5G PPP 5G IA

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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 into 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 will reinforce the European industry to successfully compete on global markets and open new innovation opportunities. The 5G PPP will deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade.

5G PPP goal 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 THIRD 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 1 PROJECTS ENDING IN 2018 AND PHASE 2 PROJECTS, WHICH STARTED IN 2017.*

Foreword

Peter Stuckmann,
Head of Unit Future Connectivity Systems
European Commission
Directorate-General for Communications Networks, Content and Technology (DGCONNECT)

Europe is entering into a critical phase in the global race to 5G and so is the 5G PPP .

The first technology building blocks are there – they led to the adoption of the early-drop 5G standard. Standardisation work – based on the latest R&D results – needs to continue and proof of concept has started. 5G PPP Phase II will be important to master 5G technologies and to look into their application with relevant users in particular vertical industries.

Let us keep in mind the European 5G targets set in the 5G Action Plan: commercial launch in at least one city per Member State by 2020 and comprehensive roll-out in all cities and along major transport paths by 2025. We have also set the wider ambition to have mobile connectivity wherever people live, work, gather, or travel.

These targets will be an important basis for sustainable growth and jobs in Europe, for the digital society as well as the digital transformation of our economy. They will only be reached in partnerships – between public authorities and market players and between digital and vertical industries. Europe has vast opportunities with its strong industry and service sectors.

Such partnerships will be the centre of Phase II and Phase III of the 5G PPP . We will soon see major 5G validation platforms up and running with all 5G players on board. They will be used for trialing and piloting 5G with verticals.

One promising example is a number of 5G corridors that have been agreed among Member States in the last few months for testing of Connected and Automated Mobility. First 5G PPP projects running on these corridors will be launched this year.

The 5G PPP trial roadmap and the vertical engagement strategy will be key to facilitate ambitious partnerships driving deployment and swift market introduction.

We need to watch the progress closely in an international context. That is why we have set up the European 5G Observatory for monitoring and reporting major market developments and preparatory actions by the private sector and public authorities.

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.

Colin Willcock, Chairman of the Board,
5G Infrastructure Association,
& Co-chair of the 5G PPP Partnership Board

It is an exciting time for 5G, with the first versions of the 3GPP specification completed and many 5G trials planned or happening across Europe. In addition to this, it is a decisive time for the form and scope of next framework programme 'Horizon Europe', which will define the future research agenda for Europe.

As reflected in this Journal, the existing 5G PPP programme has been a clear success for Europe with thousands of researchers and developers across Europe successfully working on innovative solutions for the definition of 5G. These efforts have had a significant effect on the initial 5G standards we have today, especially in the areas of system design, evaluation aspects, air interface innovations network management, security innovation, virtualization and service deployment innovations. In addition to the hundreds of standardization submissions the 5G PPP projects were the key place for building global pre-standardization consensus. As well as key input to the current 5G version, 5G PPP is closely involved in the development of further releases of the 5G standard, which will address vertical industries.

However, 2020 is not the end of the story. Communication infrastructure will continue to evolve driven by cutting-edge research and the 5G IA would like to see a continuation of research partnerships between the EU Commission and the private side to ensure that Europe stays in the forefront of this important area, which is a key enabling technology for all sectors of society and economy and which provides the basis for all Internet services and critical infrastructures.

Jean-Pierre Bienaimé, Secretary General, 5G Infrastructure Association, & Chairman of the 5G PPP Steering Board

The 5G PPP and the 5G Infrastructure Association (5G-IA) kept a high pace in their communication and visibility during the period between mid-2017 and mid-2018, on the European and worldwide scenes. Among multiple actions, let's mention three major events where the 5G-IA highlighted 5G PPP actions and projects:

- The 4th Global 5G Event, organised by the 5G Forum on "5G accelerating the 4th Industrial Revolution", took place in Seoul, South-Korea, on November 22-24, 2017, including an impressive set of demos at SKT and LGU+, and at the KT 5G field trial site in the PyeongChang Winter Olympics 2018 venue.
- The Mobile World Congress 2018, on 26 February-1st March in Barcelona, gave the opportunity to five 5G PPP Projects – 5G-Xhaul, 5GCAR, 5G-MoNArch, ONE5G and 5GCity – to present their demos, while all the others had great visibility at the 5G-IA/5G PPP booth. MWC 2018 saw the 5G-IA and 5G PPP under the spotlight, with important announcements from the telco industry and policy makers.
- The fifth Global 5G Event, "5G New Horizons Wireless Symposium", organised by 5G Americas, was held in Austin, USA, on May 16 and 17, 2018. The 5G-IA/5G PPP was strongly represented by 9 speakers and moderators presenting at an extensive set of panels on topics such as spectrum and regulation, regional visions of the 5G network, trials, network architecture, 5G trends and collaborations, 5G ecosystem, services and use-cases, and the future of 5G…

In the field of international cooperation, let's highlight the signature of a Memorandum of Understanding (MoU) between 5G-IA and TSDSI – Telecommunications Standards Development Society, India – in April 2018, thus completing the map of key 5G industry regional partnerships around the world…

In the field of verticals, the 5G-IA signed a cooperation agreement in May 2018 with PSCE – Public Safety Communication Europe – in view of ensuring that 5G will bring the necessary developments to the security and safety communications for improving the activities of the PPDR community. Moreover at the end of 2017, the Board of the 5G IA established a task force, with the aim to define and implement a strategy for supporting verticals engagement in the various industrial sectors.

The 5G PPP Work Groups were very active, notably with the production of the first Automotive White Paper "A study on 5G V2X Deployment", and of the 5G Architecture White Paper version 2. A 5G-IA IMT-2020 Evaluation WG was also established end 2017, with a mandate to perform an independent evaluation of IMT-2020 proposals to support ITU-R for the finalisation of the IMT-2020 specification in 2020.

As for the 5G PPP Contractual Arrangement, we can say that the programme is progressing on all KPIs with a good pace. In the field of business-related KPIs, we are even exceeding by far our target on the leverage effect of EU research and innovation funding in terms of private investment in R&D for 5G systems.

This edition of the 5G Annual Journal 2018 illustrates these actions and results of the 5G PPP .

Dr. Didier Bourse, Chairman of the 5G Initiative Technology Board, Chairman of the 5G-IA Trials WG.

The 5G Infrastructure PPP programme and its related projects achieved outstanding progress and impact in the period mid-2017-mid 2018. All projects were full speed during this period, several Phase 1 projects engaged in their third contractual year and the Phase 2 projects actively developing since June 2017. 40 Phase 1 and Phase 2 projects have been so far contractually active in the PPP programme, ensuring an outstanding momentum and dynamism. The first Phase 3 projects will contractually start in July 2018 and further develop the overall PPP ambitions and momentum. Beyond the Phase 1 and Phase 2 projects achievements (reported in this Annual Journal 2018) a lot of joint (cross-projects) and programmatic achievements have been achieved, thanks to the overall operation and efficiency developed through the working groups, Steering Board and Technology Board, in full synchronization 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 also highlighted in this Annual Journal 2018, 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 five major achievements (among many others) at programme, projects and working group levels:

- The Technology Board (Board of PPP projects Technical Managers) developed jointly with the 5G-IA Trials WG and the 5G-IA Verticals Task Force the Phase 2 projects Verticals Cartography.
- The approach of the PPP Phase 1 projects and programme Golden Nuggets is furthered with Phase 2 projects, towards the forthcoming Golden Nuggets Version 2.0, allowing all PPP projects to fully understand and match their individual contributions inside the overall programme achievements.

- The 5G-IA released the 5G Pan-EU Trials Roadmap Version 2.0 in November 2017 and Version 3.0 in May 2018. The Roadmap Version 2.0 was presented first during the 4th Global 5G Event organized on 22-24.11.17 in Seoul and the Version 3.0 during the 5th Global 5G Event organized on 16-17.05.18 in Austin. 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.
- The Phase 3(.I) Pre-Structuring Model has been released by the 5G-IA in Version 1.0 in October 2017 and in Version 2.0 in November 2017. The Version 1.0 was presented and discussed during the first EC Phase 3 Info Day organized on 17.10.17 in Ljubljana and the Version 2.0 during the PPP session of the EC Proposers Days organized on 09.11.17 in Budapest. The Model is presenting features and recommendations to guarantee smooth integration of the forthcoming Phase 3 projects in the existing coordinated programme. It is also targeting system recommendations to develop future efficient cross-projects cooperation.
- The PPP projects and working groups will have a major impact during EuCNC 2018 to be organized on 18-21.06.18 in Ljubljana, with many contributions to workshops, special sessions, panels, booths and technical presentations.

This Annual Journal provides you a summary overview of the recent PPP achievements, that will certainly encourage you to look for more information and details. Visit the PPP and projects websites, read the related documents, interact with us in meetings, workshop and conferences, contact us directly for any potential question... and stay tuned as there will be more and more achievements in the coming period, with the further development of the Phase 2 projects and the rapid ramping-up of the Phase 3 projects.

5G DEVELOPMENTS

Ten key results from the past 12 months

5G development is accelerating with progress in standardisation with 3GPP Release 15 NSA in December 2017, trials, cooperation between main players and projects. We selected ten key topics concerning 5G development in Europe between mid-2017 and early-2018, as outlined below.

More than 100 5G tests and experiments in Europe

Europe is home of an increasing number of 5G private trials involving a multitude of stakeholders, notably network operators, manufacturers/vendors and some vertical industries. Several major network operators in Europe have already announced first results of experimentations and plans for further demonstrations of specific 5G features, either bilaterally with a single manufacturer/vendor or multilaterally with a number of manufacturers/vendors. In March 2018, the private trials group of the 5G PPP had identified more than 100 5G tests and experiments in Europe.

The main target of the current trials is to demonstrate the high data rates and low latency communications, which are key features for 5G technology. In 2017 there were only a few 5G Private trials including vertical stakeholders. Trials in 2016-2017 were focused on enabling technologies related to the radio interface (high throughput, millimetre-waves and other new large spectrum bands, antenna technologies…), the network architecture (virtualization, cloudification, network slicing, edge computing…) and the introduction of new technologies dedicated to specific use cases (technologies for IoT, for automotive…).

Europe also collaborates with other 5G leading countries and the 5G CHAMPION Europe–Korea collaborative project provided the first fully-integrated and operational 5G prototype in 2018, in conjunction with the 2018 PyeongChang Winter Olympic Games. Among the disruptive technological solutions developed and experimented on by 5G CHAMPION during the 2018 PyeongChang Olympic Games were high speed communications, direct satellite-user equipment communications, and post-sale evolution of wireless equipment through software reconfiguration.

5G trials roadmap

The 5G Infrastructure Association launched an activity in 2016 to, first, generate a strategy for developing a Pan-European 5G Trials Roadmap, and then, second, to prepare the comprehensive Trials Roadmap. It was presented and discussed at the 4th Global 5G event in Seoul, Korea on 22-23 November 2017.

The Trials WG has been elaborating a solid and comprehensive strategy to develop the Pan-EU coordinated trials as well as international trials with non-EU partner countries. The 5G Pan-EU Trials Roadmap is addressing several of the 5G Action Plan (5GAP) key elements and targets to develop the necessary synergies between these elements.

The main objectives of the Roadmap are to:

- Support global European leadership in 5G technology, 5G networks deployment and profitable 5G business.
- Validate benefits of 5G to vertical sectors, public sector, businesses and consumers.
- Initiate a clear path to successful and timely 5G deployment.
- Expand commercial trials and demonstrations as well as national initiatives.

5G at MWC'18

Four 5G PPP Projects – 5G-Xhaul, 5GCAR, 5G-MoNArch, ONE5G and 5GCity – presented their demos, including Cost-effective and reconfigurable novel transport network, Lane merge and Vulnerable road user protection, Industrial sea-port environment, Vertical-IoT applications, Flexible network slicing allocation in cities via neutral host, while all the others had great visibility at the 5G-IA/5G PPP booth. MWC 2018 saw the 5G Infrastructure Association (5G-IA) and 5G PPP under the spotlight, with important announcements from the telco industry and policy makers. Jean-Pierre Bienaimé, 5G-IA Secretary General, and Colin Willcock, 5G-IA Board chairman & were both interviewed by international press including TelecomTV, TVE

National Spanish TV and Les Echos. At the main conference, Jean-Pierre presented an overview of the 5G-PPP Projects and expected impact on 5G & IoT applications, while Colin presented the 5G-IA orientations and challenges at a special session dedicated to the 5G-PPP initiative and projects demos.

5G was the headlining topic at the MWC 2018, shining the spotlight on smart cities, IoT, AR, VR, connected cars and more. Operators, vendors, manufacturers and networks from all over the globe showcased and presented field trials, demonstrated technologies and applications, and gave visitors a taste of the future!

5G Global events

Korea: 4th Global 5G Event, Seoul, November 22-24, 2017

After the successful events of 2016-2017, held in China (Beijing), Europe (Rome) and in Japan (Tokyo), the series of high-level events on the 5G ecosystem continued in South Korea (Seoul), on November 22-23. The event was organised by the 5G Forum on "5G accelerating the 4th Industrial Revolution".

A LGU+ 5G tour bus delivered 5G-based IPTV 4K, and a VR drone was demonstrated in the '5G for All' experience room at the LG U+ headquarters, which required data rates ranging from 20 Mbps to 100 Mbps. Huawei showcased the combination of a VR drone designed by Huawei Wireless X Labs and the world's first 5G customer premise equipment (CPE) over 3.5 GHz.

LG U+ and Huawei completed a 5G network test in a pre-commercial environment in Gangnam District, Seoul. The network consisted of both 3.5 GHz and 28 GHz base stations. The test helped to successfully verify the technologies of IPTV 4K Video and many other future-proof commercial 5G services. High-speed mobility, dual connectivity, and inter-cell handovers (under continuous networking conditions) were validated. The test results returned average data rates of 1 Gbps over the low band and more than 5 Gbps for dual connectivity over high and low bands. In a typical dense urban area, successful verification of the 5G end-to-end (E2E) solution indicated Huawei's gradual maturity in advanced preparation for the imminent commercial deployment of 5G.

On 24th November, KT organised a 5G demos tour at the PyeongChang Winter Olympics premises.

Austin May 2018 - 5G New Horizons Wireless Symposium: 5th Global 5G Event

5G Americas organised the 5th Global 5G Event also known as "5G New Horizons Wireless Symposium". 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 Center in Austin, Texas from May 16-17, 2018. There was a strong 5G-IA/5G PPP participation, with 9 speakers/moderators.

Workshops organised by 5G PPP projects

- Towards TeraHertz Communications workshop

In the context of the exploratory preparation for the next Framework Programme for Research and Innovation, the European Commission hosted an open workshop on TeraHertz communications on 7th March 2018.

- SPEED-5G Workshop on Advanced spectrum management in 5G+ networks

  SPEED-5G organised a public workshop on Advanced spectrum management in 5G+ networks in London on 7th March 2018. It was hosted at the BT centre. The workshop reported interesting novel results of international research projects on some selected aspects of 5G and beyond networks with main focus on dynamic spectrum access techniques.

- 5GEx workshop on MPVNS @ MPVNS' 17 and NetSoft 2017

  The IEEE International Workshop on Multi-Provider Network Slicing and Virtualization (MPNSV'17) will be held on July 3-7, 2017 in Bologna, Italy along with the 3rd IEEE International Conference on Network Softwarization (NetSoft 2017).

- 5G-ENSURE & CHARISMA @2nd International Workshop on Security in NFV-SDN (SNS 2017)

  The 2nd edition of the International Workshop on Security in NFV-SDN (SNS2017) takes place on 3 July in conjunction with the 3rd IEEE Conference on Network Softwarisation (IEEE NetSoft 2017), 3-7 July at the School of Engineering and Architecture, University of Bologna, Italy.

- CHARISMA Workshop on Mobile Edge Communications (MECOMM) @ACM SIGCOMM

  CHARISMA project is co-organising the first workshop on Mobile Edge Communications (MECOMM), to be held in conjunction with the ACM SIGCOMM Conference on UCLA campus in Los Angeles, CA, USA on August 21-25, 2017. The workshop focuses on mobile edge communications and in particular the challenges and opportunities arising by the introduction of virtualization at the edge of the network, in accordance to the emerging Network Functions Virtualization (NFV) and Mobile Edge Computing (MEC) paradigms.

Whitepapers

Cooperation between various 5G PPP phase 1 and phase 2 projects and the Working Groups of the 5G-IA enabled the provision of the following whitepapers:

- *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).

- *5G PPP 5G Architecture White Paper Revision 2.0 – (White Paper version 2.0 Dec 2017)*

  This paper highlights the key 5G architecture design recommendations from 5G-PPP Phase 1 and provides a baseline architecture for Phases 2 and 3.

- *5G PPP Security Landscape – (White Paper) June 2017*

  This paper provides insights into how 5G security should be addressed in terms of "what" and "why".

Spectrum for 5G

New frequency bands are going to be made available for 5G in the coming years in Europe. EU's 5G Pioneer Frequency Bands are the 700 MHz, the 3.5 GHz and the 26 GHz bands:

- The 700 MHz will provide universal coverage (10's of Mbps) of reliable connectivity e.g. for smart grids. It is harmonised in Europe and assignments are progressing.
- The 3.5 GHz band is well suited for urban coverage with dense small cells (1-3 Gbps) e.g. mobile Gb/s society, smart cities. It is harmonised in Europe and partly used. Re-farming and defragmentation for wider bandwidths is ongoing. Technical conditions are in discussion at ECC and expected for final approval in July 2018.
- The 26 GHz band will provide hot spots coverage (up to 10 Gbps) in places such as railway stations, sports events, smart factories. CEPT has identified the 26 GHz band for early European harmonisation, as it could provide over 3 GHz of contiguous spectrum. ECC PT1 has developed a Draft ECC Decision setting the harmonised conditions for the introduction of 5G in the 26GHz band. It is currently under public consultation, for final adoption in July 2018.

Satellite and 5G

The Sat5G project, part of phase 2, illustrates early integration of the satellite segment into 5G. The project vision is to develop a cost effective "plug and play" satcom solution for 5G to enable telcos and network vendors to accelerate 5G deployment in all geographies and at the same time create new and growing market opportunities for satcom industry stakeholders.

Cooperation agreements

In 2017, leading 5G visionary global organisations from the world's regions welcomed Telebrasil – Projeto "5G Brasil" as a party to the Multilateral Memorandum of Understanding (MoU) for the "Global 5G Event" with 5G Forum (Korea), 5G Americas (Americas), IMT-2020 (5G) Promotion Group (China), the 5G Infrastructure Association (5G-IA, Europe) and the Fifth-Generation Mobile Communications Promotion Forum (5GMF, Japan). A new cooperation agreement was signed between the 5G-IA and TSDSI, Telecommunications Standards Development Society, India, in April 2018.

Launch of H2020 phase 2

5G will be instrumental in digitising the traditional industry as it races for better productivity and competitiveness. 5G PPP phase 2 projects were launched in July 2017. Creating synergies across verticals, lowering individual costs via network slicing, and cost-sharing on infrastructure deployment and service operations are all possible with 5G.

Leading vertical industrials are involved from the beginning of the 5G standardisation process. Phase 2 projects are dedicated to an industrial sector or target applications for various verticals.

5G-EX

Motivation and Goals

Network Service Providers are limited in maximizing usage efficiency of their resources as well as in revenue generation capability from rigid service offerings, often taking up to 90 days to be provisioned. The 5GEx project has been working to create an agile exchange mechanism for contracting, invoking and settling the wholesale consumption of resources and virtual network services, which can be provisioned in less than 90 minutes and rapidly invoked. This will enable network operators, applications providers and other stakeholders in the 5G supply chain to deliver new service value for 5G customers, at the same time enhancing revenue-generating potential for 5G providers, third party verticals and other actors in the supply chain.

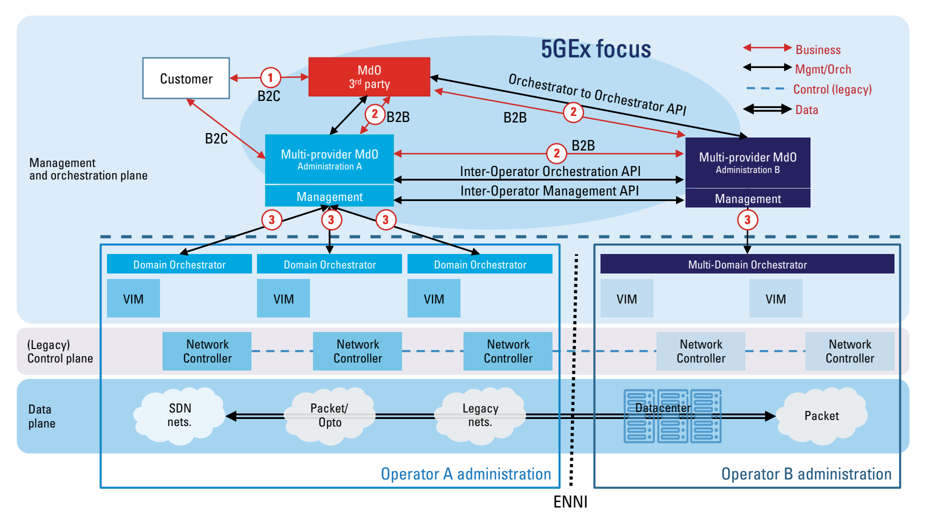

Figure 1. 5GEx reference architectural framework

The main goal of the 5G Exchange (5GEx) project is to create a multi-provider orchestration framework and deploy it as an enabler platform into its pan-European sandbox to reduce service creation time from "90 days to 90 mins". The 5GEx reference architectural framework and scope are illustrated in Figure 1, while the functional blocks of the multi-domain orchestrator (MdO) are depicted in Figure 2.

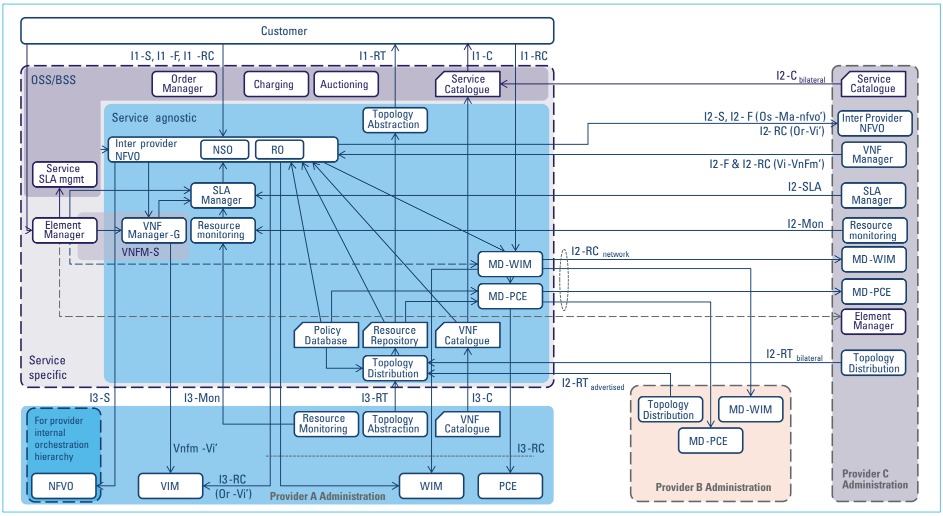

Figure 2. Functional model of multi-domain orchestration architecture

Major achievements and innovations during the third year of the project

During the third phase of the project (M18 to M33), 5GEx has focused on finalizing the design of the multi-domain, multi-provider orchestration architecture, in particular adding a business layer, as found necessary to ensure that multi-provider collaboration is feasible in a multi-operator environment and allows increasing operators' profit. In addition to the design refinement, the main activity of the project has been the implementation of the second and third releases of the designed architecture's prototype, and its evaluation in the sandbox environment, used to deploy and evaluate the system. This work has already provided some very interesting results and lessons learned.

The third release (P3) of the integrated prototype reference implementation is about to be released. P3 is able to deploy network services across multiple operators, based on the capability and topology information exchanged between the operators. After deployment, the system is able to collect monitoring measures for service KPIs. P3 provides support for life cycle management of the deployed service. P3 is also capable of provisioning paths over legacy connectivity domains by using its MD-PCE component. Several P3 components have been released as Open Source and are available at the 5GEx GitHub repository (https://github.com/5GExchange/)

The sandbox setup available in March 2018 includes 14 different administrative domains, controlled by 14 different 5GEx partners acting as Sandbox Operators. In particular, the Sandbox setup is characterized by cloud and networking resources interconnected through transit networking domains. The Sandbox, which interconnects four leading European operators, enables automated end-to-end orchestration of new multi-party 5G services to undergo accelerated prototyping and piloting prior to market launch. Using the sandbox and the latest release of the prototype implementation, we have been able to deploy different experiment, focusing on key features and multi-operator use cases. Results confirm that after the on-boarding of a network service into the marketplace the multi-provider orchestration process is fully automatic and capable of service creation across multiple layers of MdO hierarchies. Service creation times in our experiments showed completion times in the order of seconds for the simplest cases.

In addition to the system design, prototyping, and evaluation, the project is actively contributing to the main standardisation bodies including ETSI NFV (where our work has contributed to the creation of a new work item on multi-domain aspects, as well of the adoption of a new multi-domain use case), IETF/IRTF (with two adopted documents for standard publication), 3GPP (with different architecture contributions in SA5), ITU-T and ONF.

Demonstrations

Different demos of the project have been made already (including an integrated demo of two project experiments at OFC 2017 in Los Angeles, a demo during bits-n-bites at an IETF meeting, and a demonstration during our 1st 5GEx Industrial Workshop in Madrid, May 2017). Next planned demonstration events include MVNO World Congress, EuCNC 2018 and our 2nd 5GEx Industrial Workshop, collocated with NFV Virtualization Europe.

5G-Xhaul/

5G-XHaul overarching objectives

The 5G-XHaul project aims at building up an ambitious converged optical and wireless network solution that relies on a flexible infrastructure able to support backhaul and fronthaul services required to cope with the future challenges imposed by 5G Radio Access Networks (RANs). The main concepts under-pinning the design of the 5G-XHaul solution are:

1. Programmable optical and wireless network elements, which enable a tight control of the transport network.
2. Innovations on the wireless and optical domains, to enable enhanced data-rates, flexibility and novel interfaces.
3. A cognitive control plane, able to measure and forecast spatio-temporal demand variations and, accordingly, to configure the transport network elements.

Main Achievements/Innovations in Year 3

During its third year, 5G-XHaul focused on two major aspects, namely integrating individual technology components, and preparing for a city wide demonstrator in Bristol. It is also worth highlighting that 5G-XHaul was one of the three 5G-PPP projects selected to demonstrate its innovations during MWC'18.

Integrating 5G-XHaul technologies

5G-XHaul has put forward an architecture for integrated backhaul and fronthaul consisting of the following components. First, a wireless segment, consisting of a combination of transport nodes operating at millimetre wave (mmWave) and Sub-6 GHz frequencies. Traffic from Small Cells is carried over this wireless segment until fibre attachment points, whereas macro-cells are directly connected to a fibre attachment point. As optical access technology, 5G-XHaul proposes a passive solution based on a Wavelength Division Multiplexing Passive Optical Network (WDM-PON), which can transparently carry backhaul and fronthaul traffic through different wavelengths. In the metro-domain WDM-PON interfaces with a Time Shared Optical Network (TSON), an active optical technology that, through a configurable time slot allocation and a flexible optical grid, is able to allocate bandwidth in a very granular and efficient manner.

During the third year of the project the work focuses on integrating the various technologies that comprise the 5G-XHaul architecture. In the transport wireless domain, a 60 GHz IEEE 802.11ad compliant MAC and baseband platform with point-to-multipoint capabilities, has been integrated with a novel antenna, RF frontend and Beamforming IC, specially designed for Small Cell backhaul scenarios. The resulting mmWave backhaul node has also been integrated with an SDN agent in order to incorporate SDN control capabilities. In the optical domain, two major integrations took place during this year. First, the WDM-PON technology was integrated with a Massive MIMO array, which features a custom functional split developed in 5G-XHaul. The Massive MIMO array was fronthauled through WDM-PON using CPRI. Figure 3. Fronthaul integration of Massive MIMO array and WDM-PON depicts a snapshot taken during this integration process, where we can see the WDM-PON components – Optical Network

Unit (ONU) and Optical Line Terminal (OLT) – and the Massive MIMO array. Second, TSON was extended to support CPRI traffic in addition to Ethernet, and the 5G-XHaul fronthaul architecture comprising a Massive MIMO array, WDM-PON in the access, and TSON in the metro network was validated.

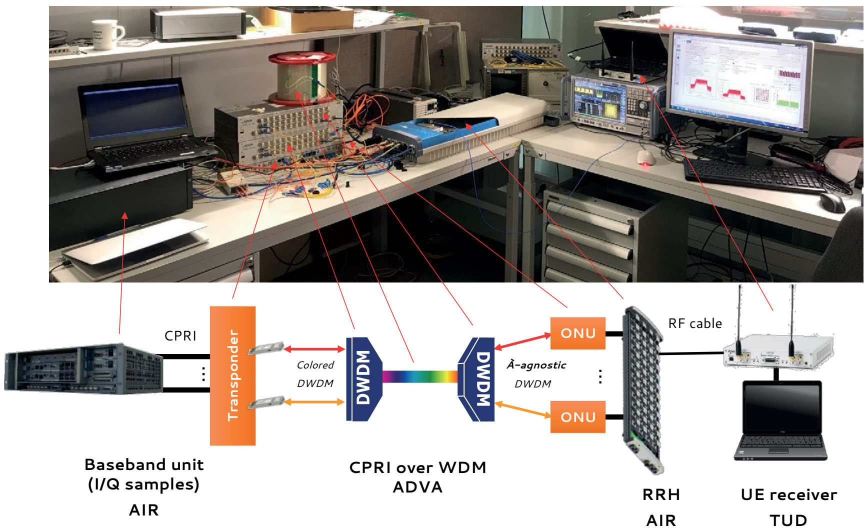

Figure 3. Fronthaul integration of Massive MIMO array and WDM-PON.

5G-XHaul final demonstrator

During the third year, 5G-XHaul has defined the final demonstration scenario, illustrated in Figure 4. 5G-XHaul planned a final demonstrator in the city of Bristol, and has begun the required integration work. The 5G-XHaul architecture will be demonstrated in the city of Bristol, with a deployment featuring an SDN enabled wireless transport segment (Sub-6 and mmWave), a passive access optical network based on WDM-PON, and an active optical metro network based on TSON. Cloud resources and SDN controllers will be instantiated in various locations in the city of Bristol, playing the role of Central Offices.

The proposed network architecture will be used to transport both fronthaul services, for the Massive MIMO array, and backhaul services for an existing RAN infrastructure, hence delivering on the promise of an integrated transport network supporting both fronthaul and backhaul services.

The final 5G-XHaul demonstration is scheduled for June 2018 in the city of Bristol.

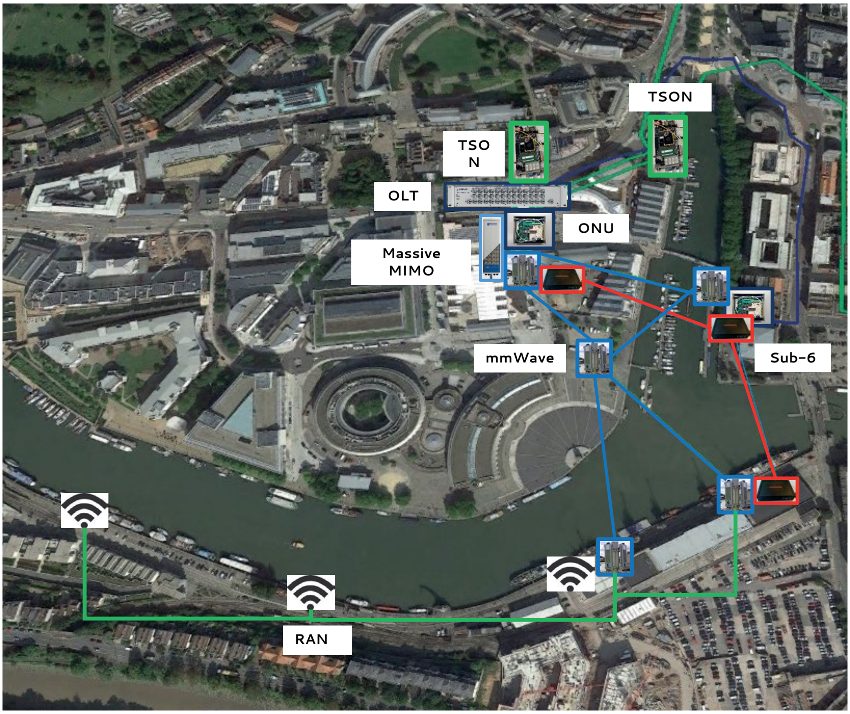

Figure 4. 5G-XHaul planned final demonstrator in the city of Bristol

SELFNET

Framework for Self-Organised Network Management in Virtualized and Software Defined Networks

Goals of the project

In current network management systems, the monitoring subsystem is typically only able to report low-level metrics such as Radio Access Network (RAN) and network Quality of Service (QoS) measurements, which cannot easily be explicitly related to the underlying network problems and therefore often hinder a timely isolation and resolution of the problem. Furthermore the increasing complexity of the network – among others due to the introduction of additional layers like virtualisation – makes human diagnosis and intervention a very challenging task. SELFNET addresses these two problems.

It introduces self-monitoring and detection capabilities to enable timely status awareness of the 5G network infrastructure based on a set of customisable and extensible high-level Health of Network (HoN) metrics to facilitate rapid and more precise identification of common network problems.

It realises a 5G Self-Organising Network (SON) autonomic management engine based on Artificial Intelligence (AI) and Machine Learning (ML). The new SON engine extends the current concept in the physical layer of 4G networks to the management plane of physical and virtual networks in 5G infrastructures. It significantly simplifies network management tasks and minimises human intervention in diagnosing complex network problems and determining corresponding reactive or pro-active tactical actions to resolve existing and prevent potential future problems.

To enable quick, coordinated network management service provisioning, configuration and deployment once the tactical actions are identified, SELFNET realises 5G SON orchestration and virtual infrastructure management based on an integrated architecture that supports autonomous physical and virtual infrastructure management and automated infrastructure and service deployment, greatly reducing service creation and deployment time.

To demonstrate the self-organising capabilities SELFNET applies its framework upon 5G use cases designed to exhibit major problems in current network management faced by the network operators.

Major achievements

· *Autonomic 5G Network Management*

SELFNET has delivered an autonomic network management framework for 5G networks that is powered by artificial intelligence and machine learning and substantially extends the current SON concept in the physical layer to the 5G physical and virtual domains. The SON engine centric framework creates an autonomic control loop that simplifies network management tasks and minimises human intervention. The framework has been applied on 3 representative uses cases: (i) Self-healing against network failures or vulnerabilities for improved reliability, (ii) Self-protection against cyber-attack threats for improved security, and (iii) Self-optimisation against network constraints for users' improved quality of experience (QoE).

· *Integrated SDN and NFV Apps management*

The SELFNET integrated SDN/NFV Apps Management provides common Apps lifecycle mechanisms and procedures for various kinds of Apps including VNFs, SDN Apps, and Physical Network Functions (PNFs) for backward compatibility. It supports fully automated lifecycle management of NFV and SDN applications, including Apps encapsulation, on-boarding, instantiation, deployment, configuration, update/modification and termination. New Apps are made available in the system with a single click action from the SELFNET Graphical User Interface.

Innovations

· *Multi-level, Multi-tenant-aware Network Monitoring*

In SELFNET, self-monitoring collects and analyses performance metrics at multiple levels: physical infrastructure, virtual infrastructure and traffic flows with multi-tenancy awareness, thereby enabling timely situation awareness of 5G network infrastructures and services. A set of high-level Health of Network (HoN) metrics are modelled and introduced, such as Virtual Infrastructure Vulnerability, Cyber-Attack Risk, and Video QoE. These customisable and extensible HoN metrics facilitate rapid and more precise identification of common network problems.

· *Automated Physical and Virtual Infrastructure Deployment*

SELFNET achieves integrated management of physical and virtual infrastructures, which enables automated deployment of 5G infrastructures and services running on top of them, including virtualization services, cloud computing, Mobile Edge Computing (MEC), SDN/NFV services and value-added services such as Service Function Chaining (SFC). Automation in SELFNET reduces the creation and deployment time for infrastructures and their services from days to minutes. Ancillary tools such as a 5G topology viewer allow to visualize correlated physical and virtual infrastructure elements and mobile users' connectivity in real time.

Performance KPIs

SELFNET demonstrated the service creation time, measured from a completely "empty" set of nodes to the deployment of an EnodeB service, in less than 90 minutes, exceeding the original 5G-PPP KPI on service deployment time. This is achieved through automated physical and virtual infrastructures and services deployment, automated and enhanced network service monitoring and performance analysis, intelligence-based network management, and integrated management and orchestration of SDN/NFV Apps for on-demand service creation.

Description of demonstrations

SELFNET demonstrates the three use cases: (i) Self-healing, (ii) Self-protection and (iii) Self-optimisation. In addition it demonstrates a complex scenario that combines the properties and capabilities of the individual use cases. This composite use case is devoted to identifying root causes of previously unknown security-related problems, where the network faces unknown threats that cause system performance degradation. Machine Learning techniques are used to identify root causes related to previously unknown network problems, resulting in improved self-protection capabilities.

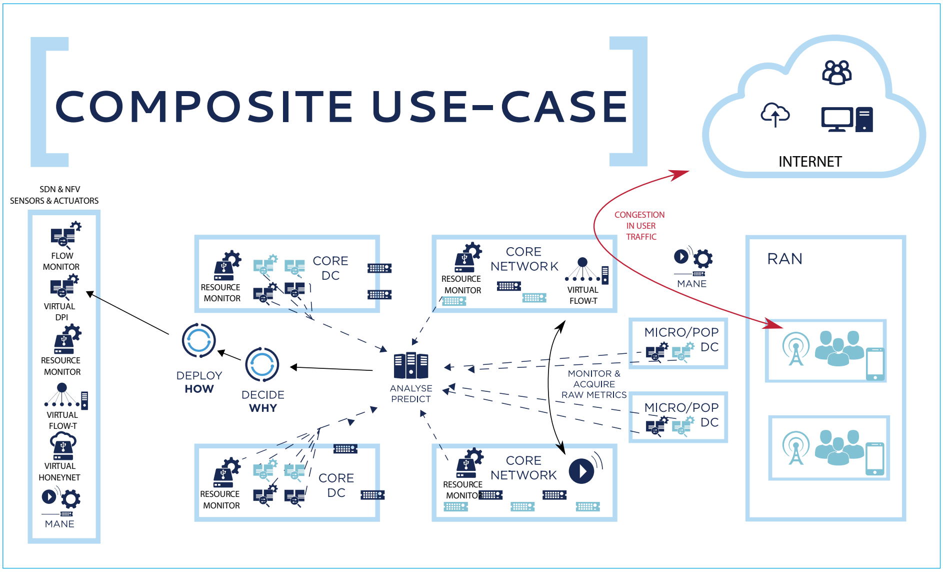

Figure 5. SELFNET Composite Use Case demonstration

5G-PPP SESAME

Small cEllS coordinAtion for Multi-tenancy andEdge services

Goals of the project

A fundamental component of the SESAME Project (GA No.671596) is the virtualization of Small Cells (SCs) and their utilization and partitioning into logically isolated "slices", offered to multiple operators/tenants. The main aspect of this innovation will be the capability to "accommodate" multiple operators under the same infrastructure, satisfying the profile and requirements of each operator separately.

SESAME proposes the Cloud-Enabled Small Cell (CESC) concept, which is a new multi-operator enabled Small Cell that integrates a virtualized execution platform (i.e., the Light Data Centre (DC)) for deploying virtual network functions (VNFs), supporting powerful "Self-x" management and executing novel applications and services inside the access network infrastructure. The Light DC will feature low-power processors and hardware accelerators for time-critical operations and will constitute a highly manageable clustered edge computing infrastructure. This approach allows new stakeholders to "dynamically enter" the value chain by acting as "neutral host providers" in high-traffic areas, where densification of multiple networks is not practical. The optimal management of a CESC deployment is a "key challenge" of SESAME, for which new orchestration, NFV management, virtualization of management views per tenant, "Self-x" features and radio access management techniques have been developed. The "core" aim of SESAME is to design, develop and implement CESCs, in order to offer access to network capacity coupled with mobile edge computing (MEC) resources, in a single device. These resources can be offered on-demand to Communications Service Providers (CSPs), profiling both access and edge computation resources to satisfy specific CSPs' needs.

The infrastructure deployed by the involved Small Cell Network Operator (SCNO) consists of a number of CESCs and the corresponding management systems. The CESC offers computing, storage and radio resources. Through virtualization, the CESC cluster can be seen as a "cloud of resources" which can be sliced to enable multi-tenancy. Therefore, the CESC cluster becomes a neutral host for mobile SCNO -or Virtual SCNO (VSCNO)- who want to share IT and network resources at the edge of the mobile network. In addition, cloud-based computation resources are provided through a virtualized execution platform. This execution platform is used to support the required VNFs that implement the different features/capabilities of the Small Cells, as well as the computing support for the mobile edge applications of the end-users. The main components of SESAME architecture are depicted in Figure 6:

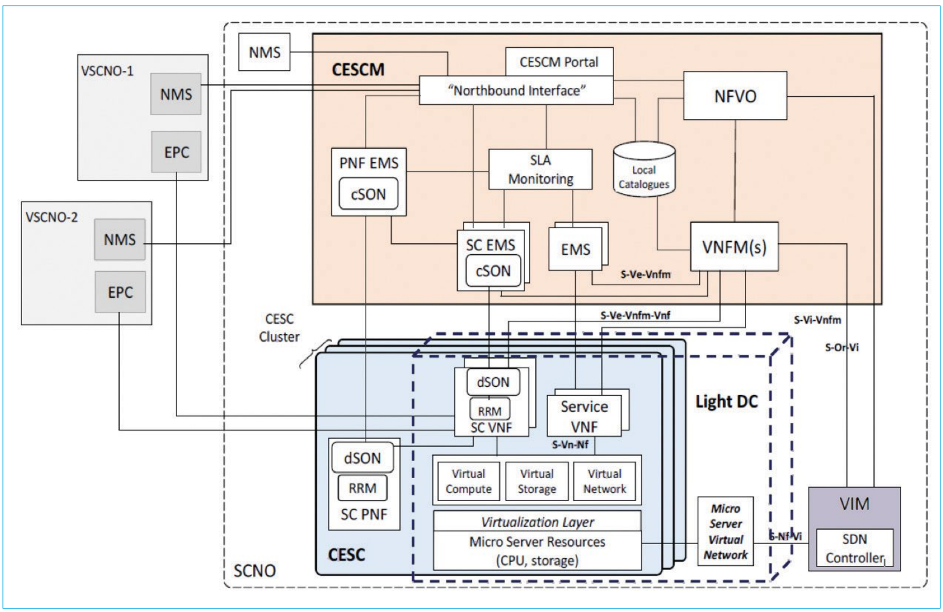

Figure 6. SESAME fundamental architectural approach

The main goals of the SESAME are focused upon three central elements in 5G:

- The placement of network intelligence and applications in the network edge through Network Functions Virtualization (NFV) and Edge Cloud Computing.
- The substantial evolution of the Small Cell concept, already mainstream in 4G but expected to

deliver its full potential in the challenging high dense 5G scenarios.

- The consolidation of multi-tenancy in communications infrastructures, allowing several operators/service providers to engage in new sharing models of both access capacity and edge computing capabilities.

Major Achievements and Innovations of the project

The SESAME Project is an innovative effort to realize multi-tenant cloud enabled Radio Access Network(s) RAN(s), through a substantial change on the architecture of commercial Small Cells. New orchestration, NFV management, virtualization of management views per tenant, "Self-x" features and radio access management techniques have been developed. SESAME's main achievements include, inter-alia:

- *Definition and specification of the system architecture and interfaces for the provisioning of multi-operator Small Cell networks, optimised for the most promising scenarios and use cases*. Also further update/enhancement and/or validation of the developed architectural modules, per case and where relevant.

- *Specification, design and implementation of a multi-operator CESC prototype, supporting "Self-x" features enabling multi-tenant and multi-service access infrastructure.* In particular, the evolution of "Self-x" properties has been towards realizing a more enhanced network and/or service management. This change paves the way towards "placing" network intelligence and applications in the network edge, with the help of virtualization.

- *Specification, design and implementation of a low-cost Light DC prototype as NFV Point-of-Presence (PoP) providing support for intensive low latency applications, secure connections and high quality of experience, while simultaneously minimizing space, infrastructure costs and energy consumption.* The Light DC features low-power processors and hardware accelerators for time critical operations and builds a high-manageable clustered edge computing infrastructure.

- *Launching of several high-impact sample VNFs for demonstration and assessment of SESAME CESC platform.* Small Cell virtualisation through providing MOCN (Multi-Operator Core Network) as a VNF allows an efficient RAN sharing for multi-tenancy and provides logical isolated pieces ("slices") of the access infrastructure to individual tenants.

- *Design and development of a framework for efficient resource planning and coherent management of the multi-operator Small Cells as light NFV distributed infrastructure.* SESAME has established the Virtual Infrastructure Management (VIM) mechanisms that separate and scale radio and computing resources to different mobile operators. These VIM mechanisms with the VNF solutions at the very end of the network enable a reduction in transaction time (avoidance of data congestion) and, therefore, reduce the service level latency. SESAME has provided enhancements and optimisations to the most popular network programmability platform (at least), in order to support VNF instantiation.

- *Design and implementation of CESCM, capable of chaining and orchestrating the different VNFs required to cope with the dynamic SLAs between the CESC provider and the network operators.* The CESC concept allows to decrease service creation time cycle (through dynamic service function chaining at the edge) and offer QoE (Quality of experience) per service (close to zero perceived latency for localised services). The CESCM manages the computing and storage resources so as to assign them to the CESC provider customers, along with the requested SLAs.

- *Integration into one Pre-Commercial Prototype of Small Cells, Light DC and management and orchestration functionalities*. The prototype has been used to perform testing and evaluation against solidly defined use cases. SESAME has also demonstrated a large-scale integrated operation pilot. Three use cases and scenarios have been extensively demonstrated for accessing the flexibility and scalability of CESC management solution and the traffic capacity volume of open programmable SESAME edge network.

- *Enhancement and extension of the existing "Small Cell-as-a-Service" ("SCaaS") model.* This facilitates a third-party provisioning of shared radio access capacity to mobile network operators in various localised areas, together with the provision of Mobile Edge Computing services.

- *New business opportunities between the SC infrastructure provider and the Mobile Network Operators (MNOs).* This has been achieved via efficient management of resources, rapid introduction of new network function(s) and/or service(s), ease of upgrades and maintenance, CAPEX/OPEX reduction and encouraging openness within the ecosystem.
- *Rapid deployment of new services for consumer and enterprise business segments.* Adding new revenue streams from innovative services delivered from closer to the user, together with offering the user a better service-oriented QoE, leveraging the Light DC and the CESCM entities and, furthermore, improving revenue opportunities by sharing the infrastructure for specific service providers.

Figure 7, below, summarizes a conceptual high-level architecture, together with the SECS components.

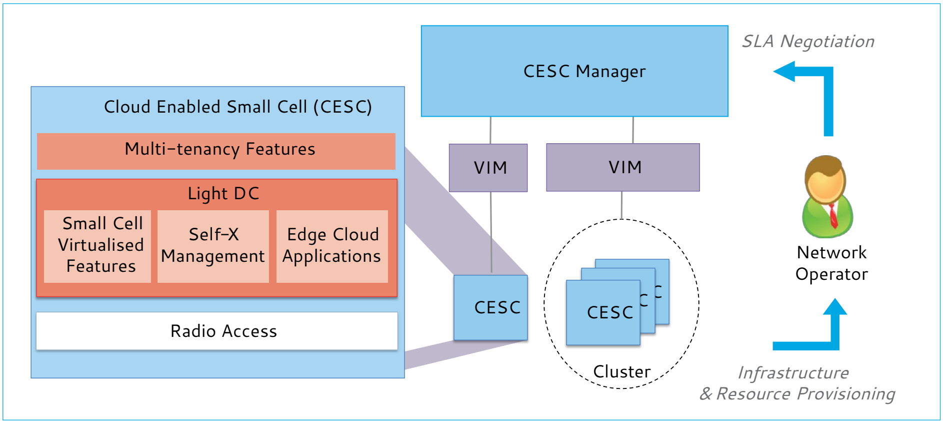

Figure 7. SESAME high-level architecture and CESC components

Performance KPIs

With respect to the originally defined 5G-PPP programme KPIs, SESAME contributes explicitly to:

- Reduce the average service creation time cycle from 90 hours to 90 minutes.
- Provide a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision.
- Ensure lower energy consumption for low power Machine type communication.
- "Address" the challenge of 1000 times higher traffic per geographical area by deploying high-density multi-service virtualized small cell networks, offering several benefits; also to support 10 times to 100 times higher number of connected devices as well as 10 times to 100 times higher typical user data rate.
- Provide increased network coverage (with ubiquitous 5G access including low-density areas) together with more varied service capabilities, and helping create novel business models through innovative sharing of network resources across multiple actors.
- Support improvements in autonomic network management and automated network control, leading to reduced network OPEX.

Description of demos

The following demos have been successfully performed during the lifetime of the SESAME activities:

- Multi-tenancy and Monitoring: SESAME PoC aims to "illustrate" the establishment of the complete chain of monitoring, decision-making and reaction. In this case, CESCM as a module with the over view of both the radio and cloud side of the ecosystem will monitor cloud/radio parameters (e.g., CPU/RAM usage, call drop rate, etc.). If a violation occurs, CESCM via processing the monitoring inputs will be able to detect and then appropriately react upon the situation. The decision-making process might be a simple threshold checking or a complicated multi parameter cognitive method. In the same way, the reaction ranges from the complete network service (NS) scaling, to the NS scaling up/down in/out, to the service function chain changes, to the change on a radio parameter (e.g., dedicated bandwidth to a VSCNO).

- Service Function Chaining (SFC): The LightDC is the component where all VNF, SC-VNFs and resulting SFC are executed. It provides heterogeneous platform, consisting of ARMv8 and x86 nodes. Some of them can be equipped with different hardware accelerators (such as FPGA, GPU), enabling offloading heavy computational tasks (e.g., video transcoding, etc.) from the CPU. This hardware is fully supported by the software baseline providing virtualization, virtualized hardware accelerators, accelerated virtual networking as well as integration with the SESAME VIM (virtual infrastructure manager) of choice – OpenStack. This demo is focusing on SFC, which is one of the very interesting features of NFV relying on Edge Cloud Computing and SDN capabilities. By utilizing a Light DC infrastructure integrated with CESCs, the orchestration, service setup and delivery, can be performed quite fast and to the edge of the network, thus improving the latency and being able to deliver various differentiated services over a smartly versatile and adaptable infrastructure. The deployed scenario demonstrates the orchestration of a service chain over a single network segment with virtualization capabilities, but could be expanded to multiple segments if an accommodating NFVO can support such functionality.
- Programmable Open Small Cell Prototype: A prototype network hosting virtualization was developed for in-lab testing with the purpose of developing new network applications, services, algorithms and technologies. The lab system is based on components with open source software. The in-lab system prototype is made of the following essential components: Open Air Interface (OAI) eNB software; Ettus Software Defined Radio B210 model; Athonet's virtualized Evolved Packet Core (vEPC); 5G-EmPOWER VIM, and; 5G-EmPOWER eNB agent.

Speed5G

Main project goals

SPEED-5G is developing key enablers to optimise spectrum utilization while providing optimised QoE. The focus is on three dimensions to increase capacity, as illustrated in Figure 8:

- Ultra-densification through small cells,
- new and heterogeneous spectrum (licensed, unlicensed and lightly-licensed), and
- exploitation of resource across technology (spectrum) silos.

In SPEED-5G, this three-dimensional model (densification, multi-technology, additional spectrum) is referred to as extended Dynamic Spectrum Access (eDSA), where several technologies are considered and managed in order to improve spectrum availability with the exploitation of a collection of technologies to support capacity increase and service provision. The main goals of the project are:

- Design, implementation and validation of the new FBMC-based and dynamic-channel selection (DCS) based MAC designs.
- Evaluation of RRM framework and resource management algorithms.
- Demonstration of project innovations and use cases using hardware-in-the-loop and real-time testbed setups as proof-of-concepts.

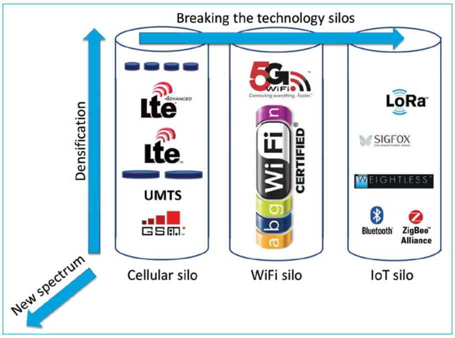

Figure 8. SPEED-5G extended Dynamic Spectrum Access (eDSA) concept showing its 3 dimensions

Main achievements & innovations

SPEED-5G has taken a multipronged approach to achieve the three main project goals described above. This approach combines the allocation of new spectrum bands, the integration of multiple RATs (Radio Access Technologies) for efficient utilization of heterogeneous resources, the reduction of cell size, and the ultra-densification of cells. Speed-5G has tackled the capacity challenge through a tight integration of different RATs at MAC layer, spectrum sharing and a much more dynamic use of spectrum and radio resources, which has resulted in significant efficiency gains and higher capacity.

The SPEED-5G project has defined and evaluated the eDSA framework based on development of two novel MAC solutions (FBMC-based MAC and DCS-MAC) and a hierarchical RRM (blending centralised and distributed RRM) using machine learning and game theory with application in ultra-dense, multi-RAT and multiband networks. SPEED-5G's introduction of different levels of resource management, operating at different time-scales, as well as the stratification of the traditional MAC layer enables the support of use-cases and application-specific optimisation of radio resources.

In addition, SPEED-5G implemented advanced, high-capacity backhaul solutions, which aim at (a) increasing the available throughput per link and capacity per area, (b) reducing the hop latency, (c) increasing network availability, and (d) balancing backhaul resources.

Proof of Concept (PoC) and demonstrations

SPEED-5G testbed deployments and trials are intended to validate the innovative solutions developed in SPEED-5G and to assess their effectiveness and performance in terms of the predefined KPIs through trials via a testbed deployment. Five individual PoCs were defined and set up. These have served to validate specific, individual project innovations, on a per-partner basis. They include:

- Design validation and testing of FBMC-MAC design & Hierarchical RRM solution,
- Design validation of DCS-MAC solution,
- Validation of interworking of HD/UHD video traffic generation & monitoring,
- Validation of cRRM functionality/algorithms and communication (remote connectivity),
- Validation of backhaul PtMP solutions.

Eventually, the individual PoCs have been combined and integrated into a single demonstrator platform (PoC 6) – the integrated SPEED-5G testbed. This testbed has been presented at the final project workshop held in London on 7 March 2018 and demos were shown to more than 50participants, to showcase the main project innovations relating to capacity improvement, aggregation and traffic offloading/steering.

The testbed has been split into 2 demos, each of them focused on highlighting specific aspects of the SPEED-5G innovation:

Demo 1: Combination of centralised and distributed radio resource management with a novel MAC protocol for higher capacity in small cells

This demo showed how the SPEED-5G outcomes can be implemented to optimise the usage of spectrum resources and deliver the best QoS in dense heterogeneous networks. The demo relied on the hierarchical RRM framework, which combined both distributed and centralised RRM agents (dRRM and cRRM, respectively) and two multi-RAT small cells. Depending on the traffic load, the dRRM agent of a small cell may decide to offload some traffic on a channel of the 5 GHz unlicensed band, and it notifies the cRRM agent about this decision. Each dRRM agent selects channels based on game theory and machine learning. The cRRM provides the MAC agent with a spectrum mask, which prevents it from transmitting on the same channel. In this demo, the second cell implemented a novel MAC protocol based on post-LTE waveform, which is capable of autonomously selecting the least interfered channel on the 5GHz band. Relying on a mandatory listen-before-talk procedure and a channel selection based on reinforcement learning, this MAC protocol is able to apply the guideline of the cRRM and determine the best possible channel to transmit data to UEs, avoiding interference from other coexisting systems like WiFi access points and stations. The demo was completed by an advanced point-to-multi point backhaul solution aggregating the small cells and providing connectivity to a video streaming server offering OTT video to potential clients on the access side.

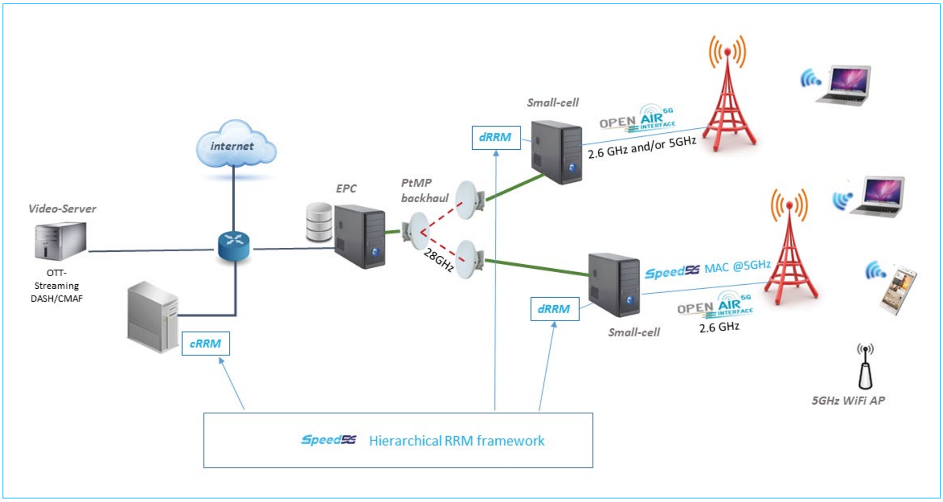

Figure 9. Centralised and decentralised radio resource management with a novel MAC protocol for higher capacity in small cells

Demo 2: Exploitation of heterogeneous spectrum resources through a tight integration of multiple RATs at MAC layer

In order to efficiently exploit heterogeneous spectrum resources, a tighter integration of multiple RATs such as LTE, WiFi, and the new 5G NR that allows efficient use of licensed, unlicensed and lightly-licensed resources, is required. In the enhanced dynamic spectrum access (eDSA) framework, proposed in SPEED-5G, a tighter integration of multiple RATs is accomplished at the MAC level, based on a MAC-level split, where the MAC layer is divided into two sub-layers, namely, higher MAC (HMAC) and lower MAC (LMAC). This is named as MAC-level RAT Integration (MACRI) for resource aggregation. The HMAC and layers above are common to all RATs, and the HMAC supports new functional modules for inter-RAT resource scheduling at MAC level, whilst there are separate LMAC and PHY entities corresponding to each RAT.

The objective of this demonstration was to highlight project innovations related to inter-RAT, e.g. LTE and WiFi, resource aggregation and traffic steering/offloading, based on the MACRI solution. The results of aggregation based on MACRI will also be compared with 3GPP legacy LWA implementations, which are used as benchmarks. The demo setup represents a collocated scenario where common LTE EPC is connected to a single PC hosting LTE eNB and WiFi via a switch. On the small-cell side, for LTE eNB, an extension of OpenAirInterface (OAI) is adopted with USRP providing RF interface while COTs WiFi AP is used for providing the corresponding RF interface. On the UE side, a dual-interface terminal is emulated using NI Chassis hosting the extended OAI protocol stack and COTs WiFi device.

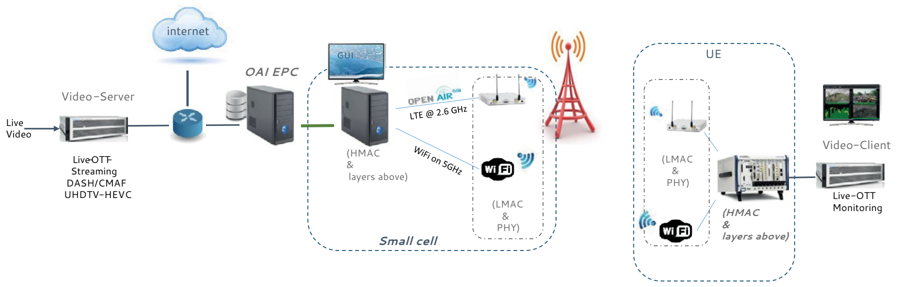

Figure 10. Exploitation of heterogeneous spectrum resources through a tight integration of multiple RATs at MAC layer

Virtuwind

Goals of the project

Project VirtuWind (5GPPP Phase 1) focuses on the problem of programmable reconfiguration of industrial networks, as per changing service demands of the industrial applications, while significantly reducing the CAPEX & OPEX, via Software Defined Networks (SDN) and Network Function Virtualisation (NFV). As a representative use case of industrial networks, a wind park control network is considered for experimentation, with field trials on an actual, operating wind park, to demonstrate the applicability and advantages of the proposed approach. The key objectives of VirtuWind are:

1. Realize industrial-grade Quality of Service (QoS) for intra-domain SDN solution: VirtuWind aims to extend SDN and NFV with industrial-grade QoS capabilities and to validate the intra-domain solution through prototyping and lab testing.
2. Guarantee inter-domain QoS for SDN based multi-operator ecosystem: VirtuWind will develop mechanisms that allow access to SDN-enabled network infrastructure in different operator environments to enforce a QoS path through multi operator domains.
3. Reduce time and cost for service provisioning and network maintenance: VirtuWind will specify and develop a suitable SDN northbound interface allowing applications to easily request communication services. Centralised control systems via SDN will take much less time to install, commission and maintain. This will bring programmability to the industrial network, thus increasing the velocity of service provisioning and reconfiguration.
4. Assure security-by-design for the SDN and NFV ecosystem: Introducing concepts like SDN and NFV for critical infrastructures requires careful investigation of the new security risks, as new threats may arise which never

before existed in legacy systems. VirtuWind will establish a comprehensive threat and risk framework for industry-grade SDN networks.

5. Field trial of intra- and inter-domain SDN and NFV prototype: The developed SDN and NFV solution will be set up and demonstrated at a field trial in the "Floe" Wind Park located in Brande, Denmark.

In order to maximise the impact of its results, VirtuWind includes a broad range of industrial domains in the project activities through the advisory committee addressing the requirements not only from the wind energy domain but also from other industrial sectors.

Major achievements so far

VirtuWind started in July 2015 and will run for 36 months and has been very successful so far in terms of timely submission of deliverables, work progress, standardisation efforts (in 3G-PPP and IETF, among others), as well as project dissemination activities at important industry and academic events. The VirtuWind consortium has already finalized the detailed intra- and inter-domain solution architecture (see Figure 11), the associated SDN & NFV, and their integration. The relevant public deliverables, with in-depth explanation, can be found on the project's website .

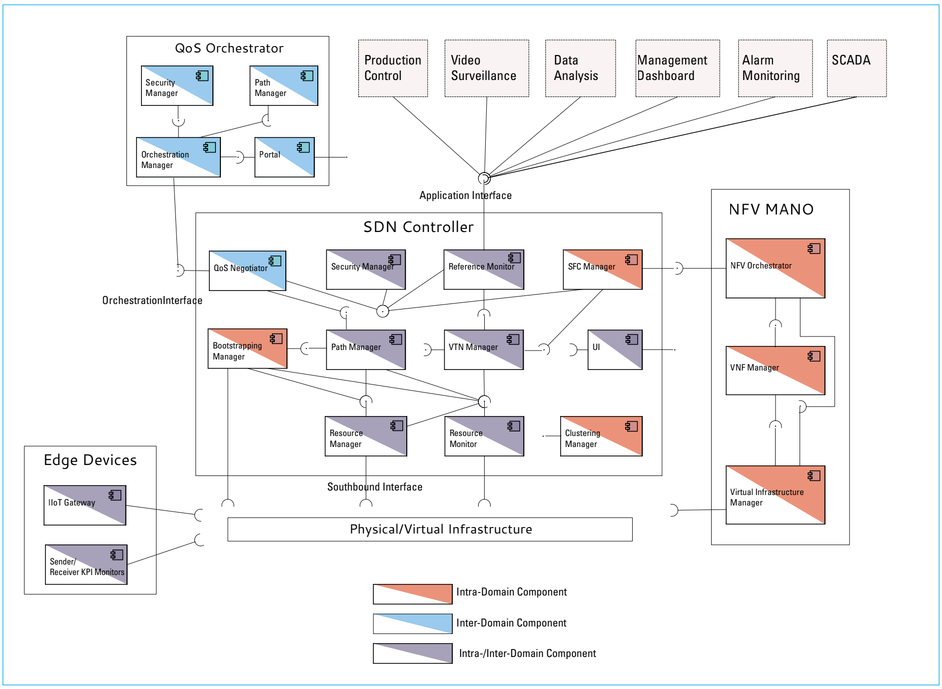

Figure 11. The combine Virtuwind intra- and inter- domain system architecture.

The above have already been successfully tested in the lab, and the testbed has been moved to the "Floe" Wind Park in Denmark for the field trials/ onsite testing of the VirtuWind solution, which is already underway (see Figure 12). Additionally, the project has created a framework for the techno-economic assessment of existing and SDN and NFV-based communication networks, and its application to the particular case of the wind park. This framework will be used to evaluate the benefits of the developed system during field trials.

Figure 12. Field trials of VirtuWind solution at "Floe" wind park (Denmark)

Key Demonstration activities

The VirtuWind consortium has demonstrated its project results in various major venues. After showing Industrial-grade QoS demo at Mobile World Congress (Barcelona, Spain, Feb. 2016), VirtuWind participated in the 2nd Global 5G event (Rome, Italy, Nov. 2016), with 2 demos covering Industrial-grade Security and Industrial IoT topics. In Industrial-grade security, a reactive security framework enabled by a Service Function Chain (SFC) aware wind park communication network was shown and secondly showed multi-tenant, isolated and virtualized access to a range of Industrial IoT sensors gathering wind park control data. Moreover, a VirtuWind demo was presented at SIGCOMM 2017 (Los Angeles, CA, USA, August 2017), and its Reactive Security Framework was showcased at the Fog World Congress (Santa Clara, CA, USA, Oct. 2017). Smart City Expo World Congress (SCEWG) 2017 in Barcelona, 14-16 of November. VirtuWind also had the chance to demonstrate its industrial-grade network programmability and enhanced security technologies and collect valuable feedback (via questionnaires) from its end users, at the Wind Europe Conference and Exhibition (Amsterdam, Holland, Nov. 2017). A more detailed report on each of the above dissemination activities can be found at the News section of the project's website (http://www.virtuwind.eu/news.html).

PHASE 2 (R&I & I)

5G Car

To enhance future connected vehicles the 5GCAR project began by identifying crucial use cases and their relevant requirements in the summer of 2017. Thereafter, evaluations and demonstrations on 5G V2X technologies and solutions have been performed to find and promote suitable end-to-end performance of the entire system. Intermediate reports on areas ranging from business and spectrum aspects, lower layer cellular and sidelink technology components as well as architectural technology components, and demonstration guidelines are being brought forward during the spring of 2018.

5GCAR has defined a constitutive set of 5G V2X use cases, building on other EU projects as well as other organisations and fora like ETSI-ITS and 5GAA. From each identified class a representative use case was selected. The selected use cases are: Lane merge, See-through, Network assisted vulnerable pedestrian protection, High definition local map acquisition, and Remote driving for automated parking. These use cases are intended to span the relevant 5G V2X space by representing a much broader set of use cases. Detailed descriptions are provided in D2.1, which has served as input to the ongoing work in e.g. 5GAA.

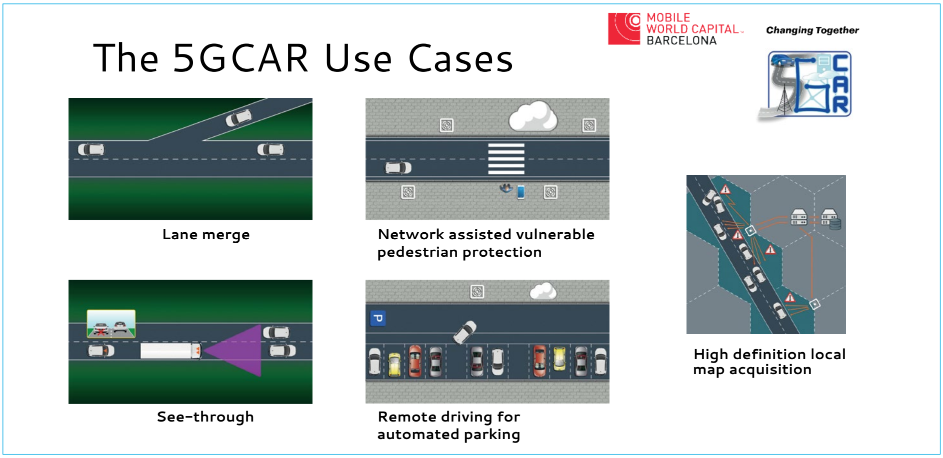

Figure 13. The 5GCAR Use Cases

The main objectives within the 5GCAR project are:

- Develop an overall 5G system architecture providing optimised end-to-end V2X network connectivity for highly reliable and low-latency V2X services, which supports security and privacy, manages quality-of-service and provides traffic flow management in a multi-RAT and multi-link V2X communication system.
- Interworking of multi-RATs that allows to embed existing communication solutions and novel 5G V2X solutions.
- Develop an efficient, secure and scalable sidelink interface for low-latency, high reliability V2X communications.

- Propose 5G radio-assisted positioning techniques for both vulnerable road users and vehicles to increase the availability of very accurate localization.
- Identify business models and spectrum usage alternatives that support a wide range of 5G V2X services.
- Demonstrate and validate the developed concepts and evaluate the quantitative benefits of 5G V2X solutions using automated driving scenarios in test sites.

In addition to the theoretical work, there is also hands on experience from three 5GCAR live demonstration use cases that will be showcased towards the end of the project: Lane merge coordination, Cooperative perception for manoeuvres of connected vehicles, and Vulnerable road user protection. Although the final demonstrations will contain real cars, we have already now presented a smaller "toy" demonstration of the Lane merge coordination use case at the Mobile World Congress 2018, both to learn and get a feeling, as well as to showcase ongoing research and to get feedback.

Apart from the dedicated work in the project, 5GCAR also contributes to several of the 5G PPP working groups. For instance, 5GCAR provided significant work and content to the first 5G Automotive WG white paper: "A study on 5G V2X Deployment" which became public earlier this year.

5G-PPP 5G ESSENCE

Embedded Network Services for 5G Experiences

Goals of the project

5G ESSENCE (Grant Agreement No.761592) "addresses" the paradigms of Edge Cloud computing and Small Cell-as-a-Service (SCaaS) by fuelling 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 global 5G ecosystem. The 5G ESSENCE framework provides 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 by providing new opportunities for ownership, deployment, operation and amortisation.

The technical approach exploits the benefits of the centralisation of Small Cell functions as scale grows through an edge cloud environment based on a two-tier architecture: a first distributed tier for providing low latency services and a second centralised tier for providing high processing power for computing-intensive network applications. This allows decoupling of the control and user planes of the Radio Access Network (RAN) and achieving the benefits of Cloud-RAN without the enormous fronthaul latency restrictions. The use of end-to-end (E2E) network slicing mechanisms will allow sharing of the 5G ESSENCE infrastructure among multiple operators/vertical industries and customising its capabilities on a per-tenant basis. The versatility of the architecture is enhanced by high-performance virtualization techniques for data isolation, latency reduction and resource efficiency, and by orchestrating lightweight virtual resources enabling efficient Virtualized Network Function (VNF) placement and live migration.

5G ESSENCE leverages knowledge, SW modules and prototypes from various 5G-PPP Phase-1 projects (with the SESAME project being particularly relevant). Building on these foundations, very ambitious objectives are targeted, culminating with the prototyping and demonstration of 5G ESSENCE system in three real-life use cases associated to vertical industries (i.e.: Edge network acceleration in a crowded event; (ii) mission critical applications for public safety (PS) communications providers, and; (iii) in-flight entertainment and connectivity (IFEC) communications, as depicted in Figure 14).

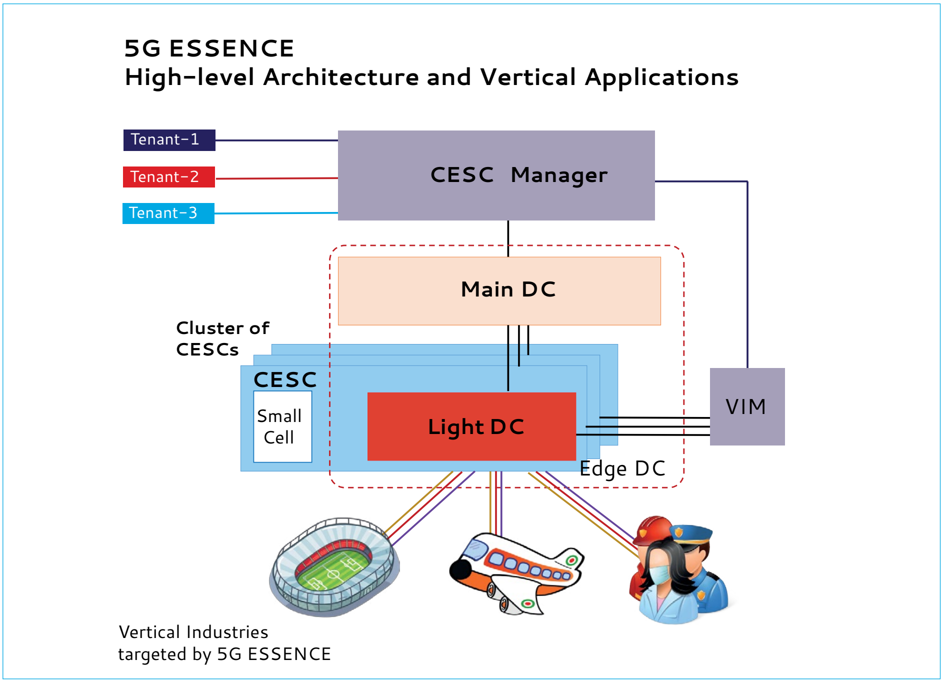

Figure 14. 5G ESSENCE high-level architecture and vertical applications

At the network's edge, each Cloud-Enabled Small Cell (CESC) is able to host one -or more- service VNFs, directly applying to the users of a specific operator. Similarly, VNFs can be instantiated inside the Main Data Centre (DC) and be parts of a Service Function Chaining (SFC) procedure. The Light DC can be used to implement different functional splits of the SCs as well as to support the mobile edge applications of the end-users. At the same time, 5G ESSENCE proposes the development of small cell management functions as VNFs, which run in the Main DC and coordinate a fixed pool of shared radio resources, instead of considering that each small cell station has its own set of resources.

The CESC Manager (CESCM) is responsible for coordinating and supervising the use, the performance, and the delivery of both radio resources and services. It controls the interactions between the infrastructure (CESCs, Edge DC) and the network operators. Also, it handles Service Level Agreements (SLAs), while upon an architectural basis the CESCM encompasses telemetry and analytics as fundamental tools for efficiently managing the overall network. The Virtualised Infrastructure Manager (VIM) is responsible for controlling the NFV Infrastructure (NFVI), which includes the computing, storage and network resources of the Edge DC.

It should be mentioned that 5G ESSENCE does not only propose the development and adaptation of the multitenant CESC platform, the virtualization infrastructure and the centralisation of the software-defined (SD) radio resource management described above; it also addresses several aspects that affect performance in 5G virtualized environments such as virtual switching, VNF migration, and Machine Learning algorithms, which allow orchestrating of diverse types of lightweight virtual resources.

Main objectives of the project

The 5G ESSENCE project is an innovative effort aiming to achieve the following objectives:

- Specify the critical architectural enhancements from 5G-PPP Phase-1 that are needed to fully enable cloud-integrated multi-tenant small cell networking.

- Define the baseline system architecture and interfaces for the provisioning of a cloud-integrated multi-tenant Small Cell network and a programmable Radio Resource Management (RRM) controller, both customisable on a per vertical basis.
- Develop the centralised SD-RAN controller that will programme the radio resources usage in a unified way for all CESCs.
- Exploit high-performance and efficient virtualization techniques for better resource utilisation, higher throughput and less delay at Network Services (NSs) creation time.
- Develop the orchestrator enhancements for distributed service management.
- Demonstrate and evaluate the cloud-integrated multi-tenant small cell network via three real-life vertical industries.
- Conduct a market analysis and establish new business models. Detailed techno-economic analysis and roadmapping towards exploitation and commercialisation by industrial partners is also a priority.
- Ensure maximisation of 5G ESSENCE impact to the realisation of the 5G vision by establishing close liaison and synergies with 5G-PPP Phase-1 & 2 projects and the Association. Pursue extensive dissemination and communication activities, as well to assess the perceived impact from the stakeholders and the wider community.

Actual achievements

The project has already elaborated the necessary system use cases, adaptation and description to the specific scenarios that will be targeted by the 5G vertical industries demonstrations. Fundamental limitations addressed, envisaged innovations, and key system requirements have been identified.

Furthermore, 5G ESSENCE has proposed a detailed system architecture and the corresponding interfaces for the provisioning of a cloud-integrated multi-tenant SC network and a programmable RRM controller, both customisable on a per vertical basis.

Fundamental use cases of the project

5G ESSENCE develops three real-life use cases, associated with vertical industries. These are as follows:

- Edge network acceleration in a crowded event: 5G ESSENCE will demonstrate a combined 5G-based video production and video distribution towards delivering benefits to both media producers and mobile operators, who will be able to offer enriched event experience to their subscribers. The production/distribution of locally generated content through the 5G ESSENCE platform, coupled with value-added services and rich user context, will enable secure, high-quality and resilient transmission, in real-time and with minimal latency.
- Mission critical applications for public safety communications providers: 5G ESSENCE will involve one or more PS communications providers that will use the resources offered by a deployed 5G ESSENCE platform for the delivery of communication services to PS organisations in a country/region. In the mission critical use case, the infrastructure owner will exploit the 5G ESSENCE system capabilities to provide the required network/cloud slicing capabilities with dedicated SLAs to different types of tenants, prioritising the PS communications providers.
- In-flight entertainment and connectivity communications: The 5G ESSENCE IFEC demo will test and validate the multi-tenancy enabled network solution for passenger connectivity and wireless broadband experience. The multi-RAT (Radio Access Technologies) CESCs will be implemented as a "set of integrated access points" to be deployed on board. Afterwards, since inflight entertainment has to consider the explosive growth of multi-screen content consumption, the 5G ESSENCE CESCs will stream on demand multi-screen video content (both from on board servers and via satellite/air-to-ground links) to the wireless devices.

Performance KPIs

With respect to the originally defined 5G-PPP programme KPIs, 5G ESSENCE contributes explicitly to:

- Reduce the average service creation time cycle from 90 hours to 90 minutes.
- Saving up to 90% of energy per service provided.
- Creating a secure, reliable and dependable Internet with "zero perceived" downtime for services provision.

- Support improvements in autonomic network management and automated network control, leading to reduced network OPEX.
- Provide increased network coverage (with ubiquitous 5G access including low-density areas) together with more varied service capabilities, and helping create novel business models.

Description of the 5G ESSENCE novel architecture

In the planned 5G ESSENCE approach, the Small Cell concept is evolved as not only to provide multi-operator radio access but also, to achieve an increase in the capacity and the performance of current RAN infrastructures, and to extend the range of the provided services, while maintaining its agility. To achieve these ambitious goals, the 5G ESSENCE project leverages the paradigms of RAN scheduling and, additionally, provides an enhanced, edge-based, virtualized execution environment attached to the small cell, taking advantage and reinforcing the concepts of MEC and network slicing.

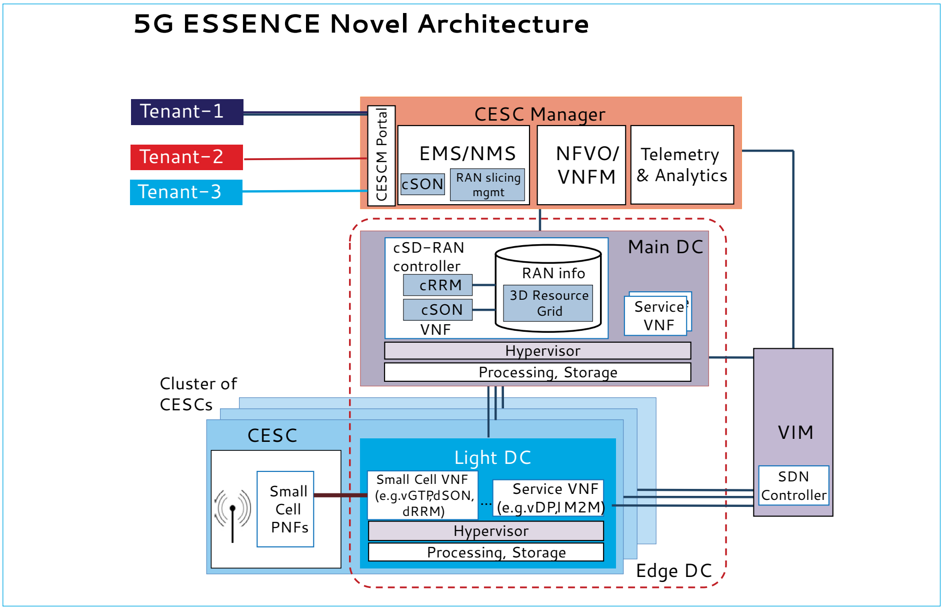

Figure 15. 5G ESSENCE novel architecture

The 5G ESSENCE architecture allows multiple network operators (tenants) to provide services to their users through a set of CESCs deployed, owned and managed by a third party (i.e., the CESC provider). In this way, operators can extend the capacity of their own 5G RAN in areas where the deployment of their own infrastructure could be expensive and/or inefficient, as would be the case of e.g., highly dense areas where massive numbers of Small Cells would be needed to provide the expected services.

The 5G ESSENCE platform is equipped with a two-tier virtualized execution environment. The first tier, i.e., the Light DC hosted inside the CESCs, is used to support the execution of VNFs for carrying out the virtualization of the Small Cell access. In this regard, network functions supporting traffic interception, GTP encapsulation/ decapsulation and some distributed RRM/ SON functionalities, are expected to be executed therein. VNFs that require low processing power, e.g., a Deep Packet Inspection (DPI), a Machine-to-Machine (M2M) Gateway, and so on, could also be hosted here. The connection between the Small Cell Physical Network Functions (PNFs) and the Small Cell VNFs can be realized through, e.g., the network Functional Application Platform Interface (nFAPI). Finally, backhaul and fronthaul transmission resources will be part of the CESC, allowing for the required connectivity. The second cloud tier, i.e., the Main DC, will be hosting more computation intensive tasks and processes that need to be centralised in order to have a global view of the underlying infrastructure. This encompasses the cSD-RAN controller, which will be delivered as a VNF running in the Main DC and makes control plane decisions for all the radio elements in the geographical area of the CESC cluster, including the centralised Radio Resource Management (cRRM) over the entire CESC cluster. Other potential VNFs that could be hosted by the Main DC include security applications, traffic engineering, mobility management and, in general, any additional network E2E services that can be deployed and managed on the 5G ESSENCE virtual networks, effectively and on-demand.

The CESC is meant to accommodate multiple operators (tenants) by design, offering Platform as-a-Service (PaaS), capable of providing the deployed physical infrastructure among multiple network operators. It exposes different views of the network resources: per-tenant small cell view, and physical small cell substrate. The CESCM is the central service management and orchestration component in the architecture. Generally speaking, it integrates all the traditional network management elements, and the novel recommended functional blocks to realise NFV operations. The CESCM functions will be built upon the services provided by the VIM for appropriately managing, monitoring and optimising the overall operation of the NFVI resources (i.e. computing, storage and network resources) at the Edge DC. The role of VIM is essential for the deployment of NFV services and to form and provide a layer of NFV resources to be made available to the CESCM functions.

5G-Transformer

5G Mobile Transport Platform for Verticals

5G-TRANSFORMER (http://5g-transformer.eu/) brings to the 5GPPP initiative its vision to expand the service scope and transform today's rigid mobile networks into a flexible and dynamic ecosystem supporting a wide range of vertical industries, such as automotive, e-Health, media, and Industry 4.0.

Traditionally, mobile networks have been composed of three segments: the Radio Access Network (RAN), the Core Network, and the Transport Network interconnecting the RAN with the Core. Developing 5G network architectures meeting the diverse and stringent requirements of vertical players in terms of capacity, latency and massive connection density, challenge the traditional split of mobile network segments, requiring the addition of computing capabilities at the mobile network edge (RAN/Transport), and thus, blurring their boundaries. These edge capabilities also bring an opportunity to leverage on a rich set of context information available not only to optimise end-to-end network performance, but also to offer new customised services, opening the door to new business opportunities.

To allow such transformation, 5G-TRANSFORMER proposes a SDN/NFV-based dynamic 5G mobile transport network relying on network slicing, multi-access edge computing (MEC), and federation concepts as key enablers to manage networking and computing resources tailored to the specific services of vertical industries.

The key architectural concept to support such adaptation to the needs of verticals and M(V)NOs is network slicing. The term network slice aligns network functionality to business needs, since it allows customers to request not just functions, but also business objectives (e.g., quality of service, security, etc.), as a sort of intent. The scope of a slice may be a single customer facing service (using TM Forum terminology) or a group of such services. The system will also allow infrastructure providers sharing the 5G mobile transport and computing infrastructure efficiently among verticals and M(V)NOs, hence enhancing 5G-TRANSFORMER provider network usage efficiency. In terms of deployment, network slices can be implemented by means of ETSI NFV network services.

The architecture is conceived to support multiple combinations of stakeholders by introducing open APIs among components. Through these APIs, the system hides unnecessary details from the verticals, allowing them to focus on the definition of the vertical services and the required Service Level Agreements (SLAs). As for interfaces, particularly relevant for the goals of the project are east-westbound interfaces, which enable service and resource federation among different administrative domains, allowing 5G-TRANSFORMER service providers to enhance the service offerings to their customers by peering with other providers.

During the first year of the project, 5G-TRANSFORMER has mainly focused on the definition of its architecture and the use cases spanning across all the previously mentioned vertical industries to validate and demonstrate the proposed concepts.

5G-TRANSFORMER defines three main architectural building blocks. They are presented in Figure 16 along with the main concepts of the project. These building blocks are:

- The Vertical Slicer (5GT-VS), is the entry point for the vertical requesting a service and it handles the association of these services with network slices as well as network slice management.
- The Service Orchestrator (5GT-SO) is responsible for end-to-end orchestration of services across multiple domains and for aggregating local and federated (i.e., from peer domains) resources and services and exposing them to the 5GT-VS in a unified way.
- The Mobile Transport and Computing Platform (5GT-MTP), acting as the manager of the underlying integrated fronthaul and backhaul transport network In fact, it provides and manages the virtual and physical IT and network resources on which service components are eventually deployed. It also decides on the abstraction level offered to the 5GT-SO.

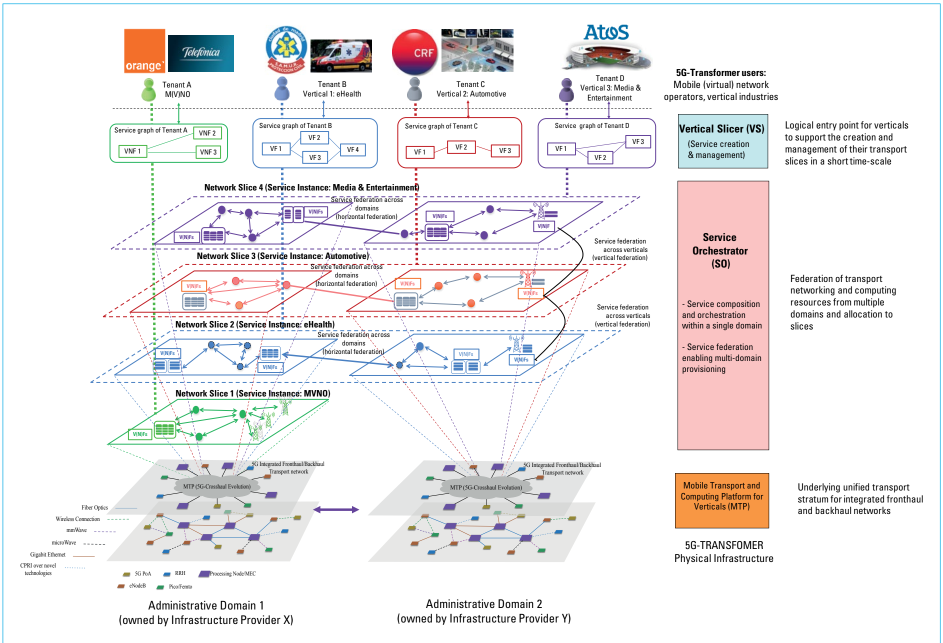

Figure 16. 5G-TRANSFORMER concept

The specification of each building block takes as starting point the work developed within related standardisation bodies and working groups (3GPP, IETF, ETSI NFV, ETSI MEC). However, this work must be adapted and complemented to meet all the needs of the different verticals. 5G-TRANSFORMER has also identified such gaps, providing this as an input for the working groups of the above standardisation bodies.

Table 1 contains the proof of concepts (PoCs), which will serve to validate the proposed architecture (selection process still ongoing). These PoCs have been identified based upon the requirements provided by the vertical partner members of the consortium and the 5G-TRANSFORMER experimentation facilities distributed across Europe. Development of such PoCs have already started, including the different concepts of the 5G-TRANSFORMER architecture during the time span of the project.

Vertical industry	Use Case
Automotive	Intersection collision avoidance (ICA) and See-Through
e-Health	Monitoring of vital signs
Media Provider	On site Fan Experience
Factory 4.0	Controlling factory robots from the cloud
Mobile Virtual Network Operator	vEPC as a service

Table 1. Relation between vertical industries and defined use cases in 5G-TRANSFORMER

5G-Monarch

Challenges and objectives

The envisaged diversity of services, use cases, and applications to be supported by 5G requires a flexible, adaptable, and programmable mobile network architecture. 5G-PPP Phase 1 projects addressed the baseline design of such an architecture at a conceptual level. In particular the concept of network slicing, which builds on the capabilities of SDN, network function virtualization (NFV), access network orchestration, and analytics, allows to logically sectorise the network for dedicated services, applications, or vertical industries. Each of these sectors may have different requirements in terms of quality and performance requirements, but multiple slices share the same physical and virtualized infrastructure.

The goal of 5G-MoNArch as a Phase 2 project is to bring this architecture design to practice. Where the baseline concepts already include the building blocks and methods for defining and instantiating slices, 5G-MoNArch completes and enhances them with methods and algorithms for orchestration and optimisation across network slices and among virtualized functions, and with functions for selected use cases. Central to the project is the experimental implementation of selected functionality into real-world testbeds to allow for an experiment-driven proof-of-concept. More specifically, the objectives of 5G-MoNArch are:

- The completion of 5G mobile network architecture baseline concepts towards a *fully-fledged architecture*, taking into account the progress in standardisation.
- The extension of the baseline mobile network architecture design with a set of *enabling innovations* related to inter-slice control and cross-domain management, native cloud-enabled protocol stack, and experiment-driven modelling and optimisation, and a set of use-case specific *functional innovations* related to resilient and secure network slices for industrial applications and resource elastic network slices for media and entertainment applications.
- The simulation-based *evaluation* of the developed architecture concepts and

technical innovations, and the *validation* of their performance

- The deployment and implementation of the developed architecture and selected enabling and functional innovations into two *real-world testbeds*, namely, the Hamburg Smart Sea Port representing an industrial environment, and the Turin Touristic City implementing a media and entertainment use case

Fully-fledged architecture

The transition from a network of entities to a network of services brought by the softwarisation of network functions and network slicing entails a totally new set of requirements for the mobile network architecture:

- *Intra- slice requirements:* To efficiently support services with very diverse requirements, the architecture shall allow the instantiation of customised network slices, each of them tailored to the specific requirements imposed by the hosted service.
- *Cross-slice requirements:* The architecture shall flexibly assign resources to slices when and where they are needed, eventually controlling the resources shared across slices to optimise their utilization

This entails the definition of a totally new set of management and control functions to deal with the requirements described above. 5G-MoNArch, defines a multi-layer architecture that includes: i) a Management and Orchestration (M&O) layer, a ii) Network Controller Layer and a iii) Network layer.

The M&O layer extends and complements the modules currently envisioned by 3GPP SA5 to specifically consider the resilience and elasticity concepts. The M&O layer also interfaces with the network controller layer. This layer includes two controllers that enforce the programmability concept to the network layer functions. The network layer is composed by the specific network functions, that build each specific network slice, finally devoted to the provisioning of a given telecommunication service. Besides the overall architecture, 5G-MoNArch is investigating specific solutions to enhance the operation of such architecture: the cloud-aware protocol stack, the experiment-driven optimisation [1] and, resilience and elasticity, as introduced below.

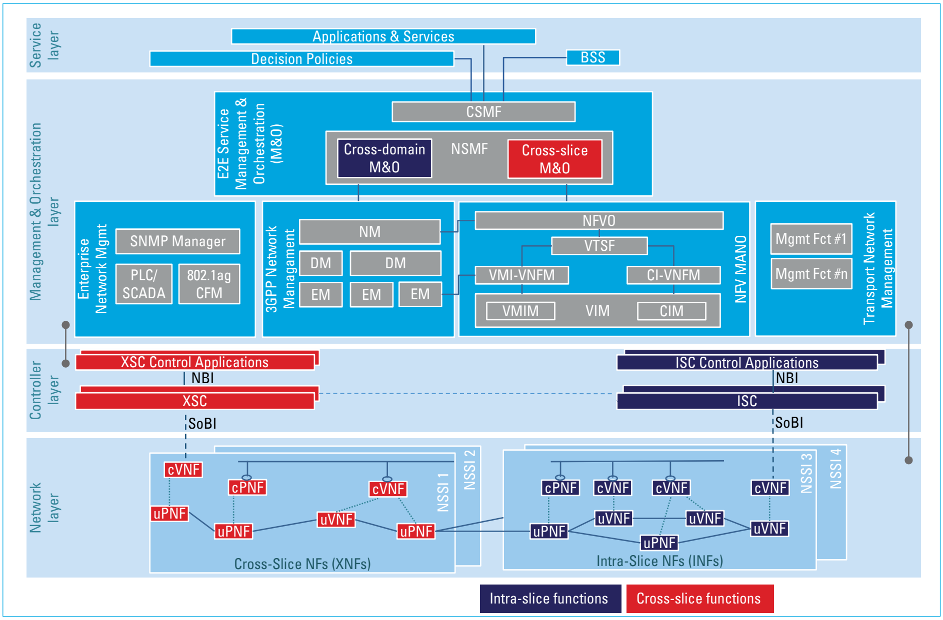

Figure 17. 5G-MoNArch overall functional architecture concept

Customised slice functionality

A major implementation aspect of network slicing relates to its ability to provide a customised functionality for given requirements. In this respect, 5G-MoNArch focuses on two major frameworks for customised functionality, namely a) *Resilience and Security* and b) *Resource Elasticity*.

Resilience and Security are studied on a common ground in 5G-MoNArch, since they are associated with a common impact on the network performance and operational cost. In fact, network slicing is catalyst for materialising resilient and secure services, since without slicing it the cost for designing such architecture would be prohibitive.

For instantiating customised resilient and secure slices, 5G-MoNArch focuses on three major pillars: i) Reliability of the Radio Access Network (RAN); ii) Resilience in telco cloud; iii) Security-driven architecture modules. In particular, a high level of *RAN reliability* is pursued via macro diversity with data duplication, as well as with specially tailored network coding approaches. Such approaches are indeed well known in the literature, yet their application towards RAN reliability is new, yielding a novel design of the corresponding network functions and the overall architecture. *Resilience in the telco cloud* is addressed via advanced fault management approaches, where infrastructure redundancy as well as controller scalability is involved. 5G-MoNArch also provides a security monitoring and active learning approach for addressing the *security requirements* of such customised slice. Besides this, the concept of security trust zones is highlighted, along with a corresponding analysis on the characterisation of security zones and their classification into profiles. An exemplary picture of such trust zone classification is provided below, where different trust zones are deployed in a slice-aware fashion.

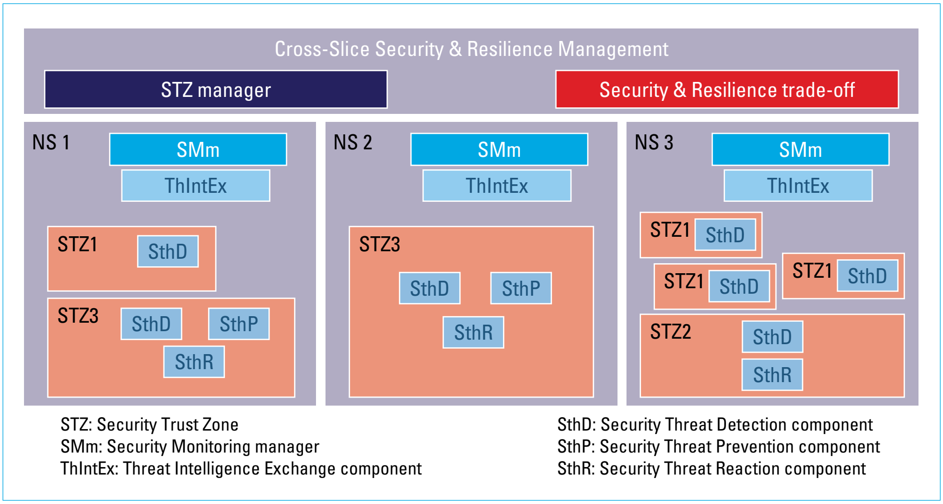

Figure 18. Network slices for resilient and secure services

The second technological enabler of 5G-MoNArch is Resource Elasticity. Elasticity is a well-studied concept in cloud computing systems, and it is defined as the degree to which a system is able to adapt to workload changes by provisioning and deprovisioning resources in an autonomic manner. In this way, at each point in time the available resources match the current demand as closely as possible. In networks, temporal and spatial traffic fluctuations require an efficient resource scaling that, in case of peak demands, allows for the adaptation of its operation and the re-distribution of the available resources as needed. That is, the system shall *gracefully scale* the network operation. We refer to this flexibility, which could be applied both to computational (i.e., CPU, memory, storage) and communications (i.e., spectrum, transport) resources, as *resource elasticity*. Although elasticity in networks has already been exploited traditionally in the context of communications resources (e.g., where the network gracefully downgrades the quality for all users if communications resources such as spectrum are insufficient), in 5G-MoNArch we focus on the *computational aspects* of resource elasticity, as we identify their management in networks a key challenge of future virtualized and cloudified 5G systems

Besides establishing a definition as well as a set of requirements and KPIs, 5G-MoNArch proposes mechanisms for the exploitation of elasticity in three different dimensions, namely *computational elasticity* in the design and scaling of network functions, *orchestration-driven elasticity* by flexible placement of network functions, *and slice-aware elasticity* via cross-slice resource provisioning mechanisms. The table below provides a summary of the elasticity dimensions as well as their associated challenges and solutions.

Innovation Areas	Challenges	Solutions
Computational elasticity	Graceful scaling of computational resources based on load	Elastic NF design and scaling mechanisms
Orchestration-driven elasticity	NF interdependencies	Elastic cloud-aware protocol stack
Slice-aware Elasticity	E2E cross-slice optimisation	Elastic resource provisioning mechanisms

Table 2. Challenges and solutions for innovations areas - 5G Monarch

Use cases and testbeds

For each of the two testbeds (Hamburg Smart Sea Port and Turin Touristic City), the project will instantiate the developed overall architecture and complement it with selected use case specific functional innovations. The Smart Sea Port thereby represents an industrial environment where the focus is on highly resilient and secure communication for applications such as logistics traffic control through a connected traffic light, environmental pollution control through ship-based mobile sensors, and a CCTV installation for access gate supervision. For the Touristic City, representing a typical use case for future (multi-)media and entertainment services, mobile broadband services including high-definition video streaming and interactive augmented reality applications will be implemented, that allow visitors of the Palazzo Madama museum in Turin a completely new experience. Both testbeds use on-site mobile network and mobile terminal installations implementing network slicing-enabled protocol stacks.

Expected impact

5G-MoNArch has a very high potential for commercial impact, including enhanced products (e.g., orchestrators or edge-cloud RAN), novel services (enabled by network slicing) and opportunities for new market players. To exploit this potential, 5G-MoNArch has elaborated a thorough and realistic innovation plan that includes patents and standards.

[1] 5G MoNArch D2.1, "Baseline Architecture based on 5G-PPP Phase 1 results and gap analysis", October 2017, [online] available at https://goo.gl/RmrhLB

5G-Picture

5G-PICTURE will design and develop an integrated, scalable and open 5G infrastructure to support operational and end-user services for both Information and Communication Technology (ICT) and "vertical" industries. This infrastructure will rely on a converged fronthaul and backhaul solution, integrating advanced wireless access and novel optical network domains.

To address the limitations of current solutions, 5G-PICTURE will adopt 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. It will also rely on network softwarization to enable an open reference platform instantiating a variety of network functions and adopt slicing and service chaining to facilitate optimised multi-tenancy operation.

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 will enable the transformation of ICT and vertical infrastructures from closed inflexible environments into a common pool of modular HW and software (SW) components that can be combined and coordinated on demand to support a large variety of services.

Technical and research challenges

5G-PICTURE will integrate network and compute/storage resources in a common infrastructure. This entails developing a hierarchical compute and storage structure supported by a network hierarchy. To this end, the integration of programmable wireless technologies at the edge and a hybrid passive/active optical transport network will be exploited.

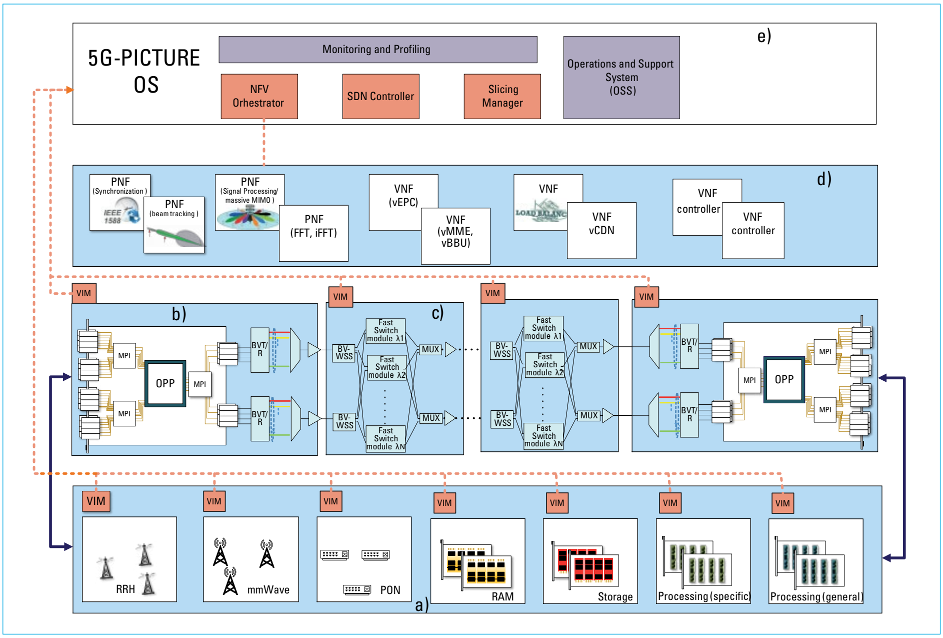

Figure 19. Proposed architecture 5G-PICTURE control and management platform for enhanced network and compute HW and SW modularity and flexibility.

5G-PICTURE will address the limitations of current distributed RAN and Cloud-RAN approaches, with the development of flexible functional splits, which can be dynamically selected based on transport network and service characteristics. This will be achieved through the notion of DA-RAN relying on a disaggregated resource pool (network/storage/compute). To enable this approach, 5G-PICTURE proposes a set of novel technology solutions as well as control and management platforms offering enhanced network and compute HW, as well as SW modularity and flexibility. Another key enabler of the proposed approach is the creation and deployment of programmable network functions as well as intelligent orchestration schemes. The proposed 5G-PICTURE architecture is depicted in Figure 19.

Major achievements & innovations

In order to drive the technical activities in support of 5G stakeholders' needs, 5G-PICTURE has initially analysed a set of ICT and vertical industry services with the aim of deriving the relevant functional requirements of the 5G-PICTURE infrastructure [1]. In particular, high speed rail, smart city and internet of things, stadium and mega event and industry 4.0 were considered. This work also defined a set of associated Key Performance Indicators (KPIs) that can be used to verify the success of the envisaged project solution. A summary of the relevant findings are shown in Figure 20.

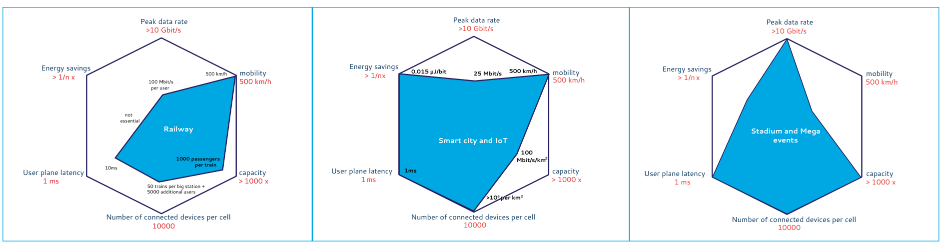

Figure 20. Synthesis of the different requirements for each of the use cases considered in 5G-PICTURE: a) Railway vertical, b) Smart city and IoT, c) Stadium and Mega events.

The analysis carried out in [1] confirms that HW programmability as well as disaggregation of network resources and functions can play a key role in supporting the great variability of services considered in these environments, as well as the associated Quality of Service (QoS) requirements with increased, efficiency, scalability and sustainability. Indicative examples of such services include network connectivity with varying delay and delay jitter requirements, infrastructure slicing for multi-tenancy, and interoperation of various network technologies maintaining specific security features.

In addition to the derivation of the functional requirements and the detailed definition of the overall 5G-PICTURE architecture, part of the first year's activities include a preliminary investigation of the performance of the 5G-PICTURE solution. Our initial results indicate that moving towards disaggregated architectures can provide significant benefits in terms of efficiency and sustainability [2] and can enable complex service bunches (synthetically verticals) that otherwise would not be easily feasible.

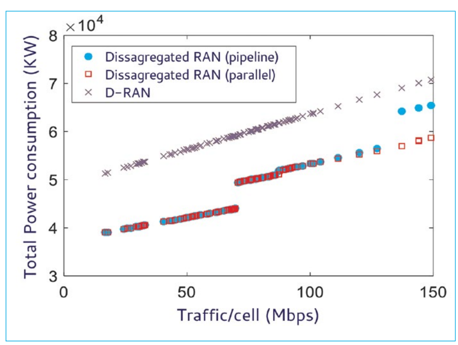

Figure 21. Power consumption as a function of traffic for distributed RAN and DA-RAN for different processing models [2].

Planned demonstrations

5G-PICTURE will demonstrate a variety of use cases (Figure 22) including: (a) converged fronthaul and backhaul services in a smart city environment hosted by the state-of-the-art 5G "City of Bristol" network infrastructure, (b) seamless service provisioning and mobility management in high speed railway environments exploiting a real 5G-railway testbed located in Barcelona, Spain, and (c) media services supporting large venues in a 5G-stadium testbed located in Bristol, UK to address scenarios with increased density and static-to-low mobility.

[1] 5G-PICTURE deliverable D2.1, "5G and Vertical Services, use cases and requirements", January 2018.

[2] A. Tzanakaki et al., Converged Access/Metro Infrastructures for 5G services, OFC 2018, invited.

Figure 22. 5G-PICTURE demonstrations.

5G-Xcast

Project goals

5G-Xcast is a second phase 5GPPP Horizon 2020 European project focussed on devising, assessing and demonstrating a conceptually novel and forward-looking 5G network architecture for large scale immersive media delivery. The project objectives are to:

- Develop broadcast and multicast point to multipoint (PTM) capabilities for 5G considering M&E, automotive, IoT and PWS use cases.
- Design a dynamically adaptable 5G network architecture with layer independent network interfaces to dynamically and seamlessly switch between unicast, multicast and broadcast modes or use them in parallel and exploit built-in caching capabilities.
- Experimentally demonstrate the 5G key innovation developed in the project for the M&E and PWS verticals.

Figure 23 shows an example of the project scope on convergence, with the three types of networks considered. Each network can carry different types of traffic such as broadcast, multicast or unicast. Different combinations of networks are available in different areas depending on where the user is located. The different convergence scenarios within 5G-Xcast are shown as being deployed across these different networks as appropriate. For example, the 5G-Xcast application and transport layers will be applicable across all three delivery networks whereas the 5G-Xcast radio layer is only targeted for wireless networks.

Mobile-broadcast convergence

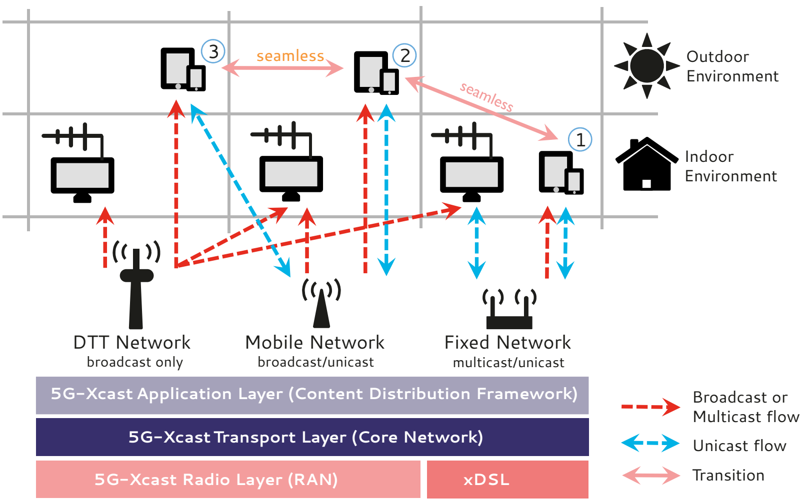

Figure 23. An example of one user moving between three different environments each of which has different combinations of networks available.

Project achievements

The project consists of two management work packages (WP1 & WP7), 4 technical WPs (2-5) and a testbed and trials WP6. Achievements to date are described below:

WP2 has defined the use cases, requirements and KPIs (key performance indicators) that the project will use to evaluate its results.

WP3 has first completed a comprehensive RAN benchmarking of existing PTM technologies (LTE eMBMS in 3GPP release 14 and ATSC 3.0). The performance of both technologies has been evaluated and compared in representative test scenarios selected for the use cases defined in WP2. Aligned with the IMT 2020 RIT evaluation process given by the ITU-R, inspection and analytical evaluations as well as link-level, coverage and system-level simulations have been carried out to investigate a selection of KPIs: spectral efficiency, coverage and mobility. WP3 has also monitored the PTP-centric 5G specifications in 3GPP release 15 and provided a gap analysis between the LTE RAN and 5G new radio, which, along with the potential limitations of LTE eMBMS RAN identified in the first stage, yields a number of mathematically exact conclusions and practical guidelines for evolving the current RAN towards 5G PTM.

WP4 describes the key drivers, benefits and use cases for full network convergence. From a mobile network perspective, WP4 has analysed the limitations of multicast/broadcast capabilities in LTE (e.g. eMBMS 3GPP release 14) and identified building blocks to enable multicast/broadcast in 5G architecture defined by the 3GPP SA2 working group. In addition, 5G-Xcast has defined architecture options which consider various techniques to enable multicast/broadcast in mobile core networks. These include eMBMS evolution, 5G-friendly and other approaches that do not rely on eMBMS architecture.

WP4 has also discussed an evaluation of current methodologies for providing partial network convergence, as well as highlighting some of their limitations. It outlines the current convergence standards activities, plus the additional technologies which will play a pivotal role in this area. The next stage is to incorporate convergence into the WP4 architectural options.

WP4 devised and evaluated several architecture alternatives to accommodate its use cases and requirements in view of, and with minimal impact on, activities in the 3GPP 5G standards, DVB and BroadBand Forum. Additional technologies such as caching, autonomous MooD and multilink are being incorporated into these architecture alternatives. WP4 has further developed relevant initial call flows to achieve the multicast and broadcast services within the network. Work on the detailed call flows and procedures are ongoing.

The goal for WP5 is to develop an overall Content Delivery Framework to clarify how the network capabilities being developed elsewhere in the project can be best exploited for content delivery. The framework allows an underlying PTM network capability to be used to manage scalability within an otherwise unicast delivery path. This dramatically simplifies the interface between the content provider and the network operator, by allowing the content provider to continue to use their existing unicast streaming technology. The use of PTM is treated as an internal optimisation choice, and should not require modification of CDNs or end device applications. In the first six months of 5G-xcast, WP5 has produced a public deliverable entitled "Content Delivery Vision" which in turn led to the first version of our "Content Delivery Framework" in February 2018. Its philosophy and principles are now being adopted by the technical work packages as they work on their technical designs and Standards contributions.

Demos and field trials

Trials are being planned for three demonstration use cases: M&E hybrid broadcast service, M&E object-based broadcasting and PW messages. The trials are to be conducted in the three 5G-Xcast testbeds: IRT in Munich (Germany), 5GIC in Surrey (UK) and TUAS in Turku (Finland).

The hybrid broadcast service trial at IRT is planned to show the integration of linear and non-linear content across both fixed and wireless networks to deploy services that make the best use of whatever network is available, even offering a seamless experience for users as they move between different areas.

The trial on Object-Based Broadcasting at 5GIC will show the delivery of content composed of multiple parts integrated at the user end, combining PTP and PTM to maximize the efficiency of delivery. Leveraging on an evolved packet core developed by 5GIC based on the 3GPP 5G service-based architecture, features such as control and user plane separation as well as mobile edge computing will be taken into account during the trial.

The multimedia PW message transmission using multi-/broadcasting for 5G will be trialled in TUAS Turku testbed. Transmission of localized PW messages such as a single-cell alert will be demonstrated. Mobility will be trialled in scenarios such as a user moving to the coverage area of a base station where an alert is active.

To advance towards designing spectrum sharing mechanisms for 5G systems, Fairspectrum and TUAS demonstrated Licensed Shared Access (LSA) on 2.3 GHz band in Turku, Finland. The spectrum was shared between Programme Making and Special Events (PMSE) equipment, LTE Mobile Network Operator, and a private LTE network. The demonstration illustrated that the Fairspectrum developed Licensed Shared Access (LSA) functions enable dynamic spectrum sharing between these types of users.

Conclusion

We summarize the objectives of the project and provide an update on the results produced so far. Aiming to devise, assess and demonstrate a 5G solution for broadcast applications such as media, V2X and public warning, the project has defined the use cases and KPIs to be used in the design. State of the art physical layer solutions such as release 14 3GPP and ATSC3.0 have been assessed. The system architecture building blocks to enable multicast/broadcast in 5G architecture defined by 3GPP SA2 have been identified. In addition, a first version of the Content Delivery Framework has been produced and its philosophy is being adopted by the technical WPs designing the overall solution. In order to demonstrate the technical proposals, LSA on 2.3 GHz band has been demonstrated and hybrid broadcast service, object-based Broadcasting, Public Warning message are being prepared. In addition, dissemination activity resulted in various technical papers and keynotes in major 5G events around the world.

blueSPACE

Building on the Use of Spatial Multiplexing 5G Networks Infrastructures and Showcasing Advanced Technologies and Networking Capabilities

blueSPACE is an EU funded project within the 2nd phase of the 5G PPP initiative, focusing on advanced optical fronthaul with infrastructures based on optical space division multiplexing. blueSPACE targets the millimeter-wave bands of the new 5G radio interface, introducing both analogue radio over fibre and optical beam forming networks.

The core concept of blueSPACE is to exploit the added value of optical space division multiplexing (SDM) in the radio access network (RAN) with an efficient optical beamforming interface for wireless transmission in the pragmatic Ka-band. blueSPACE targets the provisioning of increased bandwidth by naturally enabling and supporting hybrid multiple input multiple output (MIMO) signalling. Efficient beam forming and -steering in the photonic domain are combined with seamless interfaces between the SDM fibre medium and a radio frontend exploiting space diversity.

The developed solutions will integrate seamlessly into existing and next generation optical access network infrastructures and feature full support for software defined networking (SDN) and network function virtualization (NFV).

The main 5G related technical and research challenges addressed by blueSPACE are:

- CAPACITY: The adaptation of digital radio over fibre (DRoF) schemes in parallel with the introduction of analogue radio over fiber (ARoF) techniques to optical SDM networks based on multi-core fibres. Achieving an increased degree of integration between network elements and full compatibility among different fronthaul schemes.
- BEAM STEERING AND MIMO: Design of optimised interfacing elements between the optical SDM fibre medium and the radiating elements in the remote radio unit (RRU) sites to enable advanced MIMO and optical beam steering solutions for ARoF fronthaul architectures.
- LATENCY: Increased resource centralization at the central office (CO) with optimum allocation of the baseband unit (BBU) pool, design of switching and interconnection hardware to enable SDM compatible architectures and minimization of complexity at the RRU to strictly control and minimize latency.
- CONTROL AND MANAGEMENT: The design and evaluation of a compact infrastructure that is reconfigurable by means of SDN and NFV orchestration. This enables the deployment of virtual BBUs in the CO, as well as network slicing to support the virtualization of the network.
- 5G FACILITY: Development of advanced hardware solutions with cost efficient analogue RoF transceiver modules featuring direct compatibility with optical beam forming schemes and simplified design requirements, as well as remote power delivery to RRUs. Implementation of compact SDM splitters and multicore fibre adapters, enabling advanced SDM based optical distribution and radio access network architectures, while supporting network slicing, SDN control and network function virtualization.

blueSPACE targets a disruptive yet realistic approach for 5G fronthaul, able to address the high capacity and flexibility requirements imposed by advanced 5G services efficiently and in a scalable and future-proof manner. The proposition of blueSPACE offers unrivalled characteristics whose impacts include:

- Increased bandwidth provision with natural support for hybrid MIMO in the mm-wave frequency range and efficient photonic beam steering, by exploiting space diversity in the RF and optical domains.
- Establishing a seamless starting/ending interface between the fibre and wireless medium, establishing a unified end-to-end platform that fully integrates with existing approaches for optical access networks.
- A compact infrastructure that is reconfigurable by means of software defined networking and network function virtualization.

blueSPACE will establish a truly viable and efficient path towards 5G wireless communications with a 1000 fold increase in capacity, connectivity for over 1 billion users, strict latency control and secure, flexible network software programming.

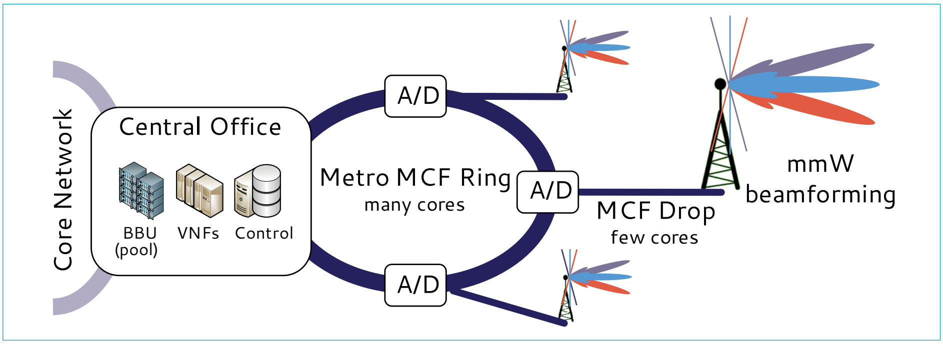

Figure 24. blueSPACE concept and architecture overview including optical fronthaul based on space division multiplexing fibres and multi-beam transmission based on optical beamforming networks.

IoRL

Internet of Radio Light

The Internet of Radio-Light (IoRL) project develops a safer, more secure, customisable and intelligent in building network using millimetre Wave (mmWave) and Visible Light Communications (VLC). The conceived solution reliably delivers increased throughput (greater than 10 Gbps) 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.

The major achievements in the first year of the project are the elaboration of the use case scenarios and the extraction of the user and technical requirements, the development of the system architecture as shown in Figure 25, the implementation plan for the benchtop demonstrators and the first steps towards their implementation. Use case scenarios were developed for private homes, public buildings including a museum and a transportation hub and buildings hosting commercial operations.

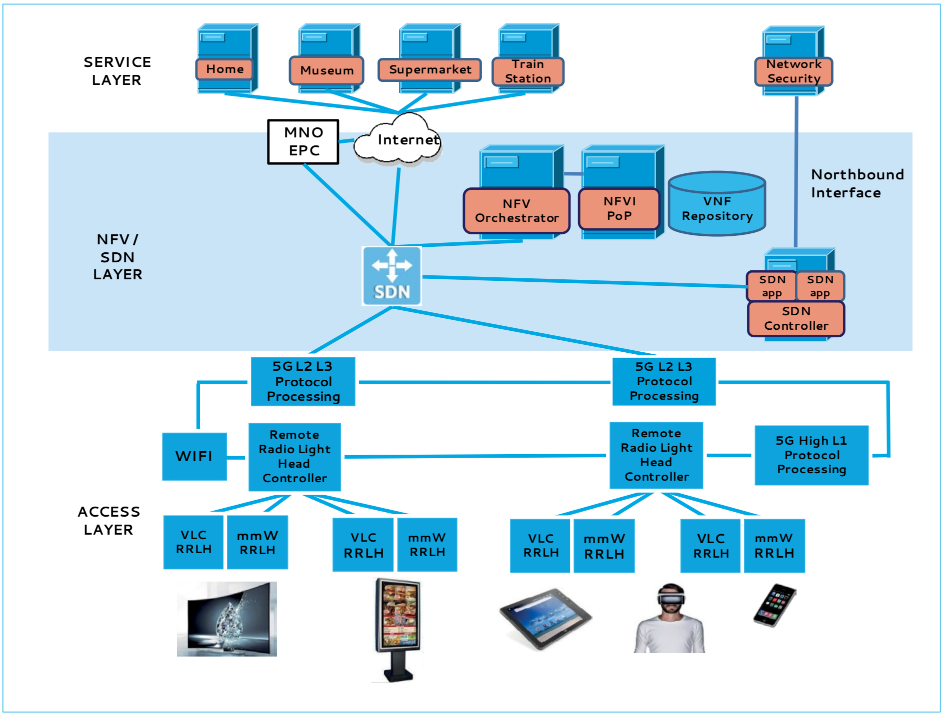

Figure 25. IoRL Layered Architecture

IoRL devised a layered architecture consisting of three layers: Service, Network Function Virtualization (NFV) / Software Defined Network (SDN) and Access; and as such our architecture is well aligned to the overall 5G architecture.

The next generation 5G Home eNodeB architecture was developed, which we are calling Home gNB (HgNB). It introduces the concept of indoor room/floor cellular coverage areas, which is suitable to the bimodal nature of visible light and mmWave channels depending on the presence or absence of line-of-sight. Furthermore, it introduces the concept of intra-handover between indoor coverage areas within the same building and inter-handover between building HgNB and outside gNB. This is a totally new concept, which increases the total bit rate that can be delivered to a building network.

Improvements to the 5G remote radio head architecture were made by including a VLCmodule, which we call Remote Radio-Light Head (RRLH), as shown in Figure 26. It uses the multi-component carrier feature of 5G architecture to transmit to these two different parts of the EM spectrum. The impact of this is that the total throughput to a building can potentially be dramatically increased.

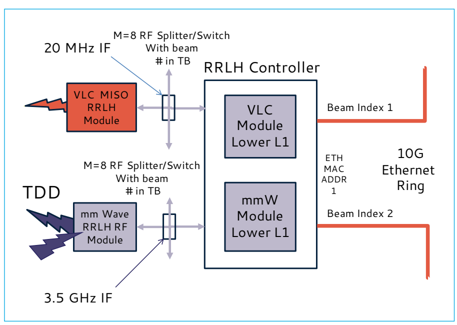

Figure 26. RRLH Architecture

The RRLH architecture uses DC offset Orthogonal Frequency Division Multiplexing

(DC-OFDM) as VLC modulation, which combines modulation efficiency and compatibility with existing 3G PPP's 5G OFDM modulation. The impact of this is that it can be readily integrated into a future 5G standard.

Algorithms estimating the location of User Equipment (UE) were developed using a combination of the Received Signal Strength of VLC OFDM reference symbols and using Round Trip Times of mmWave OFDM reference symbols. With this we expect to contribute to the development and improvement of indoor location based services.

A Distributed Radio Access Network (DRAN) architecture was developed that processes the 5G Lower Layer 1, Upper Layer 1, Layer 2 and 3 protocol stack in a parallel pipeline interconnected by a 10Gbit/s Ethernet ring. The impact of this is a reduction in processing delay and building network latency.

The 5G Home gNB can act both as an extension to the outside cellular network or as a standalone WLAN network operating independently from the 5G outside network. The impact of this is that ultra-low latency communications can be obtained by selecting the appropriate path through the network.

A NFV - SDN architecture was developed that routes IP packets to different building room/floor coverage areas and performs intra building room/floor coverage area handover. The impact of this is the total bit rate that can be delivered to a building is increased by the number of coverage areas within the building. Since VLC and mmWave frequencies in adjacent room/floor coverage areas do not interfere with each other, the frequency reuse factor is always 1.

Figure 27. Spot Light with External mmWave Torch

The NFV-SDN architecture can also increase the connection reliability of video services by Multi Source Streaming (MSS) offering different quality versions of the same content through RRLH and WLAN. The impact of this is that it overcomes the bimodal nature of visible light and mmWave channels by always ensuring a low quality – low bit rate video by WLAN. This principle can also be extended to multipath TCP protocols. The impact of this is reliable mmWave and VLC communications in buildings with a Quality of Service feedback to users on whether there is line of sight connectivity to the RRLH access points.

The envisaged Intelligent Home IP Gateway (IHIPG) provides the NFV/SDN functionality, which can be located within the building premises, but also in the Cloud. The impact of this is flexible OPEX/ CAPEX trade-off choices for Mobile Network Operator (MNO) depending on the type of customer building network being provisioned.

The concept of light systems acting as Electromagnetic access points in a room was introduced through the adaptation of the physical architecture of spot (as shown in Figure 27), pendant, strip, giotto visible light systems to include both a VLC transmitter and a mmWave transceiver torch. The impact of this is that a completely new disruptive market of radio-light EM access systems might complement the WLAN market.

Demonstrations of UHDTV (live and from streaming server), 360o AV, location based monitoring, guiding and data access, AV communications, interactive Internet, home video security surveillance and network security applications related to the use case scenarios are planned.

Key performance indicators considered are: Location accuracy of less than 10 cm, building network latency of less than 1 ms and Peak data rate of 732.16 Mbit/s per room/floor with a potential of increasing this up to 3.4 Gbit/s per room/floor depending on the NR Sub-carrier Spacing and Bandwidths selected.

Metro-Haul

Introduction

The aim of METRO-HAUL is to design and build a smart optical metro infrastructure able to support traffic originating from heterogeneous 5G Radio Access Networks (see Figure 28), addressing the anticipated capacity increase and its specific characteristics such as mobility, low latency, low jitter, etc. This infrastructure will also support a wide variety of services and use cases with special emphasis on services from various ICT vertical industries. METRO-HAUL involves the design of an efficient and adaptive optical network, connecting a number of access and metro edge nodes with storage and computing resources. The required dynamic and flexible architecture is attained by developing a Software Defined Network (SDN) control plane to control disaggregated Network Functions Virtualization (NFV) platforms, using end-to-end automation schemes and programmability features.

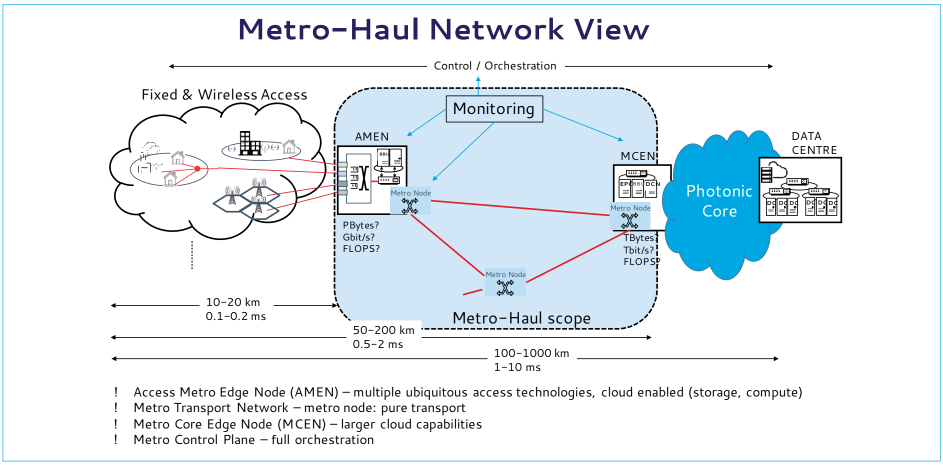

Figure 28. Metro-Haul network view

Definition of Service Requirements

In order to understand the requirements that supporting vertical industry services will impose on the Metro-Haul architecture, several highly representative services were analysed. In a complementary way, we performed a high-level analysis of trend estimates in data-centre capacities, end-user bandwidth and data consumption, as well as other technology trends (e.g. 5G, SDN/NFV, IoT/IoE, Fog Computing) to assess the expected load on the Metro segment of the overall telecoms network.

The results of these analyses have shown a great diversity of requirements, obviously highly dependent on the specific services to be supported. Nonetheless, a number of requirements mapped onto the Metro-Haul architecture can be drawn.

It must be noted that the extreme low latency requirements, across use cases, concentrated much of the necessary functionality within the access edge nodes, which need to support a traffic throughout/throughput? in the order of 1-1.5Tbit/s and have a storage capacity of around 10-50TBytes (some special use cases may require a much larger amount). Each service also requires from a few, to hundreds, of vCPU computing resources. The optical connections through the metro network need to be between 10-100Gbit/s. Monitoring and data analytics is also necessary to ensure enough reliability and network availability. Finally, the study determined some specific tasks for which a Control, Orchestration Management (COM) system is required.

Initial optical metro node architectures and specifications

A candidate physical network architecture was developed, followed by node architecture definitions, with focus on the optical components.

Commonalities of the optical nodes are scalability and flexibility, low cost, and using the same architecture regardless of the size. The amount of traffic in central offices may differ greatly from peripheral to metro core nodes. The distribution of network functions and Content Distribution Network and Cloud functionalities and the interconnection traffic is paramount for planning and dimensioning central offices. It is important to identify the node scaling and node capacity requirements, for both storage/computing as well as switching. A modular approach is taken where combined access and aggregation/core functionalities from preassembled modules should be provided and interconnected in the same Central Office space. Access, aggregation and core functionalities are made choosing the right basic components and devices. There are several levels of disaggregation in the optical domain, which need careful consideration. A critical work is the definition of the requirements for control and monitoring of the optical network elements and subsystems, including a tentative control architecture for a fully disaggregated optical network.

Control and management functional architecture

There has been an agreement on Metro-Haul control and management macroscopic architecture. The COM system that enables dynamic provisioning of services, such as network data connectivity or network slicing instances, was defined from a high level point of view. The COM is based on SDN principles with a centralised network control plane. This control plane is hierarchical, with an SDN control per technology domain. Along the SDN control plane for the provisioning of connectivity, an ETSI NFV Management and Orchestration (MANO) part is responsible for the instantiation of Network Services, understood in this context as chained Virtual Network Functions (VNFs).

As key components of the system and as examples of the innovation behind Metro-Haul, there is the Monitoring and Data Analytics subsystem, able to recommend actions to the controllers based on performance monitoring and telemetry data and a Planner component, which enables the system to off-load computations such as VNF placement or network reconfiguration to optimised entities.

Critical consideration within Metro-Haul is control of the optical layer, and the project is addressing the problem using disaggregation. Disaggregation refers to composing and assembling open, available components, devices and sub-systems, and imposes a new set of challenges in its control and management. However, optical networks are particularly challenging to model due to the lack of agreed-upon hardware models, and this is important for the development of an interoperable ecosystem around disaggregated hardware. The Metro-Haul architecture for the control of the disaggregated Optical Network relies on a centralised SDN controller and the use of NETCONF/YANG management protocol and data modelling language.

Project dissemination

Given the innovative nature of the Metro-Haul, emphasis is given to project dissemination. The project dissemination activity is split across more traditional methods such as academic impact and tutorials; however, our goals also included more industry relevant dissemination and contributions, including impact at Open Source software projects, standards and specification groups.

Conclusions

The Metro-Haul project has had less than a year of technical activities and has already produced significant results. Within the first year of the project we have had numerous success for dissemination impact, including: key note addresses, tutorials, tier-1 journal and conference publications, and early standards and specifications proposals.

NRG-5

The overall objective of NRG5 is to guarantee optimal communications of the energy grid, which is believed to be the most complex, heterogeneous and gigantic machine ever made in human history, deploying, operating and managing existing and new 5G communications techniques and energy infrastructures (in the context of the Smart Energy-as-a-Service) easier, safer, more secure and resilient from an operational and financial point of view.

Thanks to its ambitious objectives, NRG-5 aims at defining and specifying some vertical additional use cases focusing on utilities domain, mainly gas and energy. The Use Cases described in NRG-5 fall within a small set of basic 5G service classes, which have been consolidated and agreed in the context of 5G-PPP as follows

- Enhanced Mobile Broadband (eMBB), also called Extreme Mobile Broadband (xMBB)
- Ultra-Reliable Machine Type Communications (mMTC), also called Ultra-Reliable and Low Latency Communications (URLLC), and
- Massive Machine Type Communications (mMTC)

The three general Use Cases defined during the proposal time are:

Use Case 1: Realizing decentralised, trusted lock-in free Plug & Play vision

Provide a framework that will allow for easy, real-time, automated devices identification so that network auto-configuration can be achieved automatically. Unified AAA should be achieved in a homogeneous manner, 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. Last, secure communications should be achieved irrespectively of the network service provided and the physical entity initiating the connection.

Use Case 2: Enabling aerial Predictive Maintenance for utility infrastructures

Low-delay, 5G-enabled Predictive Maintenance may significantly help in more efficient operation, accidents avoidance and fast restoration of energy networks, leading to reduced maintenance costs and increasing the QoE offered by the Utilities to the citizens.

Use Case 3: Enabling resilience and high availability via Dispatchable Demand Response (DDR)

The stability and resilience of the energy grid in the presence of high share of RES, greatly depends on the fast response. Given that most of the times storage is not available on-site, ultra-low (below 5ms) response from the energy operation centre is of vital importance. The enablement of large scale DDR requires extreme (for today's standards) communication requirements as metering and associated computational processes should be performed at very high frequencies.

Starting from the NRG-5 high-level use cases, it is possible to design the layers of the NRG-5

NRG5 uses the 5GPPP architecture functionalities and is designed to support slicing; it allows to concentrate the efforts to improve the innovation aspects; in particular, NRG5 uses extended Mobile Edge Computing (X – MEC) and tailored NFV.

To achieve this the NRG-5 builds the final design on exiting work from standard and other H2020 projects adding new and innovative elements such as:

- Define an extended MEC software stack for fast and optimal deployment of generic and utility-centric VNFs.
- Build on MCM communications through the development of generic- and utility-centric VNFs
- Realize an extended 5G ETSI- MANO framework integrating analytics in the OSS/MANO layers addressing smart energy applications requirements

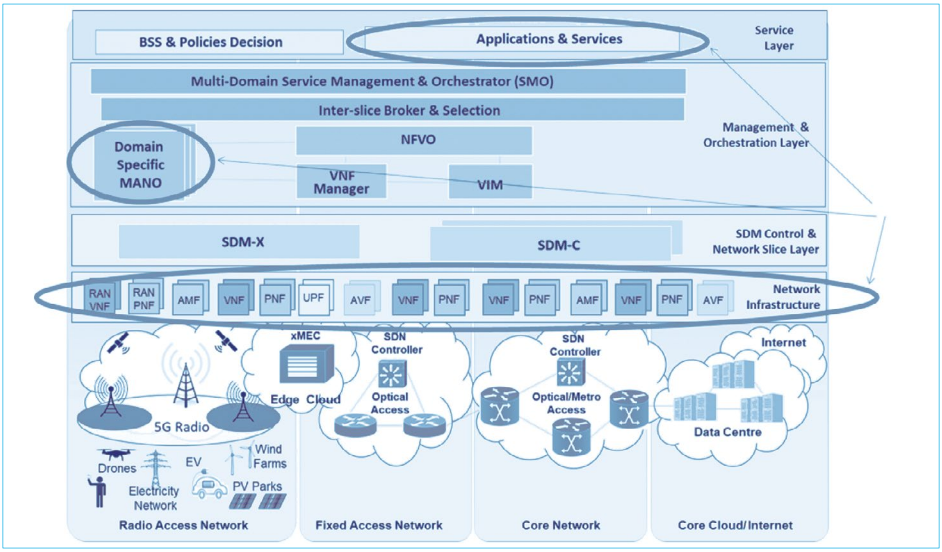

Figure 29. NRG-5 main focus in 5G architecture

Apart from the traditional ICT virtualization paradigm, NRG-5 will leverage on extensive modelling and virtualization of electricity and gas infrastructure assets combined with the telecommunications infrastructure, satisfying the full spectrum of the associated, evolving communication and computational needs exposed by the energy vertical. These rising networking requirements raise critical challenges that urge for extended flexibility in the energy service provisioning which, in turn, can be translated as stringent requirements for:

1. Security of the smart grid services provisioning and of the support of a huge number of end-points, avoiding lock-in strategies;
2. Resilience of infrastructure via enabling predictive maintenance and self-healing via assets' virtualization and timely energy re-routing;
3. Highly Availability of the smart grid services (both ICT and energy).

Being part of the 5G-PPP initiative, the NRG-5 operates on performance and societal KPIs were mapped and evaluated for both the energy sector and the NRG-5 use case scenarios. The values considered for the KPIs used for clustering the NRG-5 use case scenarios were selected by the telecom partners and then validated by the energy utilities and the technology providers by using the following ranges set by the 5G PPP .

Device Density	User Data Rate
High : ≥ 10000 devices per km²	Very high data rate: ≥ 1 Gbps
Medium : 1000 – 10000 devices per km²	High: 100 Mbps – 1 Gbps
Low : < 1000 devices per km²	Medium: 50 – 100 Mbps
	Low: < 50 Mbps
Mobility	**Latency**
No: Static users	High: > 50 ms
Low: Pedestrians (0-3 km/h)	Medium: 10 – 50 ms
Medium: Slow moving vehicles (3 – 50 km/h)	Low: 1 – 10 ms
High: Fast moving vehicles, e.g. cars and trains (> 50 km/h)	

Infrastructure	Reliability
Limited: No infrastructure available or only macro cell coverage	Low: < 95%
Medium density: Small amount of small cells	Medium: 95 – 99%
Highly available infrastructure: Big number of small cells available	High: > 99%
Traffic Type	**Availability (related to coverage)**
Continuous	Low: < 95%
Burst	Medium: 95 – 99%
Event driven	High: > 99%
Periodic	
All types	
5G Service Type	
xMBB/eMBB, where extreme Mobile Broadband is the key service requirement	
uMTC/URLLC, where the reliability is the key service requirement of the UC	
mMTC, where the massive connectivity is the key service requirement of the UC	

Table 3. KPIs for NRG-5 use case scenarios

ONE5G

ONE5G's main ambition is to investigate and propose new features and advancements (focussing on the RAN) for moving 5G towards 5G-advanced. The areas we are dealing with are advanced multi-link access and interference management supported by massive MIMO and e2e-aware performance optimisation through advanced radio resource allocation and multi-node connectivity orchestration, load balancing, spectrum management and D2D.

In the following we describe the major lines the project is working on and highlight some current outcomes. Due to the tight space constraints we restrict this article to some selected areas staying rather high level. At the time of writing this article ONE5G is in its first year and thus the technical work is still to some extent preliminary. For a broader view in general and a deep dive into specific items the interested reader is referred to the deliverables and publications being generated by the project already and being produced later in the project (the deliverables can be found in the homepage of the project: http://one5g.eu/).

Advanced framework for the validation and optimisation of 5G technical components: Deployment scenarios, use cases, system level evaluations, proof-of concepts and techno-economics

We are covering two highly diverging deployment scenarios: 'Megacities' and 'underserved areas'. The target is to provide reasonable technical solutions both for high revenue areas and for more economically challenging deployments (e.g. in scarcely populated remote areas). By doing so we aim at avoiding a similar 'digital divide' to happen as in earlier generations of wireless cellular communications. We have developed a suite of use cases providing a balanced representation of both scenarios. Some use cases (e.g. 'long range connectivity' and 'non-terrestrial networks (NTN) for disaster and emergency') are primarily applicable to 'underserved areas', while other use cases (e.g. 'Smart cities and factories', 'outdoor hotspots and Smart offices') are representative for 'Megacities'. Finally, some of our use cases (e.g. 'Automotive', 'Health/

wellness monitoring' and 'Smart grid') are of similar relevance for both scenarios. Another driver for us when selecting the use cases has been the target to cover the 3 main 5G service categories (eMBB, URLLC and mMTC).

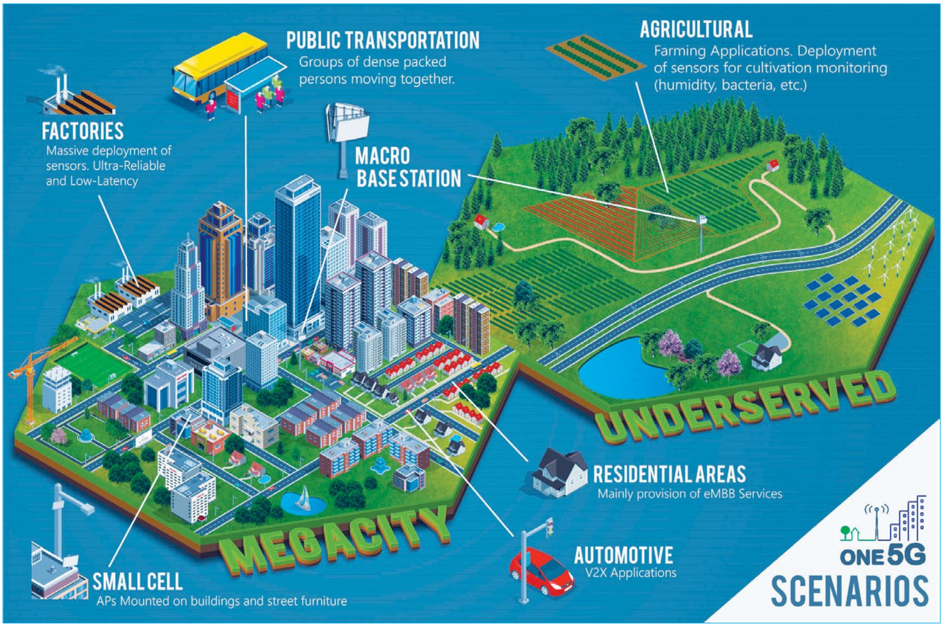

Figure 30. ONE5G scenarios

The selected use cases together with their respective set of Key Performance Indicators (KPIs)/Key Quality indicators (KQIs) act as reference points for the technical solutions being developed by the partners both by providing the technical challenges to be solved and by linking the rather abstract technologies to the concrete applications they are enabling.

In addition, we are aiming to analyse the relevant techno-economic aspects for a subset of our use cases ('automotive', 'long range connectivity', 'Smart city' and 'NTN for disaster and emergency use cases'). The use cases will be loosely bound together by the common theme of network slicing and we will mainly focus on solutions driven by mobile operators. We are planning to approach this both in a qualitative and quantitative manner.

Our ambition is to investigate selected technical components (TeCs) on a system level. For this a realistic system level simulator (SLS) is available. It will be extended accordingly to highlight the performance gains of those selected TeCs. The gains will be compared against a baseline reflecting the current state of the art (SoTA). As applicable the currently finalized 3GPP release 15 will act as this baseline. The simulation tool already has a wide pool of enabling technologies being implemented and those will be complemented as required (CRAN and DRAN, multi-node/multi-link dynamics, abstracted massive MIMO, carrier aggregation, multi-service RRM, mMTC access). Furthermore, the simulator includes realistic environments (realistic user/device distributions, mobility, traffic models for both eMBB, mMTC and URLLC). The selected TeCs will be evaluated individually in a first step, followed by a set of investigations combining those TeCs, to present the gains of the proposed technologies in a non-isolated manner.

Finally, we have a set of prototyping activities covering the whole picture of: a) "megacities" and "under-served areas"; b) a set of relevant verticals (e.g. smart city, factory of the future, automotive and agricultural applications); c) the main 5G service categories (eMBB, URLLC and mMTC) and; d) a selected set of TeCs being proposed and investigated by the partners. In particular our Proof-of-Concept (PoCs) cover: a) industrial area; b) metropolitan area with a high density of users and cells serving a wide range of service types; c) enhanced massive MIMO for multimedia applications; d) agricultural applications in underserved areas and; e) future automotive and tele-operated driving.

Advanced multi-link access and interference management supported by massive MIMO -- towards practical implementation and multi-service operation

The ONE5G air interface features optimised access technologies that are designed to be efficient, reliable, and fast. This is complemented by a large area throughput enabled by network densification and the consequent use of massive multi-antenna arrays. The three service categories mMTC, URLLC, and eMBB are supported by a range of innovative technology components: Massive MTC is enabled by non-orthogonal multiple access (NoMA), which is optimised towards the simultaneous access of a large number of devices. The overhead of short-package communication is reduced by the application of grant-free protocols. URLLC is enabled by advanced HARQ techniques optimised for short packages with stringent deadlines. Finally, eMBB, as well as the other service categories, are enhanced by the application of massive MIMO and CRAN/DRAN technologies. Those include beamforming techniques for backhauling, coordinated multicell and group-cast communications. Such advanced multi-antenna techniques require high-quality Channel State Information (CSI) with reasonable feedback overhead, thus advanced CSI acquisition strategies are being developed, aided by grouping and scheduling. Also, hybrid analogue/digital MIMO solutions are being developed, where the focus is to find a good tradeoff between performance and implementation efficiency. The increasing degree of network densification aggravates the problem of interference. Therefore, we develop techniques for multi-connectivity/multi-cell interference coordination and radio resource management. In all of this work, we consider the impact of system impairments and hardware effects. A flexible hardware architecture is being developed, involving the analysis of an array geometries and other system aspects.

E2E-aware performance optimisation through advanced radio resource allocation and multi-node connectivity orchestration, load balancing, spectrum management and D2D

ONE5G has developed new perspectives on resource allocation optimisation for a wide range of service types to further boost the E2E performance, taking advantage of the many degrees of freedom offered by the 3GPP NR. Those include more efficient means for multiplexing highly diverse service types such as eMBB and URRLC (using either preemptive scheduling or network slicing techniques), novel prediction and flow optimisation techniques to enhance scheduling decisions, and efficient centralised multi-cell scheduling policies. Orchestration of dynamic multi-node connectivity with either data split (for throughput boosting) or data duplication (for reliability boosting) is also proposed. Furthermore, a proactive context aware and QoE driven approach for enhanced load balancing is proposed as a promising optimisation method, thereby equalizing QoE between cells, rather than traditional load equalization, to further boost the experienced E2E-performance. Moreover, MEC-aware optimisation methods for UE-cell associations are being developed, including cases with decoupled uplink/downlink associations. Our research on dynamic spectrum management targets both licensed and unlicensed bands, including standalone operation and aggregation, counting also enhancements to enable low latency and high reliability in unlicensed bands. Schemes for D2D association with the objective of reducing interference are outlined and also relay-based schemes for coverage enhancement and reduction of power consumption are derived.

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:

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

Major achievements/innovations during the first year of the project

During its first year, the project selected the following SaT5G Use Cases (UC) to be further investigated:

- UC 1: Edge delivery & offload for multimedia content and MEC VNF software – Providing efficient multicast/broadcast delivery to network edges (i.e. edge of the telco network infrastructure; or at user premises) for content such as live broadcasts, ad-hoc multicast streams and MEC VNF update distribution;
- UC 2: 5G Fixed backhaul – Broadband connectivity to locations where it is difficult, or not possible, or not economical to deploy terrestrial connections, e.g. lakes, islands, mountains, rural areas, isolated areas or other areas that are best or only covered by satellites across a wide geographic region;
- UC 3: 5G to premises – Connectivity complementing terrestrial networks, such as broadband connectivity to home/office small cell in underserved areas in combination with terrestrial wireless or wireline;
- UC 4: 5G Moving platform backhaul – Broadband connectivity for passengers to platforms on the move, such as airplanes or vessels.

After defining the four main SaT5G UCs, the project identified the main requirements that are necessary to integrate satcom into a converged 5G system:

- Support plug-and-play satellite backhaul services;
- Integrate 5G satellite and terrestrial networks to create a global 5G network;
- Develop the next satcom ground segment generation compliant with 3GPP standards to support standard terminals and consequently, reduce satcom costs;
- Management of dynamic satellite bandwidth connectivity to reduce terrestrial network operators' costs and increase the satellite network usage;
- Transparent end user usage between satellite and terrestrial radio resources;
- Introduce slicing on satellite networks supporting, cloud networking, SDN and NFV paradigms.

The project has also worked on the terrestrial-satellite integrated 5G network architecture. The first step was to clearly identify the potential positions of the satellite link in 5G system architecture as defined in 3GPP; backhauling and direct access are the two principal approaches identified (Figure 31). The focus of the research activities in the project will be on backhauling-type service. The next step is to build on this initial analysis by identifying issues and requirements to derive specific architectures to be tested.

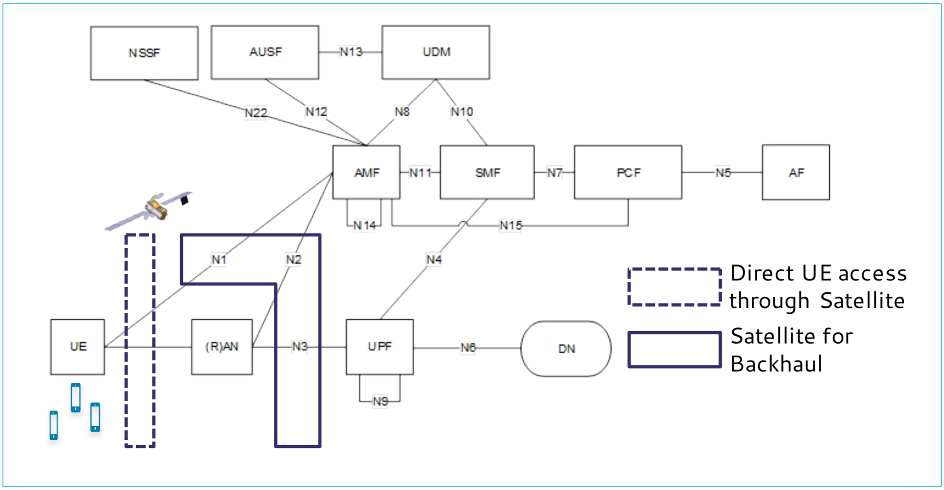

Figure 31. Generic positioning options for satellite links

Currently cellular backhaul over satellite mainly considers the satellite links as pure transport network with limited flexibility and configurability. For 5G integration, innovative adaptation functions are required with advanced features such as on-demand backhaul resourcing, QoS adaptation, support of network slicing etc. to bring real added value to and align with 5G networks. These improvements will be studied by the research pillars of the project (Figure 32) with the aim to develop prototypes for validation and integration in the demos.

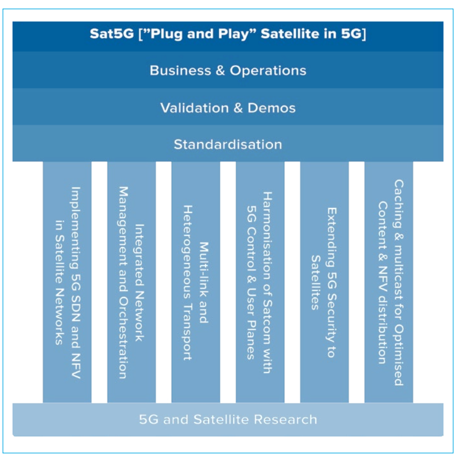

Figure 32. SaT5G Research Pillars

One of the research pillars of SaT5G is the management and orchestration of the integrated network following the ETSI and 3GPP specifications. The aim is to come up with the mixed network management, mapping the relationship between 3GPP and NFV-MANO architecture framework. The novelty SaT5G will bring into the current architecture is the inclusion of satellite and non-3GPP elements into this framework.

Additionally, in order to leverage the softwarization technologies (SDN/NFV), efforts are focused on the virtualization of the satellite ground segment specifically, identifying the reference satellite functions and the most relevant functions to be virtualized, defining the data models and the VNF chaining and platform selection for implementation.

The multi-link concept has been proposed for some project use cases including a non-satellite backhaul link in addition to the satellite backhaul link. The project will elaborate on the related architecture solution, the close integration of proxy enhanced protocol and multi-link aggregation proxies into the RAN to accelerate backhaul links and route the data to maximise the end user's quality of experience.

In parallel, we have instantiated 5G protocol stacks for several different architectures to determine the interfaces and protocols that may be impacted by the inclusion of a satellite link thereby identifying the issues. Building on this, we will build convergence solutions for integrated terrestrial- satellite 5G networks for different requirement sets and then test these.

Security architecture is recognised as a critical area, therefore SaT5G will be analysing the security architecture currently proposed for 5G and assessing its impact on the system when satellite links are integrated in the network. Appropriate modifications will be identified and proposed for implementation and standardisation contributions.

One of the key strengths of satellites is the ability to provide broadcast/multicast resources over wide areas and thereby significantly reducing the wide area delivery cost. The project will study intelligent caching prediction algorithm and traffic steering that can be implemented using services offered by the platform (e.g. location, bandwidth usage). Content pushing from the content delivery network server to the local data network can then be performed using multicast capabilities (IP Multicast or 3GPP enhanced Multimedia broadcast multicast services) over the satellite link. The benefits of these satellite strengths will be also be evaluated from a business model and cost perspective, for the different use cases and stakeholders involved.

To date the selected SaT5G Use Cases and architecture options have been disseminated through high-impact peer-reviewed scientific and technological publications:

- "Satellite Use Cases and Scenarios for 5G eMBB", IET Book: *"Satellite Communications in the 5G Era"*, Editors: S. Krishna Sharma, S. Chatzinotas, P.-D.M. Arapoglou, 2018, in press.
- "Use Cases and Scenarios of 5G Integrated Satellite-Terrestrial Networks for Enhanced Mobile Broadband: The SaT5G Approach", *Wiley's International Journal of Satellite Communications and Networking – Special Issue "Integrated Satellite-Terrestrial Networks in Future Wireless Systems*, 2018, accepted with minor revisions.
- "Architecture Options for Satellite Integration into 5G Networks", *EuCNC 2018*, June 2018, Ljubljana, Slovenia, submitted, currently under review.
- "Satellite Integration into 5G System for Enhanced Mobile Broadband," *IEEE Network Magazine - Special Issue "Integration of Satellite and 5G Networks"*, 2018, submitted, currently under review.

SaT5G has targeted standardisation as a key project outcome, accordingly the project team members have driven several initiatives at 3GPP and ETSI SES/SCN including:

- Initiation of FS_5GSAT Study Item, and associated development and rapporteur-ship of Technical Report TR22.822 "Study on using Satellite Access in 5G" in the frame of 3GPP SA1. The technical report includes 11 use cases, mostly related to the SaT5G Use Cases;
- Initiation of NR-NTN Study Item, and associated development and rapporteur-ship of Technical Report TR38.811 "Study on NR to support non-terrestrial networks" in the frame of 3GPP RAN;
- Contribution to TDOC C4-181327 "Satellite specific technical issues to be considered in 5G Core specification" in the frame of 3GPP CT4;
- Three ETSI SES/SCN work items:
  - DTR/SES-00405 "Seamless integration of satellite and/or HAPS (High Altitude Platform Station) systems into 5G system";
  - DTR/SES-00446 "Reference data model for satellite network";
  - DTR/SES-00447 "Edge delivery in 5G through satellite multicast";
- CEPT ECC FM44/ECC PT1 "Report on satellite solutions for 5G";
- ITU-R WP4B NGAT_SAT ITU-R.M Report "Key elements for the integration of satellite systems into Next Generation Access Technologies".

Description of demos

The project will be conducting validations and demonstrations across three testbeds in Europe. So far we have set the test objectives for each testbed as:

Testbed Location	Test Objectives
5GIC – UK	Demonstrate integrated satellite and terrestrial networks in a unified 5G system;
	Demonstrate satellite backhauling to remote 5G Terrestrial network;
	Demonstrate content caching for dynamic entertainment catalogue update;
	Demonstrate with in-orbit geostationary high-throughput satellite system.
Zodiac Inflight Innovations – Germany	·Demonstrate integrated satellite and terrestrial networks in a unified 5G system in mobility scenarios;
	Deliver unicast/multicast traffic to users on board the aircraft through 5G radio and core network;
	Demonstrate content caching for dynamic entertainment catalogue update;
	Demonstrate with in-orbit non-geostationary high-throughput satellite system.
University of Oulu – Finland	Demonstrate 5G New Radio over satellite link with selected required signal modifications;
	Validation of satellite access to satellite core network;
	Demonstration of end-to-end performance of 5G air interface over satellite.

Table 4. SAT5G testbed locations and test objectives

SliceNet

End-to-End Cognitive Network Slicing and Slice Management Framework in Virtualized Multi-Domain, Multi-Tenant 5G Networks

Goals of the project

Network slicing is acknowledged as a fundamental architectural requirement and critical enabler of 5G networks. Network slicing has a number of benefits, in terms of reduction of capital expenditure (CAPEX) and operational expenditure (OPEX), increased flexibility and faster service delivery, efficient sharing of network infrastructure and spectrum, and customised network service provisioning for diverging requirements from verticals. A number of gaps need to be filled to fully realize the envisioned benefits of network slicing.

Firstly, E2E slicing must be conceived as an end-to-end (E2E) concept. Currently, there is a clear gap in the extension of network slicing from one single administrative domain to a scenario where multiple providers are cooperating to achieve E2E network slicing across multiple administrative domains. Due to technical challenges, multi-domain slicing has yet to be fully achieved. Secondly, efforts so far have focused on the control plane. E2E network slicing must also consider the technical viability of a network slicing capability of the data plane. Thirdly, the 5G network infrastructure can only be successful in close cooperation among 5G technology/service provider industry and vertical business sectors. It is essential that the solutions demonstrate a cost-effective migration pathway for verticals to adopt slice-based/enabled services.

Finally, and upon achieving slicing, the next critical step and major challenge is to maintain and improve the application-level quality, which can be achieved through dynamically optimising the perceived quality of the running slices. Quality of Experience (QoE) should not be achieved via resource over-provisioning, which is expensive and not scalable.

Motivated by the above context, SliceNet drives 5G network slicing up to the next level, by pushing the boundaries significantly in fulfilling the challenging requirements from the management and control planes of network slicing across multiple administrative domains, facilitating early and smooth adoption of slices for verticals to achieve their demanding use cases, and managing the QoE for slice services. To realize this highly ambitious vision, a novel and powerful integrated network management, control and orchestration framework is entailed for realising 5G network slicing and slice-based enabled services.

Major achievements

- *Vertical Sector Requirements Analysis and Use Case Definition*

SliceNet supports a range of use cases of diverging requirements for vertical businesses. SliceNet delivers solutions for use cases in the verticals, Energy, eHealth and Smart Cities. Three representative use cases are analysed and requirements derived. For each use case, the implementation and evaluation considerations are described, and the functional, operational and interface requirements are assessed and specified.

- *Overall Architecture and Interfaces Definition*

The approach to the overall architecture is rooted in the identification of the main stakeholders and actors of the SliceNet system, as well as the main principles – Network Slicing, Plug & Play, One-Stop API, Cognition, Cross-Plane Orchestration and Multi-Domain – that guided the architecture design. The overall perspective of the architecture includes a logical and a functional view covering the relevant use-cases related to network slicing, cognition and multi-domain aspects.

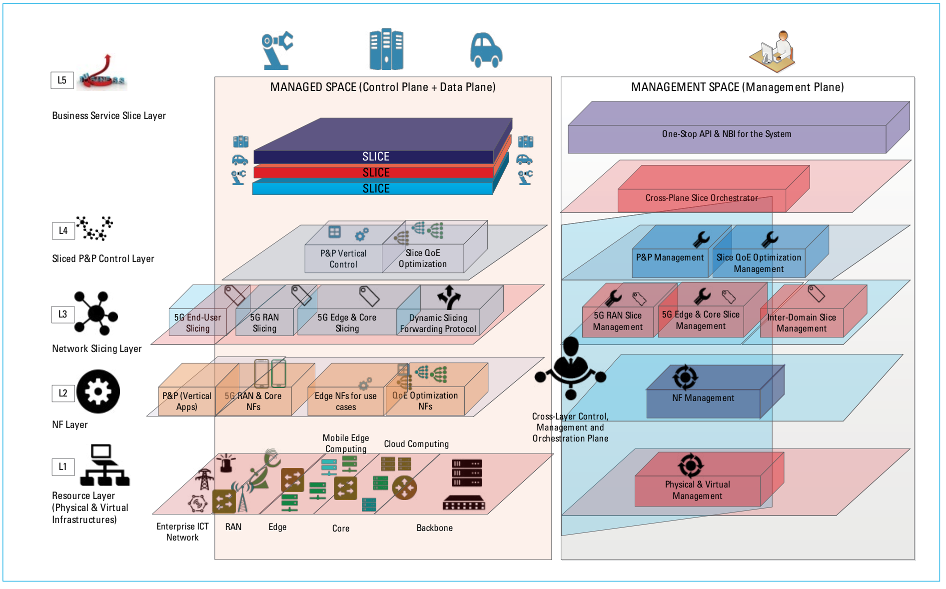

Figure 33. SliceNet Overall Architecture

Innovations

SliceNet takes the following technical approaches and will deliver innovations in the following areas, meeting the project goals.

- In the data plane, SliceNet explores the programmability of the data paths across the various network segments in the E2E network slice, and investigates virtualized slicing-friendly infrastructure.
- In the control plane, SliceNet targets to achieve truly multiple domain cooperation for multiple network operators, vendors and service providers, leading to new large-scale 5G services and new federation business models. The experiences learnt from Phase I project 5GEx will be exploited to advance this ambitious multi-domain slicing vision.
- In the management plane, it plans to deliver a new set of integrated FCAPS slice management functionalities, leading to new FCAPS products for slices management. On top of this, SliceNet proposes a novel cognition-based QoE management approach, and will deliver new QoE sensors and actuators, leading to potentially new products. The cognitive network management approach will leverage related results from Phase I projects especially SELFNET and CogNet.
- In the orchestration plane, SliceNet takes a novel cross-plane coordination approach, and will deliver a novel cross-plane orchestrator that also preserves the boundaries among the planes, leading to potentially new orchestrator product to be integrated by the network operators, in line with their exploitation plans.
- SliceNet takes a novel 'Verticals in the loop' design approach for the entire SliceNet framework (not just the use cases but also Plug & Play control, FCAPS etc.), and will deliver the innovative 'one-stop-shop' slice-based/enabled service solution for verticals to efficiently upgrade existing cases or creating new use cases the SliceNet northbound interface. This is unclear The customisation of slices featured with the novel Plug & Play control plane is a new service, leading to new business models between the verticals and the slice service provider.

Performance KPIs

With respect to the 5G-PPP programme KPIs, SliceNet contributes to

- Reducing the average service creation time cycle from 90 hours to 90 minutes
- Providing increased network coverage and more varied service capabilities, and helping create novel business models through innovative sharing of network resources across multiple actors
- Improvements in autonomic network management and automated network control, leading to reduced network OPEX
- Employing network function implementation on commodity equipment rather than on non-programmable specific firmware, leading to reduced network CAPEX, through maturation of NFV concepts and increased number of SDN controllable resources
- Improved architectural support for diverse types of terminals, traffic, network operators and Radio Access Networks

Description of demonstrations

SliceNet will demonstrate 5G-enabled use cases on 5G Smart Grid Self-Healing, 5G eHealth Connected Ambulance and 5G Smart City Smart Lighting, in the verticals, Energy, eHealth and Smart Cities, among the top vertical industries identified as the most promising/influential 5G customers. These use cases exhibit ambitious performance requirements, among others, ultra-high reliability, quality of information and experience, and ultra-low latency.

5G-MEDIA

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

Background and goals

Media applications are amongst the most demanding services in terms of resources, requiring huge quantities of network capacity for high bandwidth audio-visual and other mobile sensory streams. As a phase 2 project, the 5G-MEDIA project aims at innovating media-related applications by investigating how these applications and the underlying 5G network should be coupled and interwork to the benefit of both. The 5G-MEDIA approach aims at delivering an integrated programmable service platform for the development, design and operations of media applications in 5G networks by providing mechanisms to flexibly adapt service operations to dynamic conditions and react upon events (e.g. to transparently accommodate auto-scaling of resources, VNF re-placement, etc.). Three use cases are going to be demonstrated: Immersive media and Virtual Reality, Smart Production and User-generated Content, and Ultra High Definition over Content Delivery Network.

Major achievements and innovation

During the first year of the project a huge effort has been spent mainly i) to define the 5G-MEDIA Service Platform architecture and ii) to analyse the media related application and requirements, and to specify three 5G-MEDIA use cases. In addition, a set of APIs and Tools were setup to support DevOps CI/CD and provide an efficient environment for software development to the partners.

The main building blocks comprising the 5G-MEDIA architecture as shown in Figure 34 include: i) an Application/Service Development Kit (SDK) that enables access to media applications development tools; ii) a Service Virtualization Platform (SVP) that hosts the components related to the ETSI MANO framework, the Virtual Network Functions and the Media Application Catalogue and Repository, the Media Service MAPE and the corresponding Virtualized Infrastructure Manager (VIM) and WAN Infrastructure Manager (WIM) plugins enabling the integration to different NFVI platforms; iii) different Network Function Virtualization Infrastructures (NFVIs) comprising the "Physical Layer" that provide computing resources by different operators and supporting different cloud technologies to host generic and media-specific VNFs depicted at the "Virtualized Resource Layer".

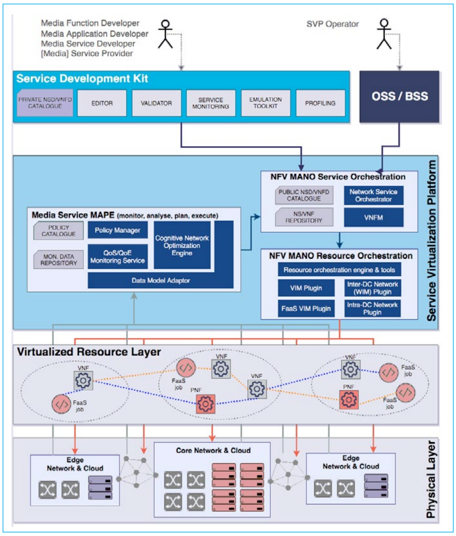

Figure 34. 5G-MEDIA architecture – main building blocks

5G-MEDIA platform pioneers application of Function-as-a-Service (FaaS) to VNF management, complementing traditional VM based VNFs with FaaS based media specific functions, aiming at dramatically reducing development cycles and slashing operational costs to 5G-MEDIA users. The combination of the FaaS approach with the VNF packaging and the enablement of inserting FaaS VNFs in a typical VNF forwarding graph is one of the main innovation aspects of the proposed 5G-MEDIA approach. Another specific innovation of the 5G-MEDIA project is the integration of the Cognitive Network Optimiser (CNO) and the related monitoring components able to gather NFVIs, VNFs and applications metrics within the SVP. The Cognitive Network Optimiser is able to respond on dynamic changes of the environment (e.g., location change of end users, varying QoS demands) and to adapt the deployment of VNF forwarding graphs seamlessly to continuously meet expected QoS requirements. Finally, in terms of the supporting physical infrastructure, the proposed architecture considers that several cloud-based Network Function Virtualization Infrastructures (NFVIs) will be connected to the Service Virtualization Platform, allowing for the instantiation of network applications closer to the user (edge computing paradigm) connecting the end-users to the 5G-MEDIA ecosystem through mobile devices, tablets and other resource-constrained devices.

During the first project year, the consortium has specified the requirements and goals for each use case as follows:

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. Within the scope of 5G-Media, this use case will demonstrate a network aware media application development through the deployment of media specific VNFs (e.g. transcoders), as well as showcasing the potential of a FaaS application development model with specific VNFs being instantiated based on trigger/rule logic (e.g. replay generation) that increases modularity and overall offers more efficient architectural design. The Cognitive Network Optimiser will be involved in determining the best placement for all VNFs, considering the trade-off between performance and cost. The machine learning aspects of the smart engine will be used to forecast traffic demand according to a combination of anticipated and historical player and spectator locations.

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. In 5G MEDIA it is planned to overcome these limitations by leveraging new options for more flexible, ad-hoc and cost-effective production workflows by replacing dedicated lines and hardware equipment with software functions (VNFs) facilitating (semi-) automated smart production in remote locations. Virtualized and flexible media services will reduce complexity for the user and ensure operational reliability (QoS, QoE). This use case is about the contribution of content in broadcast production quality from remote locations to a broadcasting studio. It therefore requires high bandwidth streams between the venue and the broadcaster for both fixed camera/studio locations and for mobile-generated content. Within 5G-MEDIA, the Cognitive Network Optimiser will be validated to enhance network performance (reserve bandwidth, prioritise traffic, define network paths etc.). In addition, Function as a Service (FaaS) capabilities will be used for the instantiation of the Cognitive Service VNFs for mobile content contribution sources.

Use case 3 – Ultra High Definition over Content Delivery Network

The main purpose of this use case is to test access streaming of UHD media services through various personal devices, both fixed and mobile, while the user is on the move in the 5G network. The focus is on how UHD contents by a Media Service Provider (MSP) can serve users on the go and how the MSP can build media distribution service chains made of software defined media functions to properly serve users attached to the 5G network. This use case aims at orchestrating the lifecycle of service chains between an origin streaming server containing the UHD contents in various transcoded formats and the edge of the 5G network where media caches are to be dynamically instantiated to serve mobile devices. The target of this use case is to provide personalised view angles, with the possibility to compose UHD streams and move personal media while on the go. Key to the realization of the use case is the possibility to implement high bandwidth streams between the streaming service (origin, replicas, transcoder and viewpoint servers) and users, in a flexible and dynamic way through the mechanisms of composition of virtualized network and media functions orchestrated by a NFV MANO layer. Within the context of 5G-MEDIA, the Cognitive Network Optimiser will adapt the media service chain related to the various media distribution flows based on end-to-end media quality control metrics and policies for scaling

VNFs and optimising cache placement between the core and edge locations. The VNFs will be placed by the CNO according to predicted demand driven from a machine learning algorithm, analysing traffic demand. In addition, FaaS capabilities will be deployed for the programmatic selection of specific media streaming indicators and the activation/instantiation of e.g. new transcoding nodes at the edge to serve specific local demand from mobile users not previously transcoded.

Initial demos of the use cases are expected during 2018. Finally, the 5G-MEDIA project achievements has been presented in several events such as the NEM Summit 2018 and is currently organising the workshop "Media delivery innovations using flexible network models in 5G" at IEEE Broadband Multimedia Systems and Broadcasting (BMSB) 2018.

5G-PHOS

5G integrated Fibre-Wireless networks exploiting existing photonic technologies for high-density SDN-programmable network architectures

Goals of the Project

5G-PHOS aims at the development of novel 5G broadband fronthaul architectures and the production of a powerful photonic integrated circuit technology toolkit that will exploit the recent advances in optical technologies. More specifically, 5G-PHOS will create an integrated Fiber-Wireless (FiWi) packetized SDN-programmable 5G fronthaul that supports 64x64 MIMO antennas in the mm-wave band offering: a) up to 400 Gb/s wireless peak data rate in ultra-dense networks, adopting optical Spatial-Division-Multiplexed solutions on top of the emerging 25 Gb/s PON and b) 100 Gb/s wireless peak data rate in Hotspot areas, showcasing the benefits of WDM technology and packetized fronthauling in private C-RAN solutions. Benefiting from the partners' assets and expertise, lab/testbed experiments and field trials will be conducted towards the evaluation of the project outcomes for Dense, Ultra-Dense and Hotspot areas.

Major Achievements

During the first semester, 5G-PHOS has released the specifications for a cost-effective ultra-dense fronthaul based on an analogue Radio-over-Fibre (RoF) Physical Layer functional split architecture (Fig.35 (d)) to achieve the highest degree of RAN centralisation with strong commercial potential. This constitutes a huge leap in fronthaul capacity, allowing 5G-PHOS to meet the respective 5G User Experience and ambitious Performance Key Performance Indicator (KPI) metrics. To further increase its impact, 5G-PHOS has proposed a mixed digital/analogue RoF architectural solution offering both compatibility with the current telecom providers' equipment and coherence with the currently standardised higher layer split interfaces (Fig.35 (e)).

In addition, during the first months of the project, the following activities/developments are in progress:

- Development of novel analogue Electro-absorption Modulated Lasers (EMLs) and 60 GHz Photodiodes that are highly-linear and very low cost, to support a series of novel telecom applications in the domain of optical and/or converged FiWi fronthaul/backhaul.
- Design of novel Optical Beamforming Networks (OBFNs) providing dynamic, accurate and sufficient coverage and capacity for enhanced Mobile Broadband (eMBB) services.
- Design of novel Reconfigurable Optical Add/Drop Multiplexers (ROADMs) to provide enhanced network configurability/flexibility in future 5G C-RANs Remote Radio Heads (RRH).

- Development of mm-wave Massive MIMO antennas that increase the RRH coverage footprint, enhance the gain directivity and enable significant improvement of wireless capacity.
- Development of the Digital Signal Processing (DSP) real-time algorithms to support the transport of wide-spectrum mm-wave signals over the 5G-PHOS analog RoF mobile fronthaul; thus, effectively enabling the demarcation from the extremely inefficient CPRI-based communication between the BBUs and the RRH.

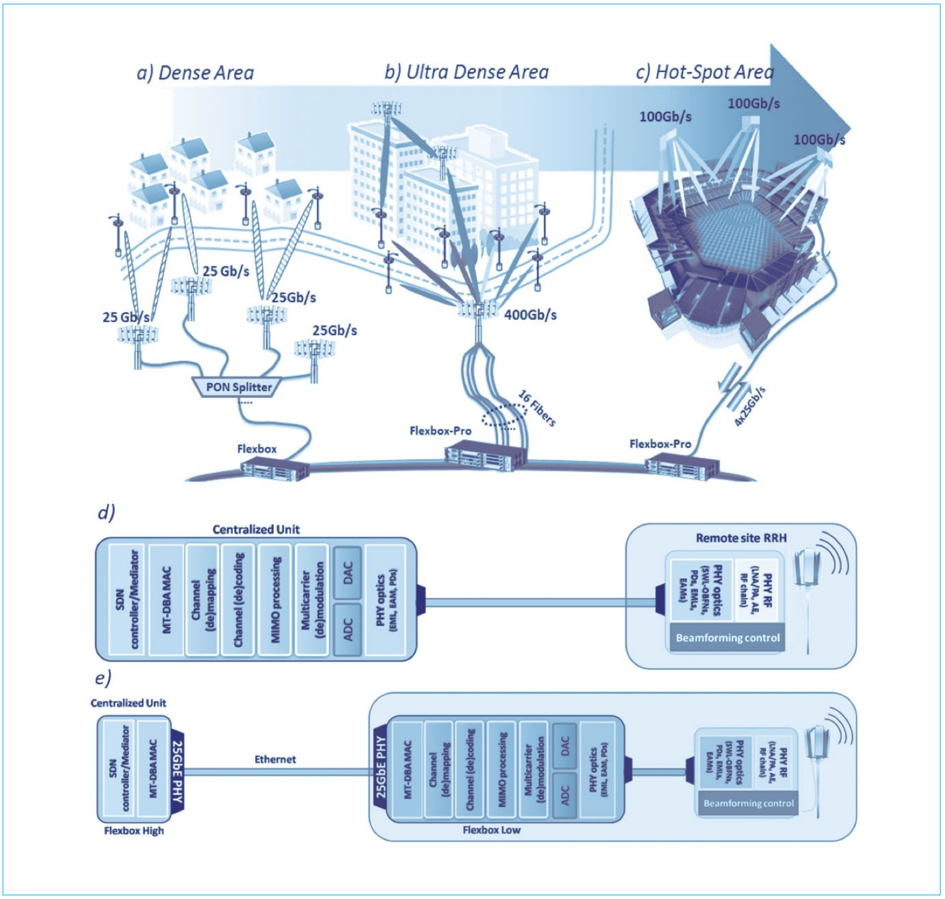

Fig 35. 5G-PHOS network for a) PON-overlaid dense area coverage, b) Ultra-Dense areas, c) Hotspot case at a stadium, d) centralized Physical Layer function split approach, e) the proposed 5G-PHOS higher-layer split architecture

Description of the Demos

5G-PHOS will conduct various demonstrations and field trials, falling into 3 main categories, one for each of the 3 demanding area types:

- 25 Gb/s PON-overlaid 5G fronthaul over currently deployed PON facilities, targeting Dense city areas applications. 5G-PHOS will initially carry out a lab-scale demonstration at Orange Lab (FR) facilities (Fig 35(b)) that will be followed by field-trial demos utilizing the PON infrastructures of COSMOTE (GR) and TIM (IT) (Fig 35 (a)).
- 400 Gb/s 5G fronthaul network, targeting Ultra Dense city applications. Spatial Division or Wavelength Division Multiplexing

technologies will be exploited to provide Gbps-grade mm-wave access at demanding areas such as city centres, business districts, etc. 5G-PHOS will perform experimental evaluation at the joint AUTH/COSMOTE (GR) testbed, followed by a field-trial demonstrator at the premises of Ericsson Italia (TEI).

- 100 Gb/s WDM-enabled 5G network characterised by extremely high population/end-devices densities, i.e., targeting Hotspot areas, such as football stadiums, airports, concert halls, etc. 5G-PHOS' infrastructure will offer multi-Gbps mm-wave access through massive MIMO antennas surrounding the hotspot area. A prototype system will be validated at TEI's Fronthaul testbed prior to the evaluation of a complete network scenario in the joint AUTH/COSMOTE testbed, concluding with a field-trial demonstrator at the PAOK F.C. stadium (Fig 35(c)).

5GTANGO

5G DEVELOPMENT AND VALIDATION PLATFORM FOR GLOBAL INDUSTRY-SPECIFIC NETWORK SERVICES AND APPS)

Goals of the project

5GTANGO is a 5GPPP Phase2 Innovation Action that enables the flexible programmability of 5G networks with: a) an NFV-enabled Service Development Kit (SDK); b) a Store platform with advanced validation and verification mechanisms for VNFs/Network Services qualification (including 3rd party contributions); and, c) a modular Service Platform with an innovative orchestrator in order to bridge the gap between business needs and network operational management systems.

5GTANGO has four main objectives:

- Reduce the time-to-market for networked services by shortening the service development cycle and by qualifying those network services to be adopted.
- Reduce the entry barrier to 3rd party developers and support the creation and composition of Virtual Network Functions (VNFs) and application elements as "Network Services".
- Enable new business opportunities with the customisation and adaptation of the network to vertical application´s requirements.
- Accelerate the NFV uptake in industry via an 'extended' DevOps model and the validation at scale of Network Service capabilities of the 5GTANGO platform in vertical show cases.

5GTANGO's open source results will have a diverse impact on an expanding telecom sector, including:

- Service Platform with Orchestrator: network operators.
- 5GTANGO's SDK: service providers, equipment vendores, SME developers.
- V&V store: network operators, service providers, equipment vendors, SME developers.
- DevOps Tools / Methodology: telecom sector.

This innovative project has a 30 month workplan, recently started in June 2017. 5GTANGO is a highly collaborative effort, with 17 partners representing telecom operators, manufacturers, system integrators, service providers, SME developers, research and academic institutes.

Major achievements

5GTANGO has released the first version of its system architecture (D2.2), which is based on the previously identified requirements (D2.1) and it serves as a reference framework to guide the developments of the 5GTANGO project.

This first release of the system architecture starts out with presenting a high-level structure of the 5GTANGO system to be created within the project. The structure of the system is described in terms of interacting software artefacts. The high-level architecture is shown in the figure below. It is split into the three large subsystems Service Development Kit, &V&/ V&V? Platform, and Service Platform. These subsystems are further broken down into individual components realizing their specific functionality. The subsystems are modelled according to three phases. These phases represent stages in the lifecycle of a service: development, verification & validation, and operation. Although these phases may overlap, they typically happen at different timescales and are performed by different actors.

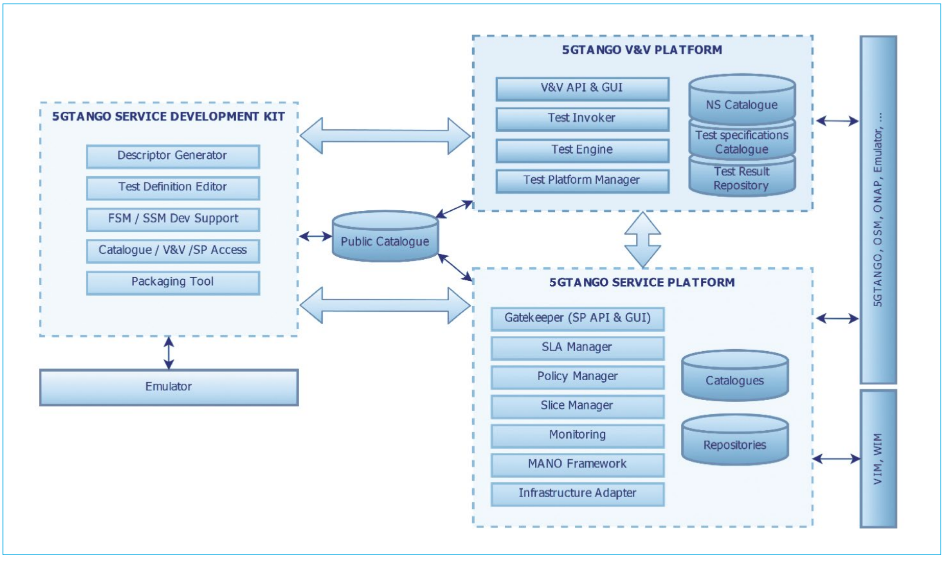

Figure 36. 5GTANGO architecture

The initial architecture is sufficiently detailed in order to start implementing the 5GTANGO system. Nevertheless, as there are many unknowns due to the novelty and innovativeness of many features, a lot will be learned during the implementation of the components and their testing with the selected vertical use cases. This experience will be fed back to create a second, more complete version of the 5GTANGO architecture.

Description of pilots

We have selected three pilots in relevant areas for 5G: smart manufacturing, immersive media and communications suite. They illustrate the added value of the service programmability, service validation and orchestration capabilities offered by the 5GTANGO framework. The proposed pilots are quite complementary in terms of requirements to be addressed by the virtualized networks. These pilots will be implemented, validated and demonstrated within the project lifetime with the participation of vertical representatives of the respective sectors.

- *Smart manufacturing*

  In the context of smart manufacturing, the given advantage is based upon the processing of operational data, machine data, and process data (O/M/P data) generated. Using this data, the process of production, the control of the intra-logistics supply chain as well as the control of components becomes possible. With 5GTANGO platform it will become possible to proactively access functions and services on the path that fulfil the order- and machine-dependent requirements in connectivity and services.

- *Immersive media*

  This pilot will design and implement an adaptive and immersive end-to-end streaming service, which is able to fuse multisource video streaming as 360° in 4K and Augmented Reality/ Virtual Reality (AR/VR) hyper personalized content.

- *Communications suite*

  This pilot will deploy an operator real-time communication platform using the 5GTANGO platform to provide a self-scalable and easy to provision system.

MATILDA

MATILDA aims to devise and realize a radical shift in 5G-ready vertical applications, by providing the tools to foster and speed up the extension/evolution of the "cloud" paradigm to the 5G ecosystem, intrinsically bridging the application and the network service domains.

In detail, in a vision that foresees a stronger integration of cloud and Mobile Edge Computing (MEC) environments, MATILDA will recognise and conform to the ongoing developments, and it will provide clear interfaces toward the multi-site management of cloud/edge computing and Internet of Things (IoT) resources, supported by a multi-site virtualized infrastructure manager. Based on this paradigm, it will support the creation and maintenance of 5G-ready applications through the selection of their service components and the generation of their own Forwarding Graphs, along with the lifecycle management of the required network slices, by properly interacting with the multi-site Network Functions Virtualization Orchestrator (NFVO) residing in the Network Providers' domain. Network- and application-oriented analytics and profiling mechanisms will be supported based on both real-time and a posteriori processing of the collected data from a set of monitoring streams.

To achieve these goals, intelligent, unified and hierarchical orchestration mechanisms are going to be applied for the automated placement of the 5G-ready applications and the creation and maintenance of their network slice instantiations. The concept of slice intention will allow the application-level orchestrator to request, negotiate, deploy, maintain and discontinue the proper application-aware slice instantiation, tailored to the specific application's needs, by also providing a set of mechanisms for runtime adaptation of the application components and/or network functions, based on policies defined on behalf of the services' provider.

As an Innovation Action, another major goal of MATILDA is to prove the effectiveness of its proposed mechanisms and architectural choices (illustrated in Fig. 37, along with their deployment configuration) in a set of 5G-ready demonstration test beds based on real vertical-industry use cases.

MATILDA has already released its reference architecture (see Fig. 37), driven by an exhaustive top-down requirements' analysis based on the vertical use cases that will be implemented in the project as demonstrators. The required abstractions have been also already designed, by the creation of detailed information models for the following items: chainable application components and 5G-ready application graphs, interaction with Virtual Network Functions (VNFs) and their Forwarding Graphs (VNF-FGs), network-aware applications, and deployment and runtime policy meta-models.

The MATILDA architecture is divided into three distinct layers; namely, a) Development Environment and Marketplace, b) 5G-ready Application Orchestrator and b) Programmable 5G Infrastructure Slicing and Management. In a nutshell, the development environment is responsible for packaging a cloud-native component in a proper format, so as to be usable by the Control Plane architectural components. Beyond that, the combination of the components in the form of complex graphs is performed by editors that will be provided in this layer. Cloud-native components and application graphs will be persisted in a marketplace, so as to be searchable by developers. On the other hand, the logically centralised service mesh control plane is the layer that is in charge of the orchestration, monitoring and policy enforcement of a 5G-ready application. The MATILDA programmable 5G infrastructure slicing and management is the interface toward the Network Operators' domain for the specification of configuration and management information of all underlying resources based on the requirements of the active policy.

To come up with a holistic approach for enhancing 5G with intelligent orchestration platforms able to support end-to-end 5G-ready applications and services' provision over a programmable infrastructure, the project is currently working along the following main lines:

- Definition of the appropriate abstractions for the design of 5G-ready applications for industry verticals able to take advantage of a 5G programmable infrastructure.
- Development of an agile programming and verification platform for designing, developing and verifying industry-vertical 5G-ready applications and network services.
- Support of mechanisms for automated or semi-automated translation of application-specific requirements to programmable infrastructure requirements.
- Support of unified and intelligent application-level orchestration mechanisms for managing the entire lifecycle of 5G-ready applications.
- Support of mechanisms for the interaction with multi-site network, compute and storage resource management.

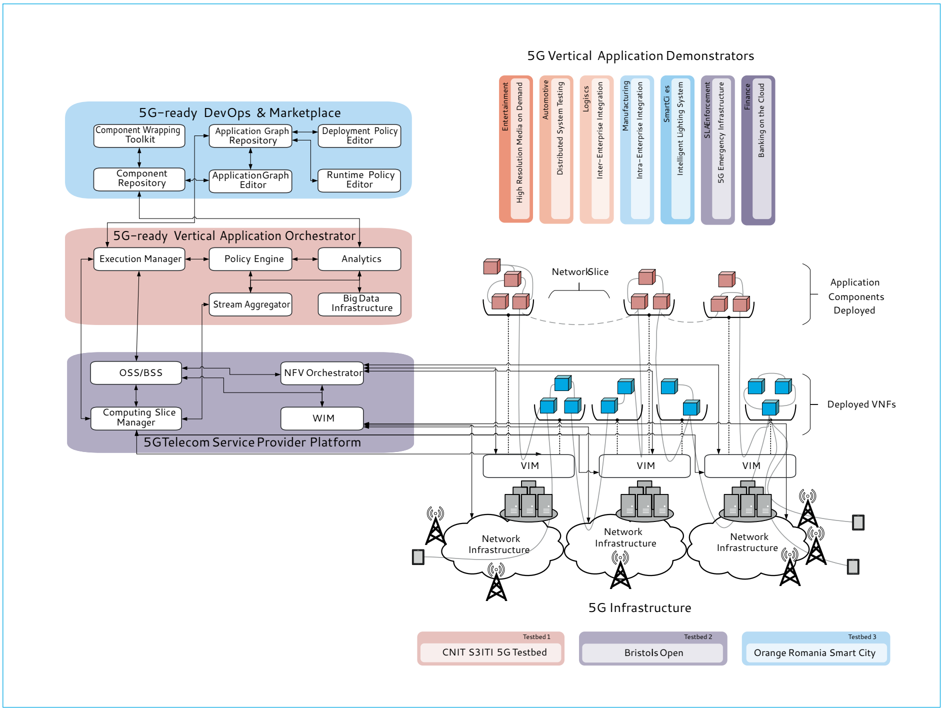

Fig 37. Overall architecture of the MATILDA platform, reference infrastructure, demonstrators and test beds.

The ongoing development will be conveyed to a number of demonstrators addressing a broad portfolio of verticals with different characteristics and application requirements. The goal here is not to demonstrate the benefits of 5G per se in diversified application fields, but rather to show the impact of the MATILDA architecture and mechanisms on the entire lifecycle of the 5G-ready applications, in terms of easing and smoothing the development, deployment and operations phases; likewise, the goal of integrating cloud-native applications in a much more dynamic NFV and MEC environment will be demonstrated.

The seven vertical applications in different domains that will be demonstrated are also shown in Fig 37, on top of the MATILDA architectural layers and components. They will be mapped over three different test beds:

- Bristol-is-Open, integrating an extensive Smart City environment of LTE radio, WiFi and mmWave devices, interconnected by fibre backhaul, and providing OpenStack on High Performance Computing nodes in Bristol, UK;
- The CNIT-S3ITI test bed in Genoa, Italy, based on WiFi and LTE radio devices, emulated Enhanced Packet Core, a MEC platform (OpenVolcano) and a cloud infrastructure stemming from a FIWARE Lab node, in a controlled laboratory environment;
- The Orange Romania Smart City test bed in Alba Iulia, Romania, integrating LTE/5G Lighting Sensors, radio access and VNFs hosted in the Orange Regional Datacentre, and a Cloud middleware IoT platform.

NGPaaS

NEXT GENERATION PLATFORM AS A SERVICE

Goals of the project

Platform-As-A-Service (PaaS) systems offer customers a rich environment in which 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" customised PaaSs, tailored to the needs of a wide range of use cases with telco-grade 5G characteristics. This 5G PaaS does not exist today. The main goals of NGPaaS are 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/public cloud in a scalable and unifying manner.
- A Dev-for-Operations model to remove the vertical barriers that create isolated silos, 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 the 5G platform, it is important to support tools for ensuring the same quality and SLA as the ones found in telecom environment.
- Decentralised OSS/BSS model, moving from fixed centralised stacks to a much more flexible and modular distributed architecture, for interfacing with cloud resources supporting the Telco-grade PaaS optimised for cost and performance in a highly dynamic environment.

Major achievements

During the 1st Year of the NGPaaS project, the architecture was defined with the scope of achieving the following high-level functionalities:

- Support of 'Build-to-order' PaaS principles: by adopting a new modelling based on Reusable Function Block, different PaaSs 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.
- Components modularity: to implement build-to-order principle and support recursion to efficiently realize complex PaaS structures and services.
- Carrier-grade enhancements: A set of new features is implemented directly in Kubernetes and Cloud Foundry to support high I/O requirements. Besides that, the support of acceleration (e.g. FPGA) in the platform, and a

high-performance virtualization technology based on Xen hypervisor are advanced.

- Decentralised OSS: a first PoC is under implementation supporting the platform based approach architecture and a highly dynamic environment (different IaaS/PaaS).
- Dev-for-Operations Model: For optimal collaboration in multi-organisational context emphasizing the vision that 5G should be considered as a platform where many players can interact (FOSS, Third party, Vertical, Vendors, Operators). The model is well advanced.

Description of pilots

A diversity of use-cases can be supported easily following NGPaaS principles and design: broadband, in-vehicle infotainment, connected healthcare, Industry 4.0, smart cities, IoT, etc.

To illustrate the "build-to-order" principle, three use-cases have been selected. One for the telco, one the IoT and one mixing components from telco and IoT. These use-cases are highly representative of the advanced capabilities of the platform.

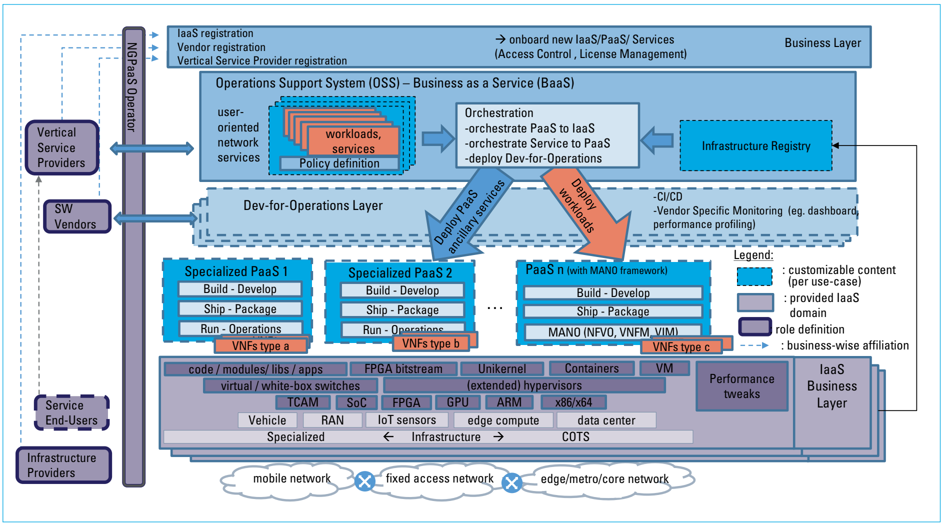

Figure 38. Architecture of NGPaaS

Telco PaaS

The Telco PaaS PoC will be based on the CORD platform, and factored into the NGPaaS framework by leveraging its modular components. The PoC will also leverage monitoring capabilities, failure detection and healing as value-added services through an innovative framework.

The Telco PaaS, is designed to provide the services that are delivered by Telco Providers nowadays, such as wholesale Layer 2 Ethernet connectivity sold to Service Providers (SPs) to connect their end customers who have on-premises Physical Network Functions (PNF). The SPs can on-board and administer VNFs (e.g., vRouter, vFirewall) and other Telco-grade value-added services (e.g. Platform and service monitoring). In the context of NGPaaS, a platform-like "App Store" will be provided to allow the SPs to have a more diverse and richer set of selections.

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, Smartcity or E-Health. The PoC will rely 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 IoT resources.

5G PaaS

For the 5G PaaS, the main objective is to demonstrate how we can combine components from Telco (vendor, operator) and the IoT in one PaaS. The most fit use case for the 5G PaaS is the Mission Critical Push to Talk (MCPTT). During an emergency operation, a private network is deployed in the needed area to connect the different teams between them. Firemen are equipped with awareness and communication apps to help them in their rescue mission. In MCPTT, we deploy the RAN and the Core network, disaggregated into microservices. All the workloads will be deployed on a refactored Kubernetes platform having carrier-grade capabilities and deployed on hybrid cloud infrastructure.

5G-City

Goals of the project

The 5GCity project is working on design, development, 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 a live demonstration and trials to be run in three different cities: Barcelona (ES), Bristol (UK) and Lucca (IT).

In 5GCity, SDN/NFV network solutions, multi-access edge computing (MEC), and optimised lightweight virtualization platforms are all integrated to manage and orchestrate the distributed 5G platform. 5GCity has a main stakeholder in the municipalities: these quite often own and manage the best urban spaces to host 5G Small Cells and are undergoing a digital transformation towards becoming Smart Cities. Here 5GCity will generate most of its impact, unleashing the power of new value-added services in the Smart City powered by 5G, for the benefit of the citizens.

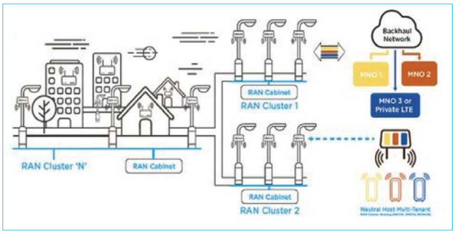

Figure 39. 5GCity Neutral Host concept.

Key innovations

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 capable of offering tight-loop interactions between applications and enabling connectivity services. Key challenges to address in this context are: i) the 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) the 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 APIs and a service SDK to a rich set of primitive functions for network and vertical application layer services (e.g. programmable connectivity with QoS, media acquisition and transcoding, traffic monitoring).

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

5G Neutral Host model. This is the network slicing mechanisms developed in 5GCity. It consists in managing a network infrastructure to host any entity that uses it to provide its services to its end users. In this model, the "Neutral Host" (infrastructure owner) is able to operate a partition of its resources and to arrange them in a set of homogeneous tenants (or slices). In 5GCity two main architectures of a neutral 5G operator are being developed:

- *MOCN – Multiple Operator Core Network*. In MOCN, the cabinet hosts centralized Small Cell components dedicated to the control of a cluster of physical Small Cells deployed in the city lamp posts and other possible urban furniture. Spectrum resources are shared by different participating Mobile Operators.
- *MORAN - Multiple Operator Radio Access Network*. In MORAN, each Mobile Operator uses his own spectrum and the different physical single carrier Small Cells support different bands that can be dedicated to a particular Mobile Operator. These are controlled by the centralized Small Cell cluster functions in the cabinet, which offer a "virtual" MORAN view of the physical small cells deployed in the lamp posts. The centralized Small Cell cluster control function running in the cabinet together with MEC functionality can enable the support of certain stringent requirements such as ultra-low latency needed for some services.

MEC Node Virtualization Platform and Guest Optimisations. The edge computing nodes are non-homogeneous pools of resources located away from centralized datacenters, with limited capabilities due to constrained resources in terms of power, computing and connectivity. For these edge infrastructures (NFVI) we are working on *unikernels* and *lightweight VM images* (i.e., in the few MBs) to minimize resource consumption at MEC nodes (i.e. the street cabinets) and reduce boot times (i.e. in 10s-100ms depending on CPU architecture). We are working to achieve VM-to-VM throughput >= 9.5 Gb/s in street cabinets, wireless virtualization for 802.11 radios with throughput >= 3 Gb/s and isolation guarantees in mesh networks of up to 20 devices.

Flexible Orchestration & Control layer. This represents the core functionality of the 5GCity architecture because it allows to: i) manage the non-homogeneous set of physical resources (computing, storage, wired network and wireless network; ii) abstract physical resources; iii) operate network slicing and cast end-to end services tailored to a multitenant framework. This layer includes *NFVO* (Network Functions Virtualization Orchestrator), *specialized VNFMs* (Virtualized Network Function Manager), Resource Placement algorithms for virtual resources (VNF) over different physical resources domain, *VIM* (Virtual Infrastructure Manager) for core and edge domains, *SDN controller*, which is in charge of the configuration of the back-haul and front-haul network. We are working to achieve a few seconds for edge service instantiation, for orchestrator response, for streaming monitoring data to analytics, for reallocation of service flows and for VM migration.

SDK (Software Development Kit) and service programming models. These consist in a set of tools for the creation, validation and test of specific items (VNF and Network services packages) available to be deployed by dashboard users upon 5GCity physical infrastructure. These tools are typically used in a DevOps framework

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

Major achievements of the period

In the first year of the project (Q3-2017, Q2-2018) 5GCity consortium has achieved the following achievements:

- *Architecture and Use cases defined.* The 5GCity architecture and use cases were designed and documented to begin in month 12 (June 2018) the development and deployment in coordination with the infrastructure.

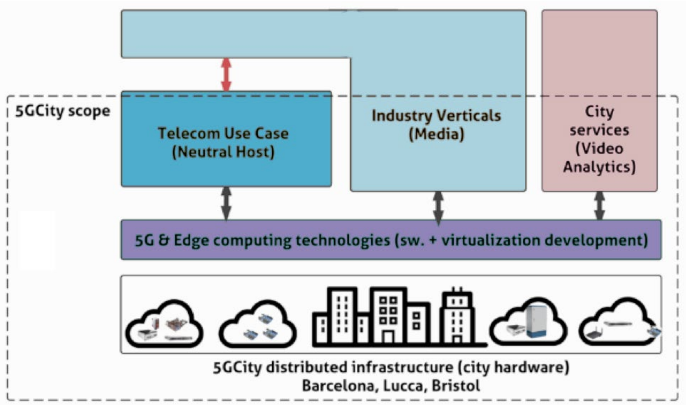

Figure 40. 5G-City scope

Use Case	Barcelona	Bristol	Lucca
UC 1 – Unauthorized Waste Dumping Prevention	–	–	■
UC 2 –Neutral Host	■	■	■
UC 3 –Video Acquisition/ Production & Community media in live events	■	■	–
UC 4 –UHD Video Distribution & Immersive Services	–	■	■
UC 5 –Mobile Backpack Unit for Real-time Transmission	■	–	–
UC 6 –Cooperative, Connected and Automated Mobility (CCAM)	■	–	–

■ *Yes*

Table 5. 5G-City use cases

- *UNIKRAFT framework publicly released* (https://www.xenproject.org/developers/teams/unikraft.html). Unikraft is an open source incubation project under the auspices of the Xen Project and Linux Foundation. It is a system for automatically building unikernels/specialized OSes/images that will be used in 5GCity
- *Deployment of City infrastructures*. In Barcelona and in Bristol we have completed the deployment of Metro DC, MEC node (street cabinet) and 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: a demo was presented at the Smart City Expo World Congress 2017 in Nov.2017 (18,000 visitors from 700 different cities) and in Mobile World Congress 2018 in Feb.2018. In Bristol a Layered Realities 5G showcase has been celebrated in Mar 2018 to demonstrate an end-to-end 5G network with massive-MIMO, millimetre wave, high speed optical network, an advanced programmable hardware platform for the edge of a 5G network (5G-in-a-BOX).

Plans for City trials and demonstrations

Starting from June 2018, the 5GCity consortium will deploy an early version of one of the Use Cases in each city to measure the level of readiness and resiliency of the infrastructure.

City	M1 Jun 2017	M6 Nov 2017	M12 May 2018	M18 Nov 2018	M24 Jun 2018	M30 Nov 2018
Barcelona						
Metro DC		■ (Deployment)		■ (Testing)	■ (Validation)	
MEC node		■ (Deployment)		■ (Testing)	■ (Validation)	
Network		■ (Deployment)		■ (Testing)	■ (Validation)	
RAN			■ (Deployment)	■ (Testing)		■ (Validation)
Bristol						
Metro DC	■ (Deployment)			■ (Testing)	■ (Validation)	
MEC node		■ (Deployment)		■ (Testing)	■ (Validation)	
Network		■ (Deployment)		■ (Testing)	■ (Validation)	
RAN			■ (Deployment)	■ (Testing)	■ (Validation)	
Lucca						
Metro DC			■ (Deployment)	■ (Testing)		■ (Validation)
MEC node			■ (Deployment)		■ (Testing)	■ (Validation)
Network			■ (Deployment)		■ (Testing)	■ (Validation)
RAN			■ (Deployment)		■ (Testing)	■ (Validation)

■ *Deployment* ■ *Testing* ■ *Validation*

Table 6. 5G-City trials and demonstrations

Demonstrations of the available 5GCity technologies are planned for next EUCNC2018 in Ljubljana (SK), and many others under planning for the next Smart City Expo World Congress 2018 and Mobile World Congress 2019.

5G-CORAL

A 5G Convergent Virtualised Radio Access Network Living at the Edge

(Complementary 5G Projects, EU-Taiwan)

Main achievements

The research and development of the fifth-generation mobile network (5G) has gained tremendous momentum during the last few years. Apart from achieving higher data rate than its predecessor, 5G also aims to satisfy several other technical requirements in a bid to cope with various emerging applications. Specific applications such as augmented reality (AR), connected vehicles, and robotics require reliable communications with very low end-to-end latency to deliver high quality services. Fulfilling such requirements is extremely challenging for a centralized network architecture and requires the gradual shifting of networking, computing, and storage capabilities closer to the end users to eliminate the delay caused by data transfer to distant cloud servers. This concept is called intelligent edge and integrates and extends the edge and fog computing approaches as explained in the following.

Nowadays, most end user devices may operate multiple independent radio access technologies (RATs) in parallel (e.g., LTE and WiFi). Such diversity can be exploited for example for traffic offloading purposes. However, this requires harmonisation and/or integration of communication protocol stacks from different RATs, selection of the best RAT for a given user/service at a given time, or interference minimization of different RATs sharing the same spectrum.

With the intelligent edge, a paradigm shift of multi-RATs convergence can be envisioned, wherein context information of different RATs could be leveraged jointly to enhance network performance, cost-effectiveness, and user QoE as shown in Figure 41. Motivated by these needs, the European Telecommunications Standards Institute (ETSI) has been the first to address this need by providing the framework of Mobile Edge Computing (MEC), which is supported by the concept of Network Functions Virtualization (NFV) that was also pioneered by ETSI. ETSI has further re-branded MEC as Multi-Access Edge Computing to highlight its goal of achieving multi-RATs coordination via the edge.

Concept of the project

The 5G-CORAL concept is illustrated in Figure 41. It takes root in a hierarchical multi-tier computing infrastructure, from clouds and central data centres (DCs) on top, down to edge data centers (Edge DCs), and further distributed down into fog computing devices (Fog CDs) available locally in the access area. The focus is on the edge and fog tiers of the distributed computing infrastructure, along with their interaction with the distant tiers. It is noteworthy that mobile (non-stationary) Fog CDs are also considered, for example when hosted on moving devices (e.g., car, train, mobile user). The concept comprises of two major systems: (1) the Edge and Fog Computing System (EFS), as the host environment for our proposed virtualised functions, services, and applications; and (2) the Orchestration and Control System (OCS) for managing and controlling the EFS, including its interworking with other (non-EFS) domains (e.g., transport aggregation network, core network, distant clouds and DCs, etc.).

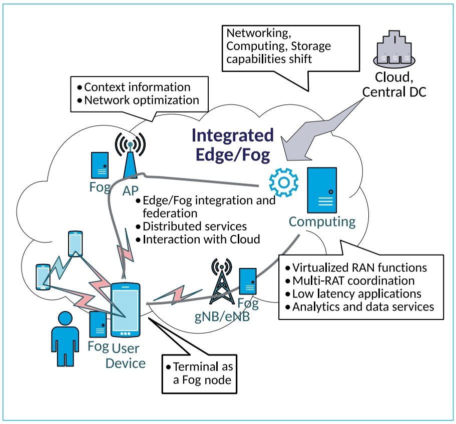

Figure 41. Multi-Access convergence leveraging Edge and Fog Computing

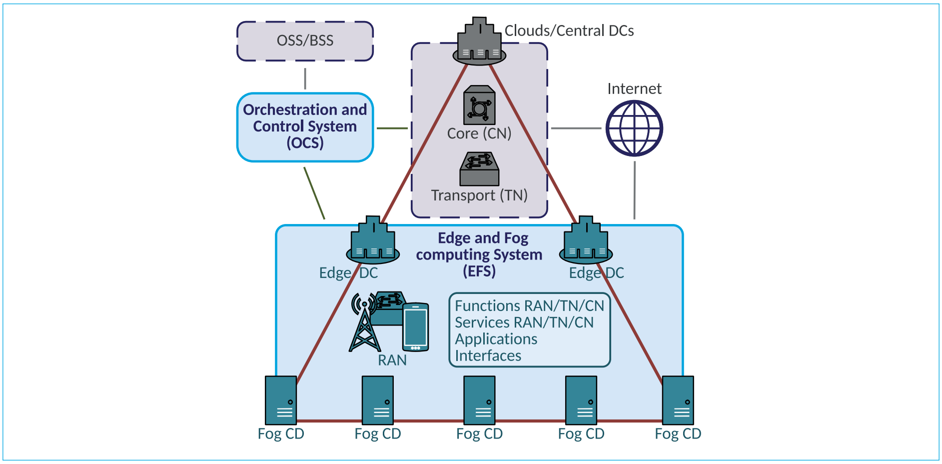

Figure 42. 5G-CORAL Concept

Architecture design

The design of the integrated Fog, Edge and Cloud system, namely 5G-CORAL architecture shown in Figure 43, follows the ETSI MEC and ETSI NFV concepts and envisages a mix of physical and virtualized resources available on the Fog and Edge devices to form an ETSI NFV compliant infrastructure. Figure 43 presents the initial idea of the proposed architecture. The proposed solution contemplates two major building blocks, namely (i) the Edge and Fog Computing System (EFS) subsuming all the edge and fog computing substrate offered as a shared hosting environment for virtualized functions, services, and applications; and (ii) the Orchestration and Control System (OCS) responsible for managing and controlling the EFS, including its interworking with other (non-EFS) domains (e.g., transport and core networks, distant clouds, etc.).

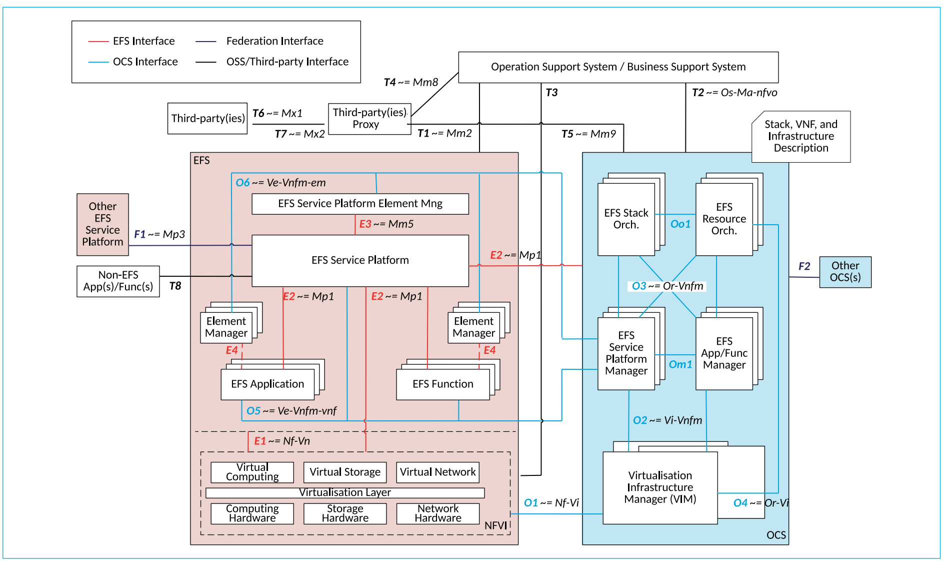

Figure 43. 5G-CORAL Architecture

Project tracking and testbed

Our technology development is next logically split in two parallel and closely linked technology tracks. We have introduced these tracks to provide better tracking of development in the project, and to ensure that the critical milestones are reached in a timely manner. The two tracks are (i) the design of 5G-CORAL EFS system; and (ii) the design of the 5G-CORAL OCS system. These technology tracks will proceed in parallel with interwoven milestones and checkpoints, and they will finally deliver their systems and results to a track, cover the system integration work as well as to another track for a refined system architecture and an assessment of the impact of the developed technologies on the targeted KPIs. The integration work will first provide an initial verification milestone at the system level (composed of both the EFS and OCS) and feedback this information to each of the technology tracks. Once the initial verification is passed, the integration continues towards measuring KPIs and validating the aims of the 5G-CORAL project in each of the three testbeds shown in Figure 4, namely (i) shopping mall in Taiwan, (ii) high-speed train in Taiwan, and (iii) connected cars in Taiwan and Italy. The detail of testbeds is shown as below:

Connected cars

The testbed is located in Turin, Italy, and coordinated by Azcom and Telecom Italia. The connected cars testbed will support the trial for those use cases that exploit the connected car's communication through the cellular infrastructure (V2I). In this scenario, data regarding speed, direction and position, are collected from vehicles and can be used in different ways for improving the cars safety. In fact, the V2I communications add significant value to the advanced driver-assistance systems in terms of improved safety, traffic optimisation and improved driving experience. Within the suggested testbed setup, it could be possible to consider a number of different end-user applications such as roadworks reporting, weather conditions reporting, emergency vehicles approaching, position tracking and collision avoidance.

Shopping mall

The testbed is located in Taipei, Taiwan and is organised by ITRI. It provides facilities for performing experiments and pilot deployments in realistic dense scenarios, both regarding infrastructure and users. The testbed also allows users to take part in the demonstration trials. Computation offloading, network offloading and mission-critical services will be demonstrated in a multi-RAT dense environment. For instance, AR, Robotics will benefit from location and multi- RAT context information. Also, IoT gateways and AR application will take advantage of the vicinity of computing resources for offloading heavy processing tasks from end-user devices/sensors to the edge/fog computing devices to leverage the low latency communications.

High-speed train

The testbed is located in Hsinchu, Taiwan and is coordinated by ITRI. It is amongst the very few commercial high-speed train testbeds in the world capable of collecting and experimenting real high-speed data on real scenarios. The envisioned goal of this testbed is to verify seamless connection in the high-mobility scenario. One anticipated goal is to provision breakout and mobility functions on the fog/edge that could potentially mitigate the burden of passenger's mobility signalling on the backhaul.

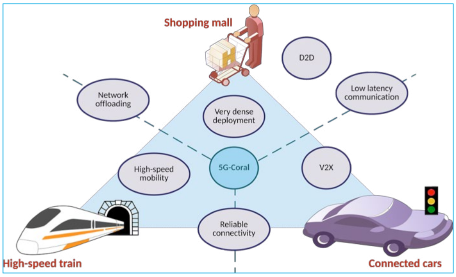

Fig 44. 5G-CORAL Testbeds Scope

Global 5G.org

Global5G.org (www.global5g.org) contributes to the European 5G PPP through its focus on vertical markets, standardisation, and dense networks 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-standardization, Trials and Testbeds, SMEs, 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 nine-months' of activities, Global5G.org has contributed to the 5G PPP in the following ways.

Advancing policy and deployment support of small cells, micro cells and dense networks

Contributing to a roadmap aimed at lowering the cost of rolling out dense networks across the EU by building consensus on guidelines and best practices through a pan-European policy dialogue. Global5G.org leads "Work stream 2 - Denser cell deployment" within the EU's Communications Committee Working Group (COCOM) on 5G. The Global5G.org interim study, Facilitation of denser cell deployment (September 2017), covered recent developments on dense network policy, while its Study on Small Cells and Dense Cellular Networks Regulatory Issues (December 2017) provides a basis for work within the COCOM.

Vertical industries - market analysis and standardisation mapping

Drawing on its initial analysis of four priority sectors for 5G in Europe, namely, automotive, energy, factories of the future and health, Global5G.org has defined a roadmap to support 5G deployments through a standards-based approach, facilitating engagement with relevant standards organisations and sharing inputs within the 5G PPP . The main findings are the basis for the Global5G.org Standardisation Tracker, covering both 5G and sector-specific standards and with practical guides aimed at facilitating intensified engagement of vertical industries.

An important first step towards forming a 5G Health group was made at the IEEE 5G Summit in September 2017, bringing together medical professionals, the Personal Connected Health Alliance, and stakeholders from industry and standards to help define priority steps for 5G pilots within the health sector.

Supporting trials and testbeds mapping

Global5G.org is fostering cross-fertilisation across 5G PPP working groups, from security to spectrum, standards and new business models. Specifically, the project is helping to identify results from vertical industries as a basis for engagement with the most relevant standards organisations.

Global5G.org also draws on phase 1 contributions to 5G security and related standardisation, its international 5G co-operation with the U.S., China, and Japan, as well as global market expertise as reflected in its growing External Advisory Group.

5G INITIATIVES AROUND THE WORLD

5G initiatives to date

The European Commission strongly supports International cooperation and seeks for 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 May 2018, MoUs were signed between 5G-IA 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-Projeto 5G in Brazil in March 2017, 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 globally promote 5G.

To date, five "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/three-day events, government representatives, high representatives from 5G programmes and other 5G supporting organisations, association leaders, many industry experts as well as leading universities and research centres participated and shared the latest Research and Development achievements.

- The First Global 5G Event took place in Beijing, China on May 31st and June 1st, 2016. It was hosted by IMT-2020 (5G) Promotion Group in China with the theme of "Building 5G Technology Ecosystem".
- The Second Global 5G Event was held in Rome, Italy on November 9th and 10th, 2016 under the responsibility of the 5G-IA/5G PPP . It dealt with "Enabling the 5G EcoSphere". On this special occasion, the final version of the first 5G Annual Journal was distributed.
- After the successful events of 2016, the Third Global 5G Event was held on May 24th and 25th, 2017 in Tokyo, Japan, with the theme "Creating the crossover collaboration for 5G Eco-Society", just one year after the First Global 5G Event. It focused on the practical use of 5G from 2020 and beyond and provided news regarding "the 5G Filed Trial Project in Japan" that began in 2017.
- The Fourth Global 5G Event, "5G accelerating the 4th industrial revolution", was held in Seoul, South Korea on November 22-24, 2017. It was organised by 5G Forum.
- The fifth Global 5G Event, "5G New Horizons Wireless Symposium", organised by 5G Americas, was held in Austin, Texas on May 16 and 17, 2018. The event has discussed the current status and progress of 5G. The 5G-IA/5G PPP was represented by 9 speakers and moderators including:
  - Peter Stuckmann, Head of Unit - Future Connectivity Systems DC CONNECT, European Commission, presented at the panel "The progress of 5G Spectrum and Regulatory Policy",
  - Colin Willcock, Chairman of the 5G-IA Board, took part in the "5G Trends and Collaborations" panel,
  - Jean-Pierre Bienaimé, Secretary General 5G-IA, moderated a panel on "Regional visions of the 5G Network" where Ashok Rao, Vice President, SES Networks, spoke.

Jean-Pierre presented also at the "Network Architecture Transformation from LTE-Advanced to 5G" panel,

- Didier Bourse, Chair of the 5G-IA Trials WG, presented European achievements and schedules in 5G Trials and Pre-Commercial Launches, at the "5G Troals" panel,
- Simone Redana, Chairman of 5G PPP Architecture Working Group, contributed to the "Future of 5G: the ultimate experts" panel, moderated by Giovanni Corazza, President, CINECA,
- Emmanuel Dotaro, 5G-IA Board member, Thales Communications & Information Systems, presented at the "5G Ecosystems" panel,
- Mustafa Ergen, Chief Technology Advisor, Türk Telecom, presented at the "5G Services & Use cases" panel.

The MWC'18 in Barcelona was also a major opportunity to promote 5G progress in Europe. The 5G-IA and 5G PPP projects had a big presence and received a lot of interest with media, policy-makers and attendees visiting the booth and demonstrations. A number of papers were released and paper-copies distributed on the booth (latest Pan-European 5G Trials Roadmap, 5G architecture design recommendation from phase 1 projects, 5G PPP Automotive White paper, the European Annual Journal 2017). Interviews and presentations were also delivered.

Future actions

The 2018 edition of EuCNC "5G and beyond" scheduled in June 2018 in Ljubljana, Slovenia, will also be a major opportunity to promote 5G PPP projects and achievements.

The sixth Global 5G Event is scheduled on 28-30 November 2018 in Rio, Brazil, and will be organised by Telebrasil 5G.

Assessing the 5G research and development investment Leverage Factor

Assessment methodology used

Our methodology is based upon gathering the published public figures from annual reports for worldwide R&D expenses.

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 used FY2016 figures. The third edition uses FY2017 figures. We do not modify the shares we applied last year as we consider the full standardisation phase has not been achieved yet. In our view, 2018 will be a transition year from standardisation to trials.

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, others 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 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 23 organisations is reliable.

Assessment of leverage ratio for 2017

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

5G PRIVATE R&D SPENDING (Million EUR)	2017 R&D	5G as 10% of global R&D	5G as 5% of Global R&D	5G as 2% of Global R&D
Infrastructure Vendors				
Ericsson	3 932	393	197	79
Nokia (Incl. ALU)	4 916	492	246	98
Huawei	11 772	1 177	589	235
NEC Europe		*50*	*25*	*10*
Samsung*	13 185	659	330	132
MNOs				
British Telecom		*50*	*25*	*10*
Deutsche Telekom	*5 500*	550	275	110
Orange	781	78	39	16
Portugal Telecom		*7*	*3*	*1*
TIM	*1 900*	*190*	*95*	*38*
Telefonica	906	91	45	18
Telenor	60	6	3	1
Test equipment				
Keysight Technologies*	442	22.1	11	6
Rohde & Schwartz	285	29	14	6
Chipset				
Intel*	11 618	576	288	115
Sequans	23	2	1	0
IT				
ATOS		29	14	6
IBM	*1 350*	135	68	27
Others				
ADVA	*24*	2	1	0.5
CEA	*47*	*7*	*3*	*1*
Hewlett Packard Enterprise		*7*	*3*	*1*
Thales	*750*	75	38	15
IHP	*22.4*	2	1	*0*
TOTAL 5G PRIVATE R&D SPENDING (Million EUR)	**57 514**	**4 630**	**2 312**	**926**
Phase 1 total funding from EC	125	125	125	125
Phase 1 third year funding	45	45	45	45
The players in the table share of EU funding is	50%	50%	50%	50%
Phase 1 third year funding for above mentioned players	23	23	23	23
Phase 2 total funding from EC	150	150	150	150
Phase 2 first year funding	33	33	33	33
The players in the table share of EU funding is	50%	50%	50%	50%
Phase 2 first year funding for above mentioned players	17	17	17	17
Leverage factor 2017**		104	52	**21**
Leverage factor 2017 for above mentioned players		207	*104*	**42**

Assumptions are in italics when R&D expenses are unknown

** For companies not based in Europe* *** (Phase 1 third year funding and Phase 2 first year funding) divided by total 5G private R&D spending*

Table 7. 5G R&D expenses

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 21** considering the whole 5G PPP 2017 investment (Phase 1 third year and Phase 2 first year).

The 5G PPP funding for phase 1 and phase 2 projects was about 70 M€ for bigger industry, which facilitated projects with a value of around 30 M€ per year – allowing for projects with different durations (between 24 to 26 months). The total funding budget for 5G PPP Call 1 was 125 M€. It was 150 M€ for phase 2.

Conclusion on Leverage ratio for 2017

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.

SME participation and success stories in 5G

Small and Medium-sized Enterprises (SMEs) have an important role to play in developing, piloting and deploying 5G technologies, both to help with disruptive technologies and to address the needs of various vertical sectors. European SMEs have a great added value in providing innovative concepts and solutions that are having an important impact on the 5G value chain. They have the agility and flexibility required in a fast evolving technical and market landscape.

The SME Working Group, supported by the To-Euro-5G Coordination and Support Action, succeeded in increasing the visibility and exposure of SME's expertise and skills to the point that SMEs represent almost 20% of the participants in budget in the 5G PPP Phase 1 and Phase 2 projects. The objective that was therefore set for 2017-2018 was to reach at least 20% involvement of SMEs in the Phase 3 projects. 20% is the minimum share that was set originally as a KPI or "Key Performance Indicator" by the EC and the 5G IA for the 5G PPP .

To reach this ambitious objective, the "Find the SME you need!" web page was completely revamped to match SMEs' experience and expertise with the new requirements set for Phase 3 of the 5G PPP , looking for developing 5G platforms and large-scale trials in various vertical industrial sectors . The page now includes the way to find SMEs via topics of the 5G PPP calls, and by vertical industrial sector. Detailed information is provided for each SME under the form of a dedicated sheet. New success stories have been published.

An active promotion of SMEs was performed via social channels and participation in events. In June 2017, a dedicated "SME booth" was set at the European Conference for Networks and Communication (EuCNC). Several SME videos are available on the 5G PPP YouTube channel .

Although it is too early to know whether the objective of 20% participation in Phase 3 has been reached, there is already some positive feedback. SMEs participating in the SME Working Group have confirmed that their presence on the SME web page has increased their visibility and exposure, and in some cases has facilitated their involvement in 5G PPP Phase 3 proposals -in addition to being contacted by organisations that they had already known and worked with.

In 2018, an SME booth will again be organised at EuCNC 2018 that shall be held in Ljubljana, Slovenia, on 18-21 June . A new version of the "SME Expertise and Skills in the 5G Domain" brochure will be released, to show once again the expertise and skills from selected SMEs in 5G and related domains.

All those activities are more especially dedicated towards large organisations, whether industry or academia, from Europe and beyond, seeking to cooperate with SMEs in 5G.

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.

The Board of the 5G Infrastructure Association includes since 2017 two SME representatives: Nicola Ciulli from NEXTWORKS, and Jacques Magen from INTERINNOV.

NetWorld2020 is the European Technology Platform for telecommunications and related services and applications. The SME Working Group is the networking place for SMEs. It helps promote SME activities and expertise (including but not limited to 5G) towards other stakeholders, in particular large companies. The SME Working Group is chaired by Jacques Magen, INTERINNOV. The Vice-Chair is Guillaume Vivier, SEQUANS.

European 5G trials roadmap

The 5G Pan-European Trials Roadmap is covering a broader scope than the 5G Action Plan (5GAP) and the 5G Infrastructure PPP Phase 3 (2018-20+). Most of the Roadmap implementation is and will be covered by the Industry on a private basis, with part of this implementation supported by EC through the 5GAP, EC 5G Infrastructure PPP Phase 3, EC 5G Investment Fund and by Member States through specific National programmes.

Technical aspects & innovations

The 5G Pan-European Trials Roadmap has been elaborated and reviewed by the Trials Working Group Member organisations, coordinated by the 5G Infrastructure Association (5G-IA).

It is addressing several of the 5GAP key elements and targets to develop the necessary synergies between these elements. The version 1.0 was made available in view of public release at the 3rd 5G Global Event taking place on May 24-25, 2017 in Tokyo. The version 2.0 was presented and discussed at the 4th Global 5G Event in Seoul, South Korea on the 22-23 November 2017.

The Roadmap Version 2.0 addresses the latest up-dates of the Roadmap strategy, the 5G Private Trials, the 5G Platforms, the 5G Vertical Pilots, the 5G Pan-EU Flagship event for UEFA EURO 2020 and the 5G Trials Cities.

The main objectives of the Roadmap are to:

- Support global European leadership in 5G technology, 5G networks deployment and profitable 5G business.
- Validate benefits of 5G to vertical sectors, public sector, businesses and consumers.
- Initiate a clear path to successful and timely 5G deployment.
- Expand commercial trials and demonstrations as well as national initiatives.

Most of the Roadmap implementation is and will be covered by the Industry on a private basis, with part of this implementation supported by the EC through the 5GAP, EC 5G Infrastructure PPP Phase 3, EC 5G Investment Fund and by Member States through specific National programmes.

The Roadmap version 3.0 was publicly released at the 5th Global 5G Event on 16th May in Austin.

The Roadmap strategy is summarized in the following Figure included in the Roadmap Strategy document (https://5g-ppp.eu/wp-content/uploads/2017/01/5G-IA-Action-Plan-Event-Press-Release-_-MWC2017.pdf).

In the context of 5G trials and pilots, each of the ICT stakeholders, vertical sectors, participants, sponsors and contributors will have different objectives, expectations or KPIs and outcomes by which they will want to measure the success of the 5G trial(s)/pilot(s). These will be driven by the user requirements and will need to be measured (quantitative or qualitative) during the trial/pilot.

The core part of the 5G trials and pilots will be achieved through private trials (commercial and precommercial) between network operators and manufacturers/vendors and will step by step involve vertical stakeholders.

The acceleration of 5G in Europe is happening thanks to a specific joint strategy between Industry (hand in hand with Research Centres and Academics), EC and MSs and Domains specific initiatives. Expanding bilateral and trilateral private trials, the strategy relies on the development of specific projects addressing 5G vertical pilots and 5G platforms, 5G UEFA EURO 2020 such as major 5G Pan-EU Flagship events and the 5G Trials Cities programme. The 5G Pan-EU roadmap leverages a multiplier effect of the cooperation between ecosystem partners over different European countries (allowing interoperability and defragmentation). The projects and actions are and will be partly supported by specific EC and MSs programmes and funded projects and also by Domains specific programmes and projects (e.g. ESA satellite for 5G Initiative). An example to illustrate this are the 5G Corridors projects for which different network operators and manufacturers/vendors will engage in dedicated projects at Pan-EU level (e.g. 2 or 3 MSs involved). Some of these projects will be supported by EC and MSs projects (e.g. the EC H2020 5G Infrastructure PPP Phase 3 ICT-18-2018 Call on Corridors).

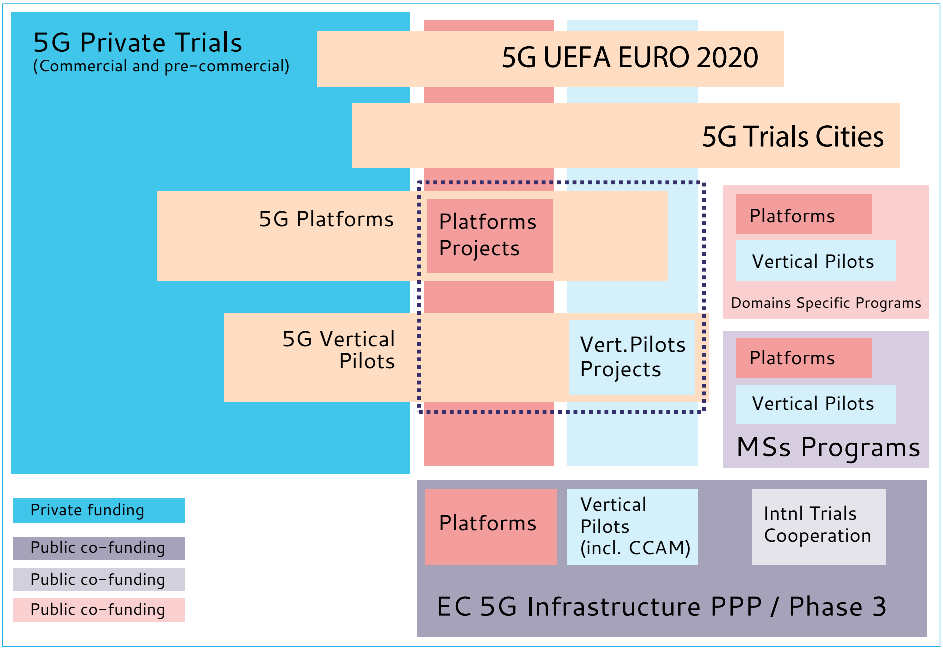

Figure 45. 5G Pan-EU Trials Roadmap Strategy

The 21 5G Infrastructure PPP Phase 2 projects (2017-2019) actively contribute to the prototyping, experimentation and trialling of 5G technologies and components for specific use cases, including vertical uses cases developed with vertical stakeholders. There will be further momentum gained through PPP Phase 3 projects (2018-2020) with a set of 3-4 projects addressing end-to-end test facilities and platforms, 2-4 projects addressing vertical pilots for connected mobility (corridors) and 6-9 projects addressing vertical pilots. In particular, Phase 3 projects will target large scale trials and pilots including complete end to end 5G systems, demonstrating 5G KPIs and key distinguishing features (e.g. end-to-end network slicing, service based architecture, diverse access technologies integration…) and proving 5G technology capability to address and integrate requirements of a multitude of vertical industries. Concerning the Domain specific programmes, the recently announced "ESA Satellite for 5G Initiative" aims to expedite space sector integration in the 5G Pan-EU trials. The intention is to bring together relevant stakeholders to accelerate the integration of Satellite in 5G through relevant projects, in particular 5G Infrastructure PPP Phase 3 projects, with ESA funding typically providing a complementary "multiplier" effect to the satellite elements in those projects.

The number of 5G private trials in Europe has doubled in a year

Europe is home of an increasing number of 5G private trials and pilots (pre-commercial and commercial) involving a multitude of stakeholders, notably network operators, manufacturers/vendors and some vertical industries. Several major network operators in Europe have already announced first results of experimentations and plans for further demonstrations of specific 5G features, either bilaterally with a single manufacturer/vendor or multilaterally with a number of manufacturers/vendors. Trials have been achieved or have been announced in most of the EU countries (100+ experimentation and trials publicly announced in the different EU countries compared to 50+ in 2017). The main target of the current trials is to demonstrate the high data rates and low latency communications, which are key features for 5G technology.

In 2017 there were only a few 5G Private trials including vertical stakeholders. Trials in

2016-2017 have been focused on enabling technologies related to the radio interface (high throughput, millimetre-waves and other new large spectrum bands, antenna technologies…), the network architecture (virtualization, cloudification, network slicing, edge computing…) and the introduction of new technologies dedicated to specific use cases (technologies for IoT, for automotive…). It is foreseen that, when the maturity level of 5G features increases, more direct vertical stakeholders will be engaged in the trials. Some of the 5G trials announced include joint work on experimentation platforms that could become open to new ecosystems, in order to develop 5G applications and services in the context of the digital transformation of vertical industries.

EU5 countries account for almost 50% of all 5G private trials in Europe

As at March 2018, there are over 100 5G private trials registered in Europe (including Turkey and Russia). Western Europe accounts for more than 60% of trials performed. West-European Trials are concentrated mostly in EU5 countries (France, Germany, Italy, Spain and the UK account for almost 50% of all 5G private trials listed from 2016).

The 3.4-3.6 GHz band is the most tested band in Europe (including Turkey and Russia)

Trials are only using frequencies above 3.4 GHz. Five distinct frequency bands ranging from mid-frequencies to millimetre wave bands are tested: 3.4-3.6 GHz, 4.5 GHz, 15 GHz, 28 GHz, 70-80 GHz. Interests are growing around very high frequency bands accounting for almost 20% of trials. However, the 3.4-3.6 GHz represents more than half of bands trialled.

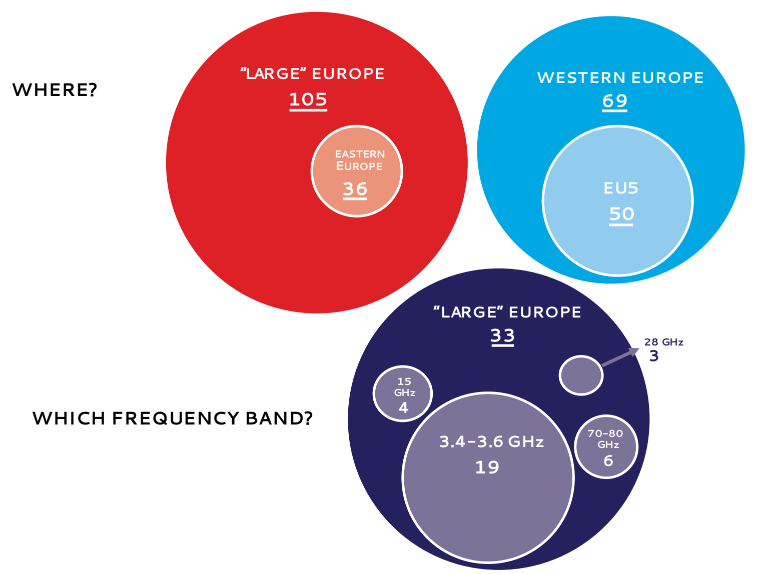

Figure 46. 5G Private Trials by country and frequency band
Source: 5G Private Trials Stream, 5G Trials WG, March 2018

Vertical Category	Project	Verticals Stakeholders	Project Trial / Pilot Focus	ITU Service Type	Location
Connected and Automated Mobility	5GCAR	Volvo, PSA, and Bosch	End-to-end V2X network connectivity for highly reliable and low-latency V2X services.	eMBB, URLLC	Montlhéry (FR)
Smart City	5GCity	City councils of Barcelona, Bristol and Lucca	Distributed cloud and radio platform for municipalities and infrastructure owners acting as 5G neutral hosts.	eMBB, URLLC (mMTC)	Barcelona (ES), Bristol (UK), Lucca (IT)
	IoRL	BRE, Issy Media and Ferrovial	Indoor delivery of very high bandwidth, low latency and location based services.	eMBB	Watford (UK), Paris (FR), Madrid (ES)
Consumer and Professional Services	5G-Xcast	BBC, EBU and LiveU	5G network architecture for large-scale immersive media delivery.	eMBB	Surrey (UK), Munich (DE), Turku (FI)
	5G ESSENCE	Smart Mobile Labs GmbH	5G Edge network acceleration for a stadium.	eMBB	Egaleo (GR)
	5G-MEDIA	CERTH/ITI, IRT and RTVE	Tele-immersive applications, mobile contribution, remote and smart production in broadcasting.	eMBB	Athens (GR), Thessaloniki (GR), Madrid (ES), Rome (IT)
	5GTANGO	Nurogames	Immersive media application showing added value of 5G service network programmability, automatic testing and NFV orchestration.	eMBB, URLCC	Aveiro (PT), Athens (GR)
Transport	5G-Transformer	CRF and SAMUR	Transforming today's mobile transport network into an SDN/NFV-based Mobile Transport and Computing Platform (MTP) which brings the "Network Slicing" paradigm into mobile transport networks.	URLLC	Turin (IT), Pisa (IT), Madrid (ES), Nice (FR)

Vertical Category	Project	Verticals Stakeholders	Project Trial / Pilot Focus	ITU Service Type	Location
Industry	5G-MoNArch	Hamburg Port Authority and Turin Palazzo Madama	A flexible, adaptable, and programmable architecture for 5G brought into practice in two testbeds: Hamburg for network resilience and Turin for resource elasticity.	mMTC, URLLC (eMBB)	Hamburg (DE), Turin (IT)
	NRG-5	Ineo Energy & Systems, Romgaz, Emotion and ASM Terni	Smart Energy-as-a-Service: Making the operation and management of communications and energy infrastructures easier, safer, more secure and resilient.	mMTC, URLLC (eMBB)	Terni (IT)
	5GTANGO	Weidmüller	Smart manufacturing showing added value of 5G service network programmability, automatic testing and NFV orchestration.	mMTC (URLLC)	Detmold (DE)
	VirtuWind (PPP Phase 1)	Siemens Wind Power	SDN/NFV to lower CAPEX/OPEX in control network infrastructure in an operational wind energy park.	URLLC	Brande (DK)
	5G-Picture	FGC Ferrocarrils de la Generalitat de Catalunya and Comsa Industrial	Adoption of the 5G disaggregated RAN (DA-RAN) architecture for demonstration of 5G rail services in a real railway testbed.	mMTC, URLCC, eMBB	Barcelona (ES), Bristrol (UK)
	NGPaaS	Vertical M2M and Virtual Open Systems	"Build-to-order" IoT Platform as a Service: Isolation of two devices (Health vs Temperature) using a single virtual IoT gateway component.	mMTC, URLCC	Paris, Grenoble (FR)
Public Safety & Digital Divide Resorption	5G-ESSENCE	Thales Communications & Security SAS	Demonstrate and evaluate the cloud-integrated multi-tenant small cell network customisable on a per vertical basis.	URLLC, eMBB	Coventry (UK)
	MATILDA	ININ Internet Institute	5G-enabled emergency response for real time intervention monitoring and critical infrastructure protection, showing Services Orchestration with SLA Enforcement.	URLLC (eMBB)	Genova (IT), Ljubljana (SL)

Table 8. Phase 2 projects across different vertical categories
Source: 5G-IA

5G CHRONICLE

Recent 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. See the events chronicle p 84.

Helsinki 5G week (18-21 September 2017)

5G PPP projects took an active part of the Helsinki week last September. METIS-II co-chaired the track on 5G Radio and Wireless Communications.Flex5GWare co-chaired two tracks: the first one was on Softwarization and Virtualization and the second one on Verticals, Services and Applications.

Wireless World Research Forum Meeting (WWRF, 18-20 October 2017)

Last year's theme was around Ready'n'Go–5G Trials and Testbeds. The meeting emphasised technical capacities to bring forth new and innovative products and services, in verticals such as manufacturing, transport, energy, health, education and entertainment. 5G PPP Projects were there (SONATA, 5GTANGO, 5GCAR, 5G-Crosshaul, 5G-Transformer…). Colin Willcock, 5G-IA chair, gave a high-level overview of the 5G Pan-EU trial roadmap. The four main pillars of the trial plans were introduced and concrete proposals were made for how to facilitate greater impact and influence from these trial activities.

Berlin 5G Week 2017 (6-10 November 2017)

The Berlin 5G week was a major opportunity for 5G PPP projects to promote activities and achievements. 5G PPP phase 2 projects MATILDA and 5GTANGO organised the 4th Workshop on Network Function Virtualization and Programmable Networks (NFVPN) in conjunction with the 3rd IEEE NFV-SDN conference. 5G PPP phase 1 projects SONATA and 5GEx jointly organised the third IEEE Workshop on Orchestration for Software-Defined Infrastructures (O4SDI) with 5G PPP phase 2 project 5G-TRANSFORMER. In addition, Jean-Pierre Bienaimé, 5G-IA Secretary General, gave a talk on 5G testbeds and trials.

Mobile World Congress 2018 (28 February-1 March 2018)

5G was at the centre stage of MWC 2018 and a large number of stands and conference sessions focused on it.

5G-IA and 5G PPP projects were present at MWC'18 with a stand, demos and presentations both in the main conference and in a specific '5G-PPP session'. This resulted in very good visibility and recognition of the Association, 5G-PPP projects and WGs and the entire 5G PPP at large.

5GCAR shared project learnings with mobile network operators, automotive original equipment manufacturers, and other stakeholders during the largest gathering of the year for the mobile industry. WINGS ICT Solutions and One5G were presented. The following key points were specifically discussed: on the need for efficient, end-to-end aware, radio resource management for serving the diverse applications and heterogeneous environments (megacities and rural/underserved areas) envisaged in 5G; on the opportunity of having 5G as the platform that will enable, encompass, enhance, and, therefore, maximize the benefits from IoT and Artificial Intelligence.

5G-MoNArch presented the project's scope approach and goals. It enjoyed interesting talks to visitors from both research and industry. The approach of 5G-MoNArch to bring the new 5G mobile network architecture to practice through two real-world testbeds, being at the forefront of applying network slicing to industrial and media & entertainment use cases, was very much appreciated.

The 5G-Xhaul project was also there and presented to both the 5G PPP community as well as to key industrial players working in 5G around the globe. 5G-Xhaul project gathered valuable feedback and very good assessment of its work given the final demonstration activities, which will be held in the city of Bristol in June 2018.

Other joint initiatives will follow in the second half 2018

- At the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting 2018, a main 5G workshop approaching the last innovations and research activities in 5G PPP is organised. Moreover, the conference will hold specific workshops organised by one Phase 1 project and several 5G PPP Phase 2 projects: 5G-Ex (Phase 1), 5G-Xcast, IoRL, 5G-Transformer, 5G-CORAL, 5GEx, Bluespace, NGPaaS and 5G-MEDIA (Phase 2 projects).
- 5G PPP projects 5G-ENSURE and IoRL will co-chair the Workshop on 5G Networks Security (5G-NS 2018) held in Hamburg, Germany (August 27-30, 2018) in conjunction with the ARES Projects Symposium 2018 at 13th International Conference on Availability, Reliability and Security.
- Organised in Valencia on June 6-8, 2018, the IEEE BSMB'18 (the IEEE International Symposium on Broadband Multimedia Systems and Broadcasting 2018) will feature several workshops focusing on 5G. A main 5G workshop approaching the last innovations and research activities in 5G PPP will be organised. Moreover, the conference will hold specific workshops organised by one Phase 1 project and several 5G PPP Phase 2 projects: 5G-Ex (Phase 1), 5G-Xcast, IoRL, 5G-Transformer, 5G-CORAL, 5G-Ex, Bluespace, NGPaaS and5G-MEDIA (Phase 2 projects).
- At the 2018 IEEE 5G World Forum (5GWF'18), on the theme "5G Vision", that will take place on July 9-11 in Santa Clara, California, three 5G PPP Projects – 5G-Xcast, IoRL and NGPaaS - are organising special topicals, whereas Jean-Pierre Bienaimé, 5G-IA Secretary General, will co-chair and present at the Industry Forums sessions.
- The sixth of the bi-annual Global 5G events will be hosted in Rio, Brazil, on 28-30 November 2018.

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