average spectral efficiency, area traffic capacity and mobility. The results will be included in the 5G IA IMT-2020 Evaluation Report, planned to be submitted by February 2020.

Demonstrations and field trials

5G-Xcast is advancing on trials and demonstrators. The project is integrating functional innovations to trial selected use cases on M&E and PWS for its three testbeds. The testbed in Turku is under development to allocate trials on public warning and spectrum management to send public warning multimedia alerts to the user

equipment (UE). Surrey testbed in 5GIC is being adapted to trial the paradigm of Object-Based Broadcasting where the UE can composite the media content delivered in the form of multiple objects. The Hybrid Broadcast Service combining live TV with ad-hoc content has been the framework of the showcase in Munich urban area related to the European Championships 2018. The project has conducted successful demonstrations at relevant events such as EuCNC and IBC during 2018, and the MWC in 2019 (Figure 17).

Fig. 17: 5G-Xcast live demonstration

Conclusion

5G-Xcast has achieved exceptional results during chasing the project goals in devising, assessing and demonstrating the conceptually novel 5G broadcast and multicast technologies for large scale immersive media delivery and other use cases. The comprehensive solution to enable broadcast and multicast in 5G wireless communication is proposed, verified and demonstrated. In the aspect of RAN, the 5G air interface, logical architecture, RAT protocols and RRM supporting broadcast and multicast are specified to support two specific PTM technologies: Mixed Mode and Terrestrial Broadcast. In the aspect of CN, architecture alternatives are devised and network convergence specified to enable efficient multicast and broadcast PDU session and content delivery. Those results provide a strong boost to standardisation for 3GPP new releases on relevant topics and furthermore, to the significant activity of IMT-2020 KPI evaluation for ITU-R, in which 5G-Xcast is actively participating. Multiple PoC and trials have been carried out and the project results are demonstrated in a number of major events such as EuCNC, IBC and MWC to show the 5G-Xcast excellence.

blueSPACE Concept and Goals: Space Division Multiplexing 5G Fronthaul with Analogue and Digital 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[18].

The adoption of the spatial domain in the optical distribution network (ODN) directly increases capacity manifold and adds an additional degree of freedom to support increased flexibility or larger splitting ratios. SDM is further ideally suited to supporting multi-operator and multi-service scenarios by allowing a large number of independent parallel channels on a shared infrastructure with reduced footprint.

Optical beamforming as introduced by blueSPACE, 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. Using integrated photonics for optical beamforming allows the implementation of full matrix-type beamforming networks with large available bandwidths within a reduced footprint and at reduced power consumption.

Through the combination of SDM and ARoF with optical beamforming, as shown in Figure 18, blueSPACE is capable of supporting massive and dense deployments of small cells, while maintaining fully centralised processing and control and thus maximizing the potential gain from virtualization in the access segment. To this end blueSPACE develops a software defined networking (SDN) and network function virtualization (NFV) framework adapted to the introduction of SDM and supporting both digitized and analogue RoF transmission as well as optical beamforming[19].

The project goals address a number of challenges in 5G networks, based on the technologies introduced by blueSPACE. First, capacity is addressed with regards to both the capacity of the fronthaul network, i.e., the number and density of cell sites that can be supported and their respective bandwidths, as well as the capacity in the radio access. To this end, blueSPACE adapts both DRoF and ARoF fronthaul to SDM networks based on multi core fibres (MCF) and supports the maximum bandwidth available in the new mm-wave spectrum assignments for 5G NR. Second, beam forming and steering are addressed through the design of optical beamforming networks for multi-beam transmission and an efficient interface between the SDM fibre medium and the radiating antenna elements. Third, latency will be minimized through increased resource centralization at the central office (CO) with optimum resource assignment and shared, virtualized pools for baseband processing. Fourth, improving network control and management, blueSPACE will implement its infrastructure to be fully reconfigurable by means of SDN and NFV orchestration and will provide full awareness of the SDM fibre medium, the differences between ARoF and DRoF as well as the opportunities given by optical beamforming. Finally, blueSPACE will design its architectures and hardware solutions with their facility for 5G in mind, that is, the project will design compact and cost and energy efficient hardware for ARoF transceivers, optical beamforming networks, and SDM adapters, enabling a scalable SDM radio access network architecture, while supporting network slicing, SDN control and network function virtualization.

18. *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*

19. *S. Rommel et al., "High-Capacity 5G Fronthaul Networks Based on Optical Space Division Multiplexing," IEEE Transactions on Broadcasting, Special Issue, Mar 2019, doi:10.1109/TBC.2019.2901412*

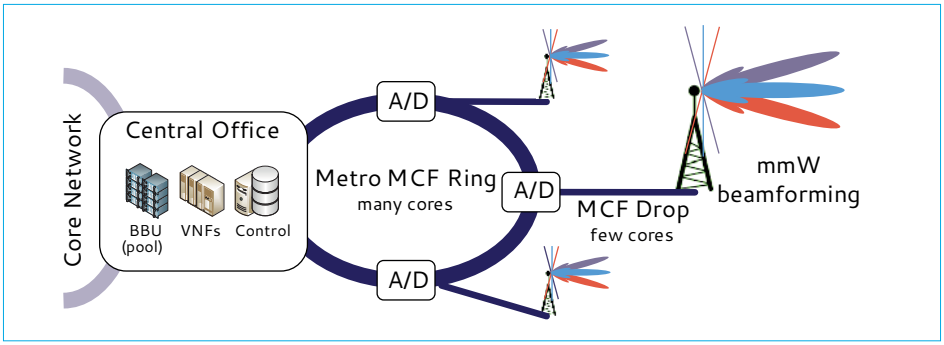

Fig. 18: blueSPACE concept and architecture overview.

blueSPACE Key Achievements

By the end of its second year, blueSPACE has successfully completed its study of requirements and design options for its physical architecture, involved subsystems and the overall fronthaul network[20]. As a result, the project has presented a number of design directives for ARoF fronthaul and discussed possible network architectures and deployment options for SDM based fronthaul as well as their respective capacity and scalability.

With regards to the hardware development of the project, final sets of requirements and specifications have been produced and initial design options evaluated. A subset of design options has been selected for fabrication and detailed evaluation and the first samples are currently under test. Specifically, blueSPACE has designed and will manufacture and test the required hardware for a full ARoF link over MCF, starting with an ARoF base band unit (BBU) designed to allow operation with the large bandwidths available to mm-wave 5G NR, via photonic integrated ARoF transceivers and optical beamformers as well as spatial multiplexers, to a complete radio frontend and antenna array at the remote site. With its designs finalized, initial samples currently under test and the final components in fabrication, blueSPACE looks to demonstrate the advantages of ARoF based on the project's developments.

The design and implementation of the blueSPACE SDN and NFV platform, designed to manage the SDM fronthaul network and the specific components developed in the project, has progressed to a similar point. i.e., design and specification of the SDN and NFV platform and supported functionality have been successfully completed and are currently being implemented.

blueSPACE has identified a number of use cases and analyzed their requirements in order to define its key performance indicators (KPIs). The project has defined its planned demonstration activities and roadmap towards demonstration of developed technologies.

Finally, blueSPACE has actively engaged with other 5G PPP projects for the organisation of joint dissemination and outreach activities, including the joint organisation of multiple workshops. A joint demonstration and further collaborations are currently in planning and expected to take place before the end of 2019.

blueSPACE Use Cases, KPIs and Demos

blueSPACE has selected four use cases where requirements include high data rates, large user density and low latency, in order to show the advantages and applicability of its technologies. First, by supporting both large bandwidths at mm-wave and concurrent multi-beam transmission via its optical beamforming networks, the solutions offered by blueSPACE are well suited to fixed wireless access. Second, blueSPACE considers broadband access in crowded areas, as with large bandwidths, low latency and multiple independent and flexible beams, it can not only provide the required capacity for massive numbers of users, but also dynamically tailor its distribution based on actual requirements. Third, indoor ultra-high capacity broadband access is considered, where, e.g., in smart office spaces, massive data rates must be supplied

20. blueSPACE Consortium, "Physical architecture, system and network requirements," Deliverable 2.2, Aug 2018.

wirelessly, while minimizing latency to enable direct interaction during video or holographic conferencing. Finally, blueSPACE considers the use case of Industry 4.0, where latency critical and bandwidth hungry services need to coexist or for some applications may even coincide. By introducing ARoF fronthaul blueSPACE minimizes latency by avoiding the need for digitization and digital transport and in combination with optical beamforming and SDM supports unprecedented levels of capacity.

To allow evaluation and comparison of its achievements, blueSPACE has identified six relevant key performance indicators: 1) the peak data rate achievable when assigning all radio resources to a single mobile station, 2) the data volume (or area traffic capacity) offered by its network over a geographic area, 3) the energy efficiency of its ARoF fronthaul network, 4) the service deployment time achieved via its integrated, SDM aware SDN and NFV platform, 5) low latency support via its ARoF fronthaul, and 6) the spatial efficiency of spectrum usage, where the concurrent multi-beam transmission and reduced emissions in unwanted directions achieved by optical beamforming allow a much denser spatial reuse of spectrum.

In order to demonstrate the advantages of the technologies developed in the project, blueSPACE is planning a series of demonstrations, initially demonstrating the separate technologies on their own, before combining them towards the end of the project for an overall project demonstration. The initial demonstrations include demonstrations of both DRoF and ARoF fronthaul over MCF, of the integrated SDM aware SDN and NFV platform, of the remote power delivery over fibre concept and of optical beamforming. The final demonstration will bring together parts of all these 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 develops 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 ITU's 5G global standard.

VLC Receiver: the EVM was tested with or without digital compensation, and the peak throughput. With digital compensation, the EVM is 3.0% with 40 cm measurement distance. Without digital compensation, the EVM is 6.84%. The measured throughput with QPSK, 16QAM, 64QAM and 256QAM are 7.5Mbps, 16.02Mbps, 29Mbps and 36.2Mbps separately. The commercial receiver provided by Tsinghua performs better that that provided by Oledcomm. The first is equipped with an avalanche photodiode (ADP) while the second by a low-price PIN photodiode. New tests to estimate SNR at different frequencies were carried out by ISEP and Oledcomm to find the origin of Oledcomm's Rx. The variable gain amplifier was replaced by two modules of linear amplifiers in cascade that fit for the use cases in this project. The lens manufactured by Oledcomm and integrated on the PIN surface proved to perform 6dB better that the lens integrated by the PIN manufacturer. The SNR performance of the enhanced VLC Rx

outclasses the commercial receiver by at least 15 dB, at the same time it broadens the spectrum at least 10 MHz (at 180 cm). The last advantage when compared to the commercial Rx is that Oledcomm's concentrator has a higher acceptance angle as it was designed for that.

60GHz mm-wave: The initial experiments were performed at 60GHz frequencies. The final experiments will be done in one of the mm-w 5G bands (n257, n258, n260, or n261). The initial experiments were performed in a (length, width, height) indoor scenario. By default, the distance and the angle between transmitter (TX) and receiver (RX) antennas are and (facing each other). With the default setup, the best EVM of PDSCH is 6.5% with 18dBm TX gain that can satisfy the 64QAM decoding requirement, while the best EVM of PBCH is 3.3% with 22dBm. For the different bandwidths, the lower bandwidth can have a better EVM. The EVM of PDSCH with 10MHz and 100MHz bandwidth are 3.54% and 6.03%. The trend of EVM are similar to PBSCH, but with lower values. Besides EVM, we also measured the throughput of PDSCH;the maximum can reach 310Mbps with 64QAM and 873/1024 code rate. After benchmarking, the effect of different distances and angles are tested. The best EVM of PDSCH at 7m, 3m and 1m distances are 6.51% with 18dBm TX gain, 8.17% with 13dBm and 13.83% with 13dBm separately. At 1m, the EVM results are all around 14% with 8dBm, 13dBm and 18dBm. For PBCH, the best results are very close at each distance with 8dBm, 13dBm and 18dBm TX gain, which are around 14%, 8% and 5%. For different angles of TX and RX antennas, the best EVM is obviously with and is 6.33%. In addition to , if the TX angle is and the RX angle turns its direction within , the EVM can be still around 8%.

User Equipment (UE): For the UE, the cell search is done and the sync channel support multiple SSB blind decoding. The L1 progress of downlink is listed as: 1) PDCCH: common/ UE search space, interleaved/non-interleaved CORESET, semi blind detection; 2) PDSCH: dynamic decoding using DCI information, 256QAM at 35dB SNR ~590Mbps, Uplink control channel.

For the uplink, they are: 1) Uplink preamble: test vector based; 2) Uplink control channel (PUCCH): support ACK/NACK feedback; 3) Uplink data channel (PUSCH): scheduled by DCI, support open-loop test, support 256QAM

Layer 2 Protocol Processing: About L2 processing, we defined the L1 and L2 interface at base station side. And based on the definition, the related programme was also implemented. Because the mm-wave uplink is not ready, the current version of definition only involves the mm-wave and VLC downlink. Due to the agreement we made before, the L1 and L2 of the base station side are communicated with each other by UDP packets through the Ethernet. Therefore, the transmission sequence in each slot is defined. Additionally, the three different types and sizes of data carried by the UDP packet are also defined. At the end, the interface downlink processing is also introduced. Based on the definition, the related programme is developed. The next step is to test the programme to ensure L1 can receive the correct data.

Multisource Streaming and Transcoding VNF: Two Virtual Network Functions (VNFs) have been developed, namely Multiple-Source Streaming (MSS) and ffmpeg transcoding, and have been integrated into the IoRL SDN/NFV environment to operate jointly for the benefits of reliability and efficiency at application level that there is now one seamless mechanism to create video segments from video data transcoded in numerous different qualities; such a process is typically subject to two independent VNFs. Instead, our single-unit transcoder/ MMS can simultaneously 1) create sub-flows of transcoded video data, 2) stream them from different external sources, and 3) transmit from the MSS to the users either through radio or light links. We performed laboratory experiments considering triggering events of a congested bottleneck at the VLC access links of the home users to show that the joint transcoder/ MMS algorithm improves the trade-off between the luminance, contrast and structural terms of the transcoded data, thereby increasing the structural similarity index of the video, while transmitting in less bitrate via WiFi. This is particularly useful for the IoRL system to guarantee delivering high quality videos to users even in the case of unexpected VLC link cutoffs, which is natural to occur in the Radio Light system.

NFV/SDN Load Balancing VNF: A major challenge in the integration of the IoRL system is to limit potential QoS/QoE degradation caused by line-of-sight (LoS) misalignment and/or propagation path obstructions between VLC transmitters and receivers. To address this challenge, we have developed a VNF that can

balance the network traffic load by means of switching from VLC to WiFi access in case LoS and/or misalignment occur, and we name this VNF as Load Balancer (LB). The LB uses feedback loop to capture the luminance intensity each user is exposed to, and redirects the traffic load of users with poor VLC link quality to WiFi routes using 4 virtual switches deployed in the IoRL SDN/NFV environment. Particularly, a Ryu virtual controller is responsible for installing flows and routes at the SDN switches through southbound interface. Also, the controller communicates with an LB Application (LBA) through Restful API for remote monitoring and configuration of the instantaneous traffic over both VLC and WiFi links, i.e., Ryu and LBA are standalone applications running on the same host. Furthermore, we have evaluated the LB solution using Mininet simulations considering a large-scale system setting of 50 pairs of virtual iperf servers and users, where each user requests heterogeneous load randomly over time. The results confirm that LB allocates at least the minimum QoS required by users under VLC link cutoffs, while increases the system throughput overall by approximately 3.5Mbps compared to non-LB deployment. It should also be noted that the traffic steering from VLC to WiFi, and vice versa, demonstrates good reaction to changes with average responsiveness of 1.2 sec, which is encouraging for further improvements.

Follow-Me TV VNF: A new service to improve QoE for IoRL clients, by using an SDN concept of configurable traffic routing reactively, and NFV technology for enabling flexible service deployment, as well as exploiting the huge bandwidth, and location estimation accuracy has been developed using IoRL system[21]. This new service for IoRL clients enables them to continue watching a video stream of their choice on the nearest TV set of their current location within the home. Secondly, it proves the ability of the IoRL system to accommodate multiple services that provides higher QoE for its clients due to its flexible and intelligent design. The system tests showed high QoS performance parameters (zero packet loss due to route switching, very high throughput and 0.03 ms jitter). The current service performance tests were performed by emulating the RAN network since it is in the development stage, as well as assuming the video contents exist in the local cache server.

Multicast Sharing Service (MSS): is a VNF based service offered to IoRL small cell clients. It exploits the location information accuracy of the IoRL to enable UEs to share video contents to other UEs by utilising the network infrastructure rather than their smartphone capabilities. MSS allows two modes of sharing namely: location based and subscription based sharing. In location based sharing UE determine the radius of media sharing for subscribed UEs, while in subscription based sharing, UE share media regardless of the physical distance between the host UE and the listener UE as long as they are both covered by the same IoRL network. MSS utilises Software Defined Networking (SDN) to manage the forwarding of the flows intelligently based on the preselected forwarding criteria (e.g. location, subscription)[22].

VLC Indoor Location Estimation: a VLC-based 5G IoRL localization service protocol and the experimental testbed was developed. The TDM-OFDMA based scheme was used and the 5G NR frame was adapted to enable the localization service as well as the data transmission service for the future IoRL system. The preliminary results show that the proposed scheme is able to provide an average positioning error of less than 15cm in a simple, easy way[23].

The IoRL portable demonstrator is being built which consists of a 5G multi-component carrier, Frequency Division Duplex (FDD) broadband system for buildings consisting of a VLC downlink channel in the unlicensed THz spectrum and mm-wave TDD up/downlink channels in unlicensed or licensed parts of the 30-300 GHz spectrum. The objective of the demonstrator is to present the principle of operation of the main concepts of the IoRL architecture to vertical industries in particular the communications and building Industries at EU-CNC 2018 in Valencia, Spain.

21. Nawar Jawad, Mukhald Salih, Kareem Ali, Benjamin Meunier, Yue Zhang, Xun Zhang, Rudolf Zetik, Charilaos Zarakovitis, Harilaos Koumaras, Michail-Alexandros Kourtis, Lina Shi, Wojciech Mazurczyk and John Cosmas "Smart Television Services using NFV/SDN Network Management" Accepted IEEE Transactions on Broadcasting special issue on 5G

22. Nawar Jawad, Mukhald Salih, Kareem Ali, Benjamin Meunier and John Cosmas "Indoor Unicasting/Multicasting service based on 5G Internet of Radio Light network paradigm" Accepted BMSB2019 Jiju Island Korea June 2019

23. Lina Shi, Xun Zhang, Andrei Vladimirescu, Yue Zhang, Jintao Wang, John Cosmas, Adam Kapovits "5G Internet of Radio Lighting Location-Based Service protocol and testbed" Accepted BMSB2019 Jiju Island Korea June 2019

To fill the integration gap between the digital systems that enable enhanced cloud-native services and the network layer, MATILDA provides tools for the design and development of 5G-ready applications, based on cloud-native/microservice development principles, the separation of concerns between application and network services, and the specification and management of application-aware network slices. The latter are realised by the Network and Computing Slice Deployment Platform (NCSDP, in charge of the telecommunications infrastructure provider), whereas the deployment and runtime management of an application is realised by the MATILDA vertical application orchestrator (in charge of the service provider), following a service-mesh-oriented approach. The NCSDP includes an OSS/BSS system, an NFVO and a resource manager handling the set of deployed Wide Area and Virtual Infrastructure Managers (WIMs and VIMs). Based on the interpretation of the provided slice intent, the required network management mechanisms are activated and dynamically orchestrated.

During the second year of the project this service and functional separation concept has been clearly reflected into the final architecture, whose main elements, shown in Fig. 19, are currently all under development. An original solution has been adopted for the integration of the 5G vApps into the 5G ecosystem at the VIM-level, by keeping the tenant spaces of each vApp and NFV/Mobile Edge services in each datacentre, so that each orchestrator has its own isolated resources, quotas, external networks, etc., as illustrated in Fig. 20.

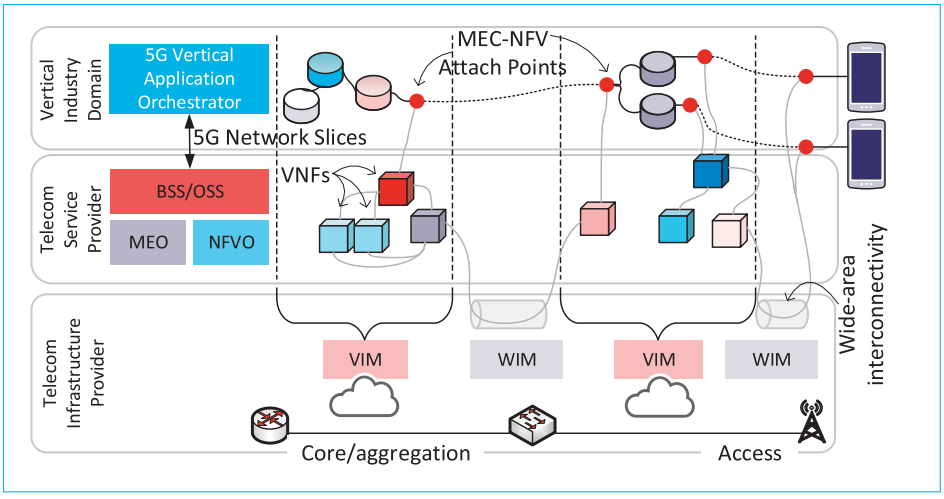

Fig. 19: Example deployment of a vApp into a 5G infrastructure, main involved stakeholders and related architectural key building blocks.

Also shown is the deployment of vApp components and VNFs into multiple VIMs, and their attachment to realize the interconnectivity among VIMs and towards UEs in the mobile network.

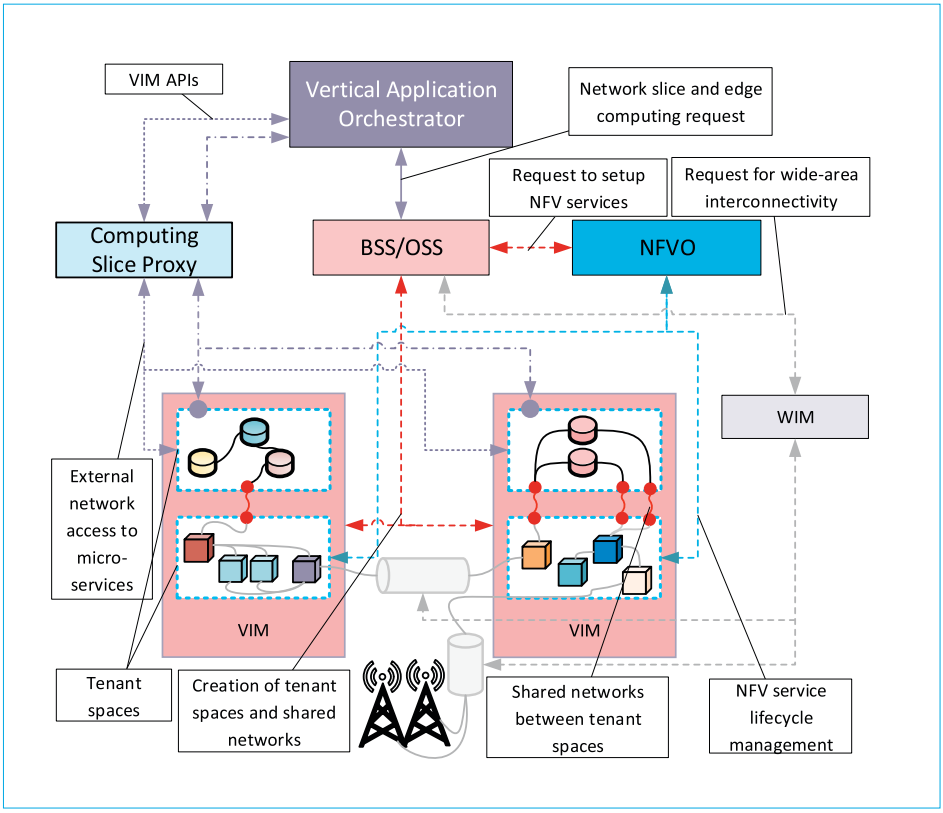

Fig. 20: VIM-level integration.

At the same time, the design of a set of **intelligent vertical application orchestration mechanisms** has been completed, and their development is ongoing. These mechanisms include: a deployment and execution manager; a set of data monitoring tools that collect feeds from network and application-level metrics; a data fusion, real-time profiling and analytics toolkit; service discovery tools for the support of registration and consumption of application-oriented services; a context awareness engine providing inference over the acquired data and support of runtime policies' enforcement; the support of interaction among the vertical application orchestrator and the 5G programmable infrastructure management. A summary of the overall lifecycle of an application created with the MATILDA framework is represented in Fig. 21, highlighting the interaction among the different stakeholders and the usage of metamodels.

Five vertical applications in different domains will be demonstrated on top of the MATILDA architectural layers and components:

- **High Resolution Media on Demand Vertical with Smart Retail Venues' Integration**, combining the functionalities of two systems, to provide 5G Personal Assistance in Crowded Events (5GPACE). The new framework can offer end-users Immersive Media Services combined with Machine Learning-based personal retail recommendations.

  Network KPIs: Device Densities in the order of ˜32 per small cell, ˜50 per WiFi Hot Spot; low Mobility between 0 and 3 m/s, Availability & Reliability >99%, User Data Rate ˜10 Mbps/user, 1 s End-to-end Max Latency. Operational KPIs: App Deployment Time ˜90 min, App On-Boarding Time ˜15 min, Scaling Time ˜20 s, Availability & Reliability >99%.

- **Testing 4.0 – Distributed System Testing**, based on FastWAN, an experimental communication technology that was developed as a solution for the enablement of geographically separated real-time industrial test benches.

  Network KPIs: Flexible Bandwidth Allocation of up to 10 Mbps/node (FastWAN Unit), Low In-Node Delay/Latency (~50¸100 ms), Interoperability with various access networks (WLAN, LTE, Ethernet).

  Operational KPIs: High Availability (99.99% of operational time), Deployment Time of ~90 min, On-Boarding Time of ~15 min.

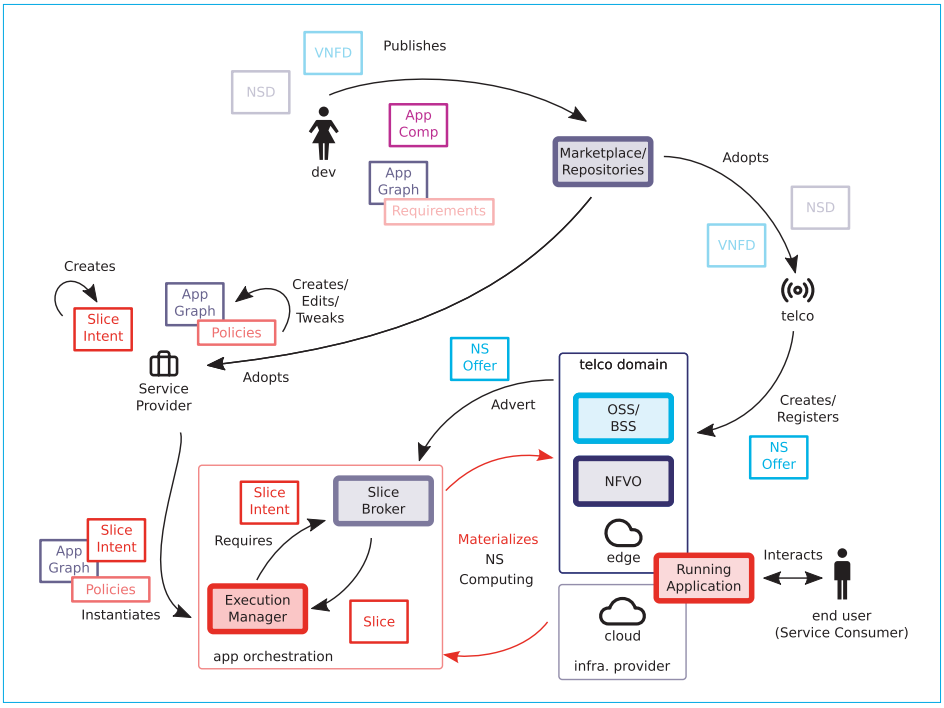

Fig. 21: MATILDA workflow highlighting the different stakeholders and metamodels.

- **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 and advanced Operation, Administration and Management (OAM) functionalities to support SLAs (qMON).

  Network KPIs: Availability & Reliability >99.999%, End-to-end Latency for Interactive Applications <20 ms, End-to-end Latency for Mission-Critical Applications <1 ms, Bandwidth of ~20 Mbps/user, Jitter <1 ms, Packet Loss <0.01%. Operational KPIs: iMON Dashboard Components On-Boarding Time of ~15 min, iMON Dashboard Component Deployment Time of ~2 min, iMON Dashboard Application Graph Deployment Time of ~5 min, Scaling Time of ~30 s, Availability & Reliability >99.99%.

- **Industry 4.0 Smart Factory – Inter and Intra-Enterprise Integration**, focusing on a logistic scenario, which offers customers the possibility to track, change and prioritize 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.

Network KPIs: Device Density of ˜100 per LAN/WiFi Hot Spot, Bandwidth up to ˜10 Mbps/user, Availability & Reliability (WLAN, LTE, Ethernet), Delay/ Latency 100¸250 ms, depending on different scenarios. Operational KPIs: Deployment Time of ˜90 min, Availability & Reliability >99%.

- **Smart City Intelligent Lighting System**, deployed in Alba Iulia, a small- to middle-size city in Romania with about 70,000 inhabitants, in order to provide an easy replicable solution with fast time to market, automated maintenance and a modular approach enabled by 5G application graphs that will assure better monetization of the intelligent city lighting solution. Network KPIs: Availability >99.99%, Total Slice Bandwidth ˜100 Mbps, End-to-End Latency <300 ms, Jitter ˜100 ms, Packet Loss <0.1%. Operational KPIs: Device Status for 100 Smart Light sensors, Service Availability >99.99%, Device Bandwidth Capacity ˜0.1 Mbps.

The five demonstrators will be mapped over three different testbeds: the one at the University of Bristol, UK, the one at the CNIT-S2N (Smart and Secure Networks National Lab) in Genoa, Italy (with equivalent testbeds being deployed by Ubitech and Cosmote in their premises in Greece), and the Orange Romania Smart City testbed of Alba Iulia, Romania.

Metro-Haul

Objectives of the Project

Metro-Haul is an EU project in the 5G PPP cluster that has been running since June 2017. It is focused on building the metro side of a future End-to-End (E2E) 5G network. The rationale behind the project is simple – we assume that an intelligent, dynamic and most importantly 5G-aware optical transport layer will assist far better in terms of performance and cost-effectiveness in the delivery and operation of 5G services, compared to an inflexible and inevitably over-provisioned transport layer. Figure 22 provides an overview of the Metro-Haul network architecture

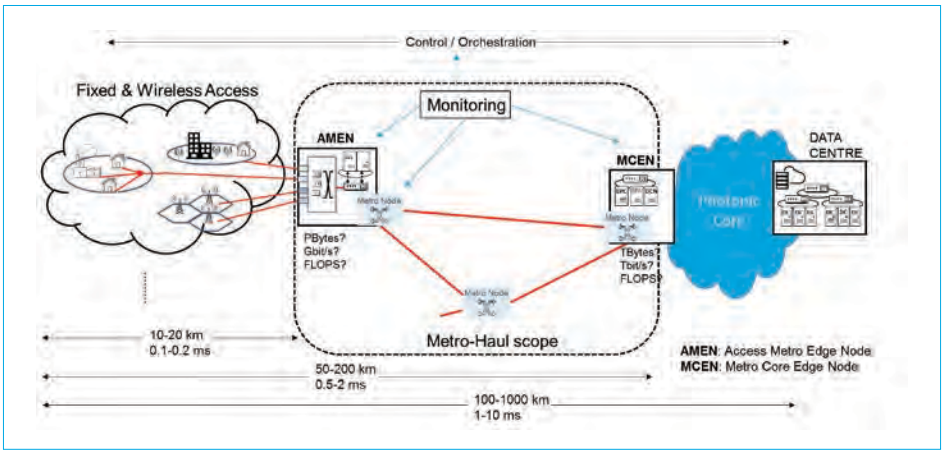

Fig. 22: Metro-Haul Reference Architecture

METRO-HAUL Key Innovations (Golden Nuggets)

Metro-Haul key innovations are summarised as follows:

1. High capacity & flexible Metro optical network with edge computing

This provides for a dynamic data plane with an intelligent control plane involving multiple network segments and layers, spanning multiple geographical Data Centre (DC) locations, and addressing resource heterogeneity including, notably, the optical transport. Without these data and control plane architectures, network resources supporting future 5G services would require enormous over-provisioning of both optical transport capacity across metro and core networks, and edge Data-Centre resources such as compute and storage.

2. Open multi-layer disaggregated network

A systematic and unified approach based on model-driven development enables the SDN control of multilayer disaggregated and open transport networks. This approach facilitates flexibility in deployment choices, extensibility for the integration of new technologies and agility in migration processes without vendor lock-in.

3. Real-time performance monitoring and analytics, and planning tool

A telemetry/monitoring framework that provides a global, real-time view of the E2E network performance. This new technology enables service configuration and reliable autonomous operation. It provides pro-active actions on early detection of issues. Machine-learning within the decision engine allows these new Metro-Haul platform and technology components to continually learn and optimize themself as real network data is collected. It includes tools for state-of-the-art advanced planning, resource placement, and network re-optimization/re-configuration, enabling holistic optimization across heterogeneous resources.

METRO-HAUL 'E2E NETWORK' KPIs

Reflecting its metro-network emphasis, as well as its reliance on exploiting optical technologies to achieve the massive capacity increases with increased flexibility and efficiency of network operation, we have defined nine KPIs in the Metro-Haul project (Table 1) to assess the success of the Metro-Haul architecture to support vertical services enabled by 5G RAT technologies.

KPI	Category	Target
1	Optical Point-to-Point connection set-up time	≤ 1 min
2	Metro-Haul E2E Point-to-Point connection set-up time	≤ 2 min
3	Set-up time of network service slice across Metro-Haul	≤ 1 hr
4	Capacity of Metro-Haul Controller	Control of 10 – 100 nodes (AMENs/MCENs, i.e., Open Disaggregated ROADMs)
5	Fault/degradation detection time	To be defined
6	Capacity of Metro-Haul infrastructure	100x more 5G capacity supported over the same optical fibre infrastructure
7	New Optical Components/Systems	To be defined
8	CapEx Reduction	To be defined
9	Energy Consumption	To be defined

Table 1: Metro-Haul KPIs

Use Case scenarios

The Metro-Haul project focuses on three demonstration testbeds. These will exercise the key use case scenarios and will provide valuable test and measurement information with respect to the emerging Metro-Haul 5G optical technologies and network architecture solutions.

1. **Crowdsourced Video Broadcasts**. The Crowdsource Video Broadcast demonstration testbed will be hosted at the University of Bristol. The setup demonstrates the ability to provision low-latency compute resources and connectivity at the AMEN locations.
2. **Real-time Low-Latency Object Tracking**. The Real-time Low-Latency Object Tracking demonstration testbed will be hosted in Berlin. This demonstration will show the ability to provision low-latency compute resources and connectivity at the AMEN locations. Utilizing these resources, real-time object tracking is performed by automatic control of PTZ cameras based on analysis of video streams from fixed and mobile cameras as well as from thermal cameras.
3. **Metro-Haul "portable" control plane demonstrator**, where all software components from the project partners are integrated into a single platform. The SDN architecture of the demonstration is based on the concept of hierarchical orchestration, serving data connectivity to an OSM-based NVF-O. The parent controller acts as the single entry-point for systems to request network resources, with two Metro-Haul nodes interconnected via the optical networks, with NFVI at each node to support VNFs according to the placement constraints. In addition, monitoring and data analytics are demonstrated in a testbed in Barcelona with monitoring probes incorporated in a Madrid-based testbed.

Conclusions and next steps

The two crucial next steps for the project are: 1) build the demonstrators and conduct key evaluations to prove that the technology works, 2) complete the techno-economic performance models to quantify the improvements Metro-Haul technology will make to E2E 5G service performance.

NGPaaS

Challenges and objectives

Platform-As-A-Service (PaaS) systems offer customers a rich environment to build, deploy, and run applications. Today's PaaS offerings are tailored mainly to the needs of web and mobile applications developers and involve a fairly rigid stack of components and features. The vision of the NGPaaS project is to enable "build-to-order" PaaS instances, which are custom-tailored to meet the requirements of a wide range of use cases with Telco-grade 5G features. This 5G PaaS does not exist today. The main goals of NGPaaS is to build it by targeting:

- A Telco-grade PaaS to support different configurations and a large set of deployment targets such as FPGA/ARM/x86, private/hybrid/public cloud in a scalable and unifying manner.
- A Dev-for-Operations model to remove the vertical barriers that create isolated silos, and not only between different teams of the same organisation or organisations of the same industry, but also between different industries (vendor, IoT/Vertical, operator).
- High quality and high-performance development and operational environments: If we want developers from the IT industry to embark on and contribute to the 5G platform, tools for ensuring the quality and SLA such as the ones found in the telecom environment are key.
- Decentralised OSS/BSS model: the move from settled centralised stacks to a much more flexible and modular distributed architecture is crucial for interfacing with cloud resources supporting the Telco-grade PaaS instances

optimized for cost and performance in a highly dynamic environment.

Major technical achievements

During the 1st year and half of the NGPaaS project, the consortium has succeeded to design, specify and prototype many aspects of the ideal 5G PaaS:

- **Definition of the NGPaaS architecture**

  To ensure maximal flexibility in permitting customized build-to-order PaaS solutions tailored to the business and technical requirements of the use cases, a new architecture with specification of interfaces has been defined to cater for the stakeholders and actors in the ecosystem including NGPaaS Operators, Vertical Service Providers (VSPs), Software Vendors, Infrastructure-as-a-Service (IaaS) Providers and End Users (Consumers).

- **Support of 'Build-to-order' principle**

  By adopting a new modelling based on Reusable Function Block, different PaaS instances can be supported following the needs and the requirements for the supported services. CORD, Kubernetes, Swarm, PaaS based MANO, to cite a few, are decomposed and deployed on the fly.

- **Telco-grade enhancements**

  A set of new features are implemented directly in Kubernetes to support high I/O requirements, including NUMA-aware CPU pinning support, huge pages support, multiple networks per pod support, SCTP protocol support and device plugin for FPGA offloading. Besides to that, more FPGA acceleration solutions, a high-performance virtualization stack with high availability support, network policy framework, multi-domain SDN framework, monitoring and component upgrade strategies are advanced.

- **Refactored OSS**

  The refactored OSS is designed with lessons and characteristics of the Dev-for-Operations and the practices of Site Reliability Engineering in mind (Observability, SLA decomposition, Alarming, Automation and learning, failure handling and resiliency patterns). It is a hierarchical, distributed, and event-based system meeting the cloud-native and microservice-based implementations that require much more granular and dynamic operational support.

- **Dev-For-Operations Model**

  This model enhances the well-known DevOps paradigm commonly used in the IT industries making it possible to use an analogous approach in a telco-grade environment where optimal collaboration in multi-organisational context is required[24]. This model emphasises the vision that 5G should be considered as a platform where many players can interact (Third party, Vertical, Vendors, Operators).

- **Monitoring as a Service**

  The proposed monitoring solution allows operators to watch specific quality attributes. The model describes how to operationalize high level monitoring goals by dividing them into sub-goals, deriving metrics for such sub-goals, and finally identifying the correct probes to collect the metrics. The resulting model for cloud monitoring is described in the article "A Model-Driven Approach to Watch the Health of Cloud Services"[25].

Description of the pilots

A diversity of use-cases can be supported easily following NGPaaS principles and design: broadband, connected healthcare, Industry 4.0, smart cities, IoT, etc. For that different PoCs are built in the project demonstrating a selection of the developed functions and features.

- **Telco PaaS**

  The Telco PaaS demonstrates the possibility of utilising the CORD platform to provide VNFaaS services, while at the same time adhering to the NGPaaS approach of modularity and build to order capabilities. The Telco PaaS can provide three levels of services; 1) Deployment of Router and Firewall VNFs, 2) Deployment of monitoring probes and 3) Deployment of network policies on top of an NGPaaS-developed policy framework. In the context of the Telco PaaS, the platform (CORD), services (Firewalls, Routers and monitoring probes) and the network policies have been fully RFBized and are deployable through the RDCL 3D tool. With regards to service deployment, the pilot allows for the design and implementation

24. ATOS, "'From DevOps to Dev-for-Operations", White Paper 2018, [online] http://ngpaas.eu/news/dev-for-operations-atos-white-paper/

25. Anas Shatnawi, Matteo Orrù, Marco Mobilio, Oliviero Riganelli and Leonardo Mariani, "A Model-Driven Approach to Watch the Health of Cloud Services", 1st International Workshop on Software Health (SoHeal 2018), May 2018.

of service graphs into the underlying CORD platform. This is achieved by the development of a number of Ansible playbooks (which comprise the core of an RFB) and interacts with the TOSCA interface in the XOS orchestrator as part of CORD. Deployment of network policies is achieved with a similar workflow, the difference being that the interface used is the REST API of ONOS. We were then able to enhance the services deployed by the addition of value-added services – a monitoring probe, to realise the vision of telco-grade. The role of the monitoring probe is to collect CPU related statistics from selected VNFs and report them to an ELK stack instance. This instance can be programmed to throw alerts when specific CPU thresholds are exceeded on a monitored VNF. Currently, there is work in progress to enhance the monitoring capabilities with healing actions.

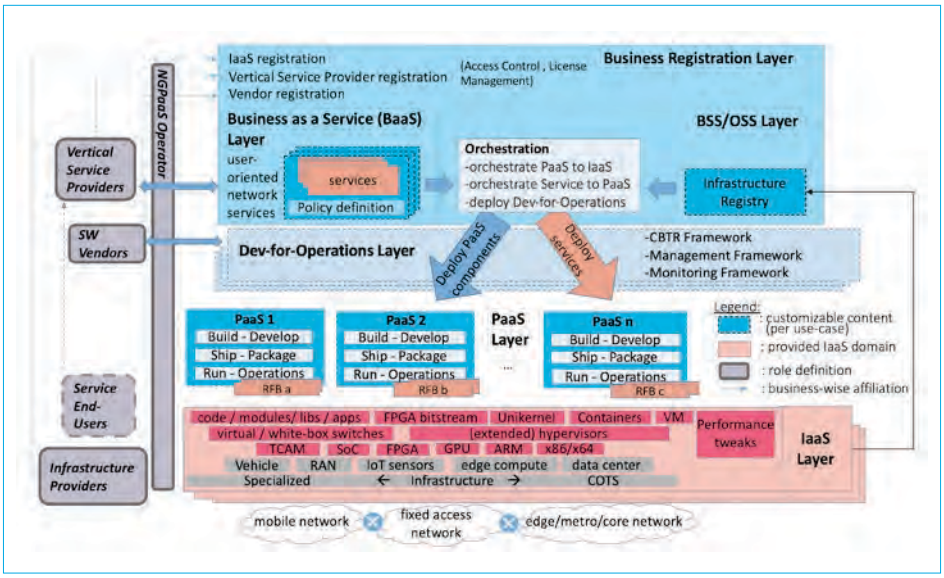

Fig. 23: Metro-Haul Reference Architecture

- **IoT PaaS**

The IoT PaaS will match specific requirements for IoT devices, and the IoT BaaS will address Business Logics related to orchestration of vertical IoT applications, such as Energy, Transportation, Smart city or E-Health. The pilot relies on CommonSense IoT platform, a software product from Vertical M2M, with some architecture changes and additional functions added to ease its distribution in the overall NGPaaS Cloud-based architecture. A use case called IoT4Energy has been defined for NGPaaS, where a set of Energy IoT Applications can be allocated on-demand to customers, allowing enhanced IoT Applications with significant improvement in end-to-end management and performance of all the IoT resources.

- **5G PaaS**

The 5G PaaS illustrates how a Mission Critical Push to Talk (MCPTT) service provider is able to easily deploy on demand in a "build-to-order" manner both the Telco Grade Kubernetes PaaS platforms and the Core and RAN mobile connectivity services that are required to run the MCPTT service. This is made possible through the implementation of the RFB model both at the PaaS and the service levels. Thanks to the "RFBization" of the whole Kubernetes components it becomes easy to tailor and deploy the required Kubernetes PaaS platforms according to the needs of the connectivity

service. Regarding Telco Grade extensions, the pilot shows two Kubernetes enhancements, a new CPU management policy with support for NUMA-aware CPU pinning in order to accelerate the data-plane of RAN network functions and a preliminary support for the SCTP protocol that is required to interconnect the RAN and the Core MCPTT service components.

- **Dev-for-Operations**

To demonstrate the value of the Dev-for-Operations model beyond the conceptual design, a practical PoC is being implemented. The focus is to show how different software vendors can interact with the NGPaaS operator to deploy their software components (in the form of RFBs) into the operator's infrastructure using the continuous integration, delivery and monitoring workflows as defined in the Dev-for-Operations model. In particular, two different use cases (for 5G and IoT services) are demonstrated. The first one (5G) shows how several components already in the operator's infrastructure can be integrated with other components developed by two independent external vendors to compose a complete operational pre-5G core network service; on the other hand, the second one (IoT) consists in the deployment of a separated network slice for IoT services. All this is done using the evolved DevOps-like principles incorporated in the NGPaaS Dev-for-Operations model but keeping the original DevOps focus on automation and continuous integration and delivery methodologies. The practical implementation is based on containers running on Kubernetes, Jenkins for the continuous integration and delivery and Prometheus & Grafana for the monitoring and the visualization part.

Impact

Besides contributing to multiple research conferences, NGPaaS has been present at multiple major events (MWC, EuCNC, EU ICT event in 2018, Zero Touch Automation Congress, SDN/NFV world congress, IWPC on SDN & Virtualization Towards Telco-Cloud, etc). NGPaaS has been selected as technology project of SDN/NFV World Congress. He has been invited in Linux Foundation/Open Network Summit 2018 where a joint workshop with ONF has been organised .

Most of NGPaaS technologies is based on Open-Source; for that NGPaaS made several contributions (Network Policy Framework for the ONOS SDN Controller, Numa aware CPU pinning policy for Kubernetes, QoS-aware SR-IOVCNI, FPGA Kubernetes plugin etc)

Several white papers have also been published, through the partners of the NGPaaS project and the collaboration inside the 5G PPP community through the different working group and cross-project collaborations.

A new product, named SmartBoxTM has been designed by joining the effort of Vertical-M2M[26] and VOSYS[27] to securely isolate critical sensors (e.g., heart rate monitors, building fire alarm, security alarms, etc.) from non-critical sensors (temperature, etc.).

26. *[online] https://www.vertical-m2m.com/fr/*

27. *[online] http://www.virtualopensystems.com/*

NRG-5 - Enabling Smart Energy as a Service via 5G Mobile Network advances

Goals of the project

NRG-5 aims at guaranteeing optimal communications of the energy grid, which is believed to be the most complex, heterogeneous and gigantic machine ever made in human history. In particular the "last mile" of the smart energy network has the highest potential for demonstrating the added value of the 5G unified approach. While smart energy grids observability (in particular in the case of smart electricity grid) is already in place in the High and mostly in the Medium Voltage branches of the energy networks, situational awareness of Low Voltage/Low-Pressure branches is lagging. Up to date, the energy network is actually for substation-level/pumps monitoring via SCADA, without considering real-time energy consumption or energy production feedback from prosumer, which would allow a finer grained prediction of the demand and an improved load balancing of the energy networks. Therefore, The NRG-5 ultimate goal is the deployment, operation and management of existing and new communications and energy infrastructures in an easier, safer, more secure and resilient way from an operational and financial point of view. In this respect, NRG-5 develops a novel 5G PPP-compliant software framework specifically tailored to the energy domain, which combines:

- Trusted, scalable and lock-in free plug 'n' play support for a variety of constrained devices
- 5G devices' abstractions to demonstrate mMTC (Massive MTC), uMTC (Critical MTC) and xMBB (Massive broadband) communications coupled with partially distributed, trusted, end-to-end security and MCM (Machine Type Communications) to enable secure, scalable and energy efficient communications extended Mobile Edge Computing (xMEC) micro-clouds to reduce backhaul load, increase the overall network capacity and reduce delays, while facilitating the deployment of generic MTC-related NFVs and utility-centric Virtual Network Functions (VNFs)
- An extended 5G ETSI-MANO predictive analytics framework to support automated, dynamic, elastic VNF reconfiguration.
- Extensive lab-based validation to complement with real-life demonstrations in two pilot sites (Italy, France) where proof-of-concept implementations for 5G-enabled electricity and gas distribution network optimised management is offered and at the same time offering support to 5G PPP phase III projects via demonstrating high replication potential towards other verticals.

Major achievements and innovation

During the last year of the project, the consortium has worked mostly on the implementation. It has defined and started implementing the self-discovery and self-organisation mechanisms, combining PUF and blockchain mechanism. Some network/logical slicing implementations coming from 5G PPP (Phase 1 and 2) projects have been analysed and taken into account in the definition of NRG5 architecture. Furthermore, within the project work, an utility-oriented Management and Orchestration (MANO) framework analysis for the provisioning 5G services to core utility operations is performed by creating new complex VNF Forwarding Graphs (VNF-FG). The project has realised an open source, micro-cloud proof-of-concept xMEC software stack, facilitating fast and optimal deployment of generic and utility-centric VNFs, pushing MTC from M2M to MCM via network self-x functions implemented as NFVs and abstract representations of terminals in the (edge) cloud. Additionally, the project has achieved truly decentralised, secure and trusted plug 'n' play environment, by combining MTC NFVs and inherited physical functions of low-end devices with distributed key management mechanisms for high interoperability at the data level by abstracting technology silos through catalogues of semantically annotated data starting from BT's information hub. Figure 24 shows the NRG5 Application Logic architecture utility specific VNFs, which model components, assets and functionalities of both the ICT infrastructure (i.e. edge computing, storage, network) and the electricity/gas infrastructure (i.e. meters, RES, DER, LPTs, PMUs, etc.) as virtual resources. When the application logic requests a function, the MANO framework

orchestrator recognises how to map this function to the ICT and utility requirements. So, the orchestrator schedules this service fine-tuning the latency or other indicators and determines the service function chaining. Once the orchestrator completes the scheduling, the subscriber's request is forwarded to the first edge cloud instance, and the first function is executed. This architecture allows to demonstrate the efficiency and lifecycle management of advanced smart energy applications as services (such as AMIaaS, DDRaaS, PMaaS), implemented as chained connected graphs of dynamically connected/ disconnected VNFs following the ETSI VNF Forwarding Graph and ETSI SFC paradigms as documented in ETSI GS NFV-EVE.

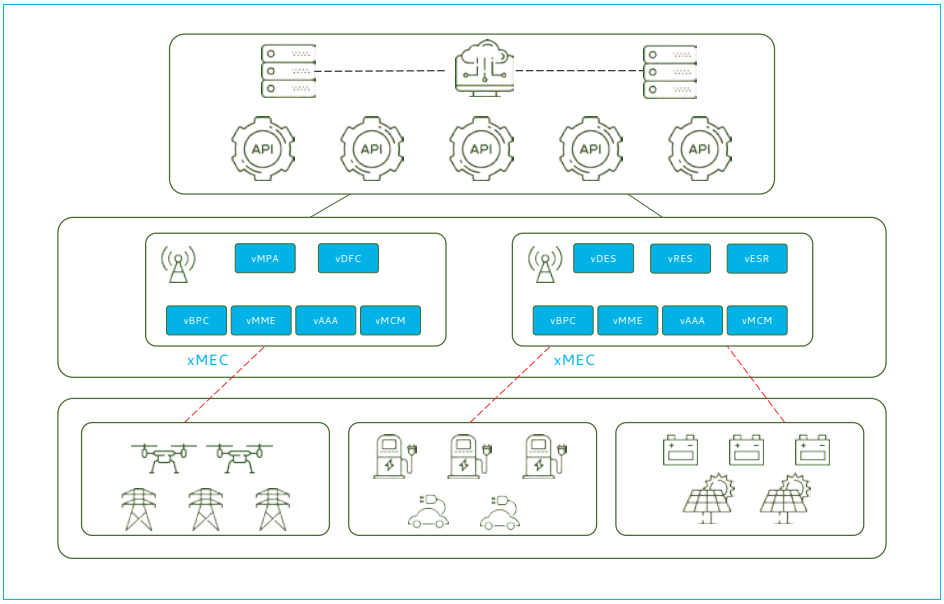

Fig. 24: NRG5 Application Logic

Use case 1 – Realizing decentralised, trusted lock-in free "Plug & Play vision":

This UC provides a framework allowing for easy, real-time, automated devices identification so that network auto-configuration can be achieved automatically. The AAA is achieved homogeneously, to reduce the chances of AAA misconfigurations among different services of the same or different tenant, to address multi-tenancy under geographically unbound mobility scenarios. In this framework, secure communications have to be achieved irrespectively of the network service provider and the physical entity initiating the connection. In such a scenario, the main actors are the smart metering devices that exhibit a far more complex profile than today, offering services beyond traditional 15 minutes reporting, including support for real-time measurements, service discovery, infrastructure automation and AAA. The NRG5 architecture defines a scalable cloud-based stack, and optional multi-RAT access interface with the goal to enrich security and trust features forming the next generation smart meter as a 5G device. Based on PUF encryption and Blockchain, this solution offers a decentralised trust &identity management mechanism, supporting end-users privacy by design and providing a novel open solution, applicable not only for smart meters but any hardware constrained device, with built-in trusted and vendor/utility lock-in free Plug 'n' Play functionality. NRG5 enables this solution making efficient mMTC communications and scalable xMEC paradigm, offering a group of VNFs to facilitate distributed, scalable and trusted plug 'n' play functionality of hardware-constrained devices.

Use case 2 – Enabling aerial Predictive Maintenance for utility infrastructure:

The Aerial Predictive Maintenance of distributed generation plants, energy transmission and distribution networks – both TSOs and DSOs, like electricity cables and isolators, and gas/LNG tanks, pumps and pipelines, is an activity of utmost importance in achieving highest power network reliability. The UC tackles the involvement of semi-autonomous swarms of drones and parallel surveys from different views/cameras able to run complex, bandwidth-demanding computationally heavy and time-critical applications. So the UC needs to meet different kinds of requirements:

- operational requirements, such as to define the flight plan for each drone in a swarm, so that they have optimal coverage with minimal resources, taking into account the flight · capability of each UAV/drone and the remaining energy,
- communication requirements, either by cellular or satellite links controlling the drone's flight and uploading captured video.
- mission requirements, such as object (i.e. lines, pipes, tanks, blades, towers) online video analysis and inspection.

So, NRG5 solution guarantees xMBB communications for video streaming from the drones and analysis to the local mobile edge processing node and the utility control centre, and uMTC for stringent real-time control of the flight of drones. The UC2's ultimate objective is to bring a way of supporting current activities responsible as maintenance director and security/Safety officer to improve the cost efficiency of their job and reduce the risks for the human. The current limitation, in terms of data streaming performance, is blocking the generalisation of drone's use.

Use case 3 – Enabling resilience and high availability via Dispatchable Demand Response:

This UC aim is to illustrate the fundamental role to be played by 5G networks in smart grid as an enabler for aggregator and system operators (TSOs and DSOs) of new slicing application tailored for optimize network operation and manage load flexibility. Using 5G network slicing for energy services ensures that network resources provided by carriers can be converted to mutually isolated network slices, to meet the differentiated network requirements of various services on the smart grid. Network slicing can also be used to collect data on electricity usage, for distributed power, for pile control at electric vehicle charging stations, for precise load control, and for other crucial services a smart power grid should offer. The UC core objective is twofold, primarily aiming at: 1) offering a real-time overview of the aggregate smart grid status with a clear focus on smart metering and, then, at the level of PMU, DES and RES; 2) enabling a micro-contract oriented, blockchain-powered marketplace framework where Utilities, prosumers and end-users can interact in a lock-in free manner. The introduction of the above objectives realised by the coordinated cooperation of the relevant VNF and application-specific developments allow the acceleration of the liberation of the energy markets, also providing to Utilities the ability to unlock the potential of 5G-based real-time monitoring and control that enables the two-way communication between utilities and customers generating two new services: Dashboard-as-a-Service (DaaS) and Marketplace-as-a-Service (MaaS). The core functionalities are based on the coordinated interworking of NRG-5 VNFs and are hence meant to serve location-sensitive purposes, addressing massive machine-type communication (MTC) and critical machine-type (UMTC). In this respect, each IoT device will have both PMU and a built-in 5G native interface.

ONE5G

ONE5G's main ambition is to investigate and propose new features and advancements, focusing on the Radio Access Network (RAN) to move 5G towards 5G-advanced and to prepare the next releases of 5G, beyond the first version (3GPP Release 15). The areas investigated are advanced multi-link access and interference management supported by massive MIMO, and E2E-aware performance optimization through advanced radio resource allocation and multi-node connectivity orchestration, load balancing, spectrum management and device-to-device (D2D) communication. The project is addressing two highly diverging deployment scenarios: "Megacities" and "Underserved Areas". Combining these two highly different scenarios is one of the specificities of this project, as the "Megacities" is a classical deployment scenario for 5G, while "Underserved Areas" has received much less attention.

A main area of innovation for ONE5G is **advanced multi-link access and interference management, supported by massive Multiple-Input Multiple-Output (MIMO)**. The project focuses on link level aspects not yet covered in Release 15, but which are crucial to meet the objectives of 5G. To address the specificities of new service categories Ultra-Reliable and Low Latency Communications (URLLC) and massive Machine-Type Communications (mMTC), the project has developed new fast and reliable access solutions. Solutions to enable grant-free access have been proposed to improve latency and sustain the massive access of mMTC devices. This is complemented by Non-Orthogonal Multiple Access (NOMA), allowing multiple users to exploit overlapping radio resources. Potential advantages include higher cell throughput with improved cell-edge performance, as well as improved reliability and lower latency.

ONE5G has also designed flexible and low-complexity solutions for massive MIMO. Channel State Information (CSI) is crucial to the efficiency of beamforming techniques, and the project has developed solutions to improve the CSI acquisition and feedback, reducing the pilot overhead. To pave the way towards practical implementation, the solutions investigated target low complexity and high flexibility for the lower layers, down to hardware implementation. For example, reconfigurable hardware implementation of modules at the physical layer is proposed. Various technical enablers have been developed, including hybrid and digital beamforming, which optimize the trade-off between energy efficiency and complexity. Recommendations are also provided regarding array deployment (shape, format) to adjust to the requirements of different scenarios and services. For dense environments, the project tackles the challenge related to inter-node collaboration in Centralised Radio Access Networks (CRAN), a promising solution to sustain high connection density. Then, ONE5G develops enhanced physical layer procedures to minimize the feedback overhead for CSI acquisition in dense CRAN deployments. Resource allocation schemes are investigated as well for CRAN deployments, with scheduling algorithms clustering the users to achieve important cost and energy savings.

Another area of innovation pursued in the project is the **end-to-end (E2E)-aware performance optimization through advanced management of radio resources and of multi-link/multi-node connectivity**. Accounting for E2E user-experienced performance in the RAN design will represent a major leap forward compared to previous generations. The E2E characteristics are formalized through Key Quality Indicators (KQIs) and used as a basis for optimization of RAN-based techniques. The project also leverages on context awareness to optimize performance and improve the E2E user-experience. Different directions are explored to achieve these optimizations. The project first explored the various degrees of freedom allowed by the QoS architecture and protocol stack adopted in 3GPP to enhance the E2E performance. Recommendations have been developed to operate the improved three-state Radio Resource Control (RRC) machinery and Discontinuous Reception (DRX) concept, to efficiently leverage the trade-offs between user-plane performance and User Equipment (UE) power consumption. These targets are also served by control plane optimizations, such as the introduction of a Device Virtualization Server, leveraging on CRAN and Multi-access Edge Computing (MEC) to partially offload the computational weight from the device to the network.

Numerous radio resource allocation enhancements have also been proposed to allow for efficient multiplexing of different services, with highly differing QoS constraints, such as network slicing, pre-emptive scheduling or multi-cell scheduler enhancements compatible with CRAN and MEC. ONE5G also proposes Multi-Channel Access solutions, another direction to address the issues of resource allocation to fulfill the QoS targets of different services. These solutions include multi-connectivity, with mechanisms for PDCP-level duplication to enhance reliability and latency for URLLC services. Also secondary cell selection for carrier aggregation belongs here, using artificial intelligence techniques to increase throughputs.

The project also leverages on mobility optimization and dynamic spectrum management to improve the E2E performance. For mobility-related optimizations, advanced traffic steering and load balancing schemes have been developed. Among others, it is proposed to migrate from traditional re-active schemes that aim for load equalization between cells, towards more promising context-aware proactive schemes that equalize the Quality of Experience (QoE) between the cells instead. Social data, such as information on social events, is exploited to forecast traffic demand and pro-actively perform traffic steering to minimize the impact of the large social gatherings on the QoE of the users. For spectrum management, solutions have been derived for dynamic spectrum aggregation and exploitation of both licensed and unlicensed frequency bands to meet requirements from multiple services, mainly to boost the capacity and user data rates for eMBB services. Finally, ONE5G has developed enhanced D2D solutions. These include both solutions for eMBB capacity boosting and relay-based schemes for coverage enhancement and for reduced power consumption to better serve mMTC in coverage challenging environments such as underserved scenarios.

Fig. 25: ONE5G scenarios

ONE5G develops all these innovations within an **advanced framework for the validation and optimization of 5G technical components**. A set of nine use cases, and the corresponding Key Performance indicators (KPIs), have been defined at the beginning of the project, covering both "Megacities" and "Underserved Areas", to set the targets for the technical work. The

various technical components are assessed individually and gains are quantified through analytical studies and simulations (at link and system level). For a global system view, a project-wide system simulator has been developed and it integrates a subset of the technical components developed in the project, such as centralised multi-cell scheduling or the component carrier manager. Integration of the following technical components is under way or will start soon: context-aware proactive QoE traffic steering, enhanced HARQ, Massive MIMO, optimized functionality placement and resource allocation in CRAN/DRAN. The project also undertakes a techno-economic analysis, focusing on selected use cases, indicative of "Megacities" and "Underserved areas" use cases identified in the project. The most appropriate deployment options are being considered for these use cases, and a first qualitative analysis has identified the cost-driving elements. This work will continue with a more detailed quantitative analysis of the main factors impacting the most on the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for these deployments. These quantitative analyses will give good indications of the associated costs of deploying networks to support two of the widely discussed vertical themes (Automotive and Smart city), to reach rural and far remote areas and to provide novel drone based communications in disaster and emergency scenarios.

A subset of the technical components is also validated through integration into one of the five Proof-of-Concepts (PoCs) of the project. These PoCs cover different verticals in both "Megacities" and "Underserved Areas".

- **PoC#1 – Cell-Less Megacity**: This PoC targets URLLC services in an industrial area with large factories, in a "Megacities" scenario. The PoC integrates E2E performance optimization techniques in combination with cell-less technologies, small cells multi-connectivity techniques (PDCP packet duplication, Single Frequency Network, coordinated multi-point transmission) for reliability enhancement, solutions for optimization of network resources in an end-to-end manner by management of network slices, slice negotiation and management techniques for the support of critical infrastructures.
- **PoC#2 – E2E optimized and context aware "smart megacity"**: This PoC focuses primarily on eMBB and mMTC service categories, in Megacities" serving a large number of users, services and cell densities. The PoC integrates E2E performance optimization techniques based on KPI to KQI mapping and monitoring, multi-node/multi-link techniques context-aware multi-service solutions (e.g. RRM optimization), enhancement of traditional load balancing techniques.
- **PoC#3 – Enhanced massive MIMO**: This PoC targets eMBB services with a large number of users and dense cell deployment in "Megacities". The PoC focuses on Massive MIMO technology in a multi-user and multi-cell environment and integrates technical components such as non-orthogonal multiple access (NOMA) and code design, array (e.g. cylindrical arrays), sector and beam management and enhanced CSI acquisition techniques.
- **PoC#4 – Agricultural use cases in "Underserved Areas"**: this PoC focused on low-cost targets and targets primarily mMTC and eMBB for agricultural applications. Technical components such as flexibility and fast reconfiguration of network elements and mechanisms for transmission path improvements or management of network slices are integrated.
- **PoC#5 – Automotive**: this PoC targets URLLC for automotive applications in "Megacities", but the scenario "Underserved Areas" could be considered as well, with less tight URLLC requirements. Technical components such as multi-antenna enhancement for improving reliability, or optimization of real-time processing in URLLC are integrated.

More detailed information on the innovations and results are available in the deliverables, available on the website of the project: *http://one5g.eu/.*

SAT5G

Goals of the project

The SaT5G (*http://sat5g-project.eu/*) vision is to develop a cost effective "plug and play" satellite communications (satcom) solution for 5G to enable telcos and network vendors to accelerate 5G deployment across all geographies and multiple use cases whilst at the same time creating new and growing market opportunities for satcom industry stakeholders. The six principal project objectives are to:

4. Leverage relevant on-going 5G and satellite research activities to assess and define optimum solutions for integrating satellite into the 5G network architecture;
5. Develop the commercial value propositions for satellite based network solutions for 5G;
6. Define and develop key technical enablers, such as network softwarisation and management and orchestration techniques, for the identified research challenges;
7. Validate key technical enablers in a lab test environment;
8. Demonstrate selected features and use cases with in-orbit geostationary and non-geostationary high throughput satellite (HTS) systems;
9. Contribute to the standardisation of the features enabling the integration of satcom solutions in 5G at ETSI and 3GPP.

Major achievements/innovations during the second year of the project

During its second year, the project analysed the architectures to support the SaT5G Use Cases, producing reference architectures, made significant contributions to standards, and made key advances in research topics. Major achievements/innovations from the business modelling and techno-economic analysis include the concept of a broker as a new stakeholder, and the development of an allocation model to analyse the costs in supporting end to end services where a satellite link is present in the path. Other examples of technical achievements/innovations are virtualization of satellite network functions related to satellite terminals, integration of core network/satellite control and data planes, and designs for satellite in backhaul links either satellite only or where both satellite and terrestrial paths are available (multilink hybrid).

Significant research and activities in the project include:

- First-of-its-kind over-the-air live demo towards satellite integration into 5G was conducted in EuCNC 2018. Among other key features, it successfully demonstrated QoE – assured live streaming over an SES GEO satellite link using MEC-based transient holding of video segments (associated IEEE Trans Broadcasting paper accepted for publication); The SaT5G EuCNC 2018 demo setup is illustrated in the figures below.
- Using satellite integration architectures specified in ETSI/3GPP a virtualized and orchestrated test bed environment has been created (EUCNC 2019 paper submitted);
- Demonstrated QoE – assured live streaming over a real GEO satellite link using MEC-based transient holding of video segments at EuCNC2016 (IEEE Trans Broadcasting paper accepted for publication);
- Demonstrated optimized layered video content delivery using application-layer protocols for satellite terrestrial multilinking using satellite emulator (EUCNC 2019 paper submitted);
- Proposed a novel business model in which a broker manages the business interactions between terrestrial and satellite operators (EUCNC 2019 paper submitted);
- Evaluated the viability of satellite backhauling for bringing connectivity to unserved areas (papers published in the ITS Europe and ICSSC 2018 conferences);
- Inputs to 3GPP RAN and SA TCs along with other SDOs.
- An initial analysis on the potential impact of satellite delay on security procedures based on simulations.

The project is working on the following research pillars:

- Integration of virtualized satellite networks with 5G Core networks. This address 2 use cases: satcom as transport networks; and

satcom as non-3GPP access network, with non-Terrestrial Network (NTN) terminals

- Development of an integrated satellite/terrestrial/cloud infrastructure coordinator for 5G networks
- Architecture design for multilink access networks based on upcoming 3GPP ATSSS feature (Access Traffic Steering Switching Splitting), and multipath algorithms performance validation
- NR simulator development for satellite; initial results on synchronisation signal detection satcom link affected by Doppler
- Architecture and performance assessment of Video streaming, based on live experimentations for distributed Mobile Edge Computing schemes, in both scenarios of single WAN link (satellite) and multiple WAN links (satellite terrestrial)
- Multilink based video content delivery through satellite backhauled 5G network, including the performance comparison between layered and non-layered video applications, as well as transport-layer vs application-layer approaches.

The following key functionalities have been defined as the key enablers for future efficient 5G satellite backhaul:

- Caching and multicast application functions to enable edge delivery;
- Registration, connection and roaming management of the GNB or the relay node with a new concept of generic GNB able to connect to any core network while not necessarily belonging to the core network provider;
- Management and orchestration of the end-to-end quality of service with the requirement of backhaul awareness and terrestrial to satellite QoS adaptation;
- Mobility management and handover within the satellite systems in order to support mobile platform backhaul;
- Multilink management both at UE level and backhaul level and inclusion of such requirements in the standards;
- Support of network slicing at the backhaul level and implementation of network function virtualization in the satellite system.

Description of demos

Building on the individual research and prototyping pillars, the project will be consolidating this work by conducting validations and demonstrations across three main test-beds in Europe.

Fig. 26: Sat5G project demonstration

Testbed Location	Test Objectives and Status
5GIC University of Surrey	A 3GPPP Rel 15 compliant 5G core and RAN test bed including multiple cells and 5G UE's is integrated with virtualized satellite NTN gateway. The test bed is connected to a satellite gateway in Goonhilly via VPN and thence over Avanti's HYLAS 4 Ka band satellite. The objectives are; To validate and demonstrate the virtualized integration of satellite and terrestrial 5G and the setting up of a satellite network slice. To validate and demonstrate use cases: -satellite backhauling to small cells; -media content delivery to the edge using multicast/caching; -multi linking delivery using satellite and terrestrial. The terrestrial 5G core plus RAN is in place and the satellite integration will be completed by mid-2019. Partial demonstrations are planned for EUCNC 2019 in Valencia with full trial demonstrations in Q4 2019. Preliminary satellite VNF deployment with OSM has already taken place, and work is on going to further refine and enhance the VNFDs and corresponding NSD for the 5GIC testbed.
Zodiac Inflight Innovations (ZII)	The ZII test bed revolves around 5G network features and service orchestration for the next generation of end-to-end connectivity in an aircraft-moving platform. The objectives of the test bed are: Demonstrate the flexibility of virtualization and unified orchestration in opposition to static pre-deployment of hardware-based networking inside airplanes; Orchestrate the satellite gateway as a virtualized network service to reduce service creation time, targeting non-GEO satellites over the SES O3b MEO HTS constellation; Demonstrate virtualized mobile core and MEC on-board airplanes, multicast over satellite to distribute content to multiple airplanes; Test aeronautical certified and personal electronic end users' devices. Demonstrations will take place in the A320 cabin mock-up at ZII premises. Final demonstration is due to Q4 2019 with an intermediate video demonstration of selected features to take place at EuCNC 2019.
University of Oulu (UOulu)	The objective is to evaluate modifications to the 3GPP NR air interface to enable operation over a satellite channel. The modified NR has been emulated using OAI to produce an NTN terminal and gNB. A satellite channel emulator is developed for testing the modified NR air interface. The system will be integrated into 5G test network where a gNB would be connected with NTN terminal to test the gNB's backhaul traffic over satellite channel. This will be shown in a video at EuCNC 2019. Phase I:- Modified NR air interface for operation over satellite channel and integrated into the test bed with 5G test network. Phase I focuses on the research pillar IV (Harmonization of satcom with 5G control and user plane). The modifications are made to the air interface and tested via a satellite emulator. In Phase II:-A gNB backhaul traffic will be routed through this NTN terminal. The user devices connected with this gNB will get data services through the satellite network emulation developed in phase I.

Table 2: Sat5G tests objectives and status

In terms of achievements in dissemination activities the key highlight – The EuCNC 2018 Demo – was a SaT5G Success Story. The extended promotional and marketing campaign resulted in high publicity.

Project demonstrated:

- Integration of satellite network with a standard 3GPP core network
- Virtualization of satellite network elements
- Deployment of virtualized satellite network elements (including 3GPP core) with OpenStack
- Integration of Broadpeak nanoCDN solution, to demonstrate efficient edge delivery, and transport of multicast traffic over satellite
- Demonstration of high-def video over "virtualized" satellite network (YouTube)

Fig. 27: Sat5G demo for EUCNC 2018

Slicenet

Objectives of the project

The main objective of SliceNet is to remove the limitations of current network infrastructures by achieving full softwarisation-friendly 5G infrastructures, and address the associated challenges in managing, controlling and orchestrating the new services for verticals, thereby maximizing the potential of 5G infrastructures and their services based on advanced software networking and cognitive network management.

SliceNet is implementing a verticals-oriented, QoE-driven 5G network slicing framework focusing on cognitive network management and control, for end-to-end slicing operation and slice-based services, across multiple operator domains, in 5G networks enabled by

Software-Defined Networking (SDN)/ Network Function Virtualization (NFV), whilst offering flexibility and capabilities to the vertical users of the services.

For 5G verticals businesses, SliceNet offers an innovative one-stop shop solution to create customized services, meeting diverging requirements. This is achieved by enabling the verticals to promptly on-board their use cases to the system and introduce their bespoke control in order to adopt, deploy and benefit from 5G slices, in a rapid, scalable and cost-efficient way through novel Plug and Play slicing functions and a one-stop API. For 5G service providers and users, SliceNet provides unprecedented guaranteed service quality, by enabling advanced users' QoE-centric service creation, delivery and lifecycle management. This is achieved in an agile and optimised way through cognitive QoE monitoring, analytics, decision-making and self-optimisation enabled by machine learning and other artificial intelligence techniques. For 5G network operators, SliceNet presents an integrated FCAPS (Fault, Configuration, Accounting, Performance, Security) framework for end-to-end management, control and orchestration of 5G slices, in a secure, coordinated, robust and verticals-oriented way, by enabling secured, interoperable, reliable and QoE-driven operations across multiple virtualized administrative domains.

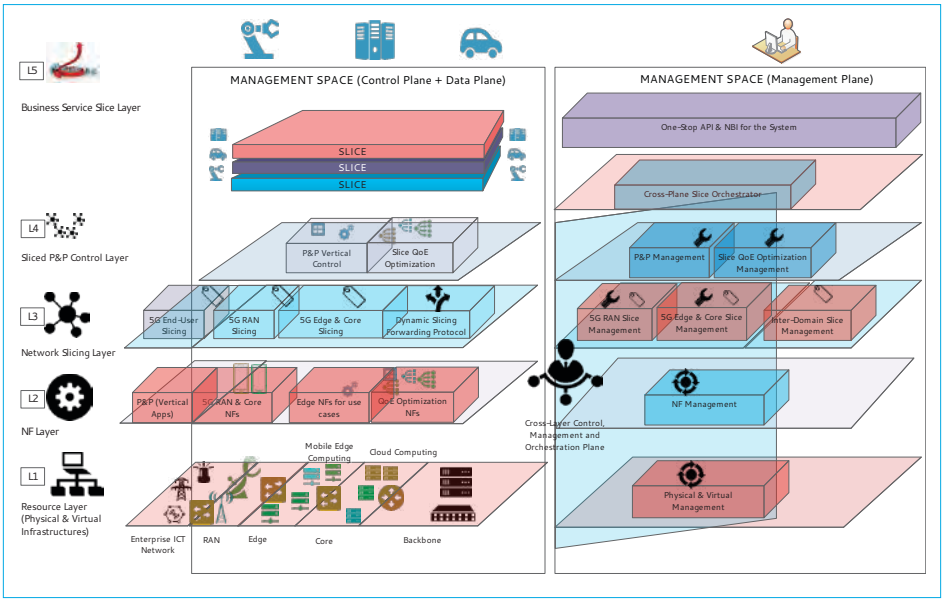

Fig. 28: SliceNet Overall Architecture

Figure 28 presents the overall architecture of SliceNet, which is composed of two architectural domains over a 5 layer architectural approach: the managed domain (infrastructure, services and control) which will establish an integrated, softwarised, slicing-ready infrastructure for 5G services in SliceNet; and the management domain (management and orchestration) that is able to cognitively manage the infrastructure and its new services by addressing a set of technological challenges such as multi-tenancy, multi-operator, multi-domain, programmable data plane, pluggable control plane and cross-layer orchestration.

More information about the project, and access to public technical documents, can be found on the project's website @*https://slicenet.eu*

Major achievements/innovations and performance KPIs

In the first twenty months of the project, SliceNet has completed its framework's architectural definitions for network slicing control, management and orchestration, which were based on the requirements analysis of the selected representative use cases presented by vertical partners. A network slicing friendly infrastructure has been prototyped, supporting a Multi-access Edge Computing (MEC) platform and programmable infrastructures. Network slicing at the Radio Access Network level has been prototyped and successfully demonstrated how to differentiate the requirements of different slices and supporting the demanded performance of the corresponding services. In addition, advances in cognitive management definition and use cases development have been achieved. In particular, Plug & Play control of network slicing has been designed and prototyped. Plug & Play control provides an innovative per-slice control environment, which offers to the verticals (and in general to slice consumers) a significantly enhanced degree of flexibility for deploying services to end users. For each slice instance, a vertical-tailored view and control of the slice is presented to the vertical through SliceNet One-Stop API, and therefore tailored control functions can be plugged to tailor the behaviour and optimize the performance of the slice instance.

These achievements will meet 5G KPIs for highly customizable runtime control, management and operation of slice instances whilst offering vertical-tailored services for a broad range of use cases with diverging control requirements. SliceNet contributed to the 5G PPP Phase 2 Golden Nuggets GN7 – 5G Network Management, by addressing cognitive network management for network slice-based services, driven by the Quality of Experience (QoE) and Service Level Agreements (SLAs) in verticals' use cases; and GN8 – 5G Multi-domain multi-tenants Plug & Play Control Plane and slicing control, by defining the various business roles and developing a set of enabling mechanisms to achieve federated cross-domain network slicing for the requested service of the agreed SLA and implementing the SliceNet Plug & Play control framework as a key enabler for advanced slice customization (D2.2, D2.3 and D2.4 @ *https://slicenet.eu/deliverables/*).

Description of demonstrations

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). The innovative, verticals-oriented, network slicing framework will be demonstrated through selected 5G use cases featuring these service requirements, targeting three different vertical industries: smart-grids, e-health, and smart-cities:

- The 5G Smart Grid Self-Healing use case, focuses on Smart Grid Self-Healing, proposed by EFACEC, a company of the EFACEC Power Solutions Group, the largest Portuguese group in the electromechanical area. Self-healing will enable system operators to benefit from a significant reduction in the outage duration, number of affected customers as well as in the number of switching manoeuvres required during power grid network reconfiguration procedure involved in fault detection, isolation and service restoration (FDIR).
- The 5G e-Health Connected Ambulance use case, proposed by Cork Institute of Technology and DellEMC in Ireland, with the support of the Irish National Ambulance Services through the Irish Department of Public Expenditure and Reform, will advance the emergency ambulance services be demonstrating new collaborative models with their healthcare stakeholders to help create improved experiences and outcomes for patients in their care.
- The 5G Smart City use case, proposed by Orange Romania and supported by the city of Alba Lulia, deals with critical smart lighting infrastructure to exploit an open data strategy and architecture facilitating further development of new applications that can aggregate information from the city itself.

Global5G.org (*www.global5g.org*) contributes to the European 5G PPP through its focus on vertical markets (impacts and business models), standardisation, KPI tracking, and dense networking in the EU. Its aim is to foster the adoption of best practices and standards-based deployments and boost market impacts across the EU, both for large companies and SMEs. Global5G.org plays an active role in several 5G PPP working groups, spanning Pre-standardisation, Trials and Testbeds, SMEs, Spectrum, Automotive, **Vision and Societal Challenges. From an international perspective, Global5G.org seeks synergies on current collaborative approaches with links to industry while investigating future research directions.**

In its second year of activities, Global5G.org is contributing to the 5G PPP in the following ways:

Verticals Cartography

Global5G.org has designed and developed an online verticals cartography with the support of the 5G PPP TB (*https://www.global5g.org/cartography*), covering the experiments planned by 5G PPP phase 2 projects 2018-202. With this online tool, users can select the type of experiment (PoCs, prototypes, demonstrators, trials and pilots), vertical cluster (automotive, energy, health, industry – factory and process automation; farming and agriculture, media and entertainment, public safety, smart cities, transport and logistics), country (13 EU countries) and ITU-defined functionalities (eMBB, mMTC, URLLC). The cartography tracks 63 such experiments in 40 cities across Europe. Global5G.org also provides an online complementary analysis of maturity levels and timelines, the number of experiments per vertical, and functionalities targeted, as well as vertical partners, industry and public sector organisations supporting the experiments. Overall, the cartography supports cross-project collaboration while showing gaps for future research programmes. Future developments will let users visualise the cartography as European cityscapes.

On-going work on high-level performance KPIs will show coverage and intensity across the phase 2 projects as a cross-WG activity.

Regulatory Analysis and Deployment of Small Cells for 5G

Network densification is a way of increasing capacity and improving coverage particularly indoors. It can also improve energy efficiency and reduce radiation. The first Global5G.org study on small cells (*https://www.global5g.org/small-cells*) examines the regulatory framework, the issue of supporting cells with high bandwidth both backhaul and fronthaul, with an extensive discussion on radio network sharing and network slicing covering different business models. RF exposure is described in detail as are the regulatory factors impacting deployment. Case studies from four countries are given, showing some barriers to deployment with suggestions on how to overcome them. Global5G.org has simultaneously supported a study with a similar theme conducted within the EC Communications Committee (COCOM) Working Group on 5G. The forthcoming white paper (Q2-2019) will analyse a new set of case studies, some of which are identified through the verticals cartography and Pan-European Roadmap 4.0, highlighting good practices for a lightweight regulatory regime, including coverage in rural areas as a good measure to reduce the digital divide. It will also draw on new European regulation, namely the European Electronic Communications Code (EECC). It assesses work within standards organisations to develop Open Ran specifications, such as ORAN Alliance, TIP, 3GPP (RAN 4) and the Small Cell Forum (SCF).

Standards Tracker

The online Global5G.org Standards Tracker is designed to facilitate the participation of vertical industries in on-going standardisation work, primarily in 3GPP (from release 16 onwards). Users can track study items in terms of vertical or technical focus. A practical guide also explains how verticals can join the standards organisation. Parallel work within the 5G IA Pre-Standardisation Working Group tracks contributions to standards from the phase 2 projects and their vertical partners based on a blueprint developed by Global5G.org. The main outcomes will also feed into the online tool. Collaboration with 3GPP and ETSI tracks progress on relevant study and work items, identifies and analyses requirements from verticals, and coverage of

5G functionalities. On top of this, Global5G.org assesses the impacts of contributions to 5G standards by the projects and 3GPP market representation partners, supporting the high-level evaluation at the programme level. A report (Q2-2019) will zoom in on the overall impacts of the 5G IA WG and its partnerships, concluding with a roadmap for 2020+.

Webinars on Key Vertical Industries

Global5G.org partners organised and produced a series of high-quality webinars on key vertical industries, featuring known experts from industry and respected consulting organisations speaking on the challenges and opportunities arising in the coming years. In 2018, webinars were held on the topics of "5G: what will it change for the Energy industry?" and "How 5G Can Support Transformation in the Automotive Industry?". Further webinars on important verticals will continue over the course of 2019.

To-Euro-5G

The To-Euro-5G project has a clear prime objective to support the activities of the European 5G Initiative, as outlined in the 5G contractual Public Private Partnership (cPPP) signed between the 5G Infrastructure Association (5G IA) and the European Commission, with the intention of maximising the return on this investment for Europe.

The project develops a strategic communications plan to ensure the best possible impact is achieved with the technical results of the 5G PPP projects and the horizontal activities of the 5G PPP programme.

It supports 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 during the second phase of the 5G PPP from June 2017 to June 2019. The To-Euro-5G project facilitates the new Trials Working Group, which was launched by the 5G Infrastructure Association in 5G PPP in September 2016.

The To-Euro-5G 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 can provide, and thus can bring support to the 5G IA Vertical Task Force actions.

The To-Euro-5G project works 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 is to support activities where the 5G PPP can contribute to the implementation of the European 5G Action Plan, which was published by the EU Commission in September 2016.

The purpose of the To-Euro-5G support action is exactly to orchestrate effective and efficient communication and co-operation between all projects of the 5G PPP. This includes supporting cross 5G PPP project working groups on technology fields of common interest and policy-oriented working groups under the responsibility of 5G IA in order to facilitate programme level positions on key horizontal issues of common interests (standards, spectrum, relations to verticals, etc.). These activities support the 5G PPP initiative (5G PPP projects) and 5G IA. The support action must also anticipate supporting 5G PPP related activities stemming from the 5G Action Plan.

The To-Euro-5G project assists the emergence of a supported European vision for 5G and actively promotes this vision with the peer organisations across the globe and promotes global interoperability of 5G solutions by international

cooperation activities through the 5G IA Vision, Pre-standards working groups and International Cooperation activity, conducted in relation with the partner 5G Industry Associations of other countries/regions of the world. The project supports the 5G IA Spectrum working group to coordinate the exploitation of 5G PPP results towards global standardisation via established channels on project partners, which are members of respective standards bodies.

The To-Euro-5G project, through the spectrum and other cross project working groups, supports contributions to regulatory bodies towards the WRC 2019 preparatory process.

The To-Euro-5G project operates the 5G PPP. eu website, and publishes news, monthly newsflashes and quarterly newsletters. It also publishes the 5G Annual Journal.

Impact

Some of the strategic KPIs involve the community knowing how the set of running projects are progressing the goals of the programme and the degrees of achievement of the specific target parameters of the programme. The basic KPIs are listed in the 5G PPP Contractual Arrangement and these will be complemented with work on the metrics to be used to measure the progress against the KPIs. This work is performed in cooperation with the 5G Infrastructure Association.

5G PPP PHASE 3, PART 1: INFRASTRUCTURE PROJECTS

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 advanced labs, e.g. 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 will be interconnected to provide a seamless single platform experience for experimenters from vertical industries. The 5G EVE end-to-end facility will enable experimentation and validation with full sets of 5G capabilities – initially Release 15 compliant and by the end of the project Release 16 compliant.

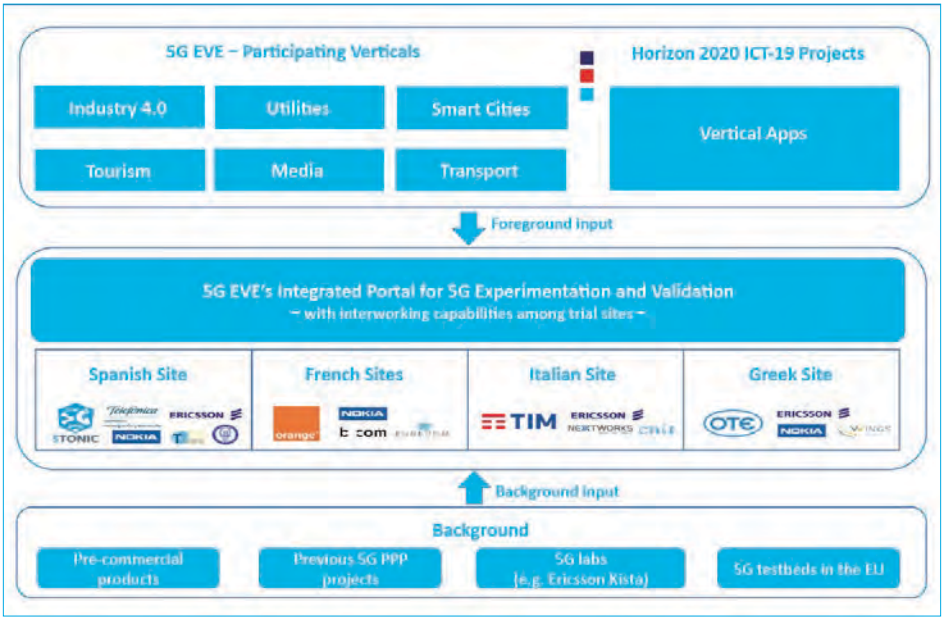

Fig. 29: 5G EVE end-to-end facility – functional architecture

Specifically, the technical objectives include: 1) Implementing Release 16 compatible technologies in the four sites, starting from the evolutions of current Release 15. Specific pilots will validate that 5G KPIs can be achieved; 2) Creating intent-based interfaces to simplify access to the 5G end-to-end facility; 3) Designing and implementing site interworking and multi-x slicing/orchestration mechanisms; 4) Implementing a vertical-oriented open framework; 5) Creating advanced 5G testing and measurement mechanisms to validate advanced 5G features and KPIs; 6) Advanced data analytics on the output of monitoring processes for anticipating network operations.

Major achievements

In its first six months since July 2018, 5G EVE has already established the foundations for meeting its project objectives. The focus was on four major lines of action: 1) Detailed analysis of the first six 5G use cases to be addressed by 5G EVE in 2019; 2) Planning and initial deployment of the required 4G and 5G capabilities at each 5G EVE site for 2019; 3) Design of advanced features for supporting E2E validation tests from 2020 onwards; 4) Dissemination and outreach for attracting more vertical sector player to the 5G EVE innovation ecosystem from 2019 onwards.

Use case analysis – 5G EVE systematically analysed a variety of use cases. They include: 1) intelligent railway for smart mobility (Smart Transport), 2) augmented fair experience (Smart Tourism), 3) autonomous vehicles in manufacturing environments (Industry 4.0), 4) fault management for distributed electricity generation in smart grids (Smart Energy), 5) safety and environment in Smart Cities, as well as 6) UHF media, on-site live event experience and immersive, integrated media (Media & Entertainment). The analysis was translated into requirements for the 5G EVE end-to-end facility. For each use case a detailed 5G KPI radar chart visualizes the general requirements on network performance. Each chart provides information on the adequacy of the existing 4G/LTE networks and the need for 5G network capabilities per use case.

Planning and deployment of 5G capabilities – 5G EVE will open its E2E facility to the verticals within the project consortium in April 2019 so they can start implementing and validating their 5G-ready applications. To this purpose the project has already analysed the capabilities of the four 5G EVE site facilities and planned/started the deployment of the 4G and 5G capabilities required for the testing activities to be carried out in 2019. For each site facility, 5G EVE provides a description of its architecture with all technical features at several levels and a roadmap with the dates of availability for each component of the integrated site facility.

Design of advanced features for supporting E2E validation tests – Beyond offering early access to 5G capabilities, 5G EVE aims to provide verticals with value-added services for enabling advanced E2E validation tests from December 2019 onwards. To this purpose, 5G EVE has designed a comprehensive framework encompassing interworking, testing and KPI measurement features. The key aspects related to interworking are already specified.

Dissemination and outreach – From the start, 5G EVE has been actively communicating its goals, activities and results to its target audiences. 5G EVE particularly managed to attract the interest of potential experimenters from vertical industries who were considering joining the 5G EVE innovation ecosystem. The project actively participated in numerous events, including the 5G PPP Phase 3 Info Day (14 September 2018), the FOKUS FUSECO Forum in Berlin (15-16 November 2018), the 5G Italy Global Meeting in Rome (4-6 December 2018), and ICT 2018 in Vienna (4-6 December 2018). In addition, 5G EVE organised a webinar specifically for ICT-19 proposers (20 September 2018) and contributed an overview of 5G EVE's scope and plans to the 5G Pan-EU Trials Roadmap v4.0 (November 2018).

Site facilities and use cases

At its four interconnected sites, the 5G EVE end-to-end facility enables different use cases and experimental validation of services and applications by verticals.

France – The entrance point of the French site cluster is based at Orange in Châtillon, where the ONAP orchestrator manages the other facilities interconnected via VPN IPsec tunnels. It rests on two main pillars: 1) a pre-commercial Nokia 4G/5G E2E network facility in Paris-Saclay; 2) Open Source building blocks. It is distributed across several facilities – Châtillon-Paris, Rennes (b<>com), and Sophia Antipolis (Eurecom). At the French site, 5G EVE implements use cases on media video and smart grid.

Greece – The Greek site facility covers a region of Northern Athens, operated by OTE and supported by Ericsson Greece, Nokia Greece, and WINGS ICT Solutions. The facility is constantly upgraded through R&D operations and will be upgraded with 5G capabilities based on equipment and technology from the two vendors to initially support three vertical use cases, including a Smart Cities use case.

Italy – The Italian 5G EVE site facility is operated by TIM with the help of Ericsson IT, Nextworks and CNIT; the City of Turin and train operator Trenitalia participate as vertical users. The site facility will be a coherent synthesis of live and laboratory-based experimental environments for the evaluation of 5G features. At the site, 5G EVE will implement Smart Transport and Smart Cities use cases, supported by the City of Turin.

Spain – The Spanish 5G EVE site facility is located at the IMDEA Networks premises in Leganés/Madrid. It relies on the 5TONIC Open 5G Lab created in 2015 by Telefónica I+D and IMDEA Networks Institute, supported by Ericsson ESP, Nokia ESP and UC3M. At the site, 5G EVE will implement conceptual showcases on Media & Entertainment, Industry 4.0 and Smart Tourism.

Further information is available on the 5G EVE website at *www.5G EVE.eu*

5Genesis

5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing

The 5GENESIS Facility shall be geographically distributed across Europe and comprise various Platforms. Instead of building a centralised infrastructure, 5GENESIS leverages existing assets and testbeds across Europe and evolves them to include 5G technologies, thus establishing a fully distributed experimentation facility. In this manner, technological developments are more focused and less costly, exploiting already deployed local assets and human resources. Furthermore, the access to the Facility is significantly improved, since experimenters can choose the Platform which most suits their needs, in terms of technological capabilities and geographical proximity.

Fig. 30: Distribution of the Platforms around Europe

Table 3 summarizes the distribution of the major targeted KPIs among the Platforms of the 5GENESIS Facility.

KPI	Platform				
	Malaga	Athens	Limassol	Surrey	Berlin
Capacity	✓	✓			
Ubiquity			✓	✓	
Speed	✓	✓		✓	✓
Latency	✓	✓	✓	✓	
Reliability	✓		✓	✓	✓
Density of Users	✓			✓	✓
Location accuracy	✓				
Energy efficiency				✓	
Service creation time	✓	✓	✓		✓
Network management CAPEX/OPEX	✓	✓			

Table 3: Allocation of major network KPIs to the 5G platforms

Targeted Test Trials

The use cases have been carefully selected to cover a wide range of complementary 5G showcasing scenarios.

The Athens Platform will demonstrate how 5G enables innovative applications for drastically augmenting the creation of content and the experience of the audience in big events (sports, cultural, etc.). The Egaleo municipal stadium will be the place where these events will take place. More precisely, two service scenarios are foreseen:

Content creation: this scenario will demonstrate adaptive upstream content transmission via the 5G network. It will assume a low-cost content producer with inexpensive cameras covering the event. Without the need to employ costly microwave links and satellite connections for video streaming transmission and also avoiding the overhead on the cellular macro cell infrastructure (Figure 3), the content producer employs a service slice over the stadium's cloud-enabled small cell (CESC) infrastructure with both guaranteed QoE and network edge processing (adaptive multimedia transcoding) and connectivity (MEC), to allow local traffic to stay local and thus meeting the high-throughput and low latency requirements.

Low-latency AR (Augmented Reality) applications: the second scenario will be based on an AR application, to be developed in the project and installed in the smartphones of the audience. Using the AR application and the smartphone camera, the users can focus on any object in the scene (e.g., a particular player in a football match) and instantly receive either real-time information about the object or watch a video stream (served by the content producer, see previous scenario). The mobile edge computing infrastructure will be used to i) host part of the AR application, thus reducing the processing overhead at the mobile device, and ii) serve the associated content, thus relieving the backhaul link and drastically reducing the response time (low latency is critical for AR applications).

The Málaga Platform will test MCS in the city of Málaga using the deployment depicted in Figure 4. Since current Professional Multi Radio (PMR) services are still limited to narrowband voice when using technologies such as TETRA and TETRAPOL, The Málaga Platform will make the deployment of MCS for several configurations over 3GPP networks networks possible. MCSs will request specific capabilities to the network with standard 3GPP interfaces and APIs that the platform will make available to third-party applications and legacy systems.

Several terminals are considered, including cameras deployed on the fly and specific equipment to be carried by Police agents. The measurement of all the relevant 5G KPIs for this use case will be included in the context of the QoE evaluated by real users. How custom terminals using MCS can operate E2E will also be demonstrated. For instance, slices could be established for Video, Data, Voice (3GPP MCPTT R13 services) and eMBMS support.

The Limassol Platform will be used to demonstrate two scenarios, one related to 5G maritime communications and the other related to 5G services in rural/underserved areas including the management and interconnection of heterogeneous IoT devices and platforms existing in 5G environments (Figure 5).

Seamless Maritime Communications: Validation of the "5G hotspot" on the vessel (tanker), served by a hybrid satellite/terrestrial backhaul and evaluating local and remote real-time multimedia communication, as well as sensor network interconnection. Candidate users: Shipping companies (passenger and cargo ships), yacht owners, oil rig holders, and so on.

5G capacity-on-demand in rural/underserved areas: Ad-hoc deployment of a "5G hotspot" and IoT access gateways within areas not (adequately) covered by the existing cellular network infrastructure. Scenarios will include capacity boost for a flash crowd event, administration and interoperability of IoT sensor systems connected to the network and/or the dynamic provision of network slices for multimedia services for large-scale events in rural/underserved areas. Candidate users: Event organisers, local authorities, first responders and public safety, hotel owners, TV and media broadcasters (next-generation Satellite News Gathering). Applications will focus on voice/video communication as well as sensor network interconnection, using the IoT interoperability service (see Sec. III. Both use cases, especially the first one, are of particular relevance to the Limassol stakeholder ecosystem, in which the maritime sector is key element. The evaluation plan also includes demonstration and assessment in open public events, such as the Mediterranean Science Festival in Limassol.

The Surrey Platform will be used for the demonstration of effective massive IoT and multimedia communications in a multi-RAT and multi-spectrum licensing scheme environment, by employing novel RRM solutions. More specifically, a 5G NR and a number of RATs, including LTE-A, WiFi, NB-IoT and LoRa, will be deployed in the area of the Surrey Sports Park (SSP), one of Europe's premier sites for sport and leisure (Figure 6). The aim is to validate 5G KPIs during large scale sports events, mainly benefitting the eHealth and, the multimedia and entertainment verticals. Specifically, the particular use case that is targeted aims at providing an immersive experience with pervasive connectivity during ad-hoc and large scale get-togethers (sports events, concerts, special events). To this end, a massive IoT network slice combined with a dynamic eMBB slice will facilitate the use of information provided by the audience terminals and by a variety of sensors deployed in the venue, for the provision of up to date information and improvement of the provided in-stadium services. The flexible RRM will be supported by self-adaptive policy mechanisms, and intelligent analytics and learning mechanisms. Moreover, the use case considers the real-time monitoring of athletes' healthcare information during a sports event. The rich, truly connected user experience will be complemented by the use of an eMBB slice that will allow the uploading, sharing and curation of real-time video generated by the audience.

The Berlin Platform will assess a "Dense Urban Use Case" realizing 360deg VR streaming. The platform will be used to provide network connectivity at the Humboldt-University during the "Festival of Lights Berlin", which is attended by thousands of visitors. The "dense urban use case" will demonstrate to future European R&D projects, industry, and SMEs that the Berlin platform can be used for 5G evaluations involving a myriad of public users. The chosen 360deg VR application will be of interest to the city of Berlin and local (media) businesses, hence will likely increase the visibility of the trial. Additionally, the targeted use case will allow the validation of 5G PPP KPIs in a real urban environment. It is expected that the trial on the Berlin platform will provide insights on how 5G advances the state-of-the-art regarding the following use of: 1) Mobile Edge Computing to reduce latency and achieve high throughput, 2) VNFs to support slicing, 3) cloud utilities to reduce service creation time, and 4) link aggregation across multiple RATs to increase reliability and resilience.

5G-Vinni

Objectives of the project

5G-VINNI will accelerate the uptake of 5G in Europe by providing an end to end (E2E) facility that demonstrates the key 5G PPP network Key Performance Indicators (KPIs), and lowers the entry barrier for vertical industries to pilot innovative use cases, to further validate core 5G KPIs in the context of concurrent usages by multiple users. 5G-VINNI aims at a longer term evolution of its E2E facility towards the full commercialisation of "5G-Infrastructure as a Service".

The project main objectives are:

- Design an advanced and accessible 5G end to end facility
- Build several interworking sites of the 5G-VINNI end to end facility
- Provide user friendly zero-touch orchestration, operations and management systems for the 5G-VINNI facility
- Validate the 5G KPIs and support the execution of E2E trial of vertical use cases to prove the 5G-VINNI capabilities
- Develop a viable business and ecosystem model to support the life of the 5G-VINNI facility during and beyond the lifespan of the project
- Demonstrate the value of 5G solutions to the 5G community particularly to relevant standards and open source communities with a view to securing widespread adoption of these solutions

The 5G-VINNI facility is composed of several facility sites, which means that the 5G-VINNI architecture is deployed in several administrative domains (e.g. operators). The 5G-VINNI facility sites are classified into two different types:

- **Main Facility sites**: E2E 5G-VINNI facility that offers services to ICT-18-19-22 projects with well-defined Service Level Agreements.
- **Experimentation Facility sites**: 5G-VINNI sites that provide environments for advanced focused experimentation and testing capabilities on elements and combinations of elements of the E2E model. The results of these tests and experiments serve as input to 5G-VINNI E2E implementations and the 5G ecosystem on critical and novel areas such as software and hardware components, architecture, optimizations, models, specific standard validation, etc.

Figure 31 presents the 5G-VINNI facility sites. The main sites are deployed in Norway, UK, Spain, and Greece, while the experimentation sites are deployed in Portugal and Germany, in Munich and Berlin. In addition a mobile experimentation facility site in the form of a rapid response vehicle for public protection and disaster relief (PPDR) use cases is available.

5G-VINNI is not only intended to be simply a group of interconnected test facility sites, as it is underpinned by principles that will allow for highly dynamic and flexible network architectures, service deployment and testing, that will create new technical and commercial service deployment models. These drive inter-facility interconnection to enable virtualized functions from the network and service layer to be called upon from any facility, with complete location agnosticism – a truly cloud-based network instantiation that has no functional boundaries, implemented across multiple facility sites.

More information about the project, access to public technical documents and details about the 5G-VINNI facility release milestones, can be found on the project's website (*https://www.5g-vinni.eu/*).

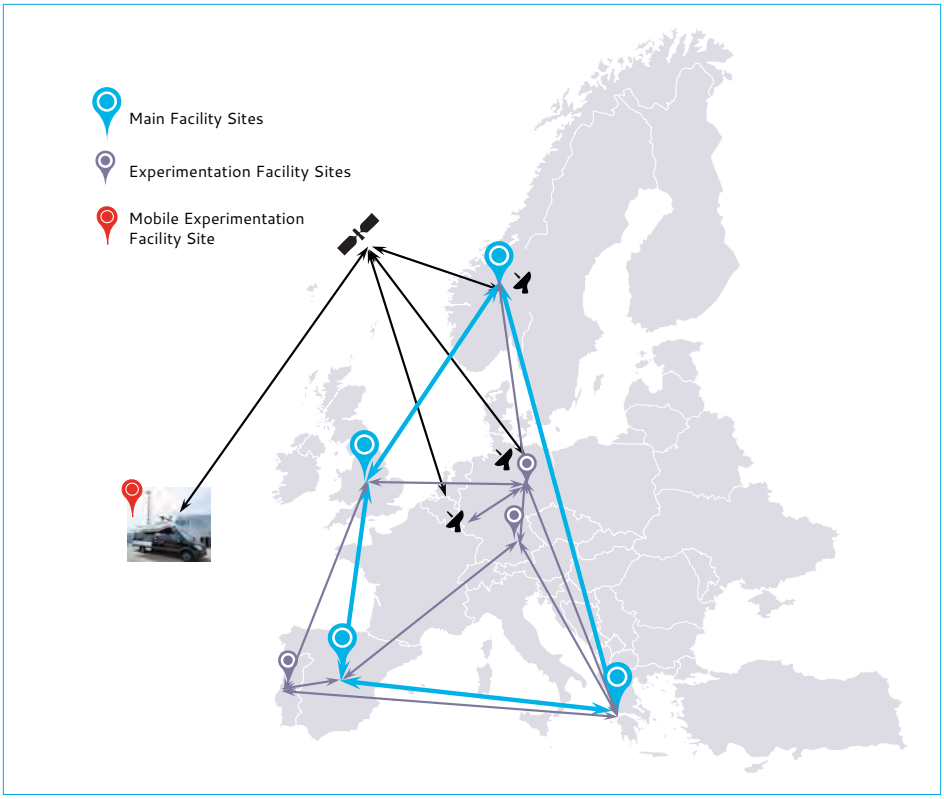

Fig. 31: 5G-VINNI E2E facility

Major achievements/innovations so far and performance KPIs

5G-VINNI started mid-2018 and has delivered the design of infrastructure architecture and subsystems that guides the design and deployment of each individual facility site. This common architecture allows 5G-VINNI facility sites to implement their networks with some degree of consistency, and with the potential for interoperability and interconnection between facility sites. This draws heavily on pre-existing work from standards, as well as from previous 5G PPP projects and more specifically the 5G architecture as defined by the white paper[28] of the 5G PPP architecture work group. The various building blocks of the 5G-VINNI E2E facility are organised in three levels: the *Service Level, Network Level and Resources & Functional Level*. The *Resources and Functional Level* will be comprised of the Radio Access Network (RAN), Backhaul, Mobile Core and Cloud Computing facilities. The latter comes either in the form of Edge or Centralised Clouds that will provide the resources to host the *Service Level and Network Level* elements, which are interconnected to build dedicated logical networks, customized to meet the requirements of the identified service categories, namely eMBB, URLLC and mMTC.

In collaboration with other phase 3 projects, 5G-VINNI has been driving the establishment of the new 5G PPP workgroup on *Test Measurement and KPI Validation – TMV WG*, and is chairing it. The TMV WG has started its work and is bringing together the projects within the 5G PPP that have common interest in the development and advancement of topics related to test and measurement methods, test cases and procedures.

28. https://5g-ppp.eu/wp-content/uploads/2018/01/5G-PPP-5G-Architecture-White-Paper-Jan-2018-v2.0.pdf

Description of demonstrations

5G-VINNI will develop an E2E 5G facility that can be used to first demonstrate the practical implementation of infrastructure to support the key 5G KPIs, and then to allow vertical industries to test and validate specific applications that are dependent upon those KPIs.

A testing platform embedded in the 5G-VINNI facility will facilitate rapid on-boarding of verticals use cases by using network slice templates and exposure of network slice life-cycle management functions through an open API. This will allow demonstration of system performance and functionalities in different vertical industries.

Through its External Stakeholder Board, involving key vertical stakeholders, 5G-VINNI is currently defining the details of the experimentation with initial vertical use cases that will serve as an initial pool of demonstrations that will be showcased from mid-2019.

5G PPP PHASE 3, PART 2: AUTOMOTIVE PROJECTS

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 Mobile (Virtual) Network Operators, Over-the-Top providers, and service providers with a multi-tenant platform that can support the automotive sector transformation towards delivering safer, greener, and more intelligent transportation with the ultimate goal of enabling self-driving cars.

Expected Impact

5G-CARMEN has planned to investigate four application scenarios: cooperative maneuvering, situation awareness, green driving, and infotainment. The project will target automation level up to SAE L3 and L4. Those use cases are expected to have a societal impact by improving both traffic safety, enabling coordinated driving by enhancing environment perception, as well as reducing emissions by aggregating heterogeneous information. Moreover, a commercial impact is expected laying automotive OEMs, the telecom operators and the roadways operators on the global forefront of Safety and Driving Assistance Systems. Moreover, the 5G-CARMEN system is expected to have an impact on the over-the-top service providers, providing advanced infotainment services to passengers in cars and/or coaches.

Technical Approach

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 capable of delivering telecom services over a combination of cellular and meshed networks, which can be operated by different M(V)NOs. The platform will employ different enabling technologies such as 5G New Radio, C-V2X, and secure, multi-domain, and cross-border service orchestration to provide end-to-end network services.

Use Cases

Use Case 1: Cooperative Maneuvering

Cooperation between drivers is a key aspect in ensuring safe and efficient navigation through intersections, lane changing, overtaking, entering/exiting highways, etc. Nowadays cooperation is based on visual communication: via braking lights, turning lights, hand gestures or mimics. The information conveyed in such manner is, however, limited and often cannot be exchanged at an optimal time point. On the highway, drivers often misjudge the distance and speed of approaching vehicles during lane changes. This leads to hard braking events, which, in turn, cause waves of traffic congestion.

Vehicle automation can mitigate this problem to a certain extent. However, recognizing the intentions of other traffic participants is key to an optimized driving behaviour for automated systems and human drivers alike. To this end, 5G can be used to exchange speeds, positions, intended trajectories/manoeuvres, and other helpful data among vehicles. The on-board systems can use this information to derive an optimized driving strategy (in the case of automated operation) or derive a recommended course of action for a human driver to follow in order to actively optimize traffic flow and avoid dangerous situations.

Cooperative lane changing on a highway, for example, can help create the needed gaps for a smooth transition. In the initial phase, a vehicle realises the need to change lane (e.g. due

to a slower vehicle in front). However, the gap between its neighbours in the target lane is insufficient for a safe lane change. Upon this realization, and through cooperation between the vehicles, the gap shall be increased in the second phase. This can be done by slowing down the vehicle in the back (vehicle #3 in the figure) and/or speeding up the vehicle in the front (vehicle #1 in the figure). Once a specified target distance for a lane change has been reached, phase 3 is reached and the considered vehicle (vehicle #1 in the figure) can merge safely.

Cooperative lane merging can be realized either in localized or centralised manner. The former involves direct exchanges between the vehicles, while the latter builds upon a MEC server and a 5G network, which support the vehicles' systems in determining the optimal behaviour to either execute or pass on to the driver as a recommendation. Both of these approaches will be explored in 5G-CARMEN, along with other cooperative maneuvers to positively impact our everyday lives by reducing traffic congestions and avoiding dangerous situations.

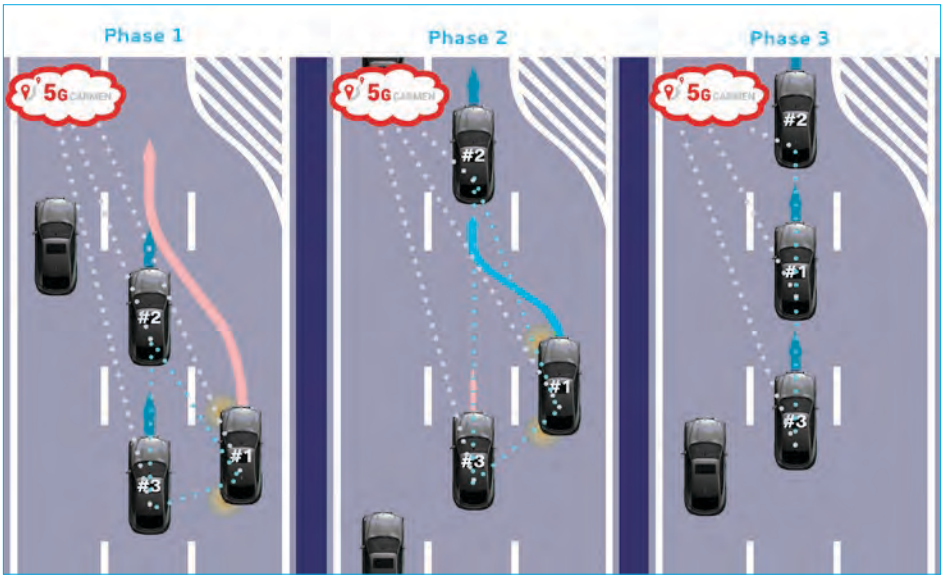

Fig. 32: Cooperative lane changing

Situation Awareness

Automated vehicles and human drivers are limited in their ability to ensure safe and efficient travel by their perception of the road traffic situation. The sensors utilized for automated driving – cameras, lidars, and radars, can only "see" until the next obstruction and the same applies to the human eye. Hence, sources of danger (e.g. objects on the road, other vehicles or vulnerable road users like pedestrians or motorcyclists) are often hidden until the very last moment. Moreover, sudden changes in the weather conditions (e.g. dense fog, fog benches, ice on the road) dramatically increase the risk of accidents if the traveling speed is not adapted accordingly.

In order to help reduce the dangers in vehicular transportation, 5G-CARMEN will promote extended situation awareness by enabling vehicles and infrastructure to share their perception of the environment. This allows for potentially dangerous situations to be recognized well in advanced, so appropriate actions can be derived to mitigate the risk of property damage or physical harm.

5G-CARMEN aims to improve the safety of motorcyclists. Their high travelling speeds, small footprint and frequent lane changes often lead to late detection by drivers; resulting is serious accidents with serious consequences to the motorcyclists owing to their relatively low protection.

Therefore, recognizing their presence in time, either by means of shared sensor data or announcement made by themselves, will lead to increased driver sensitivity and safer overtaking.

The extended situation awareness is also beneficial when considering emergency vehicles arriving from the rear. Knowing about their approach in advanced (even before they are visible or audible) will allow drivers to create a safety corridor earlier and limit their obstruction, resulting in reduced probabilities of accidents and saving in critical time.

Fig. 33: Extended situation awareness

Green Driving

European road operators and authorities have extended their management capabilities beyond safety and traffic efficiency. Air quality and air pollution have become hot topics in our society. Although the transportation sector strives to limit its impact, it is a significant contributor to pollution with Nitrogen Oxides (NOx), Carbon Monoxide (CO), Carbon Dioxide (CO2) and Particulate Matter (PM). In fact, around 12% of CO2 emissions in the EU are produced by vehicles.

5G-CARMEN will provide solutions towards the promotion of greener driving attitudes leading to meaningful improvements in terms of air quality as well as providing elements for entirely new solutions for road operators, road authorities and transport authorities. Obtaining an accurate depiction of the current situation in a given area is key in this regard. To this end, the 5G-CARMEN platform will take advantage of sensor-based information, either coming from connected vehicles or from smart sensors measuring the local emissions. In addition, data on the weather condition, on the current traffic situation, legislation databases and more can be leveraged to determine a course of action that limits the negative impact of vehicular transportation on the public health and the environment.

One prominent example for such actions is the use of electric drive mode by hybrid vehicles in critical areas. Once such an area is recognized, this can be communicated to the hybrid vehicles approaching it, such that their automated systems or the driver are informed in advance of the need to utilize electric drive. If such planning is done on time, it can be ensured that the battery has a sufficient charge in order to pass through the critical area. On top of the above, area-based predictions to be provided by the 5G-CARMEN platform regarding the estimated emissions and air quality status could substantially help drivers with this planning (i.e., allowing to make sure that their electric vehicle is charged in case they plan to pass by a sensitive area).

By exploiting the aforementioned sources of information, added-value services can also be offered to local authorities and other interested stakeholders. Up-to-date information on the air quality and emissions will allow them to take appropriate action when necessary. Examples of such services are descriptive analytics providing an overview of the air quality situation

at a particular location as well as prescriptive and predictive analytics providing targeted insights for future vehicle emissions and air quality status.

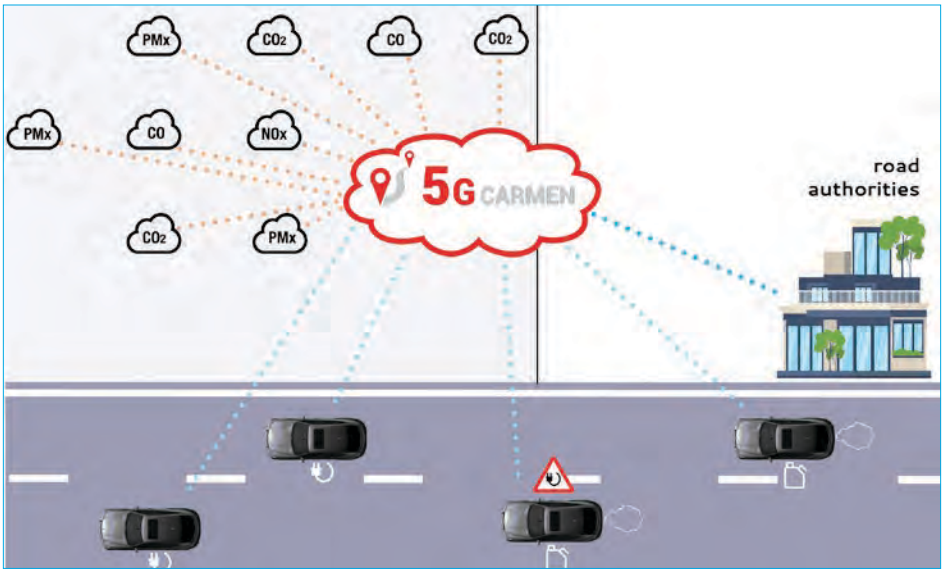

Fig. 34: Solutions towards the promotion of greener driving attitudes

Infotainment

As wireless networks and phones have become more advanced, we can see that the content consumed by its users has evolved as well. The on-demand streaming of movies, live broadcasts and HD videos is one of the most popular forms of entertainment and dominates the internet traffic today. It would be a passenger's expectation to be able to enjoy the same service in an autonomous vehicle, i.e., an always-on-connection, which delivers the kind of speed and latency needed for high-quality video streaming, no matter where they are. Especially with high levels of autonomous driving, passengers' expectation will be to sit back and enjoy multimedia entertainment (e.g. a movie) during their daily commute, just as if they were in the comfort of their homes.

5G-CARMEN will explore different network architectures and configurations, aiming to satisfy users' Quality of Experience (QoE). Key in this regard is the prediction of the expected network QoS and the proactive adaptation of streaming applications in order to avoid interruptions in the service whenever possible. High quality service should always be available, even in cross-country border situations and inter-operator scenarios. Therefore, mobile network synergies between LTE, 5G, C-V2X and other technologies will also be investigated by 5G-CARMEN, in order to guarantee not only the data rate requirements but also the needed coverage at all times.

5G Croco

Fifth Generation Cross-Border Control

Project Goals

The vision of cooperative, connected and automated mobility (CCAM) throughout Europe can only be realized when harmonized solutions that support cross-border traffic exist. The possibility of providing CCAM services throughout different countries when vehicles traverse various national borders has huge innovative business potential. However, the seamless provision of connectivity and the uninterrupted delivery of real-time services across 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

5GCroCo aims at validating 3 key CCAM services: 1) Tele-operated driving (ToD), 2) high definition (HD) map generation and distribution for automated vehicles, and 3) Anticipated Cooperative Collision Avoidance (ACCA). While the actual trials and validations in 5GCroCo will be focused on these particular use cases with envisioned high potential market opportunities, the activities of 5GCroCo aim at deriving recommendations and insights which can be valid for a wider set of CCAM use cases

5G Technologies in 5GCroCo

5GCroCo has identified a set of key 5G technologies which will become enablers for CCAM. They have all been thoroughly evaluated in previous and ongoing research and innovation projects. Some of them are even commercially deployed already. The motivation of 5GCroCo is to evolve them to also fulfill their purpose and role in overall Quality of Service (QoS) fulfillment in cross-border, cross-MNO (Mobile Network Operator), cross-vendor, and cross-OEM (Original Equipment Manufacturers) deployments. Service continuity is a particular goal in this context. The key identified technologies are:

- Distributed Computing enabled by Mobile Edge Computing (MEC).
- Predictive QoS.
- End to End QoS with Network Slicing.
- Precise Localization supported by mobile networks.
- Security.

The V2X (vehicle-to-anything) services that will be studied and trialed in 5GCroCo for the use cases have unique characteristics which make the use of these technologies particularly interesting.

First, there is a limited area of interest. Information is often only needed close to the source where it was generated. This is true for many, but not all applications. It particularly applies to the use cases of HD maps generation and ACCA. Direct communication omitting the cellular network and MEC-enabled cellular networks must be, therefore, part of the V2X architecture.

The second unique property is the multi-OEM and multi-MNO challenge. This one is tightly coupled with the first use cases; ToD. For a typical mobile radio network providing services like voice and data communication, it does not matter that peering points between MNOs, vehicular clouds, and public data networks are located far from the "edge". However, in a MEC-enabled V2X architecture this problem must be

solved and the solution cannot be to have just one MEC provider.

The third unique property is the role of the road authority as another source of information. This comes along with often closed, sometimes even proprietary, IT-systems (Information Technology) needing integration in a MEC-enabled distributed computing V2X network architecture. A particular challenge arising from this is that crossing national, in some cases also regional, borders results in a new road authority with its own IT infrastructure becoming responsible. With these technologies, 5GCroCo will address the gap of existing cellular V2X technologies (such as LTE Release 14) by enhancing a number of Key Performance Indicators (KPIs) in the 5G network, such as latency, reliability, and packet error rate, even under cross-country, cross-MNO, cross-OEM and cross-vendor operations.

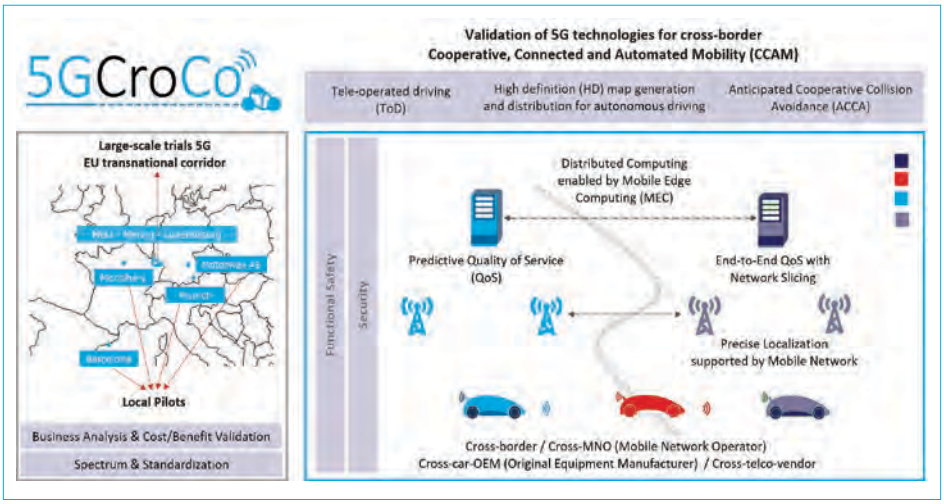

Fig. 35: 5GCroCo – Technical Overview

5GCroCo Test Sites

Trials at both large and small scales will be conducted in 5GCroCo to validate the 5G technologies for the three identified use cases, especially in cross-border, cross-vendor, cross-OEM and cross-MNO environments.

5GCroCo will concentrate its large-scale trials in the 5G European corridor which connects cities of France, Germany, and Luxembourg, and is part of the pan-European network of 5G corridors facilitated through several regional agreements. These agreements allow Europe to count with hundreds of kilometres of motorways where tests can be conducted up to the stage where a car can drive autonomously with a driver present under certain conditions (third level of automation). These corridors count with the support of the European Commission as part of its 5G Action Plan, which aims at ensuring commercial deployment of 5G technologies by the end of this decade.

In addition to the large-scale trials in the corridor, 5GCroCo also plans to deploy local pilots, as a step before large-scale deployment in the corridor. These pilots will be deployed in Montlhéry (South of Paris, France), two in Germany (in a section of the motorway A9 and a test-site in the Munich city center), and one in the city of Barcelona (Spain) where a cross-border city setting will be emulated. These pilots will allow to test 5G functionalities locally (geographically close to the different involved partners), and possibly in restricted closed areas, so that the complexity of doing the trials in the large scale corridor can be managed. These trials will allow selecting and fine-tuning the 5G capabilities that will be then integrated in the large scale

trials, thus reducing the uncertainties associated with their deployment and trial.

Business Innovations

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

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

5G Mobix

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

The new 5G-MOBIX project is an integral EU 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 will execute CCAM trials along two cross-border corridors and six urban trial sites. The trials will 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 utilized 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 overall concept & trial architecture

5G-MOBIX trials

The vision of 5G-MOBIX is to enable innovative, previously unfeasible, automated driving applications, both from a technical as well as from a business perspective. To do so, 5G-MOBIX will showcase the potential of different 5G features on real European roads and highways and create and use sustainable business models for the corridors' development.

The dual nature of the 5G-MOBIX trials, comprising both cross-border corridors and urban trial sites of significantly diverse road conditions and driving cultures and needs, allows for a multi-modal approach to the effort of advancing CCAM use cases, optimizing their functionality depending on the environment and defining innovative upgraded functions based on 5G connectivity.

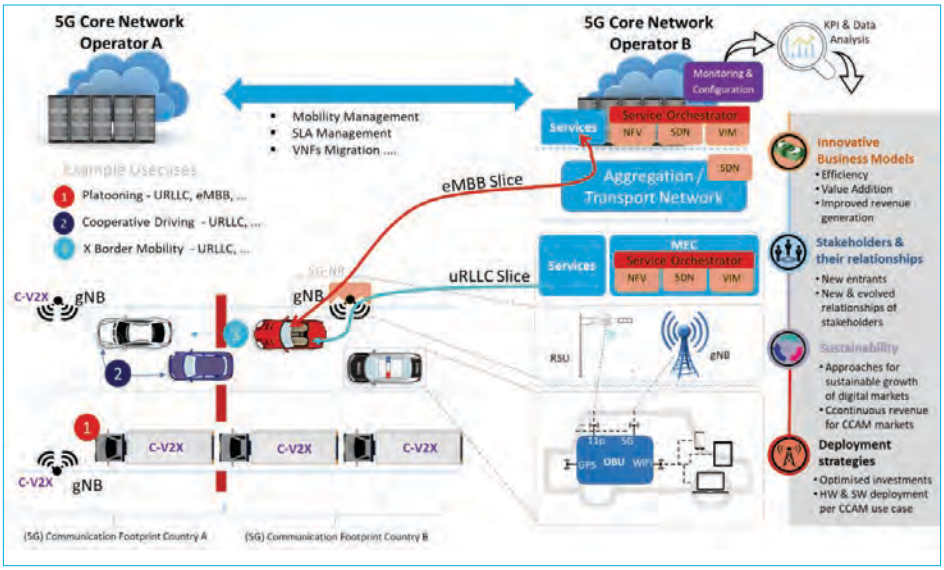

Fig. 36: 5G-MOBIX overall concept & trial architecture

Two European cross-border corridors located between Greece-Turkey and Spain-Portugal are the flagship of 5G-MOBIX, showcasing the capabilities of 5G connectivity for higher-level automated driving cases in all conditions and building the foundation for the support of SAE L4 (and possibly beyond) automated driving on all major European transport paths by 2025.

Four European urban trial sites are located in Espoo (Finland), Versailles (France) Berlin and Stuttgart (Germany) and Helmond Brainport (The Netherlands). These sites offer the flexibility of experimenting with the deployment and integration of novel 5G technologies on an existing infrastructure (e.g. UDN), trying out different deployment and configuration strategies, approaching similar use cases with different deployments, vehicles and equipment or even investigating cost-effective models for infrastructure rollout and component integration. The variety offered by the trial sites allows for the execution of multiple CCAM use cases as well as business cases that are of relevance to the local as well as the European industry and stakeholders, showcasing and progressing the most suitable and scalable solutions for pan-European deployment.

Finally, two Asian urban trial sites located in China (Jinan) and South Korea (Yeonggwang) are tightly coupled to 5G-MOBIX, providing a world-wide perspective for the deployed technologies and the applicability of selected use cases and harmonizing the approach among them, ensuring the maximization of the impact of 5G-MOBIX results and proposed solutions.

EU-Taiwan: 5G Coral

5G-CORAL: A 5G Convergent Virtualized Radio Access Network Living at the Edge

In recent years, the research and development of 5G has gained importance. The main goals of the research performed in the 5G projects has been the increase of bandwidth, reduction of the latency and improvement of the network to allow the increasing number of mobile users. Most of this work has been done over centralised networks, however, less research work has focused on the edge of the networks. For specific applications such as augmented reality (AR), connected vehicles and robotics, other technical requirements are very important. These applications require guarantees of end-to-end latency to deliver high quality services, thus, it is necessary to shift networking, computing and storage capabilities to the edge of the networks (intelligent edge), close to the end users. This is the key argument of the 5G-CORAL (*http://5g-coral.eu/*) project, focusing on the intelligent edge concept to integrate and extend the edge and fog computing approaches.

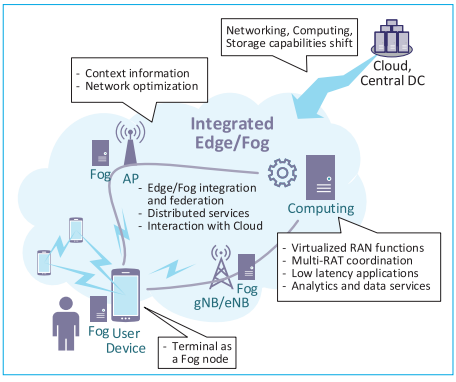

Fig. 37: Multi-Access convergence leveraging Edge and Fog Computing

The project is motivated by the fact that nowadays most end user devices operate multiple independent radio access technologies (RATs) in parallel (e.g. LTE and WiFi). This diversity requires harmonization and/or integration of communication protocol stacks from different RATs, selection of the best ones for a given user/service at a given time, or interference minimization of different RATs sharing the same spectrum. Thus, this paradigm of multi-RATs convergence can be possible thanks to the intelligent edge, and all together can enhance network performance, cost-effectiveness and user QoE, as shown in Figure 37.

Hence, during the first year, the 5G-CORAL has defined its architecture extending the framework provided by ETSI for Multi-Access Edge Computing to a multi-tier Fog, MEC and Cloud infrastructure, following the features of ETSI Network Function Virtualization (NFV). The architecture is a hierarchical multi-tier computing infrastructure, composed of clouds and central data centres (DCs) on top, down to edge data centres (Edge DCs), and further distributed down into fog computing devices (Fog CDs) available locally in the access area. These three tiers are gathered in two major building blocks: 1) the Edge and Fog Computing System (EFS) merging the physical and virtual resources available on the fog and edge devices; and 2) the Orchestration and Control System (OCS) responsible for managing and controlling the EFS, including its interwork with other (non-EFS) domains. This architecture is shown in Figure 38.

During this second year, the project has focused on the proofs of concepts (PoCs) in order to verify the feasibility of the solutions/innovations proposed in the 5G-CORAL project. To validate the concepts, in all these PoCs and demonstrations, some key performance indicators (KPI) such as latency, jitter, throughput, energy efficiency, number of supportable connections, etc. have been measured.

- **Multi-RAT IoT Gateway**: The IoT Multi-RAT PoC introduces a technology-agnostic IoT access system for future-proof IoT support. It follows the Cloud-RAN approach, centralizing baseband processing at the Edge in EFS. The system is comprised of three parts: radio heads, Ethernet network and edge cloud, as shown in Figure 37. The radio heads are in charge of transmitting and receiving radio signals. They are connected to communication stacks, running on the EFS in an Edge cloud, and in charge of modulating/demodulating the radio signals for one RAT, as well as of handling all upper layers. This PoC was demonstrated at EuCNC 2018.

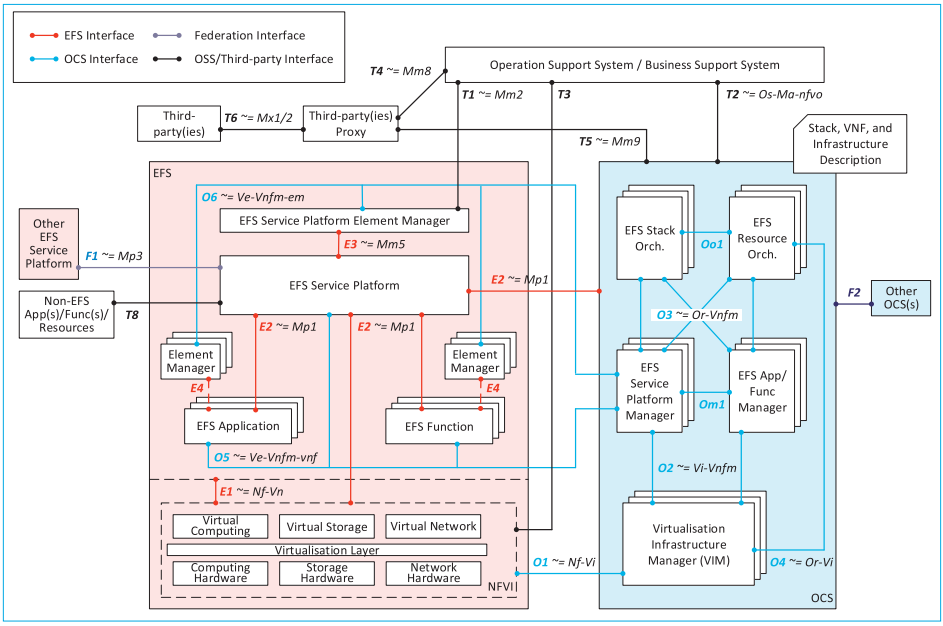

Fig. 38: 5G-CORAL Architecture

- **Virtual Reality**: The Virtual Reality (VR): PoC aims at showcasing the benefits of a 360° video live streaming delivered by 360° cameras located in specific points of interest inside a shopping mall. This PoC makes use of the EFS distributed Fog computing scenario to achieve high bandwidth and low latency. This scenario is shown in Figure 39 and was demonstrated in November 2018 in Nangang global shopping mall, Taiwan.

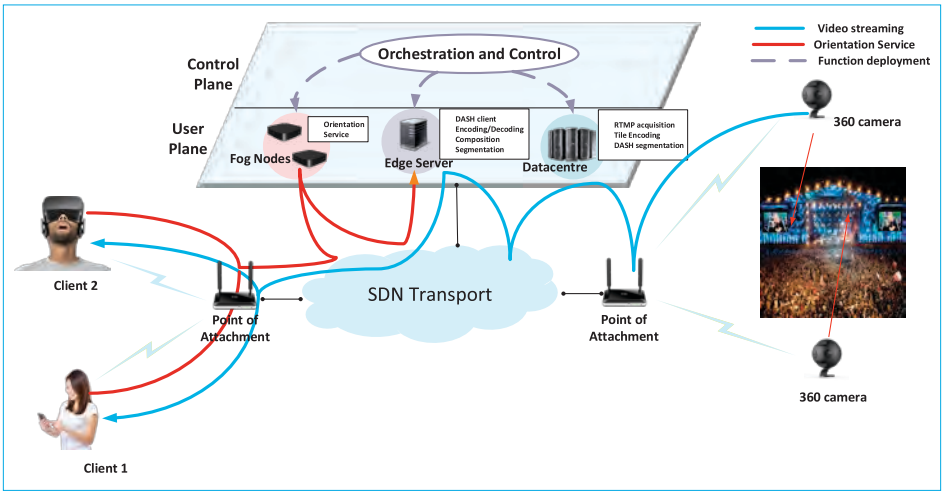

Fig. 39: VR 360° video live streaming scenario

- **Augmented Reality Navigation**: This PoC focuses on Augmented Reality (AR) Navigation to provide a continuous indoor AR navigation experience for the users inside a shopping mall. The video captured by the smartphone camera is sent to an Image Recognition (IR) application residing in a Fog node. The location of user is estimated using iBeacon and the IR analysis. This scenario was demonstrated in November 2018 in Nangang global shopping mall, Taiwan.

- **Fog Assisted Robotics**: The Fog Assisted Robotics PoC consists of two demo scenarios: cleaning robots and delivery robots. In the cleaning scenario robots will autonomously clean areas of the shopping mall based on the density of visitors. In the delivery scenario multiple robots in synchronous cooperation will carry large items from the warehouse to the shops. This scenario is shown in Figure 40 and was demonstrated in November 2018 in Nangang global shopping mall, Taiwan.

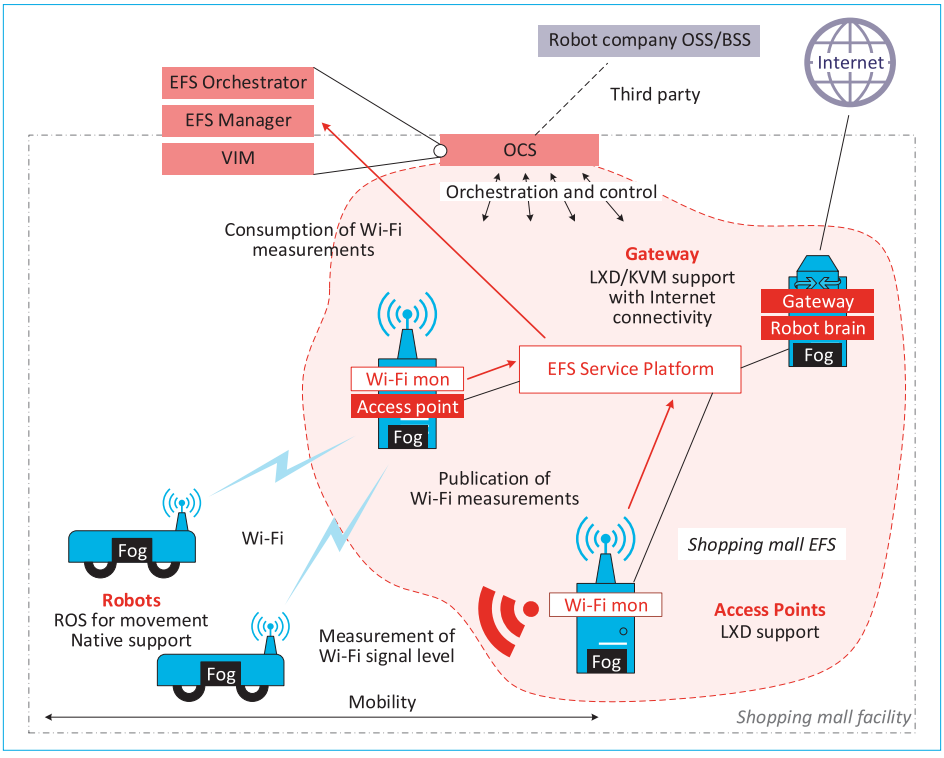

Fig. 40: Interconnection of EFS entities in cloud robotics use case

5G PPP PHASE 3, PART 4: COMPLEMENTARY PROJECT

5G-DRIVE

Concept and objectives

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 will realize 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 will develop key5G 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.

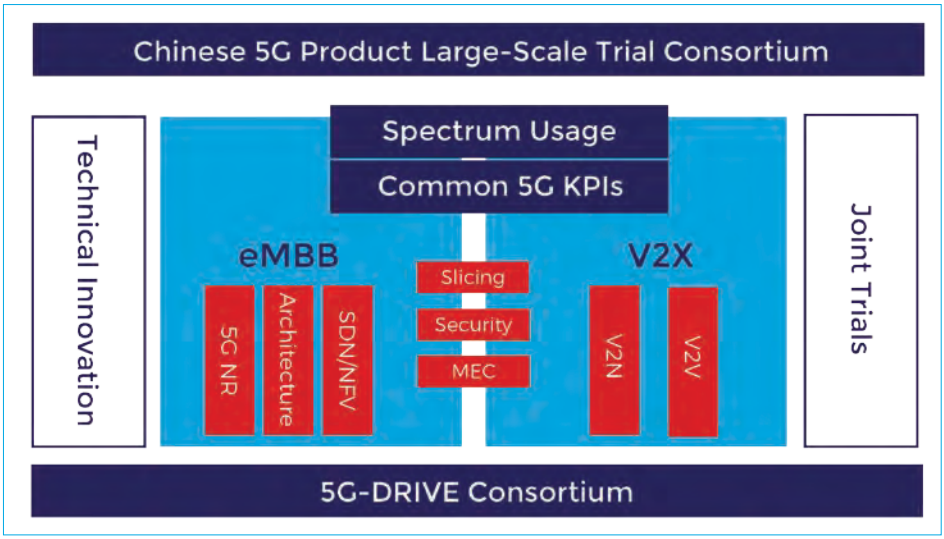

Fig. 41: 5G-DRIVE concept

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 trialling 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 3GPP 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 3.5GHz 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.

eMBB development and test plan

In the eMBB scenario, 5G-DRIVE aims to build pre-commercial end-to-end (E2E) testbeds with sufficient coverage to evaluate the performance of eMBB on the 3.5 GHz spectrum band. The building of such testbeds is to allow the testing of 5G NR (New Radio) with a focus on eMBB using close-to-commercial equipment in realistic settings that can reproduce near real-life network performance. The trialling activities will use the 5G trial and testing pre-commercial network trials framework provided by the NGMN (Next Generation Mobile Networks) Alliance.

For eMBB, the trials to be deployed will cover three scenarios: indoor hotspots, focusing on high user density and high capacity/throughput in indoor small coverage areas; dense urban areas, focusing on high user density and high traffic loads in city centres with outdoor coverage scenario, and indoor hotspots, focusing on continuous coverage in urban areas and macro cells. The trials conducted will be in either the SA (Stand Alone) or NSA (Non-Stand Alone) architecture.

The eMBB trial activities will be carried out at three sites. JRC (Ispra, Italy) will focus on the performance characterisation of commercial 5G NR base stations delivering eMBB services in the 3.5 GHz band; the VTT 5G testbed (Espoo, Finland) will facilitate the testing of SDN/MEC, indoor positioning, latency reduction, reliability, among others; the 5G Innovation Centre (Surrey, UK) will focus on the evaluation of eMBB, including 5G service with controlled latency to support AR services across two regions.

The methodology used for the eMBB trial measurements includes an initial specification of the technical requirements and respective system functionality to support the eMBB use cases. It also includes the definition of Key Performance Indicators (KPIs) to measure the success criteria of system functionality and to determine test network setups for validating the eMBB use cases. The test measurements and analysis of results for each setup will be realised according to 3GPP recommendations. The main KPIs to consider in the analysis include peak data rate, user experienced data rate, cell-edge user data rate, user plane latency, control plane latency, cell capacity, spectral efficiency, coverage, mobility, reliability and area traffic capacity. These KPIs will be tested at one or more of the eMBB trial sites.

Trial results will be analysed within the 5G-DRIVE project and together with the Chinese twinning project, in order to assess and validate the interoperability.

V2X development and test plan

In the V2X scenario, 5G-DRIVE aims to demonstrate 5G technologies at pre-commercial testbeds with V2X services and then demonstrate Internet-of-Vehicle (IoV) services using Vehicle-to-Network (V2N) and Vehicle-to-Vehicle (V2V) communications. The demonstrations will be carried out through different trials with the objective of testing 5G network capabilities to deliver ultra-reliable lower-latency communication (URLLC) for self-driving scenarios. They will also aim to validate 5G KPIs in terms of bandwidth, latency and communication coverage in different scenarios and pilot sites as well as to evaluate V2V and V2N communications resilience against cyber/RF attacks and interference under real-life conditions.

The V2X scenario trials will be carried out in three phases. The trial setup and preparation phase will define and specify the trial environment, the trial scenarios and the evaluation methodology. The execution phase will provide a description of the methodology to implement and coordinate the execution of the trial. The evaluation phase will evaluate the results of the trials and deliver conclusions about the benefits and challenges of using 5G in the context of V2X scenarios. The information in these three phases is specific to the activities of each trial site.

To evaluate the potential benefits of 5G on V2X scenarios, trials scenarios will be carried out at two pilot sites: Espoo (Finland) and JRC (Ispra, Italy), each trial site having complementary objectives.

Trials at Espoo aim to demonstrate 5G benefits for the automated driving use case and will be done in three phases: setting up the V2I devices (LTE and ITS-G5) on the cars and drive baseline data for identifying latencies and bandwidth capacity; implementing C-V2X devices (LTE Uu, release 14) to two different cars operating on the 2.6 GHz and 5. GHz band; and implementing C-V2X devices (LTE, release 15/16) which are operating on the 5.9 GHz band, depending on the availability of communication modules. The aim is to understand eMBB, URLCC and also slicing feature opportunities when proceeding forward with real 5G networks.

The trials at Ispra aim to evaluate the co-existence of ITS-G5 and LTE-V2X and will focus on the experimental evaluation of V2X scenarios both at the laboratory and field test levels. V2X testing will address two scenarios: on-the-field C-ITS service demonstration and LTE-V2X/ITS-G5 coexistence in the 5.9GHz band. The former one aims to demonstrate a selected day-1 C-ITS service using ITS-G5 and LTE-V2X equipment. The demonstration will involve a non-automated vehicle, two roadside units (one LTE-V2X, one ITS-G5) and two on-board units (one for each V2X technology). The latter one will evaluate the "out-of-the-box" coexistence of commercial off-the-shelf ITS-G5 and LTE-V2X devices. This particular demonstration will involve the conducting of a subset of the RF compliance tests and the characterization of the co-channel interference of each technology by evaluating the same RF metrics in a joint ITS-G5/LTE-V2X deployment.

The V2X demonstrations will combine two main types of testing. At the Espoo site, vehicles will drive in a real environment, while at Ispra, testing will be done in a controlled environment, based on harmonised standards. This combination intends to provide the required diversity of testing for evaluating the suitability and benefit of 5G for V2X scenarios.

GLOBAL 5G EVENTS (G5GE)

5G initiatives to date

The European Commission strongly supports International cooperation and seeks a global consensus on 5G for the development of globally accepted standards and spectrum requirements. Agreements have already been signed with all regions in the world. In 2015, the 5G Infrastructure Public Private Partnership, 5G PPP, established partnerships with similar 5G programmes outside Europe. From June 2014 to April 2018, MoUs were signed between 5G PPP and peer organisations throughout the world (respectively with the 5G Forum in South Korea in June 2014, 5G Americas in the US and the 5GMF in Japan in March 2015, the IMT-2020 (5G) Promotion Group in China in September 2015, Telebrasil in Brazil in March 2017 and TSDSI in India in April 2018).

In October 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 promote 5G globally. 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 programs 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 begins in 2017.
- The Fourth Global 5G Event was held in Seoul, South Korea on November 22-24, 2017. It was organised by 5G Forum.
- The Fifth Global 5G Event took place in Austin, TX and was organised by 5G Americas on May 16-17, 2018. The 5G IA was represented by eight speakers and moderators. The 5G New Horizons Wireless Symposium discussed the status and progress of 5G.
- The Sixth Global 5G Event was held in Rio de Janeiro, Brazil on November 28-30, 2018. The event was hosted by 5G Brasil. 5G IA and 5G PPP projects were present with 9 5G-IA/5G PPP speakers.

The Mobile World Congress 2019 held in Barcelona, Spain from 25-28 February was a great opportunity for the 5G Infrastructure Association (5G IA) and for 13 projects of the 5G Public Private Partnership (5G PPP) initiative to showcase the latest developments of their work under the motto 'experience the future of 5G now'.

Future actions

The 7th Global 5G Event "Creating the smart digital Future" will take place in Valencia, Spain on June 17-18, 2019. The event is organised by 5G IA/5G PPP and the European Commission.

The preliminary agenda is already available. On the afternoon of Monday 17 June, a session on 5G regional trends will be held. On Tuesday 18 June, sessions on 5G for Business the future of 5G and the upcoming 8th Global 5G Event will be organised. On the afternoon of Tuesday 18 June, technical sessions on cross-regional projects and 5G KPI measurement are scheduled.

The event will be co-located with EuCNC 2019 (June 18-21, 2019). Both events will be major opportunities to promote 5G PPP projects and achievements.

Assessing the 5G research and development investment Leverage Factor

This section 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.

Assessment methodology used

Our methodology is based upon gathering the published public figures from annual reports for worldwide R&D expenses. It was developed by the To-Euro-5G project.

The main challenge is then to assess the declared R&D figures of a representative set of Key ICT players and deduce which proportion of their R&D spend is 5G related. We also discussed if the 5G spend in Europe could be identified or at least assessed.

So we made conservative assumptions on what the 5G activities share of their worldwide R&D was – usually in the order of 10% and then we further reduced that to reflect what European share of the 5G activities as part of the total R&D expenses could be – typically we ended up with a figure of about 5% of global R&D. To further eliminate over-assessment risks and to give us a very conservative figure we also considered the European 5G as 2% of Global R&D. These proportions of 5G research of total research expenses will increase as 5G moves into full standardisation, development and production over the next few years and future iterations of these assessments will take account of this.

Our first release dated July 2016 was based on publicly available figures for FY2015. The second edition uses FY2017 figures. We do not modify the shares we applied last year as we consider the full standardisation phase has not begun yet. In our view, 2018 was a transition year from standardisation to trials. This year, we used FY2018 figures for our evaluation.

For direct evaluation purposes, we took into account a representative set of players active in the 5G PPP. For a second reference figure we have considered a wider set of players in different aspects of the ICT sector including: equipment manufacturers, mobile network operators, test equipment manufacturers and device manufacturers, and chipset manufacturers.

Main biases from the methodology and declared figures

There are significant methodology biases that we have to be aware of.

First, R&D figures are often considered as critical by companies. As such, data on trends are not always consistent and public figures can be misleading. Some companies disclose information on Capital Expenditures, other on "innovation" – innovation appears as a portmanteau word that leaves much space for interpretation-, and still others prefer to use the term "R&D expenses", without one knowing the method actually used of what is counted.

Second, the assumptions we made on what the 5G activities share of the worldwide figures collected was are based on our expertise but could significantly vary depending on companies. We tried to lower the uncertainty in this field as much as possible and correct misperceptions.

Third, we selected a wide set of players involved in the 5G field but could not gather information from all companies. Information could remain fragmentary in some areas. However, we consider our sample of 21 organisations is reliable.

Assessment of leverage ratio for 2018

Redoing the same exercise as in 2017, we get the following result for 2018:

5G PRIVATE R&D SPENDING (Million EUR)		2018R&D	5G as 10% of glob. R&D	5G as 5% of Global R&D	5G as 2% of Global R&D
Infrastructure Vendors					
	Ericsson	3 686	369	184	74
	Nokia (Incl. ALU)	4 620	462	231	92
	Huawei	15 000	1 500	750	300
	NEC Europe	859	50	25	10
	Samsung*	14 572	729	364	146
MNOs					
	British Telecom	598	50	25	10
	Orange	786	79	39	16
	Portugal Telecom		7	3	1
	TIM	2 400	240	120	48
	Telefonica	947	94.7	47	19
	Telenor	70	7	4	1
Test equipment					
	Keysight Technologies*	536	26.8	13.4	7
Chipset					
	Intel*	13 100	655	262	131
	Sequans	25	2	1	0
IT					
	ATOS	300	29	14	6
	IBM	2500	250	125	50
Others					
	ADVA	25.66666667	3	1	0.5
	CEA	90.00	7	3	1
	Hewlett Packard Enterprise	1663	7	3	1
	Thales	879	88	44	18
	IHP	25.00	3	1	1
TOTAL 5G PRIVATE R&D SPENDING (Million EUR)		62 682	5G as 10% of glob. R&D 4 656	5G as 5% of Global R&D 2 261	5G as 2% of Global R&D 931

Phase 1 total funding from EC	125	125	125	125
Phase 1 fourth year funding	6	6	6	6
The players in the table share of EU funding is	50%	50%	50%	50%
Phase 1 fourth year funding for above mentioned players	3	3	3	3
Phase 2 total funding from EC	150	150	150	150
Phase 2 2nd year funding	61	61	61	61
Phase 3 part 1. total funding from EC	60	60	60	60
Phase 3 Part 1. 1st year funding	10	10	10	10
The players in the table share of EU funding is	50%	50%	50%	50%
Phase 2 2nd year for above mentioned players	31	31	31	31
Phase 3 1st year for above mentioned players	5	5	5	5
Leverage factor 2018**		60	29	12
Leverage factor 2018 for above mentioned players		121	59	24

Table 4: 5G R&D expenses

Assumptions in italics when R&D expenses are unknown
**: for companies not based in the EU*
***: (phase 1 fourth year, phase 2 second year, phase 3 first year) divided by total R&D spending*
Source: To-Euro-5G, based on publicly available figures and estimates

It now can be seen from the table, that the most conservative assessment of 2% of the Global R&D spend being invested in 5G would increase in **a leverage factor of 12** considering the whole 5G PPP 2018 investment (Phase 1 fourth year, Phase 2 second year, Phase 3 first year).

The 5G PPP funding for phase 1, phase 2 and phase 3 (Part 1) projects was about 130M EUR for bigger industry, which facilitated projects with a value of around 20M EUR per year – allowing for projects with different durations (between 24 to 36 months). The total funding budget for 5G PPP Call 1 was 125M EUR. It was 150M EUR for phase 2 and 60M EUR for phase 3 part 1.

Conclusion on Leverage ratio for 2018

From the above exercise, even allowing for the assumptions and generalisations, we can confidently state that the European ICT sector is achieving, and most probably exceeding, the planned level of investment leverage expected in the 5G PPP Contractual Arrangement.

A more direct leverage ratio in relation with the 5G PPP Projects will be assessed in the 5G PPP Progress Monitoring Report 2018, that will be issued by end June 2019.

SME success stories and results from the 5G PPP projects

The participation of Small and Medium-sized Enterprises (SMEs) in the 5G PPP is not far from reaching the 20% share, as originally targeted with one of the 5G PPP KPIs (Key Performance Indicator) by the EC and the 5G IA when the initiative was launched. This shows the key role that SMEs are playing in developing, piloting and deploying 5G technologies. Some examples of recent results and success stories from European SMEs involved in 5G PPP projects are shown below. 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.

Thanks to their involvement in the 5G PPP, the SME InnoRoute from Munich, Germany, developed business around their TrustNode router platform. CHARISMA allowed InnoRoute to optimise the platform for ultralow latency, while the SELFNET project helped optimise the platform to support SDN (Software Defined Networking) modularity and extension. Thanks to those features, InnoRoute was able to enter the Industry 4.0 business by adding TSN (Time Sensitive Networking) functionality to the TrustNode. InnoRoute is now interacting with major players in the industrial and automotive sectors for further TSN developments.

IS-Wireless from Warsaw, Poland, benefitted from their participation in the 5G Essence project to demonstrate the benefits of 5G mission critical applications in coexistence with centralised RAN (Radio Access Network). This has allowed the company to seriously contribute to the delivery of a complete Software Defined (SD) RAN solution, that should be showcased in 2020.

Visiona Ingeniería de Proyectos from Madrid, Spain, has been contributing to the 5G-Crosshaul and the NRG5 projects. Visiona's approach to the preventive maintenance aims to detect different changes in the target zones to predict possible dangerous conditions on the environment or in the structures. This is based on images obtained from UAVs (Unmanned Aerial Vehicles), in this case, an autopilot drone. Thanks to 5G features, Visiona has implemented VNFs (Virtualized Network Functions) to deliver computer vision services through the network by deploying them in the edge of the network, to increase drone autopilot reaction. Visiona is also using artificial intelligence applied to vision and developed a people and vehicle detection system in critical locations, a change recognition system on UAV imagery, and an abnormal hot points detection through thermal image. This will allow for example to find environmental changes in areas close to key infrastructures.

Incelligent, a Greek SME located in Athens, delivers AI-powered products for proactive network resource and customer experience (CX) management, as well as AI-powered products for the fintech and public sectors. Through its participation to the 5G PPP projects Matilda and Pg-Phos, Incelligent was enabled to mature its technology (in terms of functionality, positioning in standards, etc.) and to conduct showcases, by interacting with verticals entities involved in areas like malls, venues, stadiums, and with large ICT companies.

Nomor Research from Munich, Germany, took advantage of their involvement in the 5G MoNArch and in the 5G XCast projects to strengthen their position as number one among the independent providers of simulation results for mobile communication networks. This has happened thanks to their contribution to system-level simulation results in the 5G IA IMT-2020 Evaluation Group, where they are evaluating the 3GPP proposal for 5G ("New Radio") against the IMT-2020 requirements[29].

Although the 5G EVE project has only recently started, the SMEs involved can already see the benefit of participating in the project. Telcaria from Madrid, Spain, has motivated current employees to develop their professional careers to pursue Ph.D. and has been able to hire new employees. Ares2t from Rome, Italy, has hired

29. Cf. white paper available at http://nomor.de/wp-content/uploads/2018/11/White_Paper_5G_SLS_Calibration.pdf.

one new employee and plans to hire a second one; they have increased their overall budget by 20% and already extended their network of potential customers thanks to the connection with top companies participating in the consortium.

5G PPP projects helped WINGS ICT Solutions from Athens, Greece, to progress its offerings around hardware and solutions for verticals, and to prepare for the future. Through its participation in One5G, WINGS enhanced its utility solutions, developing mechanisms for enabling a utility-operator to interact with the network (slice) management systems of a 5G network operator. These technologies were demonstrated at MWC 2019 and were part of the project booth that received the "best booth award" at EuCNC 2018[30]. Thanks to the 5G PPP, WINGS has enhanced its headcount, as well its competence.

In the context of its activities across several 5G PPP projects[31], the Italian SME Nextworks, from Pisa, has developed a strong asset of software prototypes for an advanced NFV MANO framework targeting 5G infrastructures and integrating innovative features for 5G telcos, service providers and vertical industries. The core of Nextworks service management and orchestration framework is built around the 5G Apps & Service Catalogue, TIMEO (Transport Infrastructure and MEC Enabled Orchestrator), SEBASTIAN (SErvice BAsed Slice Translation, Integration and AutomatioN), the Plug & Play control of virtualized functions for 5G, and the 5GCity Software Development Kit. Thanks to its involvement in the 5G PPP, Nextworks performed demonstration activities at major events, which have become key references and success stories to present the company expertise to potential customers, thus increasing competitiveness and differentiation with competitors.

Interesting initiatives to support the development of SME solutions in 5G environments are appearing in Europe and beyond. In Sweden, a new project called "Wireless Innovation Arena" aims to create favourable conditions for SMEs in the region of Upper Norrland to develop innovative services based on 5G technologies. An important part of the project is the 5G test environment, "5G Innovation Hub North", based at Luleå University of Technology, in collaboration with Telia. There, companies can perform different types of tests and experiments to validate new products and services. A similar initiative called ENCQOR (Evolution of Networked Services through a Corridor in Québec and Ontario for Research and Innovation) has been launched mid-2018 in Canada, focusing on providing means for SMEs, researchers and academia both for unlocking the technological promise of 5G in the near term, and for driving long-term economic growth in Québec and Ontario and in the broader Canadian innovation ecosystem[32]. Some of the 5G PPP platform projects, launched in Phase 3, also have open calls for SMEs. Such initiatives should be broadened soon to ensure a strong involvement of SMEs in the deployment of 5G in Europe and beyond.

A second version of the brochure entitled "SME Expertise and Skills in the 5G Domain" was released mid-2018. It included the description the expertise and success stories of 34 European SMEs. Now that a new phase of the 5G PPP is being launched, with on the one hand the objective of targeting vertical sectors, and on the other hand of looking beyond 5G, SMEs are faced with new challenges. A revised version of the brochure considering those new challenges will be released in time for the 7th Global 5G Event, that is hosted in June 2019 by the 5G IA in Valencia, Spain, and for the co-located EuCNC conference. A dedicated SME booth will show demos and achievements of several SMEs out of the 5G PPP projects. This year, a few SMEs will also have their own booth, taking advantage of a specific SME area designed by the organisers of the EuCNC 2019 edition.

The SME Working Group (WG) is gathering about 150 members including 110+ SMEs. More than 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 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 supported by the To-Euro-5G Coordination and Support Action and is chaired by Jacques Magen from interinnov. 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*.

30. MWC is the Mobile World Congress, cf. https://www.mwcbarcelona.com/. EuCNC is the European Conference on Networks and Communications, cf. https://www.eucnc.eu/.

31. Nextworks has been involved in SelfNet, 5G-Crosshaul, 5G-TRANSFORMER, blueSPACE, 5G-MEDIA, 5GCity, SliceNet, 5G-EVE, and 5GCroCo.

32. See https://www.wirelessinnovationarena.se/english-41316771 and http://www.encqor.ca/.

EC H2020 5G Infrastructure PPP

The 5G Infrastructure PPP programme and its related projects achieved outstanding progress and impact in the period mid-2018-mid-2019. All projects developed a very strong momentum during this period, with Phase 2 projects running full speed (some Phase 2 projects concluding mid-2019) and Phase 3 ICT-17 Platforms projects and Phase 3 ICT-18 Corridors projects, having started respectively in July 2018 and November 2018, ramping-up very actively and rapidly developing cross-projects synergies and programmatic actions. 46 projects in total have been so far contractually active in the PPP programme, ensuring an outstanding momentum and dynamism. The forthcoming Phase 3 ICT-19 Verticals Pilots projects to contractually start in June 2019 will further develop the overall PPP ambitions and momentum. Beyond the Phase 2 and Phase 3 projects achievements (reported in this Annual Journal 2019), a lot of joint (cross-projects) and programmatic achievements have been further developed, thanks to the overall operation and efficiency in the working groups, Steering Board and Technology Board, in full synchronisation with the 5G IA Board and the 5G IA Verticals Task Force, and with the strong support of the two CSAs projects. Some of the major achievements at programme level are highlighted in this Annual Journal 2019, including white papers, workshops, Global 5G Events, massive dissemination in worldwide conferences... all reflecting the very high level of interactions between projects participants.

To highlight a few major achievements (among many others) at programme (e.g. Technology Board (TB)), projects and working group levels:

- The TB furthered the approach defined in Phase 1 with the definition of the Programme Golden Nuggets (GNs), elaborated on the basis of the key projects achievements. The PPP GNs Version 2.0 was released in February 2019 (Figure 41), allowing all PPP projects to fully understand and match their individual contributions inside the overall programme achievements. (*https://5g-ppp.eu/phase-2-key-achievements/*).
- The TB developed jointly with the Global5G.org CSA, the 5G IA Trials WG and the 5G IA Verticals Task Force the Phase 2 projects Verticals Cartography (Figure 42) (*https://5g-ppp.eu/5g-trials-roadmap/* and *https://www.global5g.org/cartography*). The TB also developed the Platforms Cartography jointly with the Trials WG (Figure 43) (*https://5g-ppp.eu/5g-trials-roadmap/* and *https://5g-ppp.eu/5g-ppp-platforms-cartography/*). Both Cartographies are expected to be further developed and converge into a Meta-Cartography, considering the forthcoming integration of ICT-19 Verticals projects (Verticals Trials over Platforms).
- The TB organised the PPP technical workshop in November 2018 in Kista. The workshop gathered 30+ PPP Phase 2 and Phase 3 (ICT-17 Platforms) projects members. Participants comprised Technical Managers, scientific experts and specific working groups Chairs. The Technical workshop included the 2 day PPP Performance KPIs workshop followed by a TB meeting. Significant progress was achieved in defining 5G Infrastructure PPP Performance KPIs for how the KPIs themselves will be evaluated, as well as qualifying and quantifying projects innovation/enablers on these KPIs. The PPP technical workshop also offered great experience of team work / team building, with very active and engaged participation from representatives of almost all PPP Phase 2 projects and all PPP Phase 3 ICT-17 Platforms projects (*https://5g-ppp.eu/newsflash-december-2018/*).
- The 5G IA released the 5G Pan-EU Trials Roadmap Version 4.0 in November 2018. This Roadmap was presented during the 6th Global 5G Event organised on 28-30.11.18 in Rio. The Roadmap is worked out by the 5G IA Trials WG (open membership), expanding the work initiated by the Industry and EC in the context of respectively the 5G Manifesto and the 5G Action Plan (*https://5g-ppp.eu/wp-content/uploads/2018/11/5GInfraPPP_TrialsWG_Roadmap_Version4.0.pdf*).
- 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 will be released in June-July 2019 and the Version 3.0 in November 2019. The PSM is worked out by the 5G IA Vision and Societal WG. The Model 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 (*https://5g-ppp.eu/wp-content/uploads/2019/02/190228_5GInfraPPP_PSM-Phase3.II_V1.1.pdf*).

- All working groups have been very active and impacting with dedicated White Papers, Positions Papers and workshops, as detailed in specific sections of this Annual Journal 2019.
- The PPP projects and working groups will have a major impact during EuCNC 2019 to be organised on 18-21.06.19 in Valencia, following the 7th Global 5G Event to be organised on 17-18.06.19 also in Valencia, with many contributions to workshops, special sessions, panels, booths and technical presentations (*https://www.eucnc.eu/*).

This Annual Journal provides a summary overview of the recent PPP achievements, that will certainly encourage readers to look for more information and details, visit the PPP and projects websites, read the related documents, interact with PPP participants in meetings, workshop and conferences... More and more achievements are expected in the coming period, with the further development and completion of the Phase 2 projects and the further development of the Phase 3.I projects and the set of Phase 3.II project to be contractualized starting in November 2019.

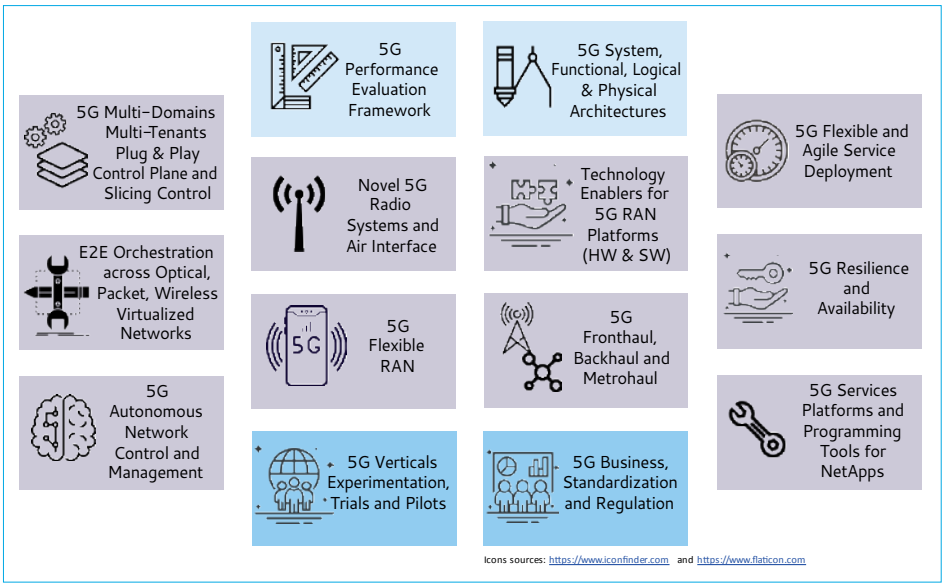

Fig. 42: PPP Key Achievement Phase 2 Projects (Golden Nuggets Version 2.0)

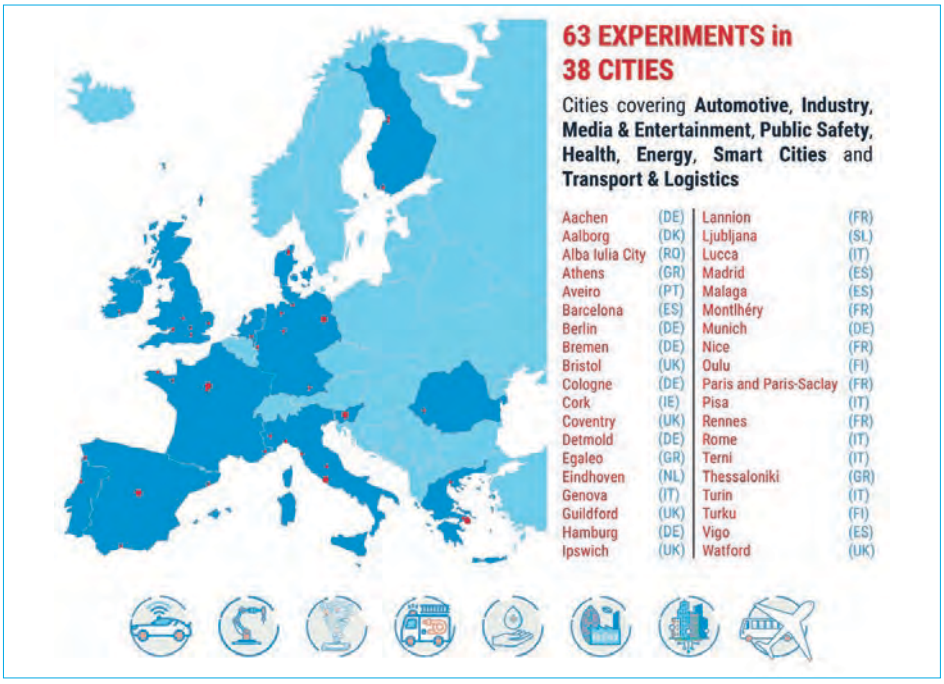

Fig. 43: PPP Verticals Cartography

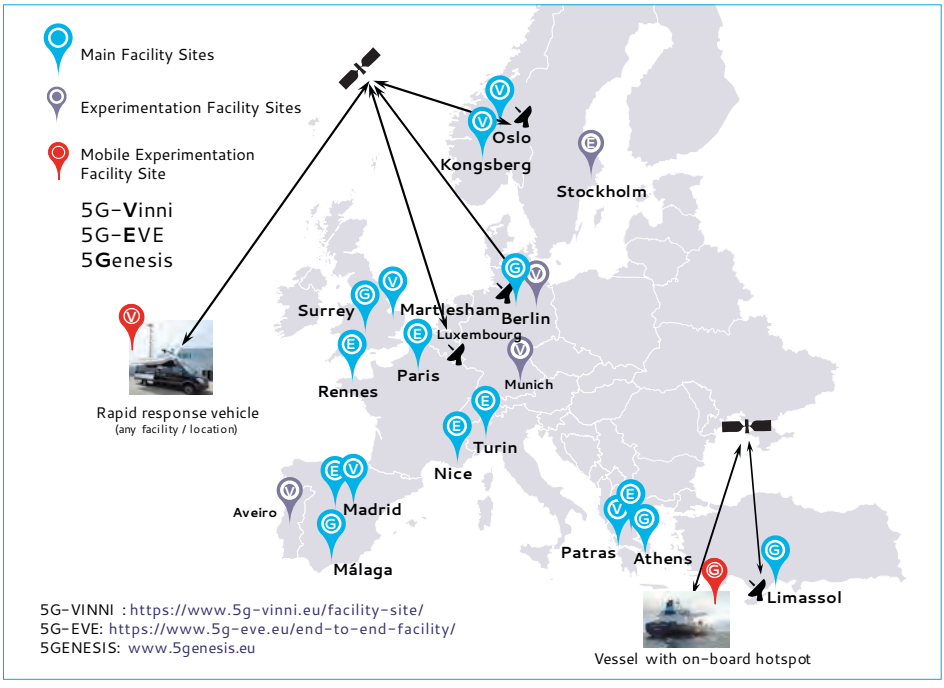

Fig. 44: PPP Platforms Cartography – Highlight Geographic Cartography

5G trials in Europe

Data available on the 5G Observatory online platform

The 5G Observatory (*http://5gobservatory.eu/*) provides access to a database of major 5G trials in EU-28. The following information fields are available for each trial:

- Country
- Date of announcement
- Operator
- Manufacturer
- Spectrum
- Vertical
- Additional stakeholders
- Trialled functionalities
- Level of maturity
- Source

Analysis of the 180 trials registered so far[33]

147 5G trials in the 28 MSs of the European Union and 180 trials including Russia, San Marino, Norway, Turkey and Switzerland. A little more than a third of the 180 trials are technical tests (58 trials). The share of technical tests dropped significantly in the past six months. The number of technical tests also decreased over the last quarter as mobile operators are now planning 5G network deployment.

Media and automotive are the verticals major driving trials

The most trialled verticals are media and entertainment (32 trials) followed by transport (25 trials) and automotive (18 trials).

33. The analysis was made with the data available on the 5G Observatory on 1 April 2019

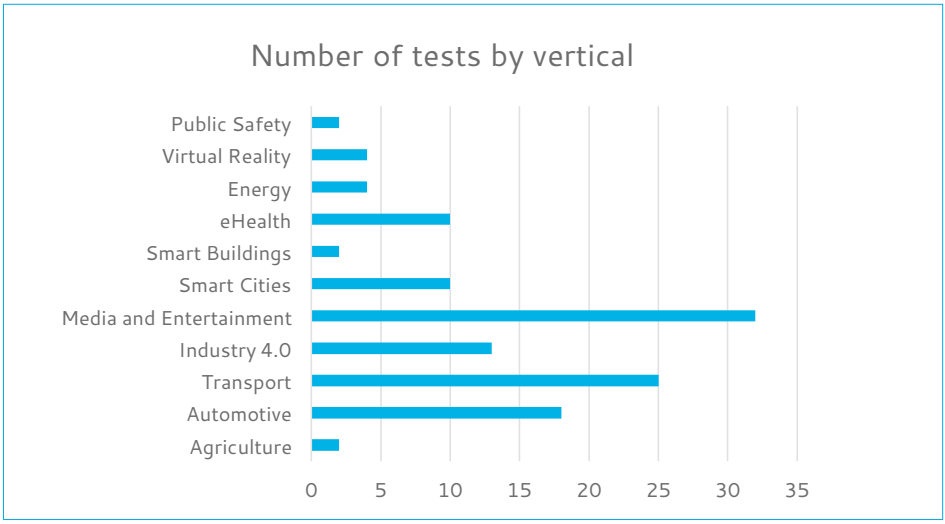

Fig. 45: Verticals tested in 5G trials

Source: IDATE DigiWorld, April 2019

The most numerous trials performed in Spain, France and Italy

Trials are the most numerous in Spain, France, Germany and Italy. These top four countries are totalling 40% of trials. Spain remains the first and France the second, however Italy has overtaken Germany in the number of tests lately, pushing Germany to the 4th position.

On average, more than six trials per country have been listed so far.

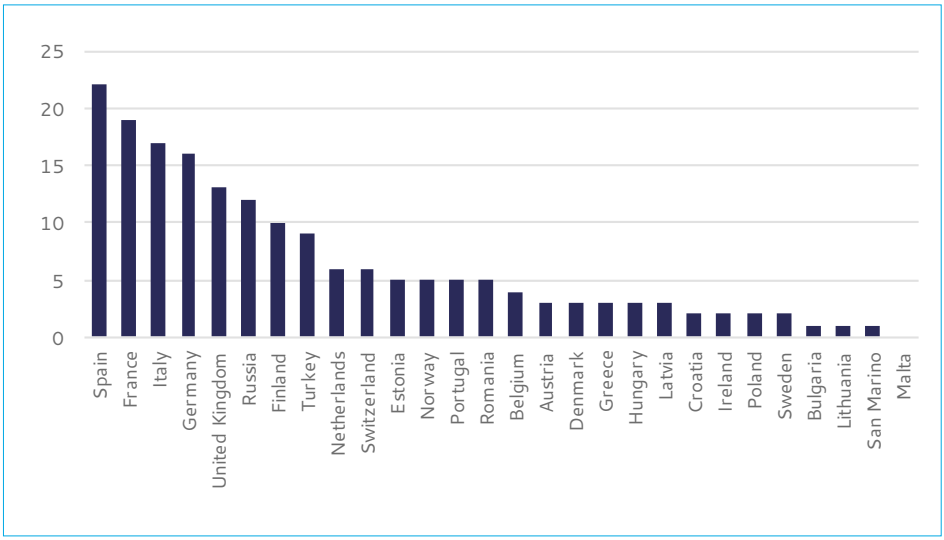

Fig. 46: 5G trials by country

Source: IDATE DigiWorld, April 2019

The 3.4-3.8 GHz is again the most tested frequency band

When indicated (frequency bands tested are available only in selected trials, representing 47.7% of all trials listed), the most used frequency band for trials is by far the 3.4-3.8 GHz (59 trials tested the 3.4-3.8 GHz frequencies out of 86 trials mentioning which band was considered). The 26 GHz band which have been tested 4 times in Europe is progressively gaining traction.

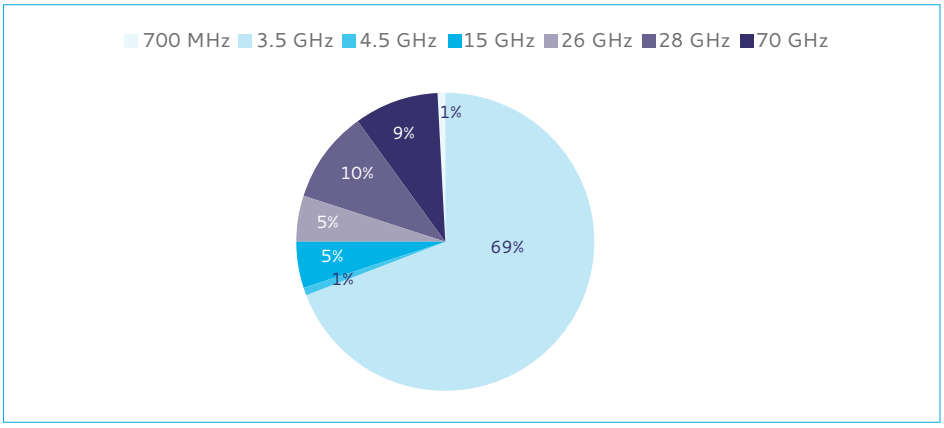

Fig. 47: Frequency bands tested

Source: IDATE DigiWorld, April 2019

5G CHRONICLE

The past months have been rich in events and promotional activities. This section provides a global overview and reports in particular on major past events.

In particular, Memorandum of Understandings (MoUs) paved the way to a global harmonised 5G promotion and workshops allowing close and smooth cooperation among the various 5G PPP projects and effective dissemination actions to be orchestrated. 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), and obviously the 5G Infrastructure Association Public Private Partnership (5G PPP) (Europe) all acknowledged the need of a global and common 5G promotion as 2020 approaches.

The parties have agreed to jointly organise two "Global 5G Events" per year to focus their efforts and leadership. The first six "Global 5G Events" were held from May 31st to June 1st, 2016 in Beijing (China) under the responsibility of IMT-2020 (5G) Promotion Group, in November 9-10th, 2016 in Rome (Italy) under the responsibility of the 5G Infrastructure Association, on May 24-25th, 2017 in Tokyo (Japan) under the responsibility of the 5GMF, on November 22-23, 2017 in Seoul (South Korea) under the responsibility of 5G Forum, on May 16-17, 2018 in Austin (TX, USA) under the responsibility of 5G Americas and on November 28-30, 2018 in Rio de Janeiro (Brazil) under the responsibility of 5G Brasil.

Telecommunications Standards Development Society, India (TSDSI) and the 5G Infrastructure Association also signed a Memorandum of Understanding (MoU) in April 2018 to foster collaboration on Research, Standards, Regulation and Policies over the next three years.

In October 2018, the 5G Infrastructure Association (5G IA) and the European Space Agency (ESA) signed a joint Letter of Intent to work together to enable new and innovative 5G solutions and services in support of European industry and the 5G vertical. Both ESA and 5G IA seek to support innovation within their respective industrial sectors. The Letter of Intent reflects this, with an emphasis on leveraging existing resources and facilities; planning joint activities including promotional events; and encouraging integrated, satellite-terrestrial solutions by means of verification and validation trials and pilot or demonstration projects in specific markets.

In December 2018, the 5G IA signed two additional major partnerships. The first one is a Memorandum of Understanding (MoU) inked 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.

EuCNC 2018 (18-21 June 2018)

The 5G PPP initiative was present at the EuCNC conference with many sessions, workshops, technical papers and a booth. 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 including the new SME brochure.

Eight workshops were organised the first day. An equal number of special sessions took place. Eleven booths highlighted 5G PPP project and programme achievements. Two panels were held. Fourteen projects gave projects the opportunity to showcase results and achievements and share views. The 5G PPP booth was shared with the 5G IA and the European Commission. It also provided information and demos from SMEs. Fifteen Technical Papers were read by project representatives during the conference sessions.

PPP Technical Workshop (20-22 November 2018)

Significant progress has been achieved in defining 5G Infrastructure PPP Performance KPIs for how the KPIs themselves will be evaluated, as well as qualifying and quantifying projects' innovation/enablers on these KPIs. The advancements were defined at the recent PPP Technical workshop in Kista, Sweden, on 20-22nd November.

The workshop also boosted a set of Technology Board (TB) / projects priorities and actions. These included the PPP Golden Nuggets Version 2.0 (key PPP programme and projects achievements), the PPP Verticals and Platforms cartographies, and the TB priorities and plans for 2019.

The workshop gathered 30+ PPP Phase 2 and Phase 3 (ICT-17 Platforms) projects. Participants comprised Technical Managers, scientific experts, and specific Working Groups Chairs. The Technical Workshop included the PPP Performance KPIs Workshop organised on 20th and 21st, followed by the TB meeting on 22nd. The Technical Workshop was hosted by Ericsson colleagues (PPP Phase 2 5GCAR project) in Ericsson HQ in Kista.

The PPP Technical Workshop also offered great experience of team work / team building, with very active and engaged participation from representatives of almost all PPP Phase 2 projects and all PPP Phase 3 ICT-17 Platforms projects.

ICT-2018 (4-6 December 2018)

ICT 2018: Imagine Digital – Connect Europe took place in Vienna on December 4-6. The research and innovation event focused on the European Union's priorities in the digital transformation of society and industry. ICT 2018 had four main components converging around the theme Imagine Digital – Connect Europe: Conference, Exhibition, Networking opportunities and Innovation and Startups forum. Citizens joined science community members, policymakers, and fellow ICT-enthusiasts to discuss the future in a digital Europe.5G PPP projects were very active with four 5G PPP related booths:

- A 5G PPP 'Information Kiosk' where videos, brochures and flyers will be displayed
- A 5G PPP 'Demo booth' where some projects will show their demos.
- Two project booths: 5GCity and 5GCAR

Networking sessions were also organised:

- Session title: Stimulating innovation over next generation 5G network infrastructures organised by Eurescom on behalf of 5G EVE, 5G-VINNI, and 5GINFIRE.
- Session title: Artificial Intelligence – New Solutions for Real-time Service Delivery organised by Eurescom on behalf of SliceNet
- Session title: Network Slicing organised by 5G-MoNArch

The 5G Vertical User Workshop (12-13 February 2019)

On 12 and 13 February 2019, the 5G Vertical User Workshop, an initiative of 3GPP Market Representative Partners 5GAA, 5G IA, 5G-ACIA and PSCE, was organised as a collaborative event for strategic dialogue between industries and 3GPP by exchanging on future needs and upcoming cellular standard developments. The workshop as a result, aimed to produce a report shared directly to 3GPP Project Coordination Group (PCG) as a means to stimulate and facilitate greater involvement of the 5G Vertical Users in the 3GPP process.

The workshop brought together a host of experts from 5G standardisation and a number vertical industries hoping to harness 5G including Automotive, Public Safety, Industry Automation, Utilities, Broadcasting, Satellites and Railways; as well as policy makers at the EU and Member State level.

A second event with more focus on practical steps to be taken by 5G vertical industries and SDOs to improve vertical input would be of value, however the setting of this event is yet to be determined.

India EU stakeholders workshop (5-6 February 2019)

The India EU Stakeholders' Workshop on 5G Technology Landscape organised by TSDSI-5GIA-BIF supported by Delegation of the European Union to India and India-EU Cooperation Project on ICT-Related Standardisation, Policy and Legislation was held in New Delhi, India, on 5-6 February 2019. 5G IA, 5G PPP and EC speakers took active part, alongside high-level Indian officials and experts. Attendees were warmly welcomed by Ms Pamela Kumar, Director General of TSDSI.

Mobile World Congress 2019 (25-28 February 2019)

The Mobile World Congress 2019 held in Barcelona from 25-28 February was a great opportunity for the 5G Infrastructure Association (5G IA) and for 13 projects of the 5G Public Private Partnership (5G PPP) initiative to showcase the latest developments of their work under the motto 'experience the future of 5G now'.

Three project partners of 5G-MoNArch (5G Mobile Network Architecture) – a 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'. They deployed a 5G network in the 8,000-hectare Port of Hamburg originally as a proof of concept testbed and now as an operational network. The implementation is being carried out under the auspices of the 5G-MoNArch project.

Besides the demos, other key highlights were the participation of 5G IA chairman and 5G PPP projects' representatives in a number of public events and panels as well as meetings with high level representatives from the European Commission, national governments, ICT associations and journalists.

Other joint initiatives will follow in the second half of 2019

- CLEEN/WCNC 2019 will take place in Marrakech, Morocco on April 15-18, 2019. 5G PPP projects will be present at this major event as it was the case in previous editions. 5G-Coral and 5G-Transformer are organising a workshop on CLoud Technologies and Energy Efficiency in Mobile Communication Networks @CLEEN 2019. NG-PaaS is organising 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".**
- The 7th Global 5G Event *"Creating the digital Future"* will take place in Valencia, Spain on June 16-17, 2019. The event is organised by 5G IA/5G PPP and the European Commission. It will be co-located with *EuCNC 2019* (June 18-21, 2019).

Appendix: Working Groups

Working Groups and Leaders	Origin
Pre-Standardisation WG Olav Queseth, Ericsson	5G Infrastructure Association
Spectrum WG Giovanna d'Aria, TIM	5G Infrastructure Association
5G Architecture WG Simone Redana, Nokia Oemer Bulakci, Huawei	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	5G Infrastructure Association
5G Automotive WG Mikael Fallgren, Ericsson Konstantinos Manolakis, Huawei Michele Paolino, Virtual Open Systems	5G PPP Projects
IMT-2020 Evaluation Group Werner Mohr, Nokia	5G Infrastructure Association
Test, Measurement and KPIs Validation Andrea F. Cattoni, Keysight Technologies Evangelos Kosmatos, WINGS ICT	5G PPP Projects
International Cooperation Jean-Pierre Bienaimé, 5G-IA	5G Infrastructure Association

Printed in May 2019
SEP, Nîmes

The European 5G Annual Journal/2019

This material has been designed and printed with support from the TO-EURO-5G project and the 5G Infrastructure association. The TO-EURO-5G Project has received funding by the European Commission's Horizon 2020 Programme under the grant agreement number: 761338.

Supported by the European Commission

European 5G Observatory

5G PPP

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