5G PPP

5G IA

The European 5G Annual Journal 2017

Supported by the

European Commission

THE EUROPEAN 5G ANNUAL JOURNAL/2017

Grant Agreement No.: 671617
Coordination and support action
Call Identifier: H2020-ICT-2014-2

Euro-5G – Supporting the European 5G Initiative

THE EUROPEAN 5G ANNUAL JOURNAL/2017

1. *http://creativecommons.org/licenses/by-nc-nd/3.0/deed.en_US*

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

THE AIM OF THIS SECOND 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 5G PPP PROJECTS ALMOST TWO YEARS AFTER THEIR LAUNCH.

Colin Willcock, Chairman of the Board, 5G PPP

The 5G-PPP has made a dramatic impact on European 5G leadership by supporting 5G research. As the programme moves to a new chapter, with the first phase of projects ending and the start of the second phase of projects, it was felt the time was right to renew the governance and leadership of the 5G-PPP. In the new structure, the 5G Industry Association is the sole organisation representing and responsible for the private side of the 5G-PPP.

In this context, the 5G-IA has issued new statutes and renewed its Board, leading to a clarified and simpler governance. The 5G IA formally interacts with the European Commission through a partnership Board, and closely coordinates its Policy Work Groups with the 5G Initiative Projects and Technical Work Groups. As for the Networld 2020 Experts and Task Groups, they no longer formally belong to the 5G PPP organisation, however we will continue to actively collaborate in relevant areas.

As part of the new leadership I have been elected as the new chairman of the 5G Industry Association Board. To be honest, I approach this task with mixed feelings; on the one hand it is exciting to take over this new challenging role, but on the other hand, in an ideal world the original chairman Werner Mohr would still be in place. Werner, who has been so instrumental in setting-up and running the 5G PPP, was unfortunately taken ill earlier this year and had to step down from his 5G-IA activities, we hope to see him return to the 5G-IA in the very near future.

Finally as part of this renewal I would like to highlight the objectives and action plan of the 5G IA moving forward:

- ensuring a clear European voice on 5G around the world
- reaching out to vertical industry sectors ("verticals") and ensuring the EU's support/enforcement of the required policies and regulations to embrace 5G in the various vertical sectors in Europe

- Steering the 5G PPP programme implementation through cross project cooperation in Europe, and targeting in a consistent way the exploitation of the 5G PPP results: phase 1 (research), phase 2 (optimization) beginning on 1st June 2017, and phase 3 (large scale trials)
- promoting the availability of radio spectrum, as well as a holistic standardisation roadmap with the aim of reaching a globally harmonized and interoperable 5G communications standard
- defining its "5G trials roadmap strategy" for the implementation of advanced pre-commercial and pan-European trials to be launched in key sectors, promoted through European public events, with the aim of ensuring European leadership in the context of the accelerated global agenda for the introduction of 5G.

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

The 5G-PPP and the 5G Infrastructure Association (5G-IA) conducted numerous communication activities during the period between mid-2016 and mid-2017, strongly increasing their visibility on the European and worldwide scenes. Among multiple actions including 5G PPP newsletters & newsflashes, press releases and contacts with media, organisation of and participation in events and conferences, dissemination of information and 'awareness creation' activities via social media and website, let's mention three major events where the 5G-IA highlighted 5G PPP actions and projects:

- The Second Global 5G Event: "Enabling the 5G EcoSphere", that was hosted in November 2016 in Rome by the 5G IA, with nearly 400 participants from 26 different countries, in presence of Günther H. Oettinger, European Union Commissioner for Digital Economy and Society, Antonello Giacomelli, Under-secretary of the Italian Minister of Economic Development, and Roberto Viola, Director General of European Commission DG CONNECT, as well as Representatives from 7 National Governments.

- The 5G-IA Press & Media event "5G Action Plan: from Research to Trials", at the Mobile World Congress (MWC) 2017 in Barcelona, where the 5G-IA White Paper "5G Innovations for new Business Opportunities" was presented, as well as the 1st version of the 5G-IA "Trials roadmap strategy", in presence of Roberto Viola, EU DG CONNECT and of two panels of top level digital and verticals industries Representatives. It was notably illustrated how a Roadmap Strategy for pan-European trials will support European Commission 5G Action Plan towards the 5G pre-commercial phase, and supported by a successful European collaborative research.

- The successful edition of EUCNC 2017 (European Conference on Networks & Communications) in June 2017 in Oulu, with more than 650 participants, where many 5G PPP Phase 1 projects had a booth in the exhibition area and participated in various workshops, whereas 5G-IA Representatives delivered presentations on topics such as spectrum, connected cars, security and 5G PPP collaboration. In particular, EUCNC 2017 was the occasion of the official launch of the 5G PPP Phase 2 Projects, with the presentations by each of the 23 new projects, that revealed notably a very good coverage of the work programme, as defined by the 5G-IA pre-structuring model, a leveraging on Phase 1 results and clear move towards software and cloud networks, an effective inclusion of Verticals (automotive, healthcare, energy, media...) and a strong potential to drive Europe towards 5G trials and demo paving the way towards implementation...

In the field of international cooperation, let's highlight the signature of a Memorandum of Understanding (MoU) between 5G-IA and Telebrasil – "Projeto 5G Brasil" at the MWC 2017, followed by the extension of the Multilateral MoU to Brazil, officially signed at the 3rd Global 5G Event in May 2017 in Tokyo. The 5G-IA was also successfully accepted as Market Representation Partner (MRP) of the 3GPP in October 2016, and signed a cooperation agreement with ETSI in April 2017, as well as with the CEPT/ECC in June 2017.

As for the 5G PPP Contractual Arrangement and KPIs, at this stage of mid-term review in summer 2017, 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. In the field of performance KPIs, nearly all the technical indicators, such as throughput, latency, device density, and reliability are already met. In the area of societal KPIs actions are progressing well, and actions are ongoing in reduction of energy consumption, security & user privacy, and development & availability of 5G skills curricula throughout Europe.

This edition of the 5G Annual Journal 2017 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 related projects achieved outstanding progress and impact in the period mid 2016-mid 2017. All projects were full speed during this period, some contractually terminating end of June 2017. When Phase 2 projects started beginning of June 2017, 40 Phase 1 and Phase 2 projects were contractually active, ensuring an outstanding momentum and dynamism. Beyond the Phase 1 projects achievements (reported in this Annual Journal) 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 with the strong support of the EURO-5G CSA. Some of the major achievements at programme level are also highlighted in this Annual Journal, including White Papers, Workshops, 5G Global Events, massive dissemination in worldwide conferences... all reflecting the very high level of interactions between projects participants. To highlight two major achievements (among many others) at projects and working group levels:

- The Technology Board (Board of PPP projects Technical Managers) developed the approach of the PPP projects and programme Golden Nuggets, developing a 360° understanding of the overall Phase 1 projects portfolio achievements and allowing the different projects to fully understand and match their individual contributions inside these global Phase 1 achievements. The main Phase 1 projects achievements are clustered under 15 programme Golden Nuggets. First communication was organised in the PPP MWC 2017 White Paper "5G innovations for new business opportunities" and then in several PPP presentations in 1H17.
- The 5G-IA released the 5G Pan-EU Trials Roadmap Version 1.0 in May 2017, following the introduction of the Roadmap strategy during MWC 2017. The Roadmap was presented first during the 3rd 5G Global Event organised on 24-26.05.17 in Tokyo. The Roadmap is worked out by the European 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.

This Annual Journal provides you with a summary overview of the recent PPP achievements, which 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 questions and stay tuned as there will be more and more achievements in the coming period, with Phase 2 projects developments and forthcoming Phase 3.

5G DEVELOPMENTS

5G PPP: an innovative initiative to foster R&D

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

The 5G Infrastructure PPP, in short 5G PPP, is a joint initiative between the European Commission and the European ICT industry. The Commission is investing 700 million € and the industry will leverage this investment by a factor of 5, bringing the total investment in the 5G PPP to more than 4 billion €, to rethink the infrastructure and to create the next generation of communication networks and services. The 5G PPP is aiming at securing Europe's leadership in the areas where Europe is strong or where there is potential for creating new markets such as smart cities, e-health, intelligent transport, education or entertainment & media. The 5G PPP initiative 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 European society can enjoy the economic and societal benefits these future networks will bring.

5G Manifesto & EC's 5G action plan

5G Manifesto for timely deployment of 5G in Europe

On 7 July 2016, a group of 17 operators, equipment vendors and satellite operators sent an open letter to the European Commissioner for Digital Economy and Society Günther Oettinger. The European Industry presented the "5G Manifesto for timely deployment of 5G in Europe" to the European Commission. This document sets out industry recommendations on expected support from the EU in order to facilitate and foster 5G innovation and deployment.

EC 5G Action Plan

On 14 September 2016, the Commission launched a plan to boost EU efforts for the deployment of 5G infrastructures and services across the Digital Single Market by 2020. The action plan set out a clear roadmap for public and private investment on 5G infrastructures in the EU. A staff working document accompanies the action plan communication.

To achieve that, the Commission proposes the following measures:

- Align roadmaps and priorities for a coordinated 5G deployment across all EU Member states, targeting early network introduction by 2018, and moving towards commercial large scale introduction by the end of 2020 at the latest.
- Make provisional spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference (WRC-19), to be complemented by additional bands as quickly as possible, and work towards a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz.
- Promote early deployment in major urban areas and along major transport paths.
- Promote pan-European multi-stakeholder trials as catalysts to turn technological innovation into full business solutions.
- Facilitate the implementation of an industry-led venture fund in support of 5G-based innovation.
- Unite leading actors in working towards the promotion of global standards.

5G Standardisation: an acceleration of the schedule with Non-Standalone (NSA) 5G NR planned for end-2017

There was much pressure put on the 3GPP to speed up the standardisation process! A recent acceleration followed MWC'17 for the NSA (Non Stand-Alone) version of the 3GPP standard for 5G.

A number of leading MNOs (AT&T, NTT DOCOMO, South Korea Telecom (SKT), Vodafone Group, BT Group, Telstra, KT Corp, KDDI, Telia Company, Swisscom, Telecom Italia (TIM), Etisalat, Sprint, LG Uplus and Deutsche Telekom) and equipment vendors (Ericsson, Qualcomm Technologies, Intel, Vivo, LG Electronics, Huawei and ZTE) at MWC called for an acceleration of the 5G New Radio (5G NR) standardisation process (i.e. Release 15). The objective was to enable large-scale trials in 2019 instead of 2020. The group suggests adding an intermediate milestone (set by the end of 2017) to complete specification documents. Verizon, Samsung and Nokia voted against.

Following an agreement in 3GPP in March 2017, the non-standalone (NSA) implementation of 5G New Radio (NR) was moved forward to December 2017. This intermediate milestone will enable 3GPP-based large-scale trials and deployments as early as 2019 instead of 2020 as initially planned. The work plan proposal for the first 3GPP 5G New Radio (NR) specification will be part of 3GPP Release 15.

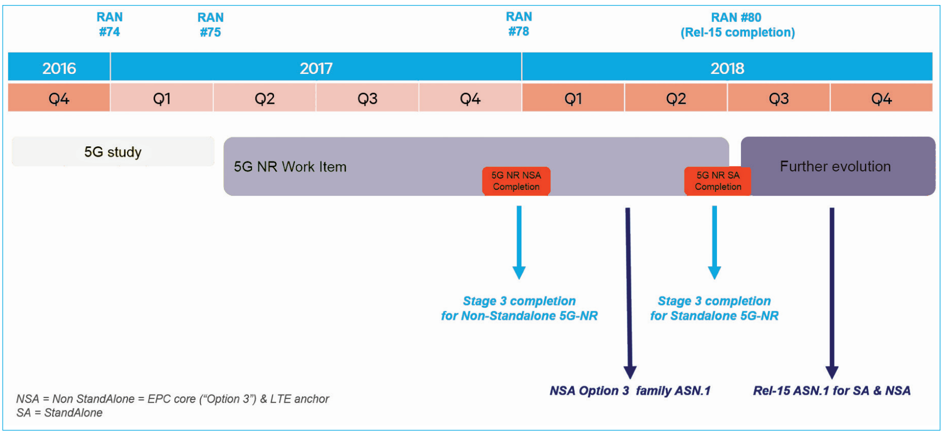


Figure 1: 3GPP standards roadmap
Source: 3GPP

Ten key results from the past 12 months

5G development is accelerating with progress in standardisation, trials, cooperation between main players and projects. We selected ten key topics concerning 5G development in Europe between mid-2016 and mid-2017, as outlined in figure 1.

Launch of phase 2 5GPPP projects

The first call of the 5G-PPP was launched in 2014 with projects starting in July 2015 and the second call was published in 2016. Most Phase I projects will be over at the end of 2017.

In the 2nd phase of 5G PPP projects, there is a special focus on vertical industrial involvement for enabling 5G scenarios. This is a crucial step towards the 5G trial programme phase 3 as indicated in the 5G manifesto and the announced 5G Action Plan for Europe. This will lead to the EU trial roadmap for implementation with end-to-end 5G platforms from 2018 and beyond integrating multiple technologies that will be operated in a pre-competitive environment showcasing several vertical-sector cases (eHealth, Manufacturing, Media, Automotive, etc).

On June 1st, 2017, new projects were launched as part of phase 2 of the 5G PPP. 21 new 5G-PPP Projects have been retained from the 101 proposals received.

Phase 3 will focus on large scale trials.

Cooperation agreements

In 2015 partnerships were signed in Asia, Russia and North America, including MoU with associations such as 5G Mobile Communications Promotion Forum Japan (5GMF), the 5G Forum (South Korea), IMT-2020 (5G) Promotion Group (China) and 5G Americas.

In March 2017, following the Joint Declaration by the European Commission and the Brazilian government at MWC'16, the 5G Infrastructure Association and Telebrasil – Projeto 5G, the Brazilian 5G initiative, signed a Memorandum of Understanding to foster industrial collaboration on 5G development.

Second and Third Global 5G events

The inaugural Global 5G event, took place on May 31st and June 1st 2016 in China. The second event took place on November 9th and 10th, 2016 in Rome. The third Event was organised by 5GMF in Tokyo May 24th and 25th, 2017 and was co-located with the Wireless Technology Park 2017. South Korea is expected to host the 4th Global 5G event from November 22nd to 24th 2017.

5G at MWC'17 & EUCNC 2017

The 5G Infrastructure Association invited press, media and ICT industry analysts to a briefing on the "Evolution of European 5G initiatives from Research to Trials" at Mobile World Congress 2017. Key topics during Mobile World Congress 2017 were 5G use cases, deployment costs, and 5G spectrum. 5G PPP projects showcased demos, organised panels and sent keynotes speakers. All players of the ecosystem took the opportunity of the MWC'17 to put pressure on the 3GPP in an attempt to speed up the standardisation process.

The briefing focused on the "evolution of European 5G initiatives from Research to Trials". Highlights of the progress achieved to date by the 19 strategic phase 1 projects were presented in the "5G innovations for new business opportunities" white paper. The MWC'17 was also the opportunity to release the 5G Pan-European Trials Roadmap Strategy. See p. 76 for more details.

EuCNC accounts for one of the biggest dissemination opportunities for 5G PPP projects alongside with MWC. The 2017 edition took place in Oulu, Finland (12-15 June 2017). See p. 77 for more details.

Cooperation between 5G PPP projects: workshops

Various workshops took place involving the cooperation of 5G PPP projects, such as:

- A cross-project workshop was held in Athens on February 6-7, 2017. The workshop, jointly organised by a set of 5G PPP Phase 1 projects after the initiative of METIS-II, was the third in the series, after those in Kista in 2015 and in Valencia in 2016. The workshop was a significant effort of the project METIS-II, which aims to bring the European research activities on 5G together, to enable collaboration among the ongoing projects to create a unified European view, and to ensure a successful start of standardisation of 5G system in the next months.
- METIS-II, FANTASTIC-5G, mmMAGIC, 5G-CROSSHAUL and Flex5GWare organised a joint Workshop with a focus on the 5G RAN design. The workshop was co-located with IEEE ICC 2017 (Paris - 21-25 May 2017).
- mmMAGIC, METIS-II, 5G-Crosshaul and 5G NORMA organised a workshop on RAN architecture and integration on March 30-31, 2017 in London.
- METIS-II, FANTASTIC-5G, mmMAGIC, 5G-Crosshaul, Flex5Gware 5G PPP projects jointly organised along with IEEE Globecom 2016 the 2nd International Workshop on 5G RAN design on 8 December, 2016 in Washington DC, USA.
- 5G NORMA and COHERENT 5G PPP projects jointly organised a workshop on VirtualizedCoordinated Spectrum Access for 5G Communications Systems at ISWCS (Poznan, Poland –September 2016).
- Flex5GWare arranged the "5G Focus day" on June 21st, 2017 where 5G highlights were presented and discussed by all organising projects and EU representatives. Demonstrations were also showcased throughout the day long. The "Cloud Technologies and Energy Efficiency in Mobile Communication Networks" workshop was also organised at CLEEN'17 on June 22nd, 2017.

White papers

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

- The 5G PPP 5G Architecture White Paper was revised. The latest version was released in July 2017. This is the updated version of the 5G PPP View on 5G Architecture after incorporating the results of public consultations and discussions.

- The Software Network Working Group (WG) of 5G PPP published in January 2017 the "Vision on Software Networks and 5G".
- The 5G PPP Security WG: Phase 1 Security Landscape is the result of joint work between 5G-ENSURE and 8 other 5G PPP phase 1 projects: 5G-Ex, 5G-NORMA, CHARISMA, COGNET, SONATA, SPEED-5G, SELFNET, and VirtuWind. It provides an in-depth analysis of major security topics: new 5G security requirements and risks, 5G security architecture and how it fits with that of the 3GPP, access control in 5G, privacy in 5G, trust in 5G, security monitoring and management, slicing, standardisation on 5G security.
- The "Cognitive Network Management for 5G" White Paper issued in March 2017 (version 1.02) is another example of successful collaborative work involving 5G PPP phase 1 projects.

Several 5G trials underway

A number of 5G commercial launches are already announced by mobile operators around the world. At regional level, South Korea and the USA have already announced 5G commercial launches. In Europe, TeliaSonera should be the first MNO to launch services in Sweden and Estonia.

Several trials or demonstrations in the mmWaves are ongoing across the world, in Australia, China, Japan, Singapore for APAC, in the USA and Brazil for America, in the UK, Germany and France at European level. The idea is to better understand mmWave propagation characteristics.

The 5G Pan-European Trials Roadmap is developed by the Trials Working Group (WG) of the 5G Infrastructure Association. Please see section 5.3 for more details on the activities of this WG.

5G spectrum: pioneer bands identified

Timely access to suitable spectrum is one of the most important keys for 5G to become a success. It is also reasonable to consider it a competitive advantage with respect to equipment availability and good planning of roll out strategies. For trials and early commercial deployment it is necessary to get access to spectrum early. It is useful to have a limited but sufficient number of bands identified for both industries and spectrum authorities to gain experience with 5G systems. For Europe the following pioneer bands have been suggested by the EU's RSPG Opinion:

- Low band 700 MHz,
- Middle band 3.4 – 3.8 GHz, and
- High band 24.25 – 27.5 GHz (26 GHz).

The "Spectrum for 5G" workshop was organised on 7th June 2017 in Brussels at the initiative of the 5G-IA Spectrum WG. The workshop brought a wide range of key players in the field, around 4 sessions covering the following areas: spectrum for 5G applications, millimetre wave technology, management of 5G spectrum, and timely access to spectrum

Vertical markets look promising

5G PPP phase 2 projects put a specific emphasis on vertical markets. Automotive, Energy, eHealth, Media & Entertainment a Factory of the Future look promising as they could fuel 5G growth. Transport & logistics, Agriculture & forestry could also contribute to 5G growth. Interest in 5G from vertical sectors was illustrated by the creation of the 5GAA in late 2016. Founded by Audi, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia and Qualcomm in September 2016; 5GAA plans to work on:

- Defining and harmonizing use cases
- Supporting standardisation and regulatory bodies
- Addressing vehicle-to-everything technology requirements
- Running joint innovation and development projects

In some verticals, large industry alliances or consortia including the EATA and 5GAA in the automotive sector or the IIC in the manufacturing industry are well-positioned to partner with 5G players to establish, drive and shape 5G adoption within their verticals. Connected Cars is considered as one of the verticals priorities for a strategic 5G European roadmap targeting vertical use cases. There are several other vertical segments such as eHealth, the various Smart X areas (X= Cities, buildings, transport, agriculture, energy) and the Public Safety, where a coordinated approach will be addressed.

From 5G exploration to 5G deployment– timeline

As already mentioned previously, the final target is to roll out commercially available 5G communication infrastructure by 2020. To achieve this goal, various milestones have been set, as pictured in the table below:

Date	Milestones
2014-2015	Exploratory phase to understand detailed requirements on 5G future systems and identify most promising functional architectures and technology options which will meet the requirements. These activities will build on previous research work in industry and research framework programmes as well as global activities in other regions and standard bodies.
2015-2017	Detailed system research and development for all access means, backbone and core networks (including SDN, NFV, cloud systems, undedicated programmable hardware...) by taking into account economic conditions for future deployment.
2016-2018	Detailed system optimization by taking into account all identified requirements and constraints. Identification and analysis of frequency bands envisaged for all 5G communications and final system definition and optimization by means of simulations, validation of concepts and early trials. Contributions to initial global standardisation activities e.g. in 3GPP. Preparation of WRC 19. Support of regulatory bodies for the allocation of newly identified frequency bands for the deployment of new systems. New frequency bands should be available around 2020.
2017-2018	Investigation, prototypes, technology demos and pilots of network management and operation, cloud-based distributed computing and big data for network operation. Extension of pilots and trial to nonICT stakeholders to evaluate the technical solutions and the impact in the real economy. Detailed standardisation process based on validated system concepts by means of simulations and close to real world trials.
2018-2020	Demonstrations, trials and scalability testing of different complexity depending on standard readiness and component availability
2020	New frequency bands available for trial network deployment and initial commercial deployment of new systems. Commercial systems deployment under real world conditions with selected customers to prepare economic exploitation on global basis.

Table 1: From 5G exploration to 5G deployment
Source: 5G PPP

In addition to the overall milestones leading up to 2020, another important aspect to consider is standardisation. It is clearly expected that the core of the 5G standardisation related to mobile technologies will happen in the context of 3GPP, e.g. 3GPP RAN, CT and SA groups. However the 5G Infrastructure PPP members will also contribute to a wide range of other standardisation bodies (IETF, ETSI, ONF, Open Daylight, OPNFV, Open Stack...). Standardisation was boosted in March 2017 after the MWC'17 on the initiative of 22 vendors (Qualcomm, Intel, Ericsson, Huawei, ZTE and LG) and MNOs (AT&T, NTT DoCoMo, SK Telecom, Vodafone, BT, Swisscom, TIM, Etisalat, Deutsche Telekom, Vivo, Sprint, Korea Telecom, and Telstra). They were willing to accelerate the standardisation process and enable commercial deployment in 2019 or 2018 instead of 2020 as currently planned. Following this move, 3GPP agreed to work on a work plan proposal for the first 3G00 5G New radio (NR) specification as part of Release 15.

H2020 5G PHASE 1 PROJECTS

5G-CROSSHAUL

It is foreseen that transport networks should be evolved to support 5G radio access network (RAN) with densely deployed transmission/reception points (TRPs). In particular, integration between backhaul and fronthaul is anticipated in a bid to deliver a truly scalable transport network that can flexibly adapt to diverse classes of traffics. In correspondence, 5G-Crosshaul project has put forward an innovative 5G transport network architecture, which unifies existing and new fronthaul and backhaul technologies/interfaces into a common-haul SDN/NFV-based packet switching network. Remarkably, the proposed SDN/NFV-based framework also serves as a foundation to implement the concept of network slicing for more flexible, sharable and cost-effective solutions. It is worth noting that the solution aligns with the architecture in ETSI NFV ISG and embraces the SDN concept of decoupled data and control planes with a logically centralized control, and exposure of abstract resources and state to applications. Moreover, the SDN framework considered aligns with open-source projects ONOS and OpenDayLight. Notably, the project has also aimed to analyse the cost model of the proposed crosshaul solutions catering for 5G RAN architecture and use cases.

The enabling mechanisms of the proposed 5G-Crosshaul solutions include a unified data plane solution featuring a multilayer architecture supporting a combination of circuit switching and packet-switching, wherein circuit-switching is provided to handle fronthaul traffic with extremely low latency requirements, and packet-switching unification is facilitated by a common frame format based on both MAC-in-MAC and MPLS-TP layer 2 technologies. In terms of transmission technologies, several new optical and wireless transport mediums such as compressed common public radio interface (cCPRI) and mmWave have been studied in this project. For the control-plane, an integrated management and orchestration (MANO) solution comprising hierarchical control of different technological or administrative network domains has been employed, with all interfaces (Southbound and Northbound) defined. A few different applications that can be launched on top of the Northbound interface have been developed in 5G-Crosshaul, namely 1) Resource Manager Application (RMA) and Virtual Infrastructure Manager and Planner (VIMaP) for dynamic network reconfiguration, 2) Energy Management and Monitoring Application (EMMA) for optimization of energy consumption by activating and deactivating network elements depending on the context, 3) CDN Management Application (CDNMA) and TV Broadcasting Application (TVBA) for media distribution, and 4) Mobility Management Application (MMA) for mobility management optimization even in the most challenging scenarios (e.g., high-speed trains). Apparently, the objectives of these applications a to permit a more agile and flexible context-aware transport network that can be re-configured dynamically.

A number of trials have been conducted or are currently being planned, in order to verify the innovative concepts that have been put forward by 5G-Crosshaul. In 2016, a month-plus trial in Berlin embracing real-world conditions has delivered an integrated fronthaul/backhaul with sub-millisecond latency and Gbps throughput, which sets stage for cost saving, flexibility in real-world deployable 5G architecture. The topology of an mmWave mesh-based crosshaul network trial in Berlin is depicted in Figure 1. Several trials relating to agile re-configuration of 5G-Crosshaul, such as resource management over a hierarchical 5G-Crosshaul control infrastructure, end-to-end network resource setup, and restoration in multi-domain multi-technology integrated fronthaul/backhaul (including mmWave and multi-layer optical domains), will also be undertaken. In addition to the trials in Europe, a trial on energy management of 5G-Crosshaul Radio over Fibre (RoF) infrastructure will be set up in High Speed Train of Taiwan. Finally, video on demand and live video streaming over a SDN/NFV-based Crosshaul composed of mmWave and optical technologies will be demonstrated, along with features of energy and bandwidth optimization. In all these trials and demonstrations, certain key performance indicators (KPI) such as latency, jitter, throughput, energy efficiency, and number of supportable connections, will be measured to confirm the feasibility of 5G-Crosshaul solutions in practical scenarios.

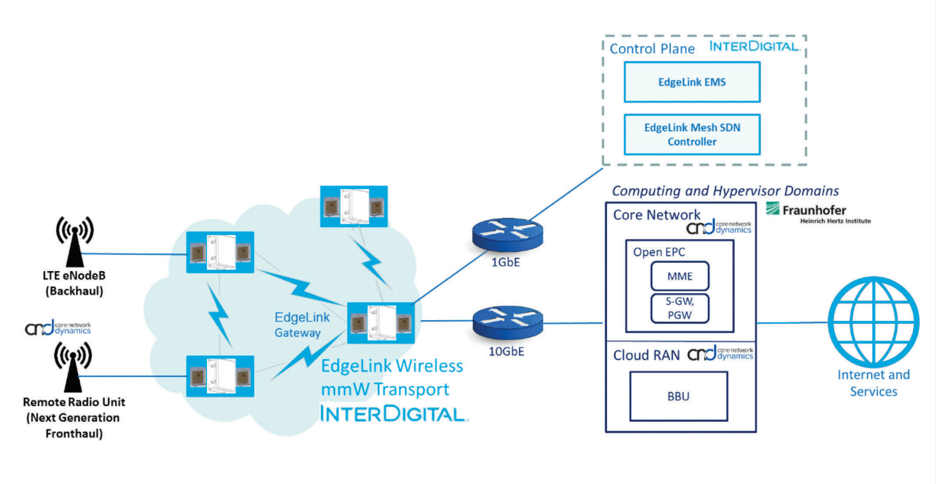


Figure 2: The topology of an mmWave-based transport network integrating backhaul/fronthaul traffics in Berlin Trial

5G-Crosshaul has contributed to relevant standard bodies such as IETF DETNET, IRTF NFVRG, ITU-T 2020 FG, IEEE1914, and eCPRI. Furthermore, some remaining gaps for future standard have been identified and elaborated in the ETSI white paper "The convergence of fronthaul and backhaul through softwarization and virtualization", which will be published soon.

5G-ENSURE

5G-ENSURE (www.5gensure.eu) focuses on driving impact across technology innovations and standardisation for a secure, resilient and viable 5G network, thereby creating and sustaining new business opportunities. 5G security is envisioned to be natively supported by the 5G infrastructure for ensuring the correct support of 5G use cases and to fulfil the needs coming from vertical industries. For this to happen, the project has illustrated 5G security and privacy requirements through representative use cases and has developed possible 5G security and privacy measures (enablers). In the meantime, the project has worked on the design of the security 5G network architecture to ensure that security and privacy properties are supported through their underlying architecture.

During the second year, a lot of advancements have been made towards the accomplishment of 5G-ENSURE security vision:

- The set of security enablers specified in the first year have been software released. A total of 17 enablers have been developed and released providing a way to concretely demonstrate their capabilities and operation in a 5G network. This has been achieved with the set-up of the 5G test bed. A second final set of security enablers have just now been specified as completely new solutions as well as additional features of the enablers already available. They contribute to have a total of 24 enablers available for the end of the second year, each one delivered with an open specification and with a software release for demonstration and integration purpose.
- The launch of 5G test bed, designed based on interconnected nodes residing in Rennes, France, and Oulu (Finland). The test bed shows, on a small scale, what a 5G network could be like, by enabling in the meantime the development and testing of complex end-to-end, multi-domain, multi-operator 5G oriented security scenarios. The test bed set-up satisfies the requirements of the 5G security enablers against the threats emerging from identified use cases and it is used to demonstrate the security enhancements provided by the capabilities/features of each delivered enabler but also to showcase the added value of combining them to improve access control, privacy, trust, as well as network management and virtualization security.
- The delivery of the 5G-ENSURE security architecture. It builds on the current 3GPP security architecture (TS 33.401) where the network and its security functionalities are represented in terms of domains, strata and security feature groups. However these building blocks have been revised in terms of concept and extended to capture the characteristics of 5G system such as the strong dependency on software defined networking and virtualization and the need to support multi domains and verticals use's case. Therefore the concept of domain has been revised to distinguish between infrastructure domains, related to physical network aspects, and tenant domains, reflecting the logical network aspects. These domains are strongly connected to the 5G trust model as many of the domains will typically be coupled to administration/ownership. The strata concept has been extended to characterize the different functional aspects related to the provisioning of a service. Finally, the security feature groups concept that comprise the set of security capabilities required to protect and uphold the security of the various domains and strata have been replaced by Security Realms and Security Control Classes to better capture "Where" Security is needed and "What" type of Security is needed. Taking advantage of the fact that 5G Security Architecture (draft) has been defined each of the 5G-ENSURE enabler has been linked to the major building blocks of the architecture showing the enhancements provided in terms of security and where these are needed.

The software release of the first set of security enablers envisioned to be complemented by the end of the project with the second set under development, together with the availability of 5G test-bed that demonstrates the enablers capabilities, as well as the 5G security architecture to which each enablers link to, are all achievements which allow to progress towards the fulfilment of the 5G-PPP KPIs selected as more relevant for the project. Specifically "creating a secure reliable and dependable Internet with "zero perceived" downtime for services provision" together with "enabling advanced user controlled privacy" are the KPIs where the project is contributing.

5G Ex

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.

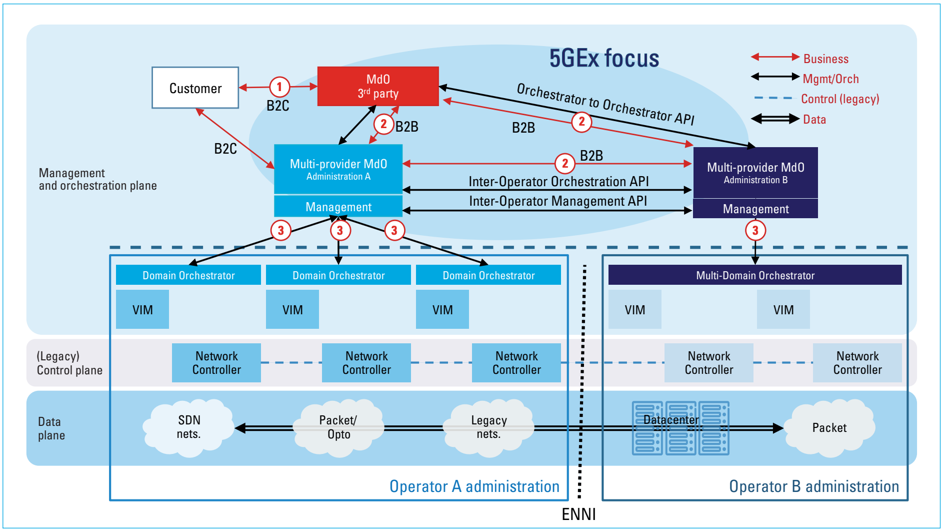


Figure 3: 5GEx reference architectural framework

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 3, while the functional blocks of the multi-domain orchestrator (MdO) are depicted in Figure 4.

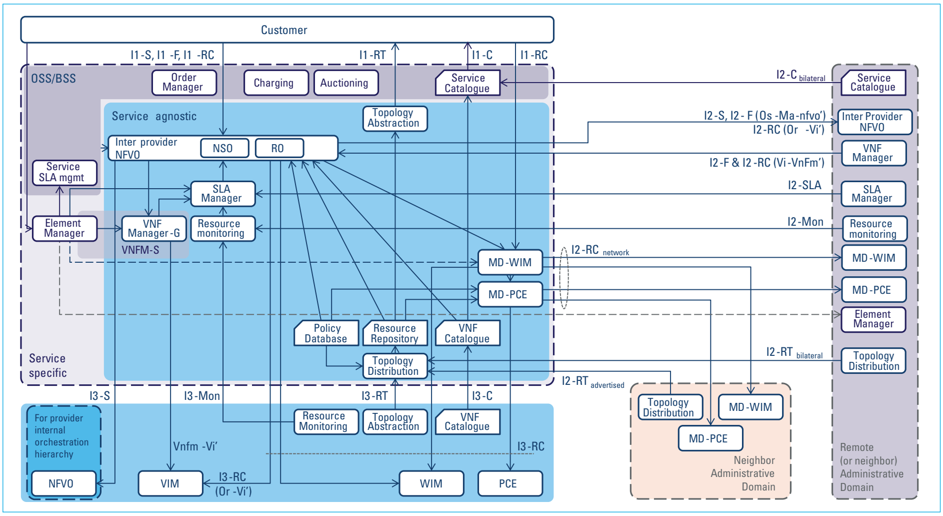


Figure 4: Functional model of multi-domain orchestration architecture

During the second phase of the project (M9 to M18), 5GEx has focused on refining the design of the multi-domain, multi-provider orchestration architecture – including the study of the business aspects, necessary step to ensure that multi-provider collaboration increases operators' profit – and implementing the first and second releases of the designed architecture's prototype. A significant outcome of this period has also been the use of the sandbox environment to deploy and evaluate the system, already allowing us to collect some very interesting results and lessons learned.

The second release (P2) of the integrated prototype reference implementation has been released in April 2017. P2 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 a limited set of service KPIs. In addition, P2 provides support for life cycle management of the deployed service. P2 is also capable of provisioning paths over legacy connectivity domains by using its MD-PCE component. Several P2 components have been released as Open Source and are available at the 5GEx GitHub repository (https://github.com/5GExchange/)

The sandbox setup available at April 2017 includes 13 different administrative domains, controlled by 13 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 already interconnects four leading European operators, will enable 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 first release of the prototype implementation, we were able to measure the 5G-PPP service creation time KPI at various interfaces of the MdO, e.g., marketplace (BSS), resource orchestration (NFVO), or even at the individual domain orchestration levels. Preliminary 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.

The project execution follows an iterative process, with three main design–implementation–evaluation cycles, in which the architecture and system design are revisited based on the lessons learned from the integration and experiments. Accordingly, the 5GEx framework is incrementally evolving to its full list of features until the end of the project. This process is complemented with contributions 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.

A 5GEx delegation showed an integrated demo of two project experiments at OFC 2017 in Los Angeles (an event with over 15,000 attendees). The demo (self-balancing robots) showcased in particular the value that 5G Exchange offers to Vertical Industries 4.0 customers. It exhibited how service function chaining can effectively be used to span multiple domains, according to the actual requirements of robots in terms of latency and processing speed.

An evolution of the robots demo and a new one about deployment of virtual CDN caches over multiple domains are being prepared to be showcased in different events, such as the 1st 5GEx Industrial Workshop (Madrid, May 2017).

5G NORMA

Goals of the project: the main objective of 5G NORMA is the definition of a future-proof, QoE/QoS aware 5G network architecture that builds on the most recent trends of network softwarization. More specifically, 5G NORMA builds on the following main 3 innovative enablers: i) the **Adaptive (de)composition and allocation of mobile network functions** between the edge and the network cloud depending on the service requirements and deployment needs, ii) the **Software-Defined Mobile network Control and Orchestration** which applies SDN principles to mobile network specific functions, and iii) the **Joint optimization of mobile access and core** network functions localized together in the network cloud or the edge cloud; and 2 innovative functionalities: i) the **Multi-service, and context- aware adaptation of network functions** to support a variety of services and corresponding QoE/QoS requirements, and ii) the **Mobile network multi-tenancy** to support on-demand allocation of radio and core resources towards virtual operators and vertical market players.

5G NORMA innovations build on specific drivers coming from the most recent research trends on network softwarization, network slicing, and multi tenancy. So far, we specified three novel controllers that take care of different aspects of the network operation, i.e., the Software Defined Mobile Network Controller (SDM-C), Software Defined Mobile Network Coordinator (SDM-X), and Software Defined Mobile Network Orchestrator (SDM-O).

These controllers are strongly related to the network slicing concept: the SDM-C is in charge of QoE/QoS Network Control of dedicated resources within a network slice, the SDM-X coordinates the usage of shared resources (such as spectrum) among different network slices, while the SDM-O orchestrates resources within and across slices. These controllers extend the state of the art controllers defined by different standardisation bodies (e.g., 3GPP, ONF or ETSI/NFV) and are interconnected by different interfaces that are used to perform in a flexible and optimized way all the operation that will be needed in future, network slicing aware, environments.

Major Achievementss: The architecture designed by 5G NORMA relies on the concept of network softwarization to provide the needed flexibility and service awareness that future 5G networks should have. This new enriching paradigm also entails the definition of new procedures that enable, for example, the flexible reconfiguration of the network infrastructure. This is usually not needed in today's network, or at least not with stringent timing constraints, as their physical network function model is not as flexible as their virtual counterpart. Moreover, with the introduction of the network slicing model, the dynamic re-configuration and re-orchestration of the network is even more important. By leveraging the statistical multiplexing gains that heterogeneously demanding network slices may offer, a novel 5G network architecture shall be capable of dynamically re-scaling the extent of a slice, orchestrating and controlling shared network resources in an efficient way.

5G NORMA designed high level procedures for managing such challenging features. This involves the elements of the architecture [1] in all their aspects. The overall framework is given by the 5G NORMA MANO architecture (See Figure 5), which is an extension of the ETSI NFV MANO architecture that considers the requirements introduced by the network slicing paradigm.

1. 5G NORMA, D3.2, "5G NORMA network architecture – intermediate report," Jan 2017

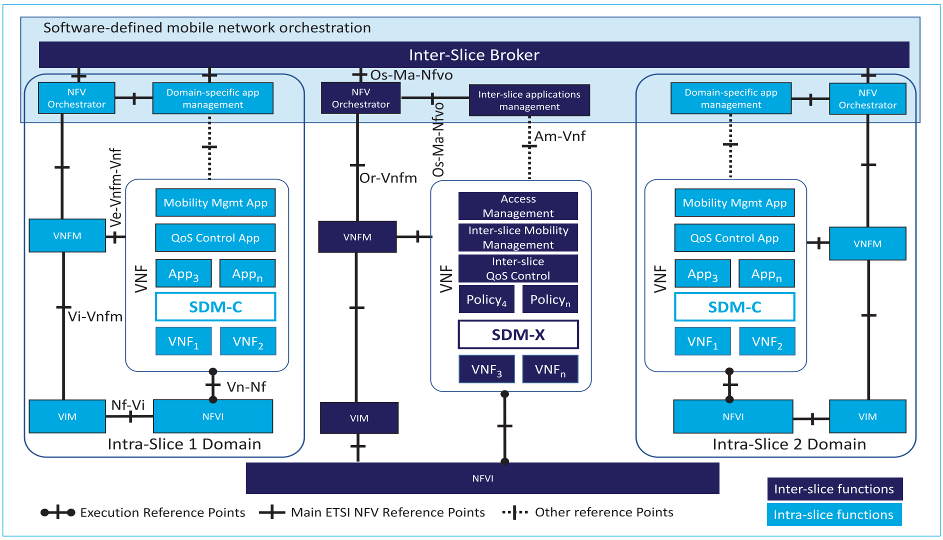


Figure 5: Network slicing aware architecture

A network slice provided by a chain of Virtualized Network Functions may need a re-orchestration for different reasons. We classified them in two categories that are eventually handled in a consistent way: re-orchestrations due to IT resources shortage and re-orchestrations due to QoE/QoS shortage events. The first category relates to the NFV infrastructure realm: a network slice may suffer from the lack of computational resources like CPU, memory or storage, so the orchestrator should re-arrange it by performing one of the usual VNF lifecycle maintenance operations such as scaling it up/out through the VIM and the VNFM. The same concept is valid when the network slice is underutilized and thus scaling it down/in may be a valid strategy. The second category is an innovative feature of the 5G NORMA architecture: while the ETSI NFV MANO elements have a limited view on what NF is placed inside a virtualization container, the 5G NORMA controllers (SDM-C and SDM-X) have full control on the network functions that are composing a network slice. So, if the controllers detect that the QoE/QoS associated to a certain network slice is degrading, they can react by promptly re-configuring the relevant network functions or, if the simple re-configuration is not enough, request to the compound orchestrator (SDM O) more (or different) network resources. Among the possible operations that the SDM O may perform to keep the QoE/QoS experienced by a network slice to the levels required by the SLA, there are the adjustment of the VNF chain that composes a network slice (i.e., change, add or remove a network function) or the addition of more network resources (e.g., spectrum, NFVI resources) to a network slice.

Further details on the 5G NORMA architecture can be found in the project's public deliverables[2].

2. 5G NORMA, D5.2, "Definition and specification of connectivity and QoE/QoS management mechanisms – final report," Jun 2017

Demonstrators: One aim of 5G NORMA is to corroborate the feasibility of the proposed network architecture by implementing part of the functionality in real-world demonstrators. More specifically, 5G NORMA will provide four demonstrators showcasing the innovations designed within the project[3]. Among them, Demo 1 (Native Multi-Service Architecture) and Demo 2 (Service-aware QoE/QoS Control) are directly related to the re-orchestration procedures described above.

Partners: Nokia (DE, FI, FR), NEC (UK), Atos (ES), Deutsche Telekom (DE), Orange (FR), Telefonica (ES), Azcom (IT), Nomor (DE), Real Wireless (UK), King's College London (UK), Technische Universität Kaiserslautern (DE), Universidad Carlos III de Madrid (ES)

Project Coordinator: Peter Rost, Nokia

3. 5G NORMA, D6.1, "Demonstrator design, implementation and initial set of experiments," Oct 2016

5G-XHAUL

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 networks 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** that 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 configure the transport network elements.

During its second year, 5G-XHaul has focused in two major work items. First, evaluating the data and control plane transport architectures defined during the first year and, second, developing the technological components required to implement that architecture, both in the wireless and the optical domains.

5G-XHaul architecture consolidation and evaluation

During the first year of the project 5G-XHaul proposed a novel transport architecture, which has been consolidated and evaluated in this second year.

In the data plane, the 5G-XHaul architecture features a first wireless segment, consisting of a combination of transport nodes operating at 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 the optical access technology, 5G-XHaul proposes a passive solution based on WDM-PON, which can transparently carry backhaul and fronthaul traffic through different wavelengths. In the metro-domain WDM-PON interfaces with 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. TSON is also capable of natively carrying backhaul and fronthaul traffic.

In the control plane 5G-XHaul proposes a hierarchical multi-domain architecture, where technology specific SDN controllers are orchestrated through a multi-domain network orchestrator. In addition, 5G-XHaul has adopted a transport slicing solution whereby per-tenant traffic instantiated at the edge of the 5G-XHaul network is mapped to a set of multi-domain transport tunnels, and tunnel bindings are dynamically updated by the SDN control plane.

The proposed architecture has been evaluated in order to understand its data-plane requirements, i.e. bandwidth at different aggregation points, as well as the scalability of the control plane. An example of the evaluation results is depicted in Figure 6.

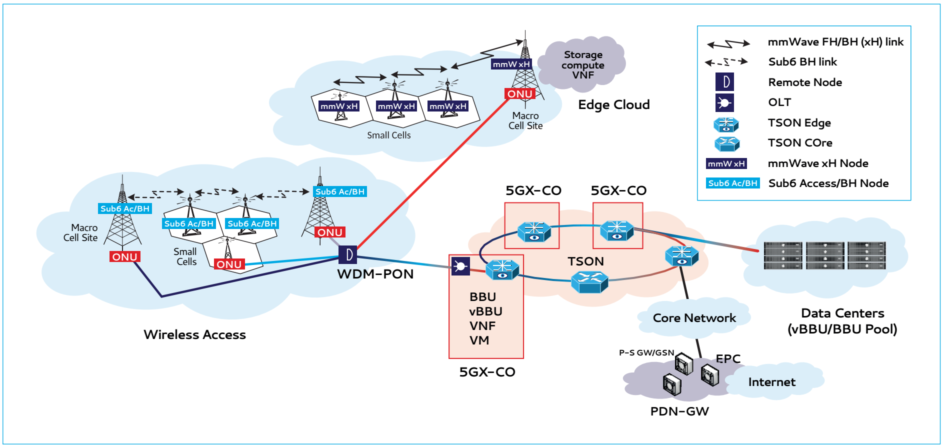


Figure 6: 5G-XHaul Data Plane Architecture

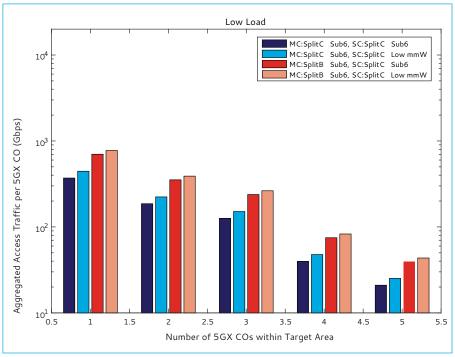


Figure 7: Traffic levels at the 5G-XHaul Central Office in an urban scenario

5G-XHaul Technology Components

During the second year there has been a strong push by individual partners to advance the state of the art on the individual technology components required to enable the 5G-XHaul architecture (see Figure 8). This effort has led to innovations both in the wireless and the optical domains.

In the wireless domain, 5G-XHaul has demonstrated a Massive MIMO array, operating at 2.6 GHz, which integrates 96 antenna elements in an effective form factor, and can transmit up to 16 spatial streams. The 5G-XHaul array features a novel functional split, whereby array processing is embedded into the antenna array. 5G-XHaul has also brought innovations on the mmWave domain, with a novel beamforming IC that enables point to multipoint mmWave mesh networks. Finally, 5G-XHaul has demonstrated the integration of an SDN control plane in mmWave and Sub-6 radio nodes. In order to provide carrier grade service in the wireless small cell backhaul, several centralized traffic engineering algorithms and distributed fast recovery agents have been developed and evaluated.

In the optical domain, 5G-XHaul has pushed the state of the art on the access and metro network segments, through the WDM-PON and TSON technologies. Regarding WDM-PON, 5G-XHaul has developed and demonstrated automatic wavelength tuning capabilities at the ONUs, which will greatly simplify the deployment and maintenance of this technology. In addition, the integration between WDM-PON and the Massive MIMO array has also been demonstrated. Regarding TSON, 5G-XHaul has developed extensions to enable the native support of CPRI and Ethernet traffic, key to providing a unified transport solution for fronthaul and backhaul. Finally, the WDM-PON and TSON technologies have also been successfully integrated.

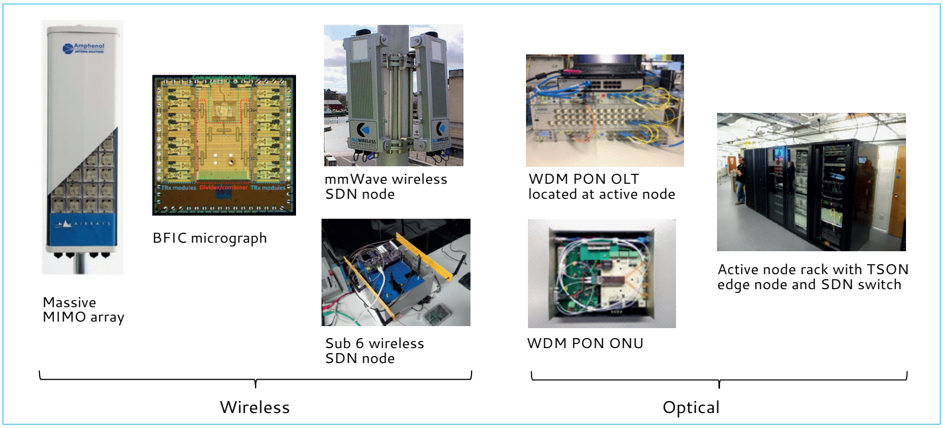


Figure 8: 5G-XHaul technological components

Facing the third and last year of the project, 5G-XHaul is now preparing to demonstrate its transport architecture in a city-wide test bed available in Bristol. This task will require the integration of the wireless, optical and control plane components that have been developed during this second year.

CHARISMA

CHARISMA is developing an innovative distributed-intelligence hierarchical architecture supported by a unified control and management plane for 5G access networks, capable of providing low-latency, enhanced security and open access. One of its key drivers is the intelligent transportation system (ITS) use case, which particularly relies on ultra-low latency, reliable and secure end-to-end wireless network connectivity. A key performance indicator (KPI) targets 5 ms end-to-end latency. Currently (end of 2nd year), CHARISMA has achieved 6.69 ms end-to-end latency, while further reductions closer to the 5 ms KPI are anticipated by project end. CHARISMA also has the objectives of developing a virtualized, secure and open access 5G network (multi-tenancy), via the slicing of network resources to different service providers, and featuring virtualized security functions (VSFs).

During its 2nd year, CHARISMA has successfully achieved its sophisticated multi-layer platform design (Figure 9), realised the enabling technologies, and developed a field-trial showcase demonstrator (based on a 5G mobile bus use case scenario) in Centelles, Spain. Figure 9 shows the final design of the integrated CHARISMA architecture across multiple planes, enabling distributed intelligence operation for the controlling of 5G network resources using SDN and NFV capabilities. The mapping of the bus use case scenario onto the CHARISMA PHY architecture is shown at the bottom of Figure 9.

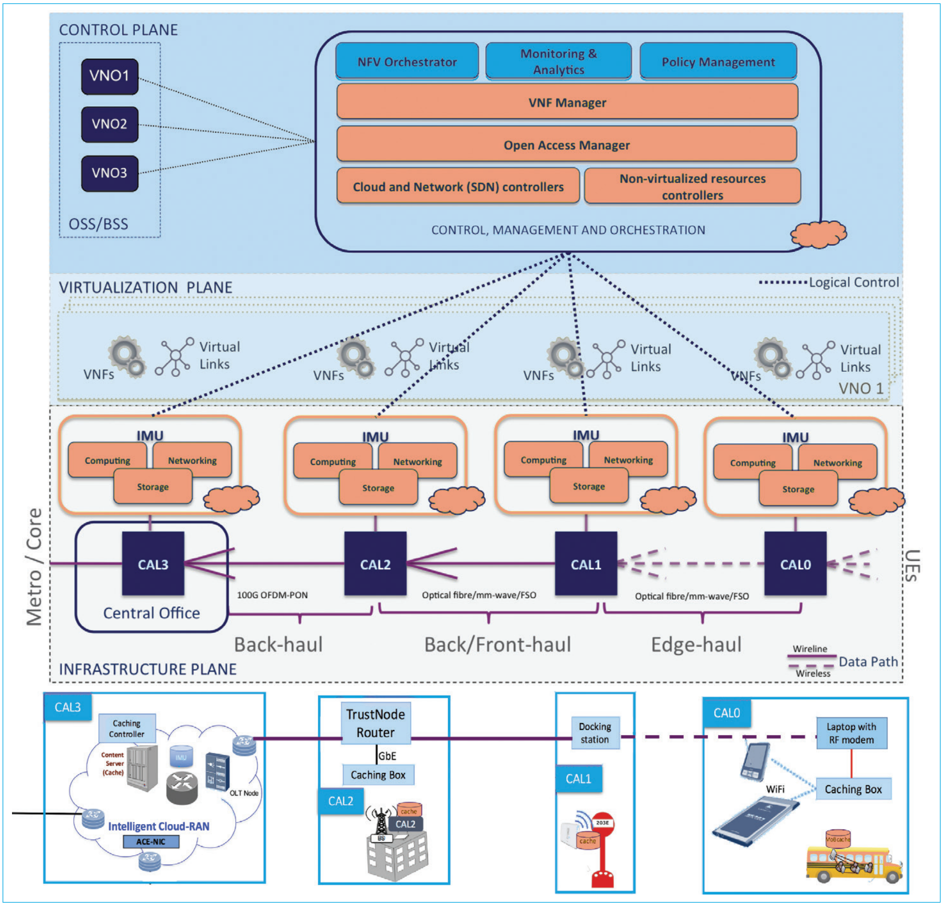


Figure 9: CHARISMA architecture with integrated PHY, virtualized infrastructure, and CMO planes, with the mapping of bus use case scenario onto the CHARISMA PHY infrastructure shown at the bottom

CHARISMA's distributed control, management & orchestration (CMO) architecture features hierarchical intelligence nodes located at points where aggregation of access, backhaul and core networks occur: the Converged Aggregation Levels (CALs). Each CAL node contains an Intelligence Management Unit (IMU) with computing, storage and networking resources, in which network functions can be deployed. Virtual network functions (VNFs) can be chosen to be instantiated (or not) at each CAL node. The Virtualization Plane above the PHY infrastructure layer is where the component elements of the IMU, present at each CAL, are realised. Each of the IMUs above the CAL2, CAL1, and CAL0 are cloudlets of the overall CHARISMA CMO.

CAL3 is associated with the main cloud infrastructure (e.g. Central Office) where the overall centralized M&O system is located. The Control Plane above the virtualized infrastructure layer represents the CMO, comprising controller entities for management and orchestration of the physical and virtual CHARISMA resources, with CMO agents distributed in multiple µDCs closer to the network edge (and the other aggregation points). These include: NFV Orchestrator responsible for life-cycle management of network services; Open Access Manager responsible for the creation of virtual slices and the cloud and network controllers for management of the intra-NFVI-PoP resources and network resources interconnecting the NFVI-PoPs respectively; Monitoring and Analytics (M&A); Service Policy Manager (SPM); Virtualized Infrastructure (VI) security; VI monitoring and virtualized security functions (VSFs). CHARISMA achieves Virtualized security (vSec) via its automated security management and VSFs; the former realised through the SPM and M&A modules, with support from VI security and VI monitoring. To achieve low-latency networking with intelligent policy management CHARISMA is proposing network processing optimization, new data forwarding algorithms and improved transport layers. These are particularly by its high speed OFDM-PON, new IP forwarding algorithms and OpenStack data path offload methods that are implemented to fit the requirements of low latency. The table below presents latency improvements in network nodes.

Network intelligent element	CAL	Reference latency	Improved latency
6Tree algorithm implemented for TrustNode IP routing with CAL's connectivity	2, 3	165 µs	2.5 µs
New intelligent data path offload with NIC	1, 2, 3	200µs-4ms	<10µs
OFDM-PON for CAL connectivity	1, 2	x1	x0.1

Table 2: Latency improvements in network nodes

For the bus use case concept, Figure 10 depicts a concrete mapping of network functions to the CAL nodes of the CHARISMA architecture, where a 5G mobile user (right) uses an application (hosted by the application server shown on the left) through a 5G access network. The user device connects via Wifi to an access point (CAL0), which is located in the bus. The vehicle is connected in the upstream to the radio unit(s) (RU), comprising CAL1. We assume 5G uses a similar protocol stack as compared to LTE, so that the respective protocol layers are depicted in orange and prefixed with 5G. The end-user device contains the complete 5G protocol stack and the TCP/IP stack for the application. In the upstream direction, the 5G-MAC information is transported over Ethernet via a CAL1 node to the 5G digital unit (DU). At the DU (CAL2) the upper 5G protocol layers are terminated for all RUs connected in the downstream direction. The DU VNFs reside in a virtual machine (VM), which allows high flexibility; if e.g., the traffic pattern changes, the entire VM can be moved to another node. From CAL2 upstream, the IP packets from the end-user are passed to the CAL3 node, which provides a VirtualizedPacket Gateway. There, the user data is transported via an IP network to its final destination – the application server. In the bus use case concept of Figure 10, the CAL0 node hosts at least two VMs: 1) the VM to provide the 5G connectivity; and 2) a VM to cache content. CAL1, CAL2, and CAL3 provide the required (virtual) functions for the 5G network, namely RU, DU and Packet Gateway. If required, an additional aggregation layer between CAL2 and CAL1 can be inserted in order to connect a larger number of RUs to a DU.

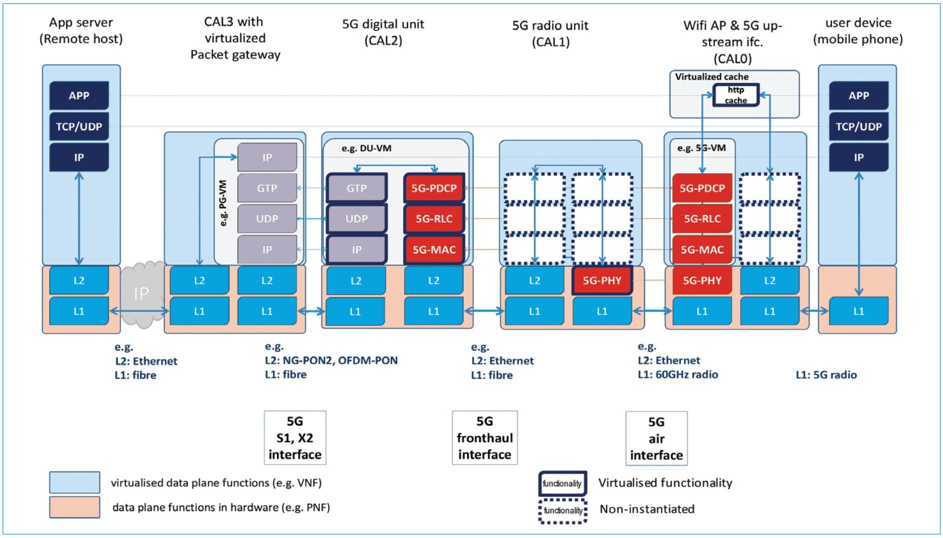


Figure 10: CHARISMA data plane architecture and VNF instantiations for bus use case

COGNET

CogNet believes that autonomic network management based on machine learning is a key technology to achieve almost self-managing networks. A key concept of the project is using network software to forecast resource demand through usage prediction and recognising security or error conditions.

A major component of CogNet is Network Function Virtualization (NFV) which virtualizes network nodes, functions and links, rather than building a network to meet estimated maximum demands. This will play a critical role in meeting changing demands for resources as the network needs to provision itself dynamically.

CogNet is using available network data and applying machine learning algorithms. This is yielding insights, recognising events and conditions, and responding to them. Ultimately, the project will:

- Enable larger and more dynamic network topologies necessary in 5G
- Improve end-user QoS
- Lower capital and operational costs through improved efficiencies

CogNet's architecture complements the NFV architectural framework of European Telecommunications Standards Institute (ETSI), with machine learning capabilities.

The state and consumption records of the hardware resources are gathered in real-time by a data collector from the NFV/SDN-based environment. These records are processed by the CogNet Smart Engine (CSE) periodically or in (near) real-time, to generate insights or to recommend policies.

Real-time analysis is one of the core contributions of this work, which is crucial to 5G network management since it aims to provide immediate response to changes. Further, the CogNet Smart Engine transmits the scores/events to a Policy Engine which will send mitigating actions to the managed environment.

To showcase its work, CogNet has developed several demos; each of which will be migrated to a common infrastructure for validation purposes. These include:

· Noisy Neighbour

'Noisy Neighbour' describes an event in cloud computing where an application's performance is degraded because some of its resources are occupied by other applications. While there should be a clear separation between different tenants on the same physical machine, in practice this isolation of the virtual machines is far from perfect.

CogNet is showing how machine learning solutions can be used to identify the Noisy Neighbour effect. It is a critical building block in creating flexible and reliable orchestration mechanisms for 5G networks, since it can ensure system performance and user experience by identifying and tackling problematic states; e.g. through migrating one of the tenants to another machine, or by allocating more resources.

KPIs are threefold: i)POSITIVE_IDENTIFICATION_RATE: % instances correctly identified; current detection level = 85%-90% ii)FALSE_POSITIVE_IDENTIFICATION_RATE: % identifications that are incorrect; current lab tests = 0% iii)IDENTIFICATION_TIME: time for system to identify and report an incident; current average = 60-90 seconds

· Connected Cars

The objective is to use information such as the user's location, and to direct a reflective ultra-broadband beam towards the highest concentration of users. Prediction of mobility patterns has two core components: (a) classification of mobility patterns, and (b) estimation of future demand. We apply our approach to relatively small areas in the urban transportation network such as road crossings and roundabouts, where the variability of communication needs of moving nodes (vehicles) may be spatial and temporally significant throughout the day.

CogNet is showing how machine learning combined with smart antennae can adapt network coverage. This is based on mobility patterns prediction corresponding to the mobility of cars, to adjust the reflecting mirrors for optimum coverage. Thus, this demo is a cross-layer network management scenario which optimizes the dynamic management of network physical resources based on vehicle traffic demands.

KPIs are twofold:

·PREDICTION_ERROR_RATE: % instances of mobility patterns not correctly identified; current rate = 9%

·PREDICTION_TIME: time for system to predict next mobility pattern change; current value = 60 seconds

· Massive Multimedia Content Consumption

Video and gaming are huge loads on the network and this demo combines targeted real-time and live applications with highly heterogeneous SLA requirements in terms of QoS, restrictive network conditions, changeable bandwidth, latency, jitter and thresholds for error resilience. In terms of data streams, estimating the network capacity even for the near future is challenging. Inaccurate estimates can lead to degraded QoS.

CogNet is showing two aspects here: (a) Identify, classify and analyse different types of network traffic flows (encrypted or not) to optimize the network response; and (b) Support the service provider to organise and schedule resources to ensure service compliance with its corresponding SLA while continuously monitoring its performance.

KPIs are threefold: i)NETWORK_TOPOLOGY_SIZE: introduces switching infrastructure size to ensure cost-efficient prediction by weighting performance and cost trade-off ii) AVERAGE_BANDWIDTH: bandwidth provided for volume of streaming sessions iii) AVERAGE_JITTER: jitter for a volume of streaming sessions

CogNet concludes in December, 2017.

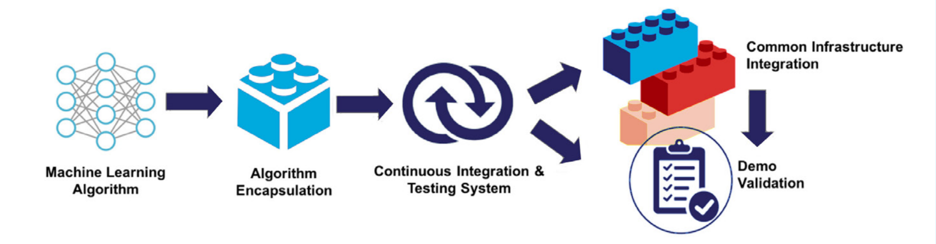


Figure 11: CogNet's procedure and assets for integration and validation

COHERENT

The COHERENT project designs, develops and demonstrates a unified control and coordination framework for 5G heterogeneous radio access networks (RANs). It has three technical focuses: software defined networking (SDN) for RAN programmability, efficient radio resource modelling and management, and flexible spectrum management.

Based on the main results from the first year, and particularly following the proposed flexible RAN control and coordination architecture, in the second year COHERENT has concentrated on RAN programmability and SDK, RAN coordination algorithms, RAN slicing, flexible spectrum sharing, and demonstration development. The results have been reflected in the contributions submitted to 3GPP and ETSI BRAN. COHERENT partners have submitted 20+ contributions to 3GPP RAN1 and RAN3 in the second project year. In ETSI BRAN, the proposal "Study of central coordination of RLANs operating in the 5 GHz frequency band" mainly backed by COHERENT partners has been approved as the work item.

The COHERENT project has released the first version of RAN SDK (Deliverable D2.3), which can be utilized to develop RAN control applications. The SDK currently fully supports WLAN and has preliminary support for LTE small cells. Full LTE support, based on the OpenAirInterface platform (https://www.openairinterface.org) and the CommAgility small cells, will be provided in the second release. The source code has been released under 5G-Empower[4], OpenAirInterface[5], and Mosaic-5G[6].

COHERENT continued the development of the flexible spectrum management framework for heterogeneous RAN where different spectrum sharing options including licensed shared access (LSA) are integrated. COHERENT aims to utilize the proposed control and coordination framework to improve the spectrum management in densified radio environment. The spectrum management demo and spectrum trial based on the research outcomes are under development.

In the 2nd year, COHERENT has the particular focus on the SDN for RAN slicing and RAN virtualization. The demos for RAN slicing have been built based on OpenAirInterface and 5G-EmPOWER platforms. The objective is to show the novel concept of the heterogeneous RAN slicing developed in the project. The demo showcases a solution provided by a newly introduced coordination framework, new RAN control components, and the combination of SDN and network function virtualization (NFV) to enable flexible and programmable network slicing in RAN.

4. https://github.com/5g-empower
5. https://gitlab.eurecom.fr/oai/openairinterface5g
https://gitlab.eurecom.fr/oai/openair-cn
6. https://gitlab.eurecom.fr/mosaic-5g/mosaic-5g

The demo shows how to slice a cloudified radio access network that consists of a fronthaul/ midhaul segment between the remote radio unit (RRU),distributed unit (DU), and centralized unit (CU) and a backhaul segment between the CU/DU (i.e. eNB) and the RAN controller. Through the separation of the RAN control and data plane coupled with the virtualized control functions and control delegation features, real-time control and coordination applications can be implemented in support of fine-grain RAN programmability. This allows different levels of coordination among RAN infrastructure elements by dynamic placement of virtual control functions following SDN and NFV principles for adapting control over time and for easing network evolution to the future. The setup of the demo by the OpenAirInterface platform is shown below:

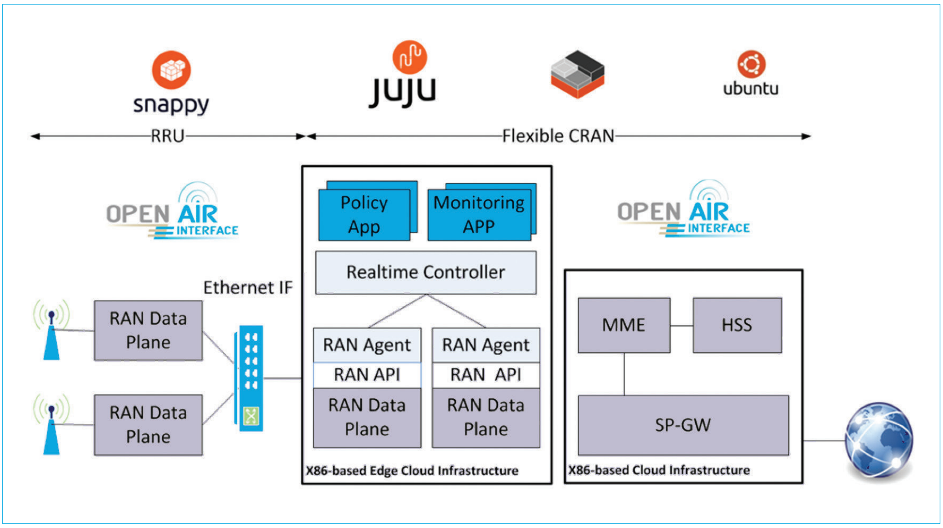


Figure 12: OpenAirInterface platform

Similarly, for the Wi-Fi segment the demo based on the 5G-EmPOWER platform shows how custom resource allocation schemes can be deployed with a slice. This is done starting from a slice template containing the slice definition and the associated resource allocation policy. The underlying system enforces strict performance isolation between mobile virtual network operators (MVNO) and ensures efficient resource utilization across the network in spite of the nondeterministic nature of the wireless medium. The setup of the demo is depicted in Figure 13.

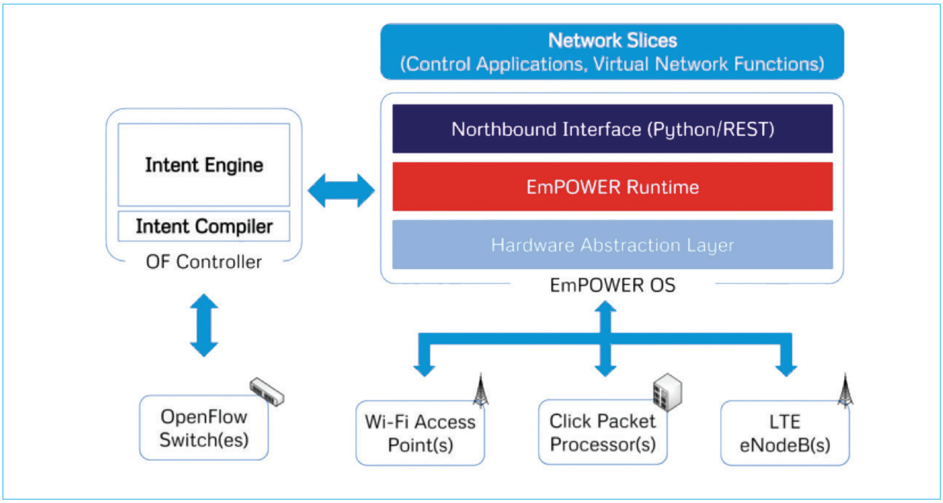


Figure 13: 5G-EmPOWER platform demo

FANTASTIC-5G

FANTASTIC-5G's main objective has been to propose and investigate enablers on PHY/MAC for the AIR interface of 5G NR (New Radio), to build up consensus between the relevant players and to push promising concepts towards 3GPP. The ultimate target is to enable 5G to efficiently support various services and the related use cases. Consistent with 3GPP those services are: eMBB (enhanced Mobile BroadBand), mMTC (massive Machine Type Communications) and URLLC (Ultral-Reliable Low Latency communications)[7]. Further services being considered by the project, which are of relevance for 5G as well, but not in the focus of the first phase of NR specifications in 3GPP, are Broad-/Multicast (BMS) and Vehicle to anything (V2X).

For achieving this target various technologies are required to handle various aspects related to the different kinds of data transfer. While 5G will use frequencies beyond 6 GHz, the project's original focus has been to stay below. In the following we provide some quick insights on the outcomes the project has generated. Due to the tight space constraints we restrict this article to some selected areas staying rather high level. For a broader view in general and a deep dive into specific items the interested reader is referred to the deliverables being generated by the project (to be found at the homepage of the project: http://fantastic5g.eu/).

In order to achieve the ambitious targets of 5G NR, we worked on both link and system levels. One of the key enablers of the link level is the selected waveform. The baseline to compare waveform proposals against has been CP-OFDM as e.g. applied in 4G. While CP-OFDM is a reasonable selection in general, some of its characteristics might be improved upon. The project has followed two different variants for improving CP-OFDM with various flavours for both. The first category applies a filtering function per

7. Within the project we have initially used a different naming being consistent to 3GPP (MCC – Mission Critical Communications - instead of URLLC and MMC – Massive Machine Communications - instead of mMTC). In the following we use the 3GPP terminologies.

subcarrier. Variants we have investigated have been: FC-OFDM (Flexibly Configured OFDM), P-OFDM (Pulse shaped OFDM), Frequency spreading Filter-Bank Multi-Carrier/Filter-Bank Multi-Carrier (FS-FBMC/FBMC), FBMC with QAM signalling (QAM-FBMC) and Zero-Tail-spreading OFDM (ZT-DFT-s-OFDM). The other line we have followed has been per sub-band filtering: Universal Filtered OFDM (UF-OFDM), Filtered OFDM (F-OFDM), Block-Filtered OFDM (BF-OFDM). Following 3GPP the partners in the project have extended these investigations by including windowed variants of OFDM (WOLA – Weighted OverLap and Add). The project has both provided improvements for the single candidates related to various aspects such as transceiver complexity and parameter optimizations for various scenarios and has conducted a major simulation campaign with calibrated simulators to directly compare the candidates. In a nutshell the outcomes of this campaign have shown that each variant has its merits. According to 3GPP both windowed and sub-band filtered variants based on CP-OFDM are selected as options under the constraint of having transparent transmitters. While per-sub-carrier filtering is currently not considered, the next phase of 3GPP might still allow for those.

Furthermore, without going into detail here, the project has produced major innovations and has provided significant insights for various air interface enablers related to modulation (FQAM) and coding (enhanced Turbo Codes, Polar Codes, LDPC), PAPR reduction techniques and HARQ (e.g., related to enriched and early feedback).

5G will be (as 2G, 3G and 4G have been) packet-switched. So, we need to employ structures for controlling the flow of packets from and to different sources/recipients. Therefore, the project has dealt with all relevant aspects related to frame design. We have proposed a reasonable set of fundamental design choices (such as bandwidths and reasonable subcarrier spacings to be supported, efficient resource block definitions), developed sub-frame configurations both for FDD and TDD allowing for energy and resource efficient data transfer, designed and investigated features (tiling concept, mini-slots, TTI tuning) allowing higher layer mechanisms such as packet scheduling to make use of the high number of degrees of freedom without being overly complicated. Furthermore, we have developed concepts for the control channel following different design targets (e.g. in-resource control) compared to 4G. These concepts avoid the so-called 'race to the bottom' (i.e. no need to configure the respective resources for the weakest possible link), allow for data and control to share the reference symbols, allow to make use of rank 1 precoding, if respective channel state information is available and have more degrees of freedom for designing the DCIs (Downlink Control Information elements).

Related to Radio Resource Management (RRM) we have enhanced the state machinery as used in 4G by introducing a new (third) state being tailored to devices transmitting very small packets in a sporadic manner while requiring very long battery life times and thus mechanisms for highest energy efficiency. At system level, multi-node connectivity is seen as one of the key enablers to increase both capacity (e.g. having devices to have concurrent connections to low-band macro-cells and high-band (mmW) capacity nodes) and reliability (by allowing for data duplication). We have investigated the various options (inter-frequency and intra-frequency, inter-site and intra-site) and have developed concepts for mobility in single- and multi-connectivity scenarios. Empowered by the flexible frame design described above we have looked into dynamic resource allocation mechanisms allowing for efficient use of the available degrees of freedom and benefitting on context awareness.

While seen as one of the key enablers for a very long time already, MIMO has still not yet fully matured and is still not able to efficiently collect all potential gains. The most recent development is massive MIMO (in the project we have mostly used the term 'enhanced MIMO', to reflect the fact that in the frequency regions below 6 GHz – the focus of the project – the number of antennae being installed grows significantly compared to e.g. 4G implementations, but still is not massive e.g. compared to the potentials in higher frequency regions). We have dealt with various relevant aspects related to system level integration of massive MIMO such as hardware calibration and robust precoding to mitigate residual calibration errors. Additionally, we have developed an overarching framework for massive MIMO and Coordinated Multi-Point (CoMP) in FDD/TDD downlink transmissions with hybrid beamforming. This framework contains 10 fundamental enablers including items known as Grid of Beams (GoB), Coded CSI RS (Channel State Information Reference Signals), enhanced

CSI reporting, cooperation areas, cover shift concept, etc.

One of the major experience degrading aspects when using wireless services is related to inconsistent performance. For efficiency reasons current and future wireless communication networks are using a given carrier frequency in every transmission point of the macro layer. With doing so, some areas are having a similarly strong connection to two or more cells. In traditional networks with the device being exclusively connected to a single basestation the transmission from the others is interfering the signal of interest. Therefore, mechanisms coordinating the transmissions of adjacent cells have been under investigation for a long period already. While major advances have been made, there is still room for improvement. So, the project has dedicated efforts towards network based interference coordination. Schemes we have studied are e.g. on-demand power boost and cell muting, inter-cell coordinated rank adaptation, inter-cell interference shaping, flexible macroscopic combining, etc.

Traditionally, cellular networks rely on scheduled unicast transmissions between basestation and the connected devices. For 5G it is foreseen that advanced connectivity options such as Device-to-Device (D2D), contention based access, and broad-/multicast will be of high value. For the former we have looked into mechanisms for proximity discovery making use of full-duplex transmissions. By combining D2D and content caching we have investigated to what extent the network can be offloaded. For being able to include mMTC services into the cellular network we have developed respective access protocols (one-stage, two-stage) in combination with the related PHY layer concepts (e.g. sequence design, sequence detection, multi-user detection, etc.). We have identified a multitude of variants and have conducted a comparison study comparing access reliability, protocol throughput, access latency and protocol overhead. While already being supported in 4G, broad-/multicast services (BMS) have not yet widely applied. With 5G it is foreseen that several use cases may highly benefit from this kind of access (e.g. during concerts and sport events). So, we have improved the state-of-the-art enabling BMS to benefit from non-orthogonal transmissions (both precoding based and by making use of multi-level coding) and from unicast retransmissions.

Finally, the project has worked on advanced multiuser detection schemes both for IDMA and NOMA. Advanced receiver design, pilot design and channel estimation, the combination of NOMA with FQAM, and dedicated code design have been some exemplary research directions.

All research items being listed above have targeted to assess performance gains, to reduce complexity and to determine required steps to push the technology towards 3GPP.

Beside the component specific research as described above, the project has made significant efforts towards system level evaluation of selected techniques and for more overarching aspects. We have conducted various simulation campaigns to evaluate specific components in a system wide manner (e.g. the grid of beams concept, selected waveform candidates, selected massive access protocols, etc.) and to assess the respective gains for overarching targets such as multi-service support (eMBB+mMTC+URLLC and eMBB+BMS), massive access, and wide area coverage.

Finally, beside concept design and simulative/analytical assessment, FANTASTIC-5G has worked on several proof of concepts. Various waveform candidates (UF-OFDM, FC-OFDM, FBMC, P-OFDM) have been implemented and compared with respect to actual implementation complexity and performance for various scenarios related to e.g. massive access, low latency communications and high velocity transmissions. Furthermore, we have implemented a proof of concept investigating and demonstrating coexistence aspects between eMBB and mMTC. Finally, a dedicated activity has implemented, investigated and demonstrated advanced techniques to enable Broad-/Multicast services in an efficient manner. FANTASTIC-5G has participated in various events showcasing its proof-of-concepts.

The overall objective of Flex5Gware has been to deliver highly reconfigurable hardware (HW) platforms together with HW-agnostic software (SW) platforms taking into account increased capacity, reduced energy footprint, as well as scalability and modularity, to enable a smooth transition from 4G mobile wireless systems to 5G. In particular, this overall objective has been implemented by pin pointing specific implementation challenges for 5G HW and SW platforms targeting both network elements and devices. This implementation complexity analysis has been used, for example, to indicate the viability of anticipated solutions for 5G. Precisely, one of the main achievements of Flex5Gware during its second (and final) year has been to provide a Proof-of-Concept (PoC) of the key building blocks that 5G HW/SW platforms will be composed of.

As it will be described next, with its 11 PoCs, Flex5Gware has covered the whole value chain of 5G platforms: starting from the antenna, RF modules and mixed signal stages and going up to digital HW and SW aspects. The following list describes the 11 PoCs that have been showcased in the Flex5Gware Final Event that took place at the TIM premises in Turin during May 21st – 22nd, 2017:

- **Active SIW antennae with integrated power amplifiers for K/Ka frequency bands**. In this PoC, an active Substrate Integrated Waveguide (SIW) antenna with integrated power amplifier for operation in the 17-30 GHz frequency range has been developed: the full-wave/circuit of the planar antenna and power amplifier are co-designed, which allows both cost reduction and performance improvement for 5G RF frontends. See Figure 14 for a picture of the integrated antenna and PA.

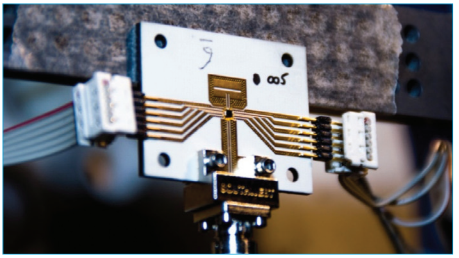


Figure 14: Assembled prototype of the integrated antenna and CMOS PA [8]

- **On-chip frequency generation**. This PoC covered the full on-chip frequency generation system including transport of signals to receiving blocks. 5G frequency bands around 30 GHz as well as 60 GHz have been considered. The main benefits of this development are cost, size, and power reduction while using state of the art CMOS technology allowing for high-level system integration.
- **APR reduction and power amplifier pre-distortion**. This PoC has developed a new Peak-to-Average Power Ratio (PAPR) reduction scheme named Weighted Selective Mapping (WSLM). The WSLM algorithm has been implemented together with Digital Pre-Distortion (DPD) techniques to achieve a more efficient operation of 5G PAs.
- **Multi-band transmitter**. The multiband transceiver solution developed in Flex5Gware exploits broadband and multiband capabilities of components to realise transceiver chains, which cover simultaneously the 5G radio bands between 2.6 and 3.6 GHz for concurrent multiband operation. The developed transmit-chain allows to reduce the hardware complexity by decreasing the number of implemented transceivers.
- **Multi-chain MIMO transmitter**. This PoC demonstrated a feasible all-digital massive MIMO transmitter approach at small scale with 8 transmit branches, with an approach that is easily scalable. The main benefit of this approach is on its ability to generate an RF signal

8. Flex5Gware D6.2 "Final PoC evaluation in Flex5Gware", available online www.flex5gware.eu

for a multi-chain transmitter in a single component together with an amplification method that is suitable for antenna arrays.

- **Full duplex FBMC transceiver**. This PoC demonstrated the practical feasibility of full duplex with possible new 5G waveforms taking Filter Bank Based Multi Carrier (FBMC) as an example. The proposed solution allows the increase of cell capacity since one resource block is used at the same time for uplink and downlink, without stringent power consumption requirements on the UE side.
- **High-speed low power** LDPC decoder. This PoC addressed the design of cost-effective Low Density Parity Check (LDPC) decoders. The expected benefits are to meet 5G requirements in terms of end-user data rates, while reducing power consumption at the UE side thanks to the reduced size of the implemented solution.
- **HW/SW function split for energy aware communications**. This PoC demonstrated how hardware-accelerated (HWA) and SW baseband and networking functions can be reconfigured, partitioning their operation across different nodes and performed an energy profiling of each partition. Different partitions can be used to satisfy different requirements of energy efficiency.
- **Reconfigurable and programmable radio platform and SW programming performed and injected by the network**. This PoC demonstrated the whole adaptation loop of 5G technologies, by reconfiguring the radio behaviour according to advanced context estimates provided by sensing devices. This allows, e.g., the configuration of device MAC rules for operating in relay-mode or direct access and switching across technologies according to the link quality.
- **Flexible, scalable and reconfigurable small cell platform**. This PoC built a flexible, scalable small cell platform endowed with multi-tenancy capabilities, while ensuring that 5G requirements are still met. This platform can be used to enable the possibility of multiple operators (or MVNOs) sharing the same physical resource while still guaranteeing segregation.
- **Flexible resource allocation in CRAN/vRAN platform**. This PoC featured a small scale prototype of Virtual RAN, consisting of a group of eNBs and multiple LTE commercial terminals, where advanced CoMP techniques, dynamic Remote Radio Head (RRH) activation/deactivation and Baseband Unit (BBU) allocation and RRH association techniques have been evaluated. As a result, inter-cell interference is reduced and the user-throughput has been increased.

METIS-II

The METIS-II project is ending at the end of June 2017. The project has completed the overall 5G radio access network (RAN) design and addressed the technical enablers needed for an efficient integration and use of the various 5G technologies and components. After two intense years, the major results can be grouped under three areas:

- 5G Overall RAN design based on novel technology components
- Evaluations of the 5G KPIs and the definition of the associated evaluation methodology
- Development of a 3D visualization platform for easy demonstration and interaction with project results

The 5G RAN design has now reached a maturity level that is adequate for standardisation. Some concepts developed in the early phase of the project have already been included in the first 3GPP release of NR and technologies developed later in the project are suitable for later releases.

METIS-II has identified eleven key RAN design questions that should be answered to be able to build 5G systems, and the developed 5G RAN design responds to these questions.

Within the common control plane framework, an agile RM architecture is developed and described in detail from functional, protocol and deployment perspectives. This architecture operates over the envisioned air interface (AI) comprising novel 5G and legacy AI variants (AIVS) and comprises innovations, such as, multi-AIV/multi-Slice resource management including dynamic traffic steering, energy-efficient RAN Moderation, and Interference Management in fixed and dynamic radio topologies. Moreover, an analysis shows how to best split the Control Plane or User Plane for different physical architecture options. Other innovations are: a new "inactive UE" state that will enable lower latency and battery savings, inclusion of D2D and self-backhauling as an integral part of 5G, a make-before-break and LTE-NR tight integration concept that enable more reliable connections and a new initial access scheme that improves access capacity and allows service prioritization, which is vital for mission-critical services. The 5G RAN design also includes a Common user plane framework where the MAC layer allows the coexistence of different numerologies and frame structures. The framework also contains a superfast harmonized multi-service HARQ and a common PDCP layer for user plane aggregation. The holistic AI enables harmonization across the protocol stack and co-existence for all AIVs including LTE.

METIS-II has also produced system evaluations of the 5G KPIs in five use cases (UCs). The results show that it is possible to meet almost all of the KPIs using the technologies developed in the project. For a few KPIs, the set goals are not fully met, e.g., the achieved range for 99.999% reliability is 45m and not 50m as defined in the 5G KPIs. To be able to conduct the evaluations, the models to be used for all UCs have been specified. In addition, METIS-II have led the work on aligning these models and assumptions across all 5G PPP projects. This work has resulted in a joint document capturing the models that have been used by other projects. The document can also be used by projects in later phases of 5G PPP. The evaluations and models have also been used as a basis for the upcoming 5G evaluations 3GPP and ITU-R, that will be conducted in the next months.

Another key achievement of METIS-II is the 3D visualization platform. The visualization platform is based on Unity 3D software that allows the user of the platform to interact in real time with some of the most important achievements of METIS-II. For example, it is possible to demonstrate, in a virtual world, how a system based on the 5G RAN design would "feel" for a user in reality. Figure 15 shows a snapshot of what a user of the platform sees. In the last months, the platform has evolved significantly with the inclusion of various technical innovations. The platform also encompasses some static material, showing the main achievements of the technical work, as well as some interactive scenes (Part 4 in the Figure).

In addition to the three main achievement areas highlighted above, METIS-II has also introduced new ways to authorize the use of spectrum, allowing for more dynamic and local use of spectrum, and has designed a holistic functional architecture based on enhanced LSA. The economic aspects of deploying 5G has also been studied to determine how to best roll out 5G.

Figure 15: METIS-II achievements represented in the Visualization Platform based on Unity3D

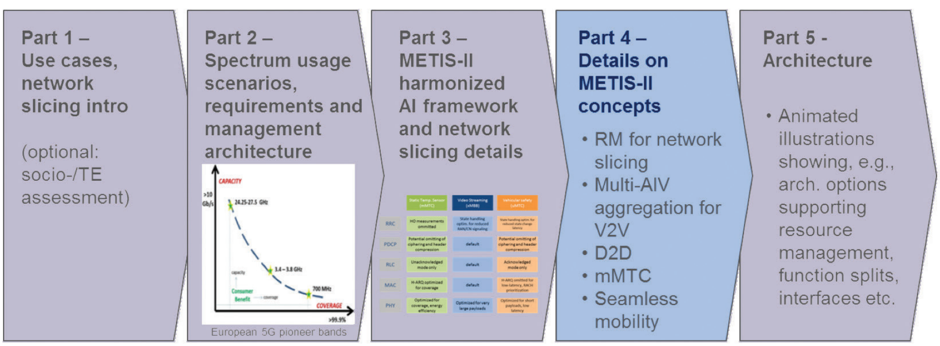


Figure 16: METIS-II Visualization Platform

mmMAGIC

The mmMAGIC project is at the forefront of the research and development of novel system concepts at the mm-wave (6-100 GHz) bands. Since the beginning of the project it has delivered key components in the 5G multi-RAT ecosystem and laid a solid foundation for global standardisation and industry alignment of new 5G technologies at the mm-wave bands. The mmMAGIC visualization tool and techno-economic assessment have paved the way towards understanding the 5G capabilities in various mm-wave scenarios, as well as the practicality of different deployment options of the mm-wave networks. The mmMAGIC channel models covering the entire frequency ranges 6-100 GHz have provided the baseline to design and evaluate the 5G mm-wave RAT, whose system concept has been accomplished by innovative and crucial technologies developed in the project, such as **RAN functions and integration, Radio interfaces, and multi-antenna multi-node design**.

mmMAGIC visualization tool: The visualization of three key technology features of mm-wave 5G radio interface concepts (as described in Deliverables D1.2 and D1.3) has been developed, through the demonstration of the interactions among antenna alignment and beamforming, link and system level analysis, and significant RAT optimization metrics that enable multi-RAT deployments within heterogeneous network indicators. Exemplary video footages have been produced, where the mm-wave 5G capabilities, with visualization of beam tracking, performance evaluation and mobile user throughput as well as of significant metrics, have been demonstrated.

Techno-economic assessment of mm-wave RAN: Quantitative comparisons of capital expenses (CAPEX), operational expenses (OPEX), and total cost of ownership (TCO), related to several standalone deployment options in mm-wave bands, have been performed. Both centralized and distributed network deployments and their RAN components, are analysed in detail, where, the degree of RAN function centralization is characterized by a pre-defined functional split. Transport network costs for both backhaul and fronthaul are, in turn, studied for two relevant cases, namely, owned lines and leased lines. A comprehensive technical report (D1.4) is under way and will be completed by June 2017.

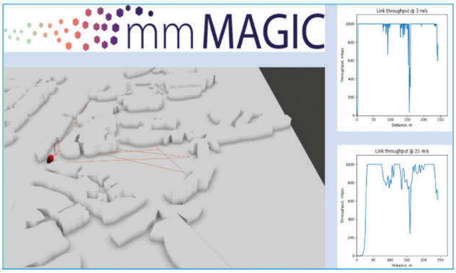


Figure 17: Snapshot of the visualization video footage illustrating, beam tracking and TCP throughput

Channel Measurement and Modelling: The availability of reliable and accurate channel models is crucial for the design, deployment, standardisation of 5G RAT, and related performance evaluation. In this context, mmMAGIC has conducted extensive measurement campaigns in the frequency range between 6 and 100 GHz, for outdoor and indoor propagation scenarios. Calibrated with the measurement results, supplementary ray tracing simulations have been performed to generate large data sets for the derivation of additional parameters for stochastic modelling. Overall, 54 single-frequency equivalent campaigns have been conducted.

The mmMAGIC geometric stochastic channel model was released in May 2017 (D2.2). Major features, such as the incorporation of ground reflection and blockage effects, the support of large bandwidths and large antenna arrays, the provision of spatial consistency, and the enhanced outdoor-to-indoor penetration loss modelling, have been included. By actively impacting standards bodies (14 channel-related submissions to 3GPP and six submissions to ITU-R), several approaches developed in mmMAGIC have been adopted and are reflected in the latest respective channel models. An open-source QuaDRiGa channel model platform has been developed in the project, and further enhanced through the implementation of a subset of the mmMAGIC features in the new release. The software supports link and system-level simulations with arbitrary antenna configurations.

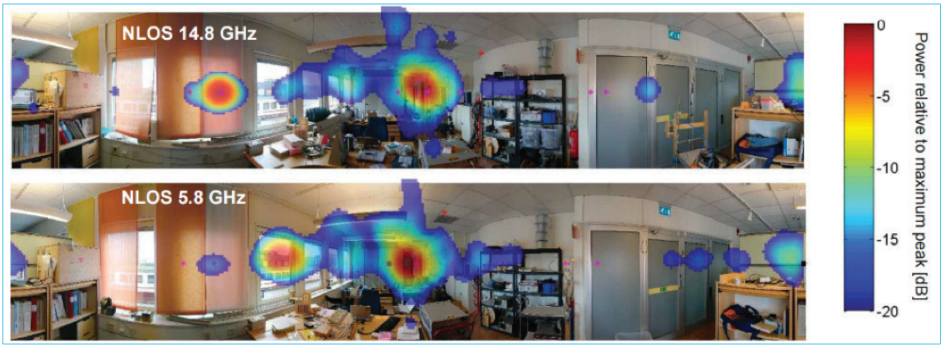


Figure 18: Directional power distribution in an office environment

RAN Functions and Architecture Integration: One of the key challenges in mm-wave network is the integration of the mm-wave system into the overall 5G environment, especially considering the huge variety of use cases and deployment scenarios under discussion. To address such challenges, the project has identified and specified key 5G enablers and several RAN functions, namely multi-connectivity for enabling a user to connect simultaneously amongst LTE and/or 5G RAT, tight-interworking with LTE will allow to optimize the use of both RATs to improve the end user performance, cell clustering to provide continuous connectivity for the active user in a dynamic environment with mm-wave channel specific behaviour, a new mobility state "RRC_INACTIVE" allowing faster reconnection of the UE, self-backhauling for network densification and dynamic backhaul capacity, network slicing to support multiple services and business operations independently on shared infrastructure, and interference coordination to increase capacity and ensure high performance in extreme dense deployments. The listed key enablers have been identified since March 2016 (D3.1), and are now part of 3GPP technical documents. Specific RAN functionalities are power-efficiency oriented KPIs, transport layer optimization, low frequency band assisted initial access and other PHY layer specific features helping to further increase performance. Further, a multi_RAT multi-layer management framework has been introduced, which can be tailored to integrate various RATs into one system and therefore can be seen as a generic method for system integration, performance and power efficiency optimization across all available links. The enablers have been described in the internal report IR3.2 and in the white paper W3.2 "Architectural enablers and concepts for mm-wave RAN integration". The final deliverable D3.2 summarizes the proposed new functionalities, clarifies the interrelation between them, and explains how to integrate them into a 5G system.

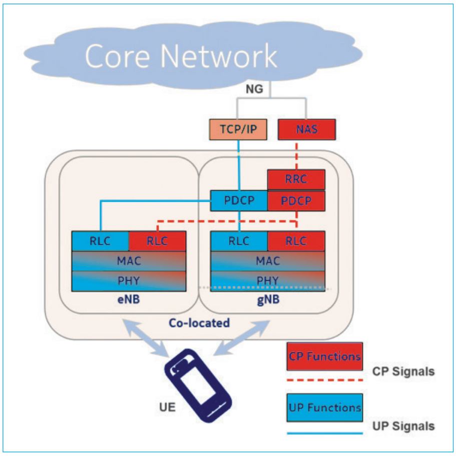


Figure 19: Access architecture with LTE-NR co-location

Radio Interface and Multi-Antenna Multi-Node Design: A radio interface concept has been studied and developed in the mmMAGIC project, considering the specific features and requirements in the mm-wave bands. The radio interface components include waveform, numerology, subframe structure, channel coding, initial access, and spectrum sharing. First, mmMAGIC has evaluated a number of waveform candidates including multi-carrier and signal carrier variants, and recommended OFDM with several enhanced techniques, including PAPR reduction, phase noise mitigation and windowing/pulse shaping for frequency localization. Further, advanced prefix such as Unique Word (UW) can be exploited to further enhance performance without adding training overhead, and a new waveform BF-OFDM has been developed and evaluated. A scalable numerology has also been proposed which can be used for different carrier frequencies and bandwidths. Five subframe structures have been defined, with extensions to support Integrated Access and Backhaul (IAB) operations. Some subframes allow fully dynamic TDD operation for a better match of DL/UL traffics and for latency reduction. Advanced decoders have been developed for LDPC and Polar codes. Such decoders allow very high throughput and can tolerate hardware impairments. An overall concept for initial- and multiple-access has also been proposed, covering cell discovery, random access, beam search/tracking, flexible multiplexing and resource allocation. Under this overall concept, a number of techniques have been developed, including efficient beam sweeping schemes, coordinated random access scheme with suitable preamble design, advanced beam tracking schemes. A new spectrum sharing concept has also been proposed, including spectrum pooling architectures, functions and beam coordination techniques. The final radio interface proposal will be presented in D4.2 by the end of June. The listed solutions have been developed in parallel with 3GPP activities, serving the purpose of pre-standards industry alignment. Some of the studied air interface solutions (e.g. waveform, numerology, channel coding, asynchronous HARQ) have been adopted in 3GPP.

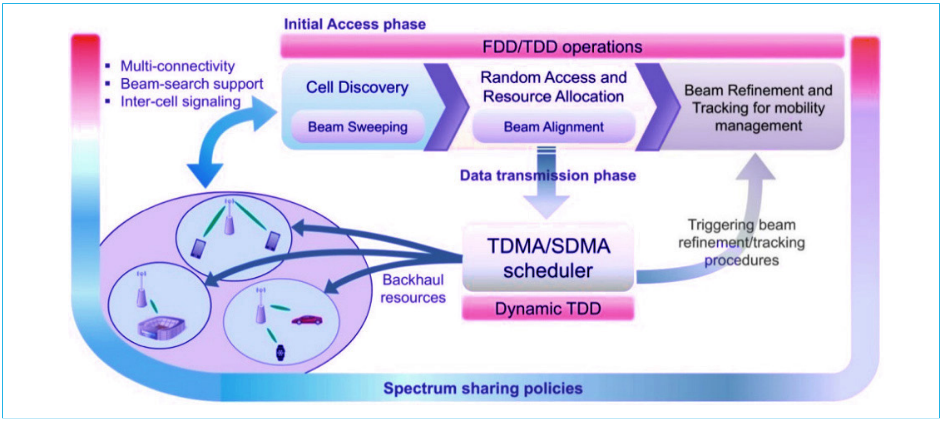


Figure 20: Initial access and multiple access concept for mm-wave system

An extensive description of new concepts and proposed solutions on multi-antenna and multi-node transceiver schemes in mm-wave spectrum will be provided in the final deliverable D5.2. A key contribution of the project is the modelling of the hardware impairments in mm-wave transceivers (contribution to 3GPP) and the analysis of their impact on system performance, paving the way towards the implementation of practical mm-wave systems. With regard to performance and impairment modelling of transceiver hardware, mmMAGIC has extensively studied the Transmitarray configurations for radio access and backhaul applications. The spatial feeding nature greatly reduces the feeder losses in Transmitarrays while the beam scanning/alignment can be fine-tuned with the number of phase shifter bits allocated. Hybrid Beamforming is recommended as the preferable architecture for most of the radio access needs in mm-wave communications, due to its flexibility and robustness against main hardware impairments. Finally, mmMAGIC stresses the need for multi-node configurations to increase the link reliability of mm-wave systems.

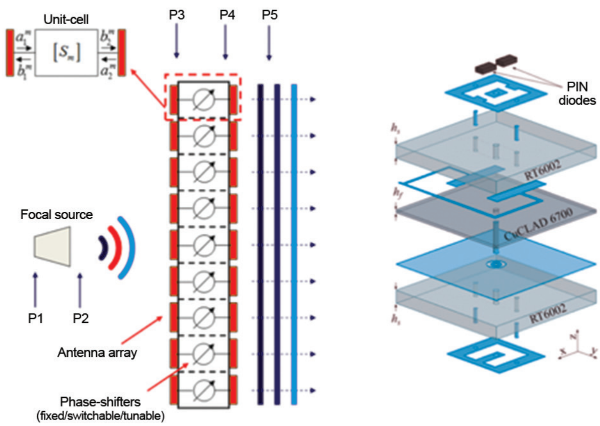


Figure 21: The Transmitarray configuration

The mmMAGIC system concept: The overall system concept integrates the technical components enhanced or developed in the project, focusing on 24 different functionalities and describing more than forty different implementations of them. Key solutions, recommendations, as well as the final system concept developed from mmMAGIC which will be detailed in a holistic manner in our final deliverable D6.6.

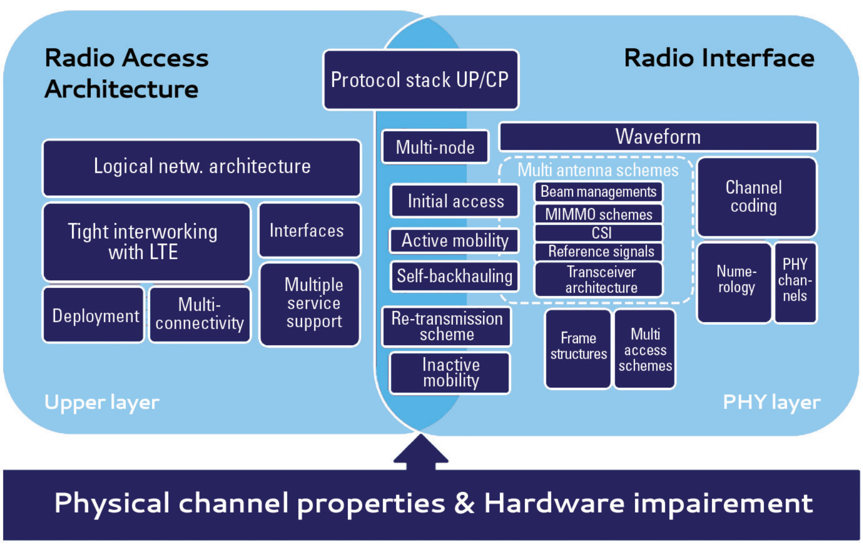


Figure 22: mmMAGIC system concept

SELFNET

SELFNET is a project focusing on 5G network management, with the main objective of developing an efficient self-organising network management framework for 5G through the combination of a virtualized and software defined network infrastructure with artificial intelligence technologies, assisting network operators in the following key management tasks: automated network monitoring, autonomic network maintenance, automated deployment of network management tools and automated network service provisioning.

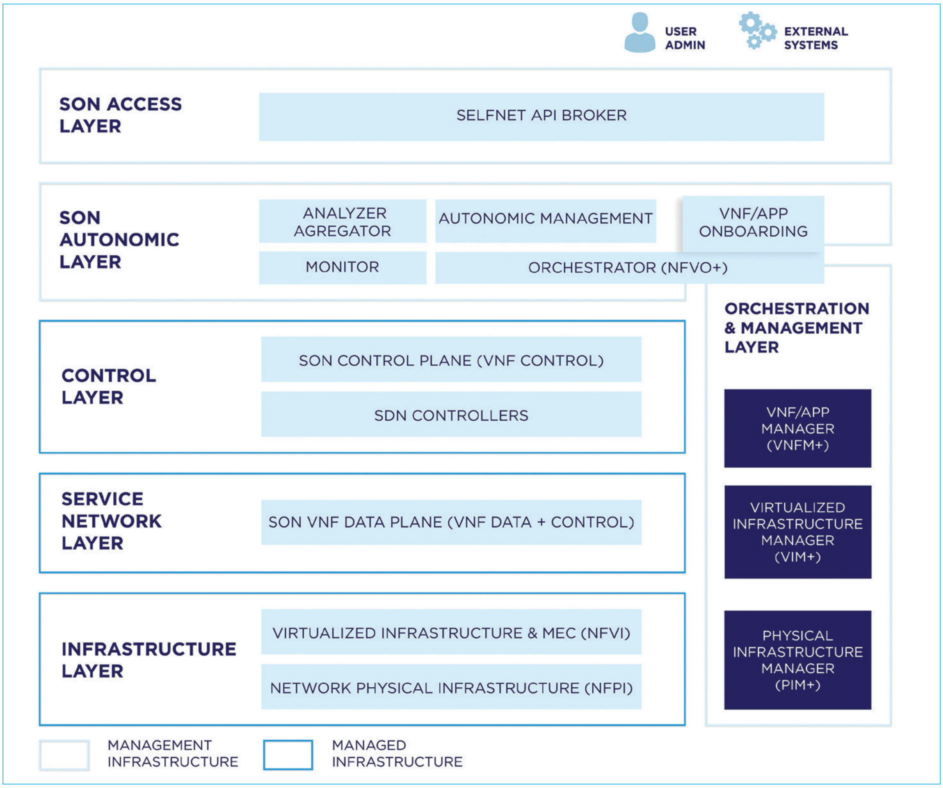


Figure 23: SELFNET Architecture

SELFNET has the specific objectives of designing, implementing and validating a self-monitoring and detection subsystem, a distributed Self-Organising Network (SON) autonomic management engine subsystem and a SON orchestration and virtual infrastructure management subsystem. Through these automated and intelligence-based operations, SELFNET will primarily contribute to significantly reducing the service creation time in software-defined and Virtualized 5G networks.

Moreover, SELFNET expects to help in realising the creation of a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision, mainly through the design and prototyping of three classes of representative use cases that demonstrate the self-organising network capabilities of the SELFNET framework. The three use cases address self-healing against existing or predicted network/service failures, self-protection against network/service security threats especially distributed denial of services, and self-optimization to maintain or improve video application performances.

During the second year of the project the overall SELFNET architecture has been continuously refined, including all the components, interfaces, information model and control loop. The SDN/NFV sensors and actuators for the use cases achieved good progress and prototypes are now ready for deployment through an APP Manager that is also completed.

All modules of the architecture were defined, and aggregator, analyser, autonomic manager, rule based tactic autonomic language and orchestrator are ready to be integrated in order to close the control loop. The full integration of all modules, including the GUI, in a testbed running the infrastructure will be the main task in the third year of the project.

Several SELFNET demos are published on the project YouTube channel and can also be visited at the project website: www.selfnet-5g.eu

- The SELF-PROTECTION demo, for instance, showcases the self-protection capabilities of the SELFNET framework in detecting and isolating hacked devices shaping a botnet by dynamically configuring detection tools as sensors, when and where they are needed, and deploying a virtualized and personalized Honeynet as an actuator network function to isolate cyber-attacks detected.
- The SELF-HEALING demo showcases self-healing capabilities of the SELFNET framework in maintaining the infrastructure QoS based on proactive decisions (Fix before Break) by deploying resource-action-based actuators on the network.
- The SELF-OPTIMIZATION demo presents the scenario where the YouQoS-Sensor gives the end-user the possibility to prioritize its data streams for his own preferences to guarantee its QoS.
- The Network Topology Viewer demo presents a network topology view that enables operators to correlate physical, virtual and user equipment resources in real time using an appealing and intuitive interface.
- The APPS MANAGEMENT showcases the SELFNET APP on boarding, encapsulation and lifecycle management, first by showing the one-click procedure for on boarding of VNFs and SDN-Apps, and then by showing the instantiation, configuration and then automated re-configuration of VNFs by means of the SELFNET VNF Manager (VNFM).
- The Discovery & Monitoring demo showcases SELFNET's Discovery and Monitoring module that enables physical, virtual, sensor and flow monitoring in the SELFNET framework.

SESAME

A fundamental component of the SESAME Project (GA No.671596) is the virtualization of Small Cell (SC) 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 high manageable clustered edge computing infrastructure.

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 wants 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 24:

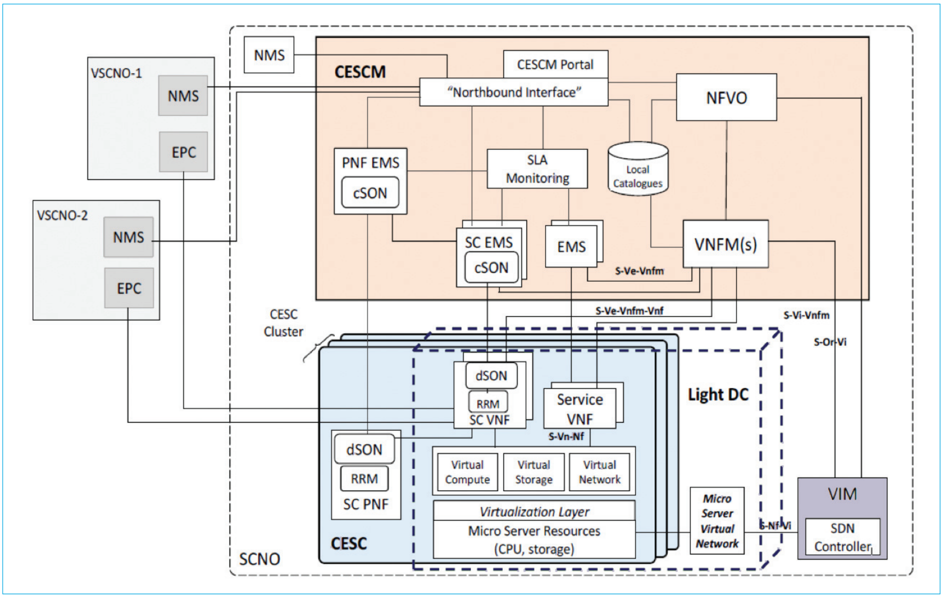


Figure 24: SESAME Conceptual architecture

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.

The main achievements of SESAME during Y2 include, inter-alia:

- Definition and specification of the system architecture and interfaces for the provisioning of multi-operator Small Cell networks, optimized 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.
- 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.

- Design and development of a framework for efficient resource planning and coherent management of the multi-operator Small Cells as light NFV distributed infrastructure.
- Design and implementation of CESCM (CESC Manager), capable of chaining and orchestrating the different VNFs required to cope with the dynamic service level agreements (SLAs) between the CESC provider and the network operators.
- Integration into one Pre-Commercial Prototype of Small Cells, Light DC and management and orchestration functionalities.

Proof of Concept (PoC) and demos description (as actually being in progress):

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 all view of 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 to 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 chaining: 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.

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.

SONATA

SONATA addresses the significant challenges associated with the development and deployment of the complex services envisioned for 5G networks, targeting both the flexible programmability of software networks and the optimization of their deployments.

SONATA proposes an integrated NFV Service Platform where the outcomes of its novel Service Development Kit (SDK) are automatically deployed with a customizable and modular Orchestrator, bridging the gap between telecom business needs and operational management systems.

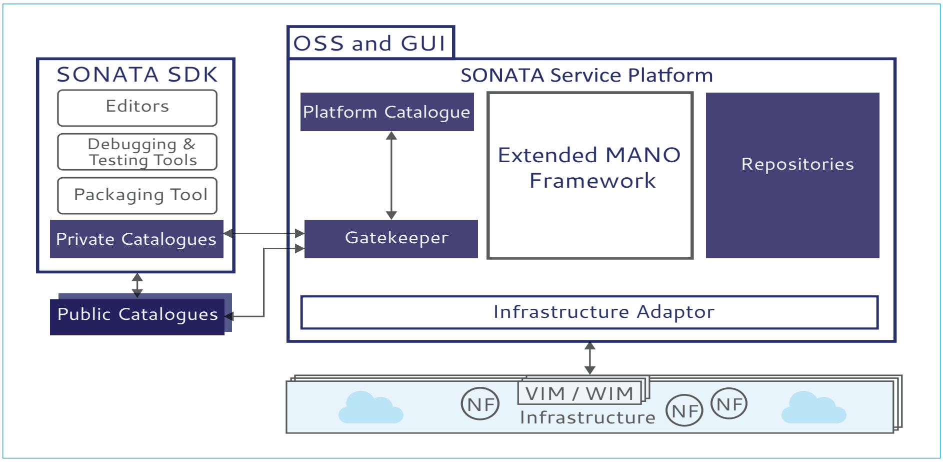


Figure 25: SONATA architecture

SONATA also implements an extended DevOps model between service developers and telecom operators to increase efficiently, facilitate the implementation of new services and accelerate the adoption of NFV technologies.

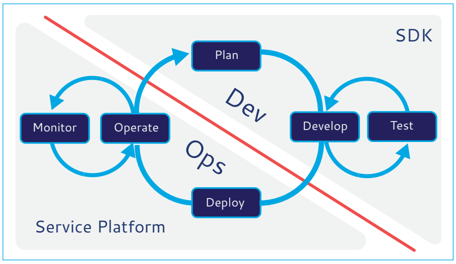


Figure 26: Extended DevOps model

Goals

- Reduce time-to-market of networked services.
- Optimize resources utilization and reduce costs of service deployment and operation.
- Accelerate industry adoption of software networks.

Key features

- First integrated approach in the NFV landscape that includes service composition, testing and orchestration.
- Invaluable tools to support developers in the creation and testing of services.
- Flexible architecture and modular design.
- Openness and multi-vendor compatibility.
- Customization opportunities depending on customer's needs, existing assets and/or future requirements.
- DevOps model for Telecom that enables the agile management of the full service lifecycle, increasing productivity and time-to-market.
- Multi-organizational by design enabling network operators the creation of an ecosystem with external and internal developers improving collaboration and enabling a more competitive offering.

In the second year of the project, the major achievements for the SONATA Service Platform include better user management, network service (VNFs forward chain) package generation and validation and VNF scaling. On the other hand, the SONATA SDK refined its programming model, extended its toolkit, streamlined the interaction with the SONATA Service Platform, improved the monitoring feedback with KPIs and now includes a range of example services. Main highlights of the latest (July 2017) release:

- The SONATA Service Platform controls who the users are and what they can do now, which is crucial to open the platform to third party developers, as indicated in the 5G trends. This also allows for a licencing/monetizing scheme to be provided, with each package, service or function carrying the owner ID in its meta-data and allowing for the verification of the existence of a licence for them to be (re-)used.

- Package on-boarding, as well as a number of other SP operations, have their Key Performance Indicators (KPIs) being shown in the GUI now, thus demonstrating the correctness of the chosen approach to disruptively decrease the time to accept and deploy new services.
- Scaling will be also supported by integrating as part of the Service Platform, the Mistral Workflow Engine, widely used in the OpenStack community. This is an additional alternative to previously available code-based FSMs (Function Specific Managers).
- The SONATA SDK has been extended with an easy-to-use graphical user interface, enabling rapid development of network function and service descriptors, as well as the resulting package, which can be easily deployed on the service platform or on the developer emulator.
- The SDK contains a service validation tool, which is able to detect a range of syntactical as well as logical errors. This greatly improves the ability of developers to quickly retrieve errors in their services and debug them.
- The SDK emulator has been extended in order to enable interoperability with other MANO solutions, such as the OSM initiative. As a result, the SONATA emulator now becomes available to a larger community. The project is currently working on the compatibility with OSM packages/descriptors.
- Adequately assessing the performance of virtualized services is important, and now it is possible using the integrated monitoring and profiling functionality in the SDK and its emulator. These enable to have a global view of the gathered monitoring metrics, as well as the detection of performance trends under different running constraints.
- The overall internal security strategy and mechanisms, such as package signing, user management, micro-service communication with certificates, etc., have been also enhanced.

In order to illustrate the added value of the service programmability and orchestration capabilities offered by SONATA, we have selected three pilots in relevant areas for 5G:

- **Virtual Content Delivery Network (vCDN).** The business case of Content Delivery Networks is well established in the current telecommunications environment. Our goal with this pilot is to enhance a vCDN service with elasticity and programmability. Two scenarios are anticipated, the classic mode, where the traffic is generated by the content provider(s), and the User Generated Content (UGC) based mode. As an extended functionality, a vTranscoder will be introduced in the forwarding graph of the service, which will be able to adapt the content by choosing the best suitable transcoding and segmentation in order to ensure the finest user experience for the available bandwidth. Its placement will be decided on-demand at the service instantiation according to the situation and the customer request.
- **Personal Security Application.** The goal of this use case is to enhance a service provider based personal security application. To this end, a security application comprising several different security components (firewall, virtual private network service and intrusion detection system) is executed in the virtual network infrastructure of the service provider. It is embedded in the data path of a user and assesses and filters its network traffic and thus protects its devices connected to the Internet. Using a self-service portal, a user can connect to the personal security application and adapt the actual composition of the network functions that constitute the service. Thus, a user might add a firewall or an intrusion detection system to its data path on demand. Two deployment scenarios will be demonstrated: dynamic Network Service Reconfiguration, to showcase the deployment of a network service that can be modified on the fly, and scaling, an extension to the first scenario which introduces elasticity to it.
- **Service Platform to Service Platform.** This is a scenario with Hierarchical Communication Service Providers (CSP), where one of them provides a Network Service (NS) to the other CSP. This allows a CSP to segment their own network and control the deployment of network services across with several MANOs. We have designed and implemented only two levels of hierarchy, but this initial solution can

be extended to an arbitrary number of levels. Our approach is that, as far as a lower-CSP is concerned, the upper-CSP is just another customer requesting service, and similarly, from an upper-CSP´s perspective, the lower-CSP is providing a component in their overall network service in a similar manner to the NFVI.

SONATA is an open source project. The project source code, published under Apache v2.0 licence, and all related technical documentation is freely available for download on the project website: http://sonata-nfv.eu.

sonatafv@gmail.com	@sonataNFV	H2020 SONATA
www.sonata-nfv.eu	SONATA NFV	sonata-nfv
	SONATA NFV	

Figure 27: SONATA's channels

SPEED-5G

SPEED-5G is developing key enablers to optimize spectrum utilization while providing optimized QoE. The focus is on three dimensions to increase capacity:

- ultra-densification through small cells,
- additional spectrum 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 to:

- 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 proof-of-concept setups

A major achievement is a new MAC framework. It is based on split-MAC design approach, allowing decomposition of legacy MAC functionalities into two sub-layers, i.e. a Higher MAC (HMAC) and a Lower MAC (LMAC), with functionality allocation dependent on the operation time-scales. The Higher MAC is in charge of a set of RAT-independent functions, intended to coordinate the underlying RATs. Its main features are coexistence management, transmission opportunity identification, traffic steering, load balancing, and scheduler configuration. The Higher MAC can be seen as a convergence point of the protocol stack dealing with the control path, decoupled from the user plane and managing the available sets of possible bearers. Such decoupling also enables support for advanced virtualization mechanisms and RAN-split options. The Lower MAC functions are on the other hand, RAT-dependent and mainly related to scheduling, logical channel management, bearer configuration, channel (de)multiplexing as well as (de)framing. The main components of the SPEED-5G architecture are depicted in Figure 28:

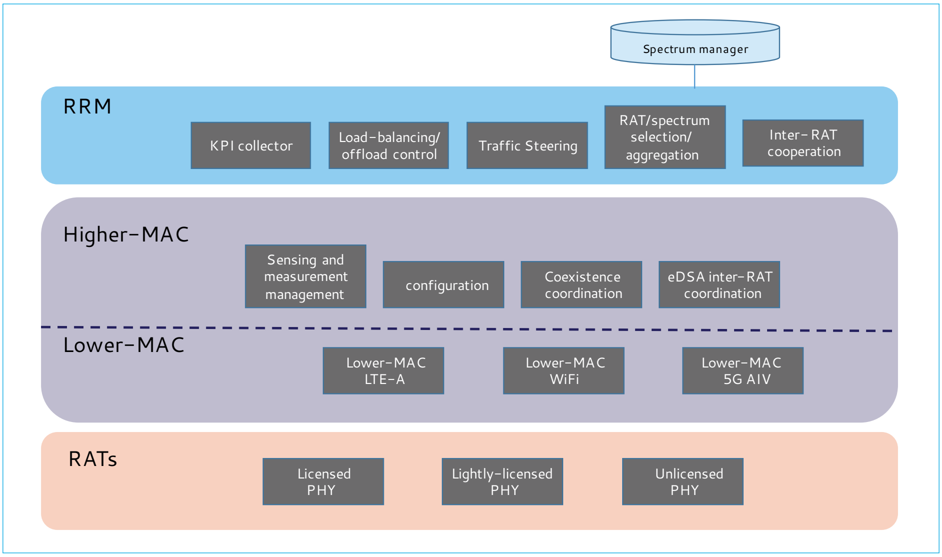


Figure 28: SPEED-5G Conceptual architecture

The RRM design acts across technology silos and is able to ensure efficient use of all kind of spectral resources. This is achieved through the use of dynamic and smart spectrum access and by exploiting any available spectrum resources (licensed, lightly-licensed and unlicensed). SPEED-5G works on hierarchical (blending distributed and centralized) machine learning-based RRM of ultra-dense multi-RAT and multiband networks. Specifically, centralized management is used as a baseline, which can be expanded with distributed management by moving management decisions related to RAT / spectrum / channel selection closer to the node level. Algorithms for RAT / spectrum / channel selection will initially run in a distributed manner in order to limit the excessive signalling of centralized solutions in dense environments. However, in cases where the distributed approach does not provide satisfactory solutions, a centralized approach is used as fall-back solution. RAT / spectrum / channel selection can be implemented in licensed, unlicensed and lightly-licensed bands (e.g. 3.5GHz band). Preliminary results show that the proposed scheme can result in as much as 70% reduction in signalling costs (signalling due to RAT / spectrum management), with details available in SPEED-5G Deliverable D4.3.

Main achievements & innovations

- Design and development of a novel MAC/RRM framework for efficient management of the common modules
- Specification, design and implementation of HMAC/LMAC and cRRM components as well as new interfaces and message elements
- Introduction and specification of a novel "monitoring plane" in support of KPI collection and sensing measurement reporting
- Hierarchical (blending distributed and centralized) machine learning-based management of ultra-dense multi-RAT and multiband networks

- FBMC-enabled MAC design in support of xMBB and mMTC: A new MAC layer has been defined for the Filter Bank Multi-Carrier (FBMC), which supports the two main 5G use cases Mobile Broadband and Massive IoT. The FBMC-enabled MAC has been validated through simulation studies
- DCS-enabled MAC design in support of xMBB: A new MAC design (waveform-independent) has been proposed and evaluated that can support the main SPEED-5G use-cases of heterogeneous resource aggregation, traffic offload/steering and dynamic channel selection, in dense small-cell deployments. It is capable of advanced interference management and capacity enhancement
- Definition of MAC-related control-plane and user-plane procedures, for the proposed MAC designs

The SPEED-5G test bed 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 test bed deployment (Deliverable D6.3). Five individual PoCs serve to validate specific solutions and project innovations, on per-partner basis – these include:

- Design validation and testing for 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 solution

The individual solutions will be combined and integrated into a single demonstrator platform (PoC 6) which will be the integrated SPEED-5G test bed, for final demonstrations and trials. PoC 6 will showcase the main project innovations relating to capacity improvement, aggregation and offload. Figure 29 depicts a generic logical view of a typical demonstrator setup with the software components installed. The logical architecture comprises of:

- The legacy LTE-A EPC and eNodeB servers running Open Air Interface (OAI) software.
- Multi-RAT/mode access-points, with servers hosting HMAC functions required by FBMC-MAC, DCS-MAC as well as legacy WIFI systems
- Multi-mode UEs (laptops) as well as cots
- An application server to test accessibility, used for stand-alone tests in PoCs 1 to 4. The integrated PoC 6 will make use of a separate, state-of-the-art video monitoring setup.

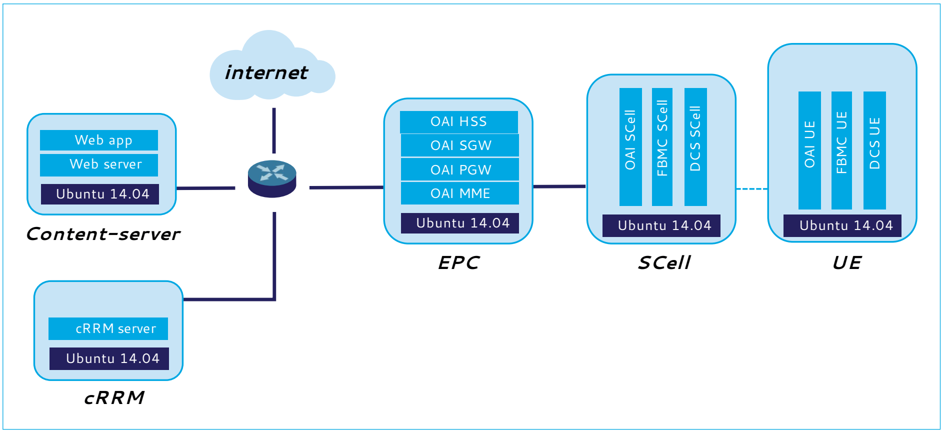


Figure 29: Logical view of the PoC demonstrator

Figure 30 shows the comparison of network capacity supported by WiFi and the new DCS-MAC. Three cases of channel aggregation are shown: i) no aggregation – only 1 channel among 10 channels is used simultaneously for communication ('10% BW per DCS cell'), ii) limited aggregation – 2 channels are used simultaneously for communication ('20% BW per DCS cell') and iii) advanced aggregation – up to 4 channels are used simultaneously for communication ('40% BW per DCS cell'). By exploiting inherent interference diversity capability of DCS-MAC, the dynamic channel selection feature can increase the network capacity.

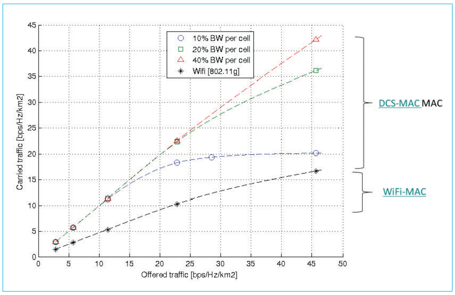


Figure 30: Comparison of network capacity DCS-MAC vs WiFi

SUPERFLUIDITY

The Superfluidity project is focused on the transformation of Telecommunications and Service Providers infrastructures to Cloud Native infrastructures in order to bridge the Cloud and Telco worlds. The vision of the project consists of a "superfluid" 5G network infrastructure, characterized by four key properties: 1) location-independence where services can be deployed (and relocated) on various networks depending on application needs, 2) time-independence where deployment and migration of services is near instantaneous, 3) scale-independence where services scale transparently in a cloud-like manner, providing massive consolidation, 4) hardware-independence where services are developed and deployed with high performance irrespective of the underlying hardware.

Following this vision, the Superfluidity project worked on a set of key innovations. Firstly, network services are decomposed into Reusable Function Blocks (RFBs). Decomposing functions into RFBs facilitates the re-use of components. The project considers heterogeneous platforms for the deployment and execution of RFBs, called RFB Execution Environments (REE). The composition and orchestration of RFBs on the REEs is modelled using the RFB Description and Composition Languages (RDCL). RFBs and REEs respectively represent a generalization of the concepts of VNFs (Virtual Network Function) and NFVI (NFV Infrastructure) defined in current ETSI NFV architecture, while the RDCLs are the generalization of the descriptors of Network Services and VNFs. With respect to the state of the art, the introduction of RFBs, REEs and RDCLs proposed by Superfluidity provides a higher level of abstraction, including the support of heterogeneous execution platforms and the possibility to decompose functions with finer granularity (i.e. into smaller components). In particular, the decomposition can be iterated as RFBs can be decomposed in RFBs resulting in a "nested" composition model.

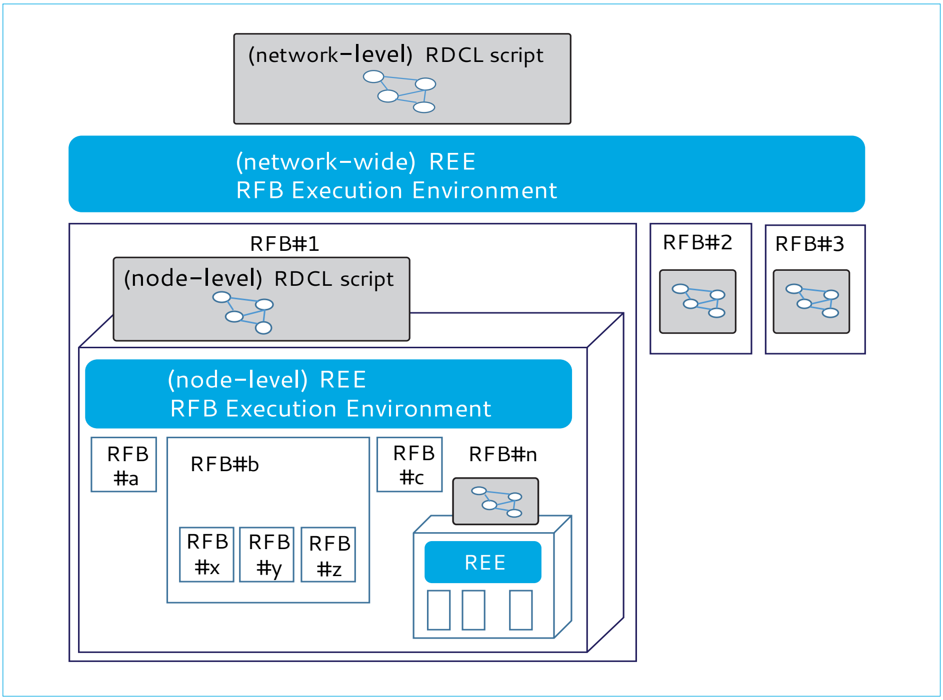


Figure 31: RFB, REE and RDCL abstractions proposed by Superfluidity

A key benefit of using RFBs is that by decomposing complex functions into their constituent parts it is possible to re-utilize their atomic functionalities to quickly compose new services. More information can be found in the SUPERFLUIDITY D3.1 deliverable.

The project has investigated Micro-VNFs, small and highly specialised VNFs that can be supported by the Unikerrnel virtualization technology. Unikernels offer very good performance in terms of memory footprint and instantiation time and have very good isolation and security properties (better than containers). In particular, the project investigated ClickOS, a Xen-based Unikernel tailored for NFV appliances, able to provide highly efficient raw packet processing. In our tests, Unikernel instances have been demonstrated to have a small footprint (around 5 MB of memory when running), an instantiation time of a few milliseconds, capable of processing up to 10Gb/s of traffic and do not require a persistent disk drive to work. In addition, they benefit from the isolation provided by the Xen Hypervisor and the flexibility offered by the Click modular router.

The project also investigated the combination of virtualization technologies (VMs and containers) in the same service infrastructure and tackled a set of challenging problems related to the manner in which they will be orchestrated and networked together. In this area, the project contributed to open source frameworks such as ManageIQ for service deployment and to Kuryr to provide the networking capabilities necessary to support the deployments of VM's and containers together.

The Superfluidity project has integrated the MEC (Mobile Edge Computing) concept into its architecture, designing and implementing a modular MEC prototype using SDN/NFV technologies. The MEC is integrated in an EDGE cloud deployment with the first prototype of a Cloud RAN that includes a front-haul re-programmable via SDN, and interacting with a decomposed core network. The different Cloud RAN and CORE components are deployed as Docker containers.

The Superfluity vision of a highly dynamic deployment of RFBs to support 5G services requires the appropriate use of telemetry, analytics and data visualisation. Telemetry or monitoring helps to provide useful insights into platform issues, which can significantly influence the performance of user-provided service-level KPIs. In fact, the type, quantity, quality and configuration of the exposed metrics by virtualized functions or host cloud environments can be limited leading to significant challenges. Metrics are typically tied to a specific type of virtualization implementation approach such as virtual machines (VMs) and can have scalability challenges. In the context of Superfluidity, a scalable and flexible telemetry platform is required to support the diverse Virtualizedenvironments i.e. VMs/containers and bare metal (non-Virtualizedenvironments). To address this challenge, the project has adopted standalone telemetry agents to provide a wide range of metrics across different virtualization methods and for different use cases i.e. operation service monitoring and service characterisation.

The characterisation methodology relies on a structured experimental approach focusing on specific service characteristics called TALE (Through, Anomalies, Latency, Entropy), which leverages a full stack monitoring approach for the collection of metrics. Collected metrics relate to both the physical and Virtualizedcompute/storage/network environments and the actual service under test in an operational context. The snap framework has been adopted by the project due to its set of capabilities, which address many of the requirements identified by Superfluidity 5G environments. For example the snap telemetry platform supports dynamic reconfiguration without interruption, can be used in "tribes" for automated replication of agent configurations i.e. change on one, replicate to many, which is an important feature for scalability.

Another critical aspect targeted by Superfluidity is related to the formalised validation of deployments. In this area, Superfluidity considers a symbolic execution tool for dataplane verification called Symnet and is working on:

- Languages that allow operators to express their policies easily and with a compact representation.
- A verification tool that performs symbolic execution guided by the operator policy, in order to reduce the number of explored paths.
- Provably correct transformations from the SEFL language (used by Symnet) to dataplane languages such as P4, ensuring that the verification results are accurate.

The Superfluidity project has the ambition to demonstrate its main achievements in an integrated test bed. The final demonstration will be in the form of a set of scenes, meant to demonstrate the key features claimed by the project: migration, scalability, resiliency, distribution etc. The demonstrator is built using two integrated test beds (connected using a VPN), which are geographically dispersed and host different elements of the end-to-end demonstrator. Test bed #1 is located at Nokia France premises and provides a hardware and wireless platform supporting the demonstration of a number of the key innovations (e.g. Cloud RAN, RFB decomposition ...) developed by the project. It acts as the EDGE cloud. Test bed #2 is a hardware platform located at BT's UK premises, consisting of 5 servers and a switch, which supports flexible virtualization experiments and demonstrations. It acts as Central Cloud.

VIRTUWIND

Today's industrial communication network infrastructure consists of different and discrete sets of decentralized networking protocols designed to deliver high performance and reliability, broad connectivity, and stringent security. However, these different protocols have been developed in isolation, solved a specific underlying problem but have added to the complexity in configuring and managing the network. During network installation, many parameters of different protocols need to be manually configured in the network devices, and during runtime, any change such as addition of new sensors or actuators (aka IIoT), requires manual intervention. With an anticipated growth of IIoT devices, future industrial networks require an open solutions architecture facilitated by standards and a strong ecosystem. 5GPPP-phase 1 project VirtuWind focuses on this problem of programmable reconfiguration of the network as per changing service demands of the industrial applications with significantly reducing the CAPEX & OPEX via Software Defined Networks (SDN) and Network Function Virtualization (NFV). As a representative use case of industrial networks, wind park control network is considered for experimentation and trial in this project to demonstrate applicability and advantages of SDN and NFV. Following are the 5 key objectives of VirtuWind:

- Realise 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.
- 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.
- 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. Centralized 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.
- 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.
- 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 include 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. This significantly increases the acceptance of the innovative SDN/NFV based solution developed in VirtuWind.

VirtuWind started in July 2015 and will run for 36 months. VirtuWind has a very successful first project year in terms of timely submission of project deliverables, project dissemination activities at important industry events such as Mobile World Congress 2016, ETSI and EUCNC, and the work progress in terms of requirements analysis of more than ten use cases of adjacent industries, as well as the definition of the VirtuWind high level architecture. In year two, VirtuWind finalized the detailed solution architecture with intra-domain SDN&NFV modules (Deliverable D3.2), inter-domain SDN modules (Deliverable D4.1), and Northbound interface definitions. The relevant public deliverables with in-depth explanation can be found on http://virtuwind.eu/deliverables.php. Following diagram illustrates VirtuWind architecture components along with the high level interfaces between component blocks.

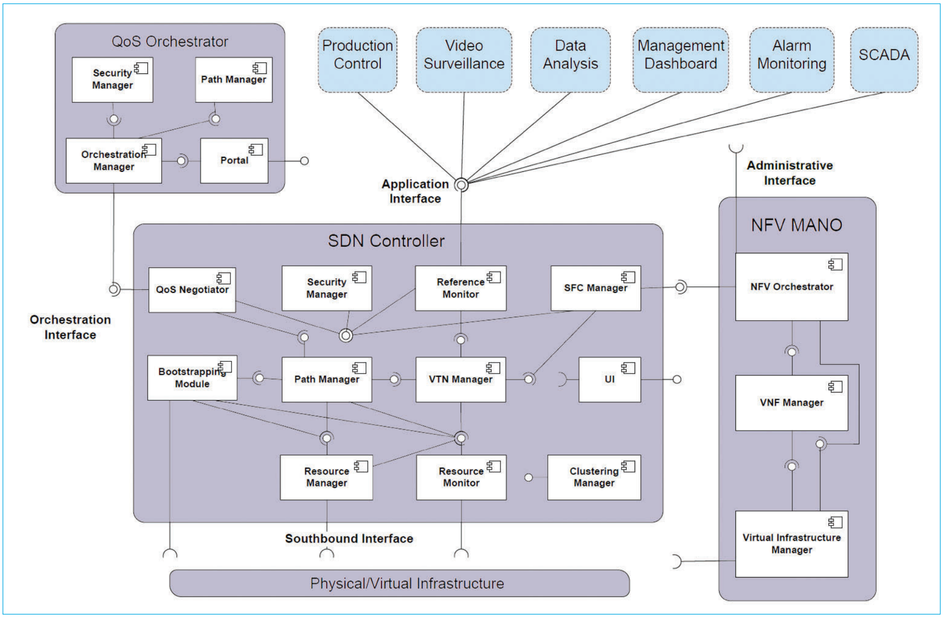


Figure 32: VirtuWind architecture components

The basic features of solution are currently being tested in lab. In July 2017, it is planned to have first field trial of VirtuWind solution in "Floe" Wind Park in Denmark. Additionally the project 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 in year three to evaluate the benefits of the developed system during field trials.

In year two, VirtuWind disseminated its project results in the following major activities:

- Demos: After showing Industrial-grade QoS demo at Mobile World Congress, Barcelona (Feb 2016) http://www.virtuwind.eu/gallery.html, VirtuWind participated at 2nd Global 5G event in Rome (Nov 2016) https://5g-ppp.eu/event/second-global-5g-event-on-9-10-november-2016-in-rome-italy/ 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 second showed multi-tenant, isolated and virtualized access to a range of Industrial IoT sensors gathering wind park control data.
- Standardisation: VirtuWind has been successful to position the project use case as one of the use cases at the IETF detnet WG, https://tools.ietf.org/pdf/draft-ietf-detnet-use-cases-12.pdf, in Generation Use Case.
- Publications: VirtuWind partners have been very active in disseminating project's results into academic conferences and journals. The list of scientific publications is available at: http://virtuwind.eu/publications.html. Key building blocks of VirtuWind solution like industrial QoS, secure-by-design industrial infrastructure have been included in different 5G-PPP WG white papers.

5G INITIATIVES

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 programs outside Europe. From June 2014 to March 2017, MoUs were signed between 5G PPP and peer organisations throughout the world (respectively with the 5G Forum in South Korea in June 2014, 5G Americas in the US and the 5GMF in Japan in March 2015, the IMT-2020 (5G) Promotion Group in China in September 2015, Telebrasil in Brazil in March 2017).

In October 2015, the 5G Infrastructure Association – Public Private Partnership (5G PPP) and partner organisations (5G Americas, 5GMF, 5G Forum, IMT-2020 (5G) Promotion Group) decided to jointly organise "Global 5G Events" twice a year to globally promote 5G. These "Global 5G Events" are intended to support multi-lateral collaboration on 5G systems across continents and countries.

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

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

During these two-day events, government representatives, high representatives from 5G programmes and other 5G supporting organisations, association leaders, many industry experts as well as leading universities and research centres participated and shared the latest Research and Development achievements.

- The First Global 5G Event took place in Beijing, China on May 31st and June 1st, 2016. It was hosted by IMT-2020 (5G) Promotion Group in China with the theme of "Building 5G Technology Ecosystem".
- The Second Global 5G Event was held in Rome, Italy on November 9th and 10th, 2016 under the responsibility of the 5G-IA/5G PPP. It dealt with "Enabling the 5G EcoSphere". On this special occasion, the final version of the first 5G Annual Journal was distributed.
- After the successful events of 2016, the Third Global 5G Event was held on May 24th and 25th, 2017 in Tokyo, Japan, just one year after the First Global 5G Event. It focused on the practical use of 5G from 2020 and beyond and provided news regarding "the 5G Filed Trial Project in Japan" that begins in 2017.

Future actions

The Fourth "Global 5G Event" is scheduled for November 20th to 24th, 2017 in Seoul, South Korea. It will be organised by 5G Forum.

The next MWC to be held on February 26th to March 1st, 2018 in Barcelona will be a major promotion opportunity for 5G PPP phase 2 projects.

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 uses FY2016 figures. We do not modify the shares we applied last year as we consider the full standardisation phase has not begun yet. In our view, 2018 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, other on "innovation" – innovation appears as a portmanteau word that leaves much space for interpretation–, and still others prefer to use the term "R&D expenses", without one knowing the method actually used of what is counted.

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

Third, we selected a wide set of players involved in the 5G field but could not gather information from all companies. Information could remain fragmentary in some areas. However, we consider our sample of 23 organisations is reliable.

Assessment of leverage ratio for 2016

Redoing the same exercise as in 2016, we get the following result:

5G PRIVATE R&D SPENDING (Million EUR)	2016 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	3 378	338	169	68
Nokia (Incl. ALU)	4 904	490	245	98
Huawei	11 060	1 106	553	221
NEC Europe		*50*	*25*	*10*
Samsung*	11 247	563	281	112.5
MNOs				
British Telecom		*50*	*25*	*10*
Deutsche Telekom	*4 900*	490	245	98
Orange	*705*	*78*	*39*	*60*
Portugal Telecom		*7*	*3*	*1*
TIM	*1 900*	*190*	*95*	*38*
Telefonica	906	91	45	18
Telenor	67	7	3	1
Test equipment				
Keysight Technologies*	384	19	9,5	4
Rohde & Schwartz	288	29	14	6
Chipset				
Intel*	11 517	576	288	115
Sequans	24	2	1	0
IT				
ATOS		29	14	6
IBM	4000	400	200	80
Others				
ADVA	24	2	1	0.5
CEA		*7*	*3*	*1*
Hewlett Packard Enterprise		7	*3*	*1*
Thales	736	74	37	15
IHP		*7*	*3*	*1*
TOTAL 5G PRIVATE R&D SPENDING (Million EUR)	**56 040**	**4 612**	**2 302**	**965**
Phase 1 total funding from EC	125	125	125	125
Phase 1 second year funding	70	70	70	70
The players in the table share of EU funding is	40%	40%	40%	40%
Phase 1 second year funding for above mentioned players	*35.0*	*35.0*	*35.0*	*35.0*
Leverage factor 2016**		66	33	14
Leverage factor 2016 for above mentioned players		*132*	*66*	*28*

Assumptions are in italics when R&D expenses are unknown
** For companies not based in Europe*
*** (Phase 1 second year funding) divided by total 5G private R&D spending*

Table 3: 5G R&D expenses
Source: 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 14 considering the whole 5G PPP phase one investment (70M €).

Results are quite similar to those disclosed last year based on 2015 publicly available figures for R&D investments.

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

Conclusion on Leverage ratio for 2016

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.

This assessment demonstrates 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 Euro-5G project organized an on-line survey in 2016 for the NetWorld2020 SME Working Group (WG) members to identify 5G related SME expertise and priorities in relation with the Phase 2 pre-structuring model[9]. The survey was a preparation phase before the 5G PPP online brokerage service was launched[10]. Its main purpose was to complement the 5G PPP online brokerage service by providing a simple view of the competence, skills and business relations of SMEs in the 5G domain. The results have been published on the "Find the SME you need!" web page that also contains SME relation and expertise with Business Verticals, and mapping of SMEs in the 5G value chain[11].

This activity contributed to increasing exposure and visibility of SME expertise in 5G. As a result, SME participation in 5G PPP has been increasing since the inception of the programme. In 5G PPP Call 1 projects, started in 2015, 29 % of beneficiaries are SMEs, with a budget share of 16.2%[12]. Preliminary information on Call 2 shows that 30% of the beneficiaries are SMEs, with a budget share of 22.2%. The total share in budget so far in the 5G PPP is therefore 19.4%, almost reaching the objective of 20% participation, which is one of the Key Performance Indicators set for the 5G PPP. In Call 2, 156 organisations are new to the 5G PPP with respect to Call 1. Among those organisations, 49 are SMEs, i.e. 31% of the new beneficiaries are SMEs.

The "Find the SME you need!" web page now also contains SME success stories, which were collected to identify SME expertise and innovation in 5G, and to better understand what SMEs had already achieved in 5G projects. In addition, and to assess future business and potential cooperation possibilities with SMEs, the success stories cover a wide area of benefits and learning on the technology side e.g. ultralow latency, hierarchical routing, 5G Small Cell Protocols, virtualized RAN with non-orthogonal waveforms, SDN/NFV implementations, Machine learning in wireless networks, etc. On the business side, some achievements can already be perceived on practical 5G technology implementation into sellable products, together with the acquisition of fundamental knowledge about 5G networks and technology. These together are helping SMEs to find new business opportunities to develop and deploy new products and service concepts for wider markets, and to offer their special expertise and know-how in 5G.

Finally, the "SME Expertise and Skills in the 5G Domain" brochure was produced to show

9. https://5g-ppp.eu/5g-ppp-phase-2-pre-structuring-model/

10. The online brokerage service at: https://5g-ppp.eu/brokerage-platform-new/

11. https://www.networld2020.eu/find-the-sme-you-need/

12. Requested EC contribution

the expertise and skills from selected SMEs in 5G and related domains[13]. It is more especially dedicated towards large organisations, whether industry or academia, from Europe and beyond, seeking to cooperate with SMEs in 5G.

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. If you wish to join the SME Working Group, please send a request to sme-wg-contact@networld2020.eu.

More information at
http://networld2020.eu/sme-support/.

European 5G trials roadmap: Technical aspects & innovations

The 5G Pan-European Trials Roadmap is covering a broader scope than the 5GAP and the 5G Infrastructure PPP Phase 3 (2018-20+). Most of the Roadmap implementation is and will be covered by the Industry on 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. Before 2018 (before the first 5G standard release by the 3rd Generation Partnership Project, 3GPP) it is envisaged to have technology trials run by independent trial consortia in various countries, independent of the status of standardisation, to demonstrate and validate the new 5G capabilities as well as foster an ecosystem around the new 5G capabilities.

The 5G Pan-European Trials Roadmap has been elaborated and reviewed by the Trials Working Group (WG) Members organisations. It 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:

- Affirm global European leadership on 5G technology, 5G networks deployment and profitable 5G business models.
- Demonstrate benefits of 5G to vertical sectors, public sector, businesses and consumers.
- Show a clear path to successful and timely 5G deployment.
- Provide robust response to the European Commission 5GAP.
- Complement commercial trials and demonstrations as well as national initiatives.

The Roadmap was made available in view of public release at the 3rd 5G Global Event taking place on May 24-25, 2017 in Tokyo.

The 5G Pan-EU Trials Roadmap is worked out by the European Trials WG (open membership) coordinated by the 5G Infrastructure Association (5G-IA), expanding the work initiated by the Industry and EC in the context of respectively the 5G Manifesto (http://ec.europa.eu/newsroom/dae/document.cfm?action=display&doc_id=16579) and the 5G Action Plan (http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=17131) and following the definition of the Roadmap Strategy introduced in MWC 2017 (https://5g-ppp.eu/wp-content/uploads/2017/01/5G-IA-Action-Plan-Event-Press-Release-_-MWC2017.pdf). 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 strategy is summarized in Figure 33 included in the Roadmap Strategy document (https://5g-ppp.eu/wp-content/uploads/2017/01/5G-IA-Action-Plan-Event-Press-Release-_-MWC2017.pdf).

13. https://www.networld2020.eu/find-the-sme-you-need/#brochure

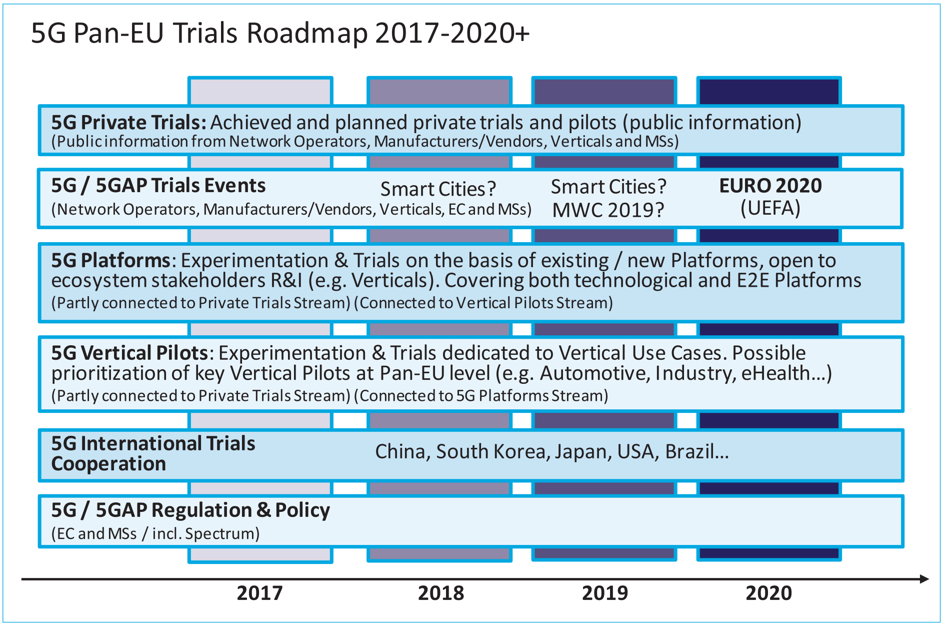


Figure 33: Pan-European Trials Roadmap 2017-2020 – Strategy and Streams

The Roadmap Version 1.0 was released on 23.05.17 and presented during the 3rd 5G Global Event organised on 24-26.05.17 in Tokyo. The Roadmap Version 1.0 is organised around 4 main pillars (1) 5G Private Trials, (2) 5G Vertical Pilots, (3) 5G for UEFA EURO 2020 and (4) 5G Trials Cities. As highlighted during the Roadmap Version 1.0 presentation on 25.05.17 in Tokyo, the major Roadmap Version 1.0 highlights are the following ones:

5G Private Trials (Highlights)

- Europe is home of an increasing number of 5G private experimentation and trials (pre-commercial and commercial) involving a multiplicity of stakeholders and notably network operators, manufacturers/vendors and some vertical actors.
- The main target of the current trials is to demonstrate key features for 5G technology, focused on enabling technologies.
- In 2017 only a few 5G Private trials including vertical stakeholders. When the maturity level of 5G features increases, more direct vertical stakeholders will be included for 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.
- Before 2018 demonstrations and trials are done to demonstrate and validate the new 5G capabilities early as well as foster an ecosystem around the new 5G capabilities.
- The running trials and demonstrations are already today building concrete know-how and readiness of the European industry to benefit from early 5G launch when the standards will be fully stable, by the end of 2019.
- The 5G readiness will be further consolidated during and after 2018, when European stakeholders will move to agree on detailed trials specifications valid for Pan-European trials, largely based on standard-compliant systems. These trials will aim to demonstrate wider interoperability and support for vertical use-cases in order to validate new business models.
- The 5G-IA Trials WG targets a tight connection with the NGMN 5G Trial & Testing Initiative

(TTI), launched in June 2016. TTI enables a global collaboration on testing activities, consolidating contributions and report on industry progress, and testing future 5G use-cases with industry stakeholders (in particular from vertical industries).

- At the international level, multiple standalone 5G network trials will be in progress by 2018. It is hence targeted to run interoperability trials in coordination with other main regions. In order to enforce the coordination with other regions the bi- and multi-lateral agreements with other 5G initiatives in China, Japan, Korea, the United States and Brazil will be leveraged.

Vertical Pilots (Highlights)

- After 5G technologies have reached a maturity level beyond pure laboratories experiments, trials and pilots will be targeted to validate 5G technologies in multi-vendor and multi-user environments.
- 5G-IA Trials WG focusing on 11 different Industry segments (66 use cases) and analyzing the common and various functional characteristics requiring 5G functionalities.
- Different verticals have different levels of 5G readiness. In some verticals large industry alliances or consortia exist, e.g. the EATA and 5GAA in the automotive sector or the IIC in the manufacturing industry, which are well positioned to partner with the 5G Industry to establish, drive and shape 5G adoption within their verticals.
- Connected Cars is considered as one of the verticals priorities for a strategic 5G European roadmap targeting vertical use cases.
- 5G-IA will assure that an umbrella perspective across all verticals will be developed to avoid siloes and a harmful segmentation of the 5G trials.

5G for UEFA EURO 2020 (Highlights)

- Target flagship event to get widespread media attention and serve as a milestone for industry, governments and the general public that 5G is coming now and is beneficial for individuals and society.
- The UEFA EURO 2020 football championships will be played in 13 different cities in Europe (Glasgow, Dublin, Copenhagen, Budapest, Bucharest, Brussels, Bilbao, Amsterdam, Saint Petersburg, Rome, Munich, Baku and London).
- EURO 2020 acting as the "launching event" for 5G in Europe with a number of 5G services that will be trialed, incl. (among others) 5G Augmented and virtual reality applications, Automated transportation and Advanced public safety services.
- In each of the cities a consortium is needed of local governments, playing stadiums, operators, infrastructure vendors and application providers.
- A Pan-European steering committee will ensure a consistent coordination of trial objectives and implementation.

5G Trials Cities (Highlights)

- In complement to the 5G private trials and the 5G for UEFA EURO 2020 flagship event, specific cities in Europe already announced their plans to become 5G Trials Cities.
- In addition 5G Research & Innovation Programs running in several Members States, include the development of specific labs and platforms, generally anchored in specific cities.
- In addition, Member States should communicate before end 2017, in the context of the 5GAP, the information on their 5G Pioneering city (or multiple cities) where 5G will be deployed in 2020.
- These different actions clearly create a strong momentum on 5G from cities and countries perspectives.
- Under the 5G Infrastructure PPP initiative, a "5G City Challenge" will be organised as a call for interest towards interested cities prepared to sign a 5G charter and aiming at supporting cooperation among the cities involved in 5G experimentation and trials.

The Trials WG is further progressing the definition of the different Roadmap Streams (incl. also the Platforms Stream not included in the Roadmap Version 1.0). The Roadmap Version 2.0 will be prepared and released before the 4th 5G Global Event to be organised on 22-24.11.17 in Seoul.

Summary "golden nuggets"

The approach of the PPP projects and programme Golden Nuggets was initiated mid-2016, starting first with the definition of the key projects achievement after Year 1. The projects Golden

Nuggets were collected on an individual basis and reviewed at programme level (Technology Board) before the European Commission Year 1 annual review, to develop a 360° understanding of the overall Phase 1 projects portfolio achievements and allow the different projects to fully understand their individual contributions inside these global Phase 1 achievements. The overall approach of the PPP Programme Golden Nuggets was then defined and organised in 3 steps. It was decided to define top-down 10 (minimum) – 20 (maximum) PPP Phase 1 Programme Golden Nuggets at Technology Board level, considering the projects Golden Nuggets and the proposed categorization of major achievements (step 1).

Next followed the definition of the arborescence and the up-to-date definition of the projects Golden Nuggets under these programme Golden Nuggets (step 2). Then finally the implementation of the programme and projects Golden Nuggets on the PPP website, hyperconnecting the projects achievements to the projects websites and related documents (e.g. Deliverables, White Papers...) (step 3).

The 15 PPP Phase 1 Programme Golden Nuggets are presented in Figure 34, that was released in January 2017 and included in the PPP MWC 2017 White Paper "5G innovations for new business opportunities" and in several 5G-IA presentations since February 2017.

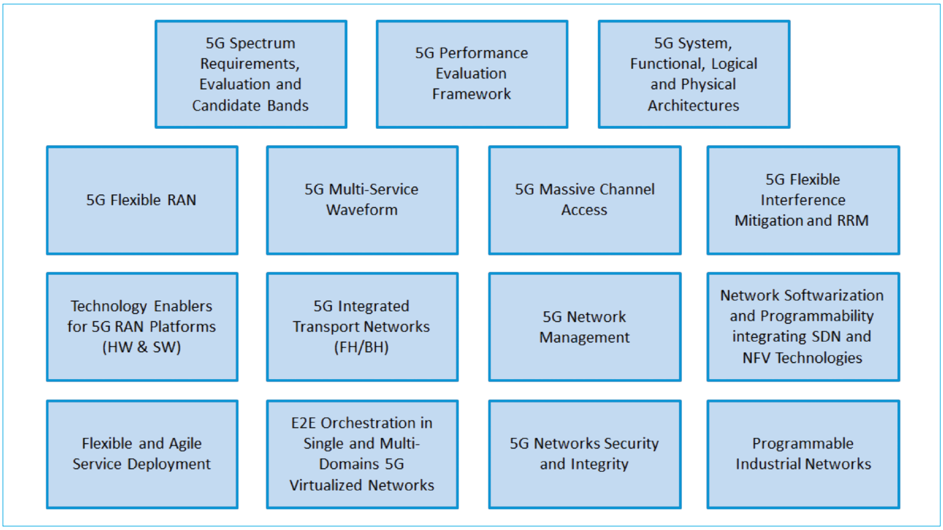


Figure 34: 15 PPP Phase 1 Programme Golden Nuggets

The up-to-date list of projects Golden Nuggets (June 2017), in the arborescence of the Programme Golden Nuggets is the following one:

- 5G Spectrum Requirements, Evaluation and Candidate Bands
- Spectrum investigations and conclusions (METIS-II).
- 5G Performance Evaluation Framework
- Overall air interface evaluation framework (METIS-II).
- Visualization platform (METIS-II).
- Visualization platform (mmMAGIC).
- 5G System, Functional, Logical and Physical Architectures
- Overall RAN design (METIS-II).
- Network architecture (COHERENT).
- 5G Security architecture (5G-ENSURE).
- Distributed (edge) intelligence (CHARISMA).
- 5G Flexible RAN
- RAN slicing (5G-NORMA).

- NGFI and RAN functional splits (5G-XHAUL).
- Low latency (CHARISMA).
- mmWave RAN integration (mmMAGIC).
- 5G Multi-Service Waveform
- New waveforms adapted for service coexistence below 6 GHz (FANTASTIC-5G).
- Air interface (mmMAGIC).
- Channel model (mmMAGIC).
- 5G Massive Channel Access
- Non-scheduled access for massive MTC (FANTASTIC-5G).
- 5G Flexible Interference Mitigation and RRM
- Flexible interference mitigation for 5G below 6GHz - FDD & TDD (FANTASTIC-5G).
- Advanced RRM interacting with higher-level entities, enabling operator spectrum policy management for all types of regulatory regime (SPEED-5G).
- Spectrum management (COHERENT).
- Flexible and adaptive multi-RAT MAC for dynamic spectrum access and aggregation (SPEED-5G).
- Technology Enablers for 5G RAN Platforms (HW & SW)
- Full duplex transceiver (Flex5Gware).
- Multiband base stations < 6 GHz (Flex5Gware).
- Dynamic HW/SW function split (Flex5Gware).
- Automated physical and virtual infrastructure deployment (SELFNET).
- Establishment of a functional prototype platform featuring multitenancy and NFV and resource orchestration (SESAME).
- Multi-antenna transceiver architectures (mmMAGIC).
- 5G Integrated Transport Networks (FH/BH)
- Management and orchestration (MANO) solution for integrated fronthaul and backhaul networks (5G-Crosshaul).
- Unified data plane solution for integrated fronthaul and backhaul networks (5G-Crosshaul).
- Fronthaul traffic compression (5-fold) (5G-Crosshaul).
- Converged backhaul/fronthaul (5G-XHAUL).
- SDN wireless backhaul for ultra dense networks (5G-XHAUL).
- 5G Network Management
- Autonomic network management (SELFNET).
- Hierarchical (blending distributed and centralized) management of ultra-dense multi-RAT and multiband networks (SPEED-5G).
- Policy management framework and code generator (CogNet).
- Process to apply machine learning models to policies (CogNet).
- Multi-level, multi-tenant-aware network monitoring (SELFNET).
- Network Softwarization and Programmability integrating SDN and NFV Technologies
- Flexible open-source service platform for NFV (SONATA).
- VNF placement at the edge of the network through appropriate GTP de/en-capsulation and steering of incoming traffic (SESAME).
- DevOps and CI/CD for NFV (SONATA).
- NFVO split into NSO-RO (5GEx).
- Initial deployment of sandbox test-bed connecting 13 sites (5GEx).
- Reusable Functional Block (RFB) concept and lightweight virtualization (Superfluidity).
- Integrated SDN and NFV apps management (SELFNET).
- Flexible and Agile Service Deployment
- Rapid software development for NFV (SONATA).
- KPI/SLA mapping and analytics pipeline (Superfluidity).
- Semantic description and symbolic execution of RFBs (Superfluidity).
- E2E Orchestration in Single and Multi-Domains 5G Virtualized Networks
- Breakdown of the multi-domain orchestration process (5GEx).

- Service and domain aware (re)orchestration (5G-NORMA).
- End-to-end orchestration (5G-NORMA).
- Multi-tenant industrial capability via NFV (VirtuWind).
- Bottom-up proof of concept prototype (5GEx).
- Open access/multi-tenancy (CHARISMA).
- 5G Networks Security and Integrity
- 5G Security enablers (5G-ENSURE).
- 5G Security testbed (5G-ENSURE).
- Virtualized security (CHARISMA).
- Programmable Industrial Networks
- SDN for programmable industrial networks (VirtuWind).
- Faster end-to-end (intra-, inter-domain) service deployment in industrial infrastructure (VirtuWind).

The implementation of the programme and projects Golden Nuggets on the PPP and projects websites is on-going in July 2017. It is planned to also possibly include and hyperconnect the related key achievements from the Working Groups (e.g. White Papers and Positions Papers).

Spectrum aspects for 5G

Timely access to suitable spectrum is one of the most important keys for 5G to become a success, see for example the 5G Action Plan [1]. It is also reasonable to consider it a competitive advantage with respect to equipment availability and good planning of roll out strategies. The activity in the 5G Infrastructure Association (5G IA) Working group (WG) 5G Spectrum and in the H2020/5G PPP projects addressing spectrum topics have provided interesting results.

Pioneer bands

For trials and early commercial deployment it is necessary to get access to spectrum early. It is useful to have a limited but sufficient number of bands identified for both industries and spectrum authorities to gain experience with 5G systems. For Europe the following pioneer bands have been suggested by the EU's RSPG Opinion [2]:

- Low band 700 MHz,
- Middle band 3.4 – 3.8 GHz, and
- High band 24.25 – 27.5 GHz (26 GHz).

The WG underlined the importance of this approach and suggested suitable bands along these lines in response [3] to RSPG public consultation that was held prior to issuing the opinion.

The coverage is very important where the low band provides it for wide area and indoor, the middle band is useful for urban areas, and the high band for hot-spots. Europe expects to be deploying trials in each of the three pioneer bands in the 2018 – 2020 timeframe.

For extreme mobile broadband (eMBB) services it is important that large enough contiguous bandwidth is made available, about 100 MHz for the middle band and 500 MHz and more for the high band.

The pioneer bands seem good candidates for global harmonization, particularly the middle band. The high band could benefit from specific radio technology for the use of adjacent spectrum bands notably in the US and some countries in Asia.

The high band is in study for the World Radiocommunication Conferences in 2019 (WRC-19), along with a number of other bands up to 86 GHz [4]. All the candidate millimetre bands are potentially of interest for 5G services.

Use of millimetre wave bands

Spectrum demand will obviously vary from use case to use case, as also indicted in last year's journal [x]. It may be very demanding and range from 5 to 15 GHz for an eMBB application as virtual reality office such as and for dense urban society it may be about 7 GHz [5]. This amount of spectrum can only be provided at the millimetre wave range.

Wireless technology for backhaul and fronthaul also requires access to adequate spectrum. An overview is provided in [6] also pointing at bands above 100 GHz, but within current allocations by ITU-R Radio Regulations [7]. Millimetre wave combined in hybrid systems with radio using spectrum below complement each other providing a trade-off between capacity and coverage [8]. The suitability of millimetre waves for coverage, capacity, and mobility e.g. Doppler effects, is assessed [9] with respect to key performance indicators (KPIs) used with 5G PPP.

Spectrum authorisation and sharing

Spectrum management and usage is tightly connected to both technical and business aspects. This was also underlined at the workshop organised by the WG [10]. To ensure agreed quality and and before significant investment can be made it is still needed to use exclusive licenses. However, there are cases where sharing regimes are possible and also favourable, and use of unlicensed bands as well. Project results are available addressing virtualization of spectrum resources and micro and localised usages [11], dynamic access algorithms [12], and improved shared spectrum by satellite and fixed links [13].

References

1. EC, 5G Action Plan, 2016 (http://ec.europa.eu/newsroom/dae/document.cfm?doc_id=17131)
2. RSPG, Opinion, 2016Opinion on spectrum related aspects for next-generation wireless systems (5G), RSPG16-032 FINAL, 9 November 2016 (http://rspg-spectrum.eu/wp-content/uploads/2013/05/RPSG16-032-Opinion_5G.pdf)
3. 5G Infrastructure Association, Response to RSPG Public consultation on the Draft RSPG Opinion on spectrum related aspects for next-generation wireless systems (5G), Initiative on pioneer 5G bands, 8 July 2016. (https://circabc.europa.eu/d/a/workspace/SpacesStore/4ed94c29-182f-418a-b202-6861f69a4f3a/Responses_5G.pdf)
4. 5G PPP, The European 5G Annual Journal, 2016 (https://bscw.5g-ppp.eu/pub/bscw.cgi/d117642/Euro%205G%20Annual%20Journal%202016.pdf)
5. Rauno Ruismäki, Thomas Rosowski, Giovanna D’Aria, Yinan Qi, Du Ho Kang, Mikko A. Uusitalo, and Ki Won Sung (METIS-II), “5G spectrum requirements”, EuCNC 2017 Conference, Oulu, Finland, 12-15 June 2017
6. Ping-Heng Kuo and Alain Mourad (5G-CROSSHAUL), ”Millimeter Wave for 5G Mobile Fronthaul and Backhaul”, EuCNC 2017 Conference, Oulu, Finland, 12-15 June 2017
7. ITU, Radio Regulation, 2016, Geneva
8. 5G-Xhaul, System Architecture Definition, Deliverable D2.2, [date], ([link])
9. Mythri Hunukumbure1, Yue Wang, Miurel Tercero, and Javier Lorca (mmMAGIC), ”Some insights into the behaviour of millimetre wave spectrum on key 5G cellular KPI’s”, EuCNC 2017 Conference, Oulu, Finland, 12-15 June 2017
10. 5G PPP Workshop, Spectrum for 5G, Brussels, 7 June 2017 (https://5g-ppp.eu/event/workshop-spectrum-for-5g/)
11. Shah Nawaz Khan, Adrian Kliks, Tao Chen, Miia Mustonen, Roberto Riggio, Leonardo Goratti (COHERENT), ”Virtualization of Spectrum Resources for 5G NetworksCoherent paper, EuCNC 2017”, EuCNC 2017 Conference, Oulu, Finland, 12-15 June 2017
12. Speed5G, RM framework and modelling , Deliverable D4.2, 19 April 2017 (https://speed-5g.eu/wp-content/uploads/2017/06/speed5g-d4.2_rm-framework-and-modelling.pdf)
13. Xavier Artiga, Miguel Ángel Vázquez, Ana Pérez-Neira, Christos Tsinos, Eva Lagunas, Symeon Chatzinotas, Venkatesh Ramireddy, Christian Steinmetz, Rudolf Zetik, Konstantinos Ntougias, Dimitrios Ntaikos, and Constantinos B. Papadias (SANSA), ”Spectrum Sharing in Hybrid Terrestrial-Satellite Backhaul Networks in the Ka Band”, EuCNC 2017 Conference, Oulu, Finland, 12-15 June 2017

5G CHRONICLE

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

In particular, Memorandum of Understandings (MoUs) paved the way to a global harmonized 5G promotion and workshops allowing close and smooth cooperation among the various 5G PPP projects and effective dissemination actions to be orchestrated. 5G Americas (Americas), The Fifth Generation Mobile Communications Promotion Forum (5GMF) (Japan), 5G Forum (Republic of Korea), IMT-2020 Promotion Group (5G) (non-profit organisation, China) and obviously the 5G Infrastructure Association Public Private Partnership (5G PPP) (Europe) all acknowledged the need of a global and common 5G promotion as 2020 approaches.

The parties have agreed to jointly organise two "Global 5G Events" per year to focus their efforts and leadership. The first three "Global 5G Events" were held from May 31st to June 1st, 2016 in Beijing (China) under the responsibility of IMT-2020 (5G) Promotion Group, in November 9-10th in Rome (Italy) under the responsibility of the 5G Infrastructure Association and on May 24-25th, 2017 in Tokyo (Japan) under the responsibility of the 5GMF.

Spectrum for 5G workshop (7 June 2017)

Brussels, Belgium- June 7

This workshop was held in Brussels, Belgium early June 2017. It presented recent research results covering the need for 5G spectrum and the suitability of the frequency bands under consideration (sub-GHz to millimetre) for 5G to provide ambitious services and adequate coverage, especially leveraging the 5G PPP projects advancements.

The sessions covered spectrum options as determined by the use cases envisaged for extended mobile broadband, massive machine-type communication, and ultra-reliable low-latency communication. In particular vertical sectors' uses cases were highly relevant. The workshop also provided introductions and research project results on expected 5G scenarios providing discussion of needed bandwidths, coverage, and availability of suitable radio frequencies.

ICT 2016 (16-18 May, 2016)

During the 23rd edition of the International Conference on Telecommunications in Thessalonica, Greece COHERENT co-organised the NetVis' 2016 workshop on "Advances on Network Virtualization for 5G Systems".

IEEE ICC 2016 and 2017

The IEEE ICC 2016 held late in May 2016 in Kuala Lumpur, Malaysia gave the opportunity to METIS-II, mmMAGIC, 5G NORMA and FANTASTIC-5G to focus on 5G architecture and specifically on RAN design.

The 3rd International 5G RAN design workshop was organised at ICC 2017 which took place on 25 May 2017 in Paris. The workshop, jointly organised by METIS-II, FANTASTIC-5G, mmMAGIC, 5G-CROSSHAUL and Flex5GWare, built upon its successful predecessors, focused on the 5G RAN design and provided the opportunity to share and discuss final results from the mentioned projects or other 5G research activities. The workshop was collocated with IEEE ICC 2017 (21-25 May 2017).

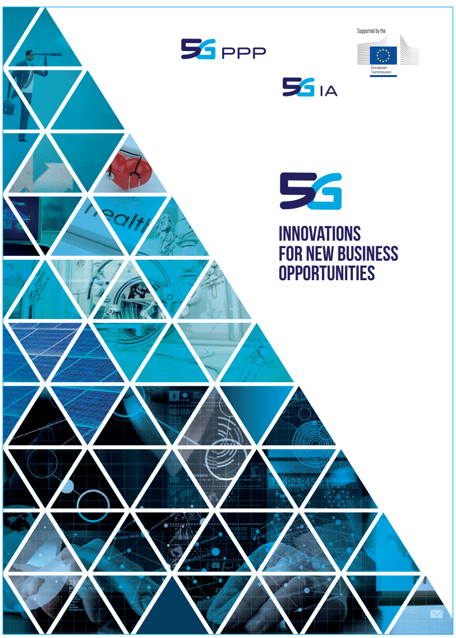
Mobile World Congress 2017 (27 February-2 March 2017)

The 5G-IA and 5G PPP projects were strongly present at MWC'17.

The members of the 5G Infrastructure Association have hosted the press, media and ICT industry analysts at a briefing on the evolution of European 5G initiatives from Research to Trials at Mobile World Congress 2017. The event was held on the 28th of Feb from 14:00 to 15:30 in the Press Conference Room 1, in the Media Village at the MWC in Barcelona. This successful press event attracted around 160 participants from different backgrounds and horizons.

The event was opened by Roberto Viola, Director General of DG CONNECT at the European Commission. Panels followed where top managers from leading global technology member companies discussed the progress being achieved through European 5G Research, the emergence of 5G standards, and prospects for investments in the new infrastructure, while representatives of the vertical industries and the public sector outlined their needs and expectations for 5G. A major discussion point was the technology experiments, validation tests, and the evolution to field trials as outlined in 5G Action Plan that will be needed between now and 2020 to facilitate the development of 5G.

The concept of a roadmap for the implementation of advanced pre-commercial trials to be launched in key sectors in 2018 and to be promoted at EU level was introduced with a view to ensuring Europe leadership in the context of the accelerated global agenda for the introduction of 5G.



The briefing focused on the "evolution of European 5G initiatives from Research to Trials".

Highlights of the progress achieved to date by the 19 strategic phase 1 projects were presented in a White Paper – "5G innovations for new business opportunities" – The paper identifies recommendations of the EU telecom sector towards harmonized 5G standardisation, spectrum, deployment and regulation.

In addition, the 5G Pan-European Trials Roadmap Strategy was released ahead of MWC'17 on 28 February 2017 and presented during the 5G-IA session with a view to informing the community of the approach being taken and to invite more contributions.

At the end of the Press Event, the 5G-IA and the Telebrazil Projeto 5G signed a Collaboration MoU to foster industrial collaboration on Research, Standards, Regulation and Policies over the next three years, particularly on 5G.

5G PPP projects showcased many demos, organised panels and sent a number of keynote speakers.

This year, 5G has grown a lot and pre-commercial services should be launched in the USA in 2017. In the longer term, 1 billion subscriptions are anticipated until 2025 according to the MWC's organiser. We did not identify any example of real innovation in 2017 but rather the continuation of last year's developments.

However, there is much pressure set on the 3GPP to speed up the standardisation process!

A number of leading MNOs (AT&T, NTT DOCOMO, South Korea Telecom (SKT), Vodafone Group, BT Group, Telstra, KT Corp, KDDI, Telia Company, Swisscom, Telecom Italia (TIM), Etisalat, Sprint, LG Uplus and Deutsche Telekom) and equipment vendors (Ericsson, Qualcomm Technologies, Intel, Vivo, LG Electronics, Huawei and ZTE) at MWC called for an acceleration of the 5G New Radio (5G NR) standardisation process (i.e. Release 15). The objective was to enable large-scale trials in 2019 instead of 2020. The group suggests adding an intermediate milestone (set by the end of 2017) to complete specification documents. Verizon, Samsung and Nokia voted against.

The group succeeded and the 3GPP agreed early March 2017 to develop an intermediate standard for 5G to be ready by March 2018.

5G technologies have grown up quite fast

On the margins of the MWC, 25 MNOs announced they are currently testing 5G. Many demonstrations could be seen at vendors' booths to showcase key 5G technologies, i.e.

massive MIMO, beamforming, network slicing and virtualization:

- A first virtualized SDN/NFV radio access network at Intel's booth
- Base stations supporting throughputs of approx. 50 Gbps and 5 Gbps per device
- Few equipment vendors showcased 5G base stations operating on millimetric frequencies and on sub-6 GHz bands.
- Nokia showed its 5G FIRST end-to-end solution. It incorporates AirScale massive MIMO adaptative antennae, the cloud packet core network and Intel's based mobile transport network platform. Nokia and Intel will collaborate on commercial deployments later in 2017.
- 5G FIRST is based on specifications defined by the Verizon 5G Technology Forum and is the basis of 5G pilots being deployed in 11 US cities.
- Ericsson, Qualcomm, NTT DoCoMo and Telstra announced their plans for interoperability testing.
- A few days before the MWC, Samsung announced a 5G Radio Base Station (a 5G access unit) and core network infrastructure, among others. They will use the 28 GHz band in the USA. On a longer term, additional bands could be used.

At last, cloud-based technologies were also present on equipment vendors' booths this year.

The first phase of 5G as fixed wireless access

Verizon and AT&T anticipate launch of 5G fixed wireless access services in 2017. In particular, Verizon is trialing the ability of its 5G fixed wireless service to transmit 4K video. This kind of service is easier to implement because it is stationary and there are no battery limits to consider. This first commercial service will help validate the use of millimetric frequency bands, massive MIMO and beamforming. Questions remain however, regarding what kind of antennae will be used: indoor or outdoor? This has a direct impact on the service scope.

What will be 5G use cases?

Few questions were raised on "good" 5G use cases. From the MNO point of view, "good" use cases are those that can be easily monetized! Many MNOs and analysts stated that network equipment prices have to decrease significantly to be affordable and ensure viable deployment and a lower TCO than in LTE. 5G supporters are betting on very low latencies achieved and on network slicing for B2B services. Augmented reality, virtual reality, autonomous cars, smart cities, drones and IoT for industrial services are poised to be ideal applications with 5G.

How much will 5G cost?

On this topic, the Deustche Telekom CEO indicated that 5G deployment in Europe would be a 300 to 500 billion EUR investment.

EuCNC 2017 (12-15 June 2017)

EuCNC accounts for one of the biggest dissemination opportunities for 5G PPP projects alongside MWC. The 2017 edition took place in Oulu, Finland.

Phase 1 projects were deeply involved in the event with many synergic initiatives. On 13 5G PPP projects' booths demos and achievements were showcased. Phase 1 projects also organised seven joint workshops and/or participated in a number of briefings. 8 innovative SMEs of the NetWorld2020 SME Working Group (AICO Sotfware, InnoRoute, Ubiwhere, CityPassenger, ARDIC Visiona Ingenieria de Proyectos, Nextworks, Montimage) presented demos on a specific booth.

Euro-5G organised two specific informative sessions (June 14^{th} and June 15^{th}). Key achievements from Phase 1 were highlighted and 5G PPP Phase 2 projects were successively presented by project leaders.

5G PPP projects jointly organised a number of workshops

5G PPP projects jointly organised a number of joint workshops highlighting strong cooperation between projects:

- mmMAGIC, METIS-II, 5G-Crosshaul and 5G NORMA co-organised a workshop on RAN architecture and integration on March 30-31, 2017 in London, UK. Along with many others, the following topics were debated:
  - Multi-connectivity, multi-RAT & multi-service aspects

- Network slicing, virtualization and flexible RAN design
- System integration and deployment considerations

- The 5G PPP projects METIS-II, FANTASTIC-5G, mmMAGIC, 5G-Crosshaul and Flex5Gware jointly organised the 3rd workshop on 5G RAN design in Paris, France on May 25th, 2017. The workshop was co-located with the IEEE ICC 2017.
- EuCNC 2017 gathered many 5G PPP projects contributing to its success. FANTASTIC-5G, FLEX5GWARE and SPEED-5G co-organised the "2nd 5G PPP Workshop on 5G Physical Layer Design and Hardware Aspects Below and Above 6 GHz". CHARISMA, SESAME, COHERENT, VIRTUWIND, 5G-NORMA, 5GEx, SPEED-5G, SELFNET and mmMAGIC projects co-held the workshop on "Business Models and techno-economic analysis for 5G networks". 5G-Crosshaul and 5G-Xhaul co-arranged (with iCIRRUS) a workshop on "New XHaul solutions for the 5G transport challenge". The Software Network Working Group (SONATA, 5GEx, 5G-CROSSHAUL, SUPERFLUIDITY, CHARISMA, SESAME, SELFNET, VIRTUWIND, COHERENT) prepared a workshop on "Software Networks and 5G: from network programmability to SDN/NFV combination for effective network slicing". SESAME, COHERENT, 5G-Xhaul and CHARISMA contributed to a Special Session on "Development of a Cloud-enabled "Small Cell as a Service" concept, for Multi-Tenancy and Edge Services in the 5G Framework." FLEX5GWare and mmMAGIC, with 5G-Champion, 5G-MiEdge worked on a workshop on "Prototyping the 5th Generation Cellular Wireless Technology". COGNET and SELFNET co-organised the "2nd Network Management, Quality of Service and Security for 5G Networks" where the work of the 5G PPP Working Group on Network Management, Quality of Service and Security was presented.
- Flex5Gware project organised a 2-days event, in collaboration with other 5G PPP projects (FANTASTIC-5G, 5G-Crosshaul, 5G-Ex, SPEED-5G, COHERENT). In this important event, 5G highlights were presented and discussed, together with the demonstration of several PoCs (11 from Flex5Gware and 5 joint with the other projects).

Other joint initiatives will follow in the second half of 2017

- 5G-ENSURE and CHARISMA will co-chair the 2nd International Workshop on Security in NFV-SDN at SNS'17 early July 2017 in Bologna, Italy.
- CHARISMA is co-organising the first workshop on Mobile Edge Communications (MECOMM) with the H2020 POINT project. The workshop will be held in conjunction with the ACM SOGCOMM Conference in UCLA campus in Los Angeles, CA, USA on August 21-25, 2017.
- METIS-II and Flex5Gware will be very active at the Helsinki 5G week in September 2017. Two tracks will be co-chaired by Flex5Gware: the first one will focus on "Verticals, Services and Applications" while the second one will be on Softwarization and Virtualization. METIS-II is preparing the track on 5G Radio and Wireless Communications.
- The fourth of the bi-annual events will be hosted in Seoul, South Korea by 5G Forum in November of 2017.

Printed in September 2017
SEP, Nîmes

PEFC
PEFC/10-31-1244
PROMOUVOIR
LA GESTION DURABLE
DE LA FORÊT

The European 5G Annual Journal/2017

This material has been designed and printed with support from the EURO-5G project and the 5G Infrastructure Association. The EURO-5G Project has received funding by the European Commission's Horizon 2020 Programme under the grant agreement number: 671617.

Supported by the

European Commission

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