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

Euro-5g – Supporting the European 5G Initiative

D2.5: Analysis of project portfolio

Version: v0.9

Deliverable type	R (Document, report)
Dissemination level	PU (Public)
Due date	31/12/2016
Submission date	14/09/2017
Lead editor	Alessandro Bedeschi (5G-IA)
Authors	Alessandro Bedeschi (5G-IA), Didier Bourse (5G-IA)
Reviewers	Uwe Herzog (Eurescom), Werner Mohr (Nokia)
Work package, Task	WP 2, Task 2.3
Keywords	Euro-5G, 5G PPP, phase 1 projects, phase 2 projects, portfolio analysis

Abstract

Deliverable 2.5 presents an overview of the progress and achievements of 5G PPP Phase 1 Projects, and a portfolio analysis of 5G PPP Phase 2 projects. This includes the coverage of the 5G PPP pre-structuring model, a mapping of projects on Targeted Actions (TAs), the phase 2 projects' interest in 5G PPP Working Groups, and their planned contribution to the 5G PPP KPIs.

To avoid overlapping with Euro-5G Deliverable D2.2 "Initial analysis of project portfolio and programme KPIs" prepared in June 2016, the report focuses on the period July 2016 - August 2017.

Document revision history

Version	Date	Description of change	List of contributor(s)
v0.1	23/08/2017	First draft	Alessandro Bedeschi (5G-IA)
v0.2	27/08/2017	Updates	Alessandro Bedeschi (5G-IA)
v0.3	28/08/2017	Updates	Alessandro Bedeschi (5G-IA)
v0.4	30/08/2017	Inclusion of 'References list'. Improved readability.	Alessandro Bedeschi (5G-IA)
v0.5	31/08/2017	Further updates	Didier Bourse (5G-IA)
v0.6	01/09/2017	Document review and revision	Uwe Herzog (Eurescom)
v0.7	05/09/2017	3 changes related to comments from Didier	Alessandro Bedeschi (5G-IA)
v0.8	12/09/2017	Further editing	Uwe Herzog (Eurescom)
v0.9	14/09/2017	Review by Werner Mohr, final editing.	Werner Mohr (Nokia), Uwe Herzog (Eurescom)

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

Executive Summary

This document follows and complements Euro-5G Deliverable "D2.2: Initial analysis of project portfolio and programme KPIs", presenting the key achievements of 5G PPP Phase 1 projects. The achievements are also illustrated by means of 15 'Golden Nuggets' that were identified in the Technology Board and that well illustrate the essential contribution of Phase 1 projects to 5G PPP KPI achievement.

As for the Phase 2, the document describes the activities related to project portfolio analysis and to the kick off activities of the projects.

Euro-5G played a key role in carrying out or supporting these activities. Its work has also been essential to inform and raise awareness among stakeholders facilitating their participation in Phase 1 and 2 projects, Working Groups and overall actions at PPP programme level.

Table of Contents

List of Figures

Abbreviations

TAs	Targeted Actions
KPI	Key Performance Indicators
5G-IA	The 5G Infrastructure Association
EC	European Commission
PPP	Public Private Partnership
SB	Steering Board
TB	Technology Board
GN	Golden Nugget

1 Information on 5G PPP Phase 1 project portfolio analysis

Information on activities related to project portfolio analysis carried out by Euro-5G in cooperation and/or coordination with the 5G-IA, the projects and the European Commission are available in the following documents:

- Euro-5G Deliverable *“D2.2: Initial analysis of project portfolio and programme KPIs”* submitted on 7 July 2016. It includes information on:
    - Pre-structuring model for Phase 1
    - Support to the Community and mobilisation of stakeholders
    - Project portfolio of 5G PPP Phase 1
    - Description and key objectives of the projects
    - Relevance and impact of Projects on 5G PPP KPIs
    - Statistics of involved organisations per country and per ‘stakeholder group’ (industry, SME and research)
    - Preparation of a ‘Collaboration Agreement’ signed by projects participants
    - Communication and outreach activities

Specific Euro-5G’s initiatives related to activities mentioned above (e.g. on KPIs, communication) are also covered in more detail in other Euro-5G Deliverables, i.e. D1.1, D2.4, D3.3.

- *“Independent Assessment of 22 Selected Projects under the Horizon 2020 ICT 2014 Call: Advanced 5G Network Infrastructure for the Future Internet”* in Phase 1 initiated by the European Commission.

  The complete report and a detailed presentation are available on the EC website [1].

  Key issues addressed in the assessment are:

  1. Coverage of the Call by the project proposals eventually retained for funding (15 RIAs, 3 IAs and 1 CSA). The Commission took into account 3 additional projects outside 5G objectives.
  2. Coverage by these proposals of the 5G PPP Pre-Structuring Model V2.0 (available on the 5G PPP website [2]).

  Euro-5G was greatly involved in the analysis of the Phase 1 projects portfolio and the corresponding mapping to the Pre-Structuring Model.

2 5G PPP Phase 1 Projects' key developments and achievements

Information on the work carried out by the 19 5G-PPP Phase 1 Projects [3] is available in the first edition of "The European 5G Annual Journal" [4].

The second edition of "The European 5G Annual Journal", currently being prepared by Euro-5G, will be published in the third quarter of 2017. It will present the Phase 1 projects' major achievements and innovations during the second year (including information related to performance KPIs and description of demos). The projects' input for the second edition of the 5G Annual Journal is included in Appendix A of this document.

The 5G Initiative Technology Board defined the key technical achievements (Golden Nuggets (GNs)) at 5G-PPP Phase 1 programme level, including the related key achievements at projects level. The intention is to implement a 3 steps approach, including the development of the corresponding PPP programme webpages and hyperlinks to Phase 1 projects and documents. The first version of the projects GNs document was released by the 5G Initiative TB on 30.08.16. It was targeted to be analysed by TB members before the EC annual projects review. Some projects made use of the projects GNs document, in order to enhance their state-of-the-art review and be prepared for possible questions on the programme relations during the EC Y1 annual review. It was decided in October 2016 to structure the PPP programmatic achievements through the PPP programme GNs, building on the projects GNs. The target was to define 10-20 (maximum) PPP programme GNs, integrating (arborescence) the key projects achievements. The definition of the projects and programme GNs was boosted in October 2016 – January 2017. 54 project inputs were received and considered and 15 programme GNs were defined, following several iterations. The programme GNs approach and figure were included in external communication for the first time in the 5G PPP White Paper for MWC 2017. In parallel to the GNs definition work, it was also decided to define possible joint projects demonstrations (co-located and possibly integrated).

The current list of projects Golden Nuggets (as of June 2017) is the following:

(1) 5G Spectrum Requirements, Evaluation and Candidate Bands

- Spectrum investigations and conclusions (METIS-II).

(2) 5G Performance Evaluation Framework

- Overall air interface evaluation framework (METIS-II).
- Visualization platform (METIS-II).
- Visualization platform (mmMAGIC).

(3) 5G System, Functional, Logical and Physical Architectures

- Overall RAN design (METIS-II).
- Network architecture (COHERENT).
- 5G Security architecture (5G-ENSURE).
- Distributed (edge) intelligence (CHARISMA).

(4) 5G Flexible RAN

- RAN slicing (5G-NORMA).
- NGFI and RAN functional splits (5G-XHAUL).
- Low latency (CHARISMA).
- mmWave RAN integration (mmMAGIC).

(5) 5G Multi-Service Waveform

- New waveforms adapted for service coexistence below 6 GHz (FANTASTIC-5G).
- Air interface (mmMAGIC).
- Channel model (mmMAGIC).

(6) 5G Massive Channel Access

- Non-scheduled access for massive MTC (FANTASTIC-5G).

(7) 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).

(8) 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).

(9) 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).

(10) 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).

(11) Network Softwarisation 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).

(12) 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).

(13) 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).

(14) 5G Networks Security and Integrity

- 5G Security enablers (5G-ENSURE).
- 5G Security testbed (5G-ENSURE).
- Virtualized security (CHARISMA).

(15) 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. It is planned to also possibly include and hyperconnect the related key achievements from 5G PPP Working Groups (e.g. from White Papers and Positions Papers).

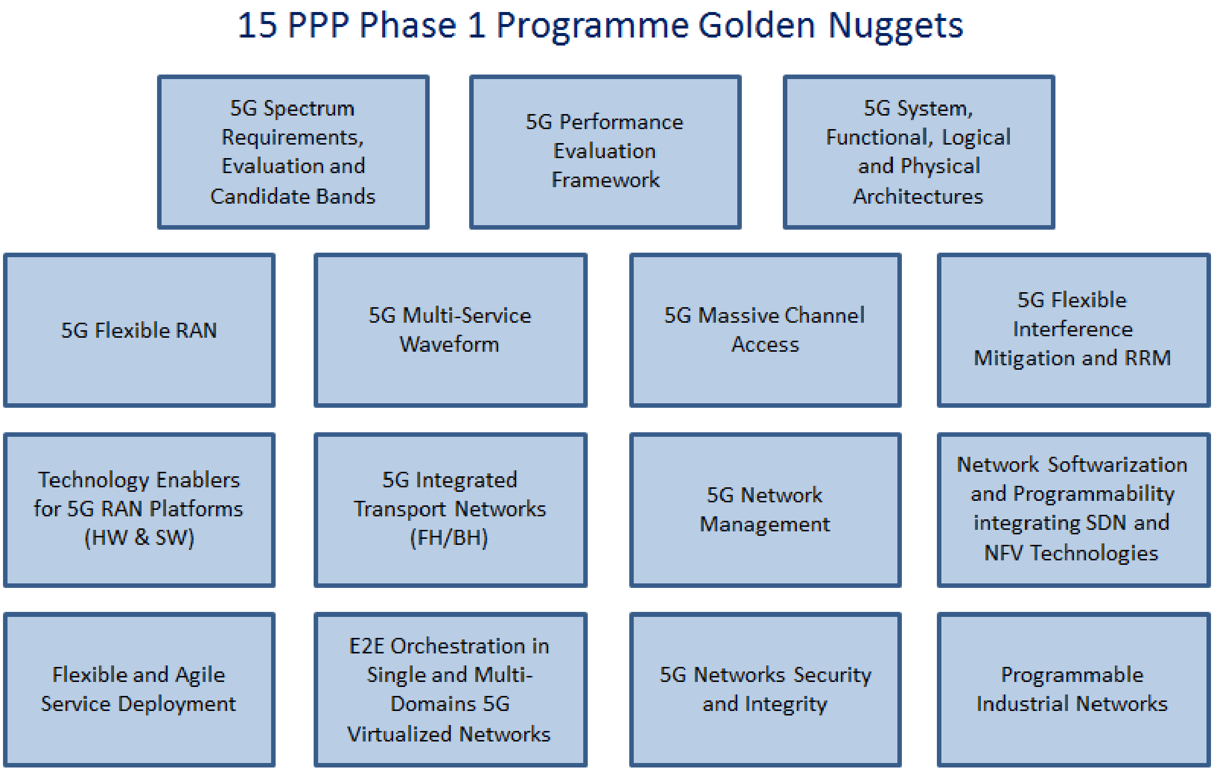


Figure 1: The 15 "Golden Nuggets" of 5G PPP Phase 1 projects

A video, prepared by Euro-5G, illustrating some of the achievements reached by Phase 1 Projects is available on the 5G PPP YouTube channel [5].

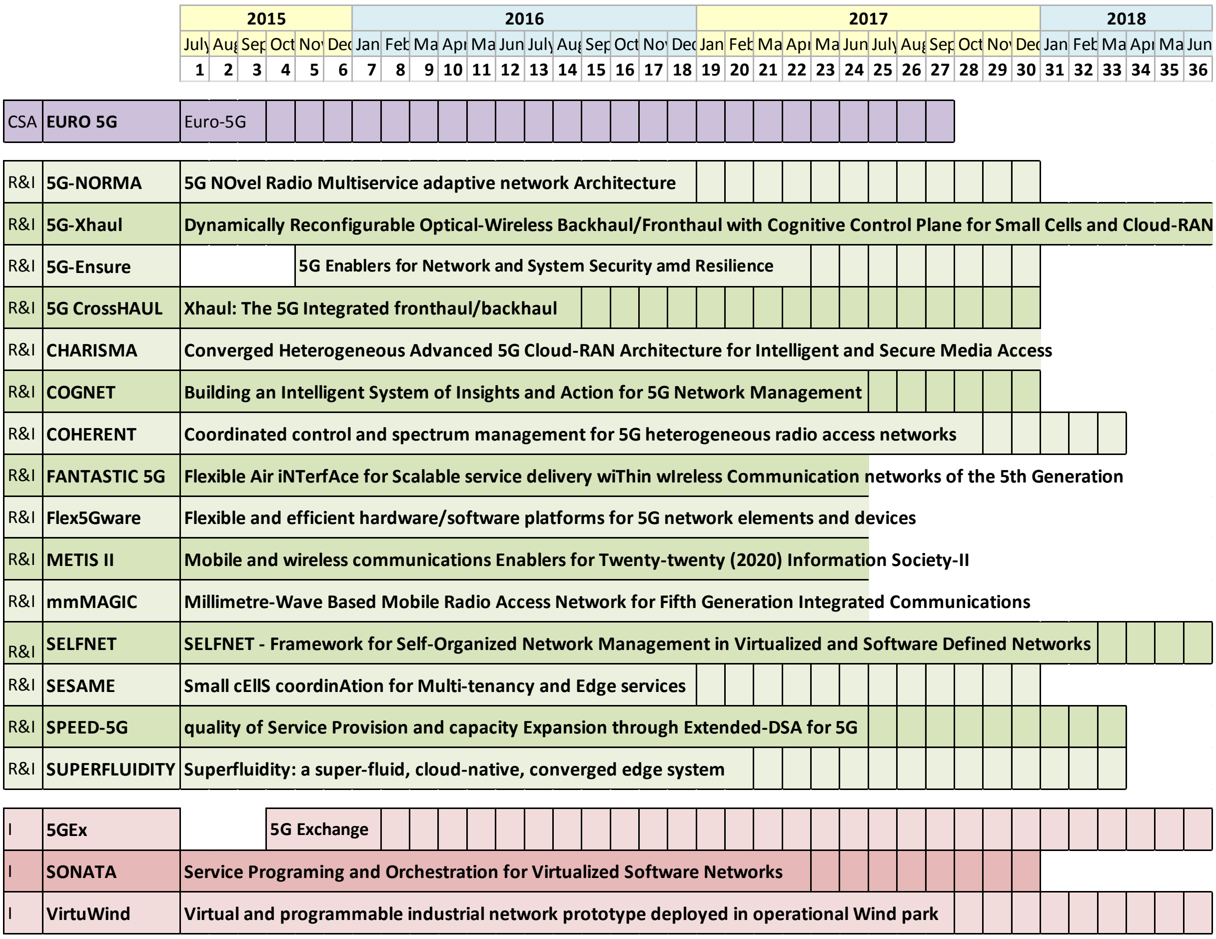


Figure 2: 5G PPP Phase 1 projects timeline

3 Activities related to 5G PPP Phase 2

3.1 5G PPP Phase 2 Pre-structuring Model

Targeting a successful and coherent 5G PPP Phase 2 research programme and building on top of PPP Phase 1 experience, the 5G Infrastructure Association members developed a Phase 2 Pre-structuring Model [6] [7]. The goal was to ensure that the forthcoming set of selected projects in Phase 2 and their portfolio are as complementary to each other as possible, and to facilitate their exchange and cooperation

i) in Phase 2,

ii) between Phase 2 and Phase 1, and

iii) later on between Phase 2 and Phase 3 by taking Phase 1 results into account.

The Model focused on suggesting a coherent Phase 2 portfolio, building on the EC Work Programme [8], i.e. the strategic objectives and related strands. The Model defined a set of Phase 2 Targeted Actions (TAs) addressing their related rationale, objective, scope and expected impact.

The 5G Infrastructure Association released the Pre-structuring Model version 2.0 (final version) on 04/03/16. This version was elaborated on the basis of version 1.0 released on 02/11/15, considering the feedbacks received through the public consultation and the first Phase 2 EC Info Day organized on 21/01/16 in Brussels.

The 5G Infrastructure Association members enriched the Model and further elaborated the definition of the different Targeted Actions (TAs) and their positioning in the context of the PPP programme. This considered aspects as e.g.

- Phase 1 experience and running projects state-of-the-art,
- 5G global standardization roadmap,
- cross-project interworking (Clause 41.4 in Model Grant Agreement) and Phase 1 Working Groups, and
- potential TAs interfaces.

Euro-5G was greatly involved in the preparation of the Phase 2 Pre-Structuring Model, supporting the 5G-IA, leveraging on the experience of the Phase 1 Model (post mortem and lessons learnt).

A detailed presentation of the final version of the 5G PPP Phase 2 Pre-structuring Model is available on the 5G PPP website [6].

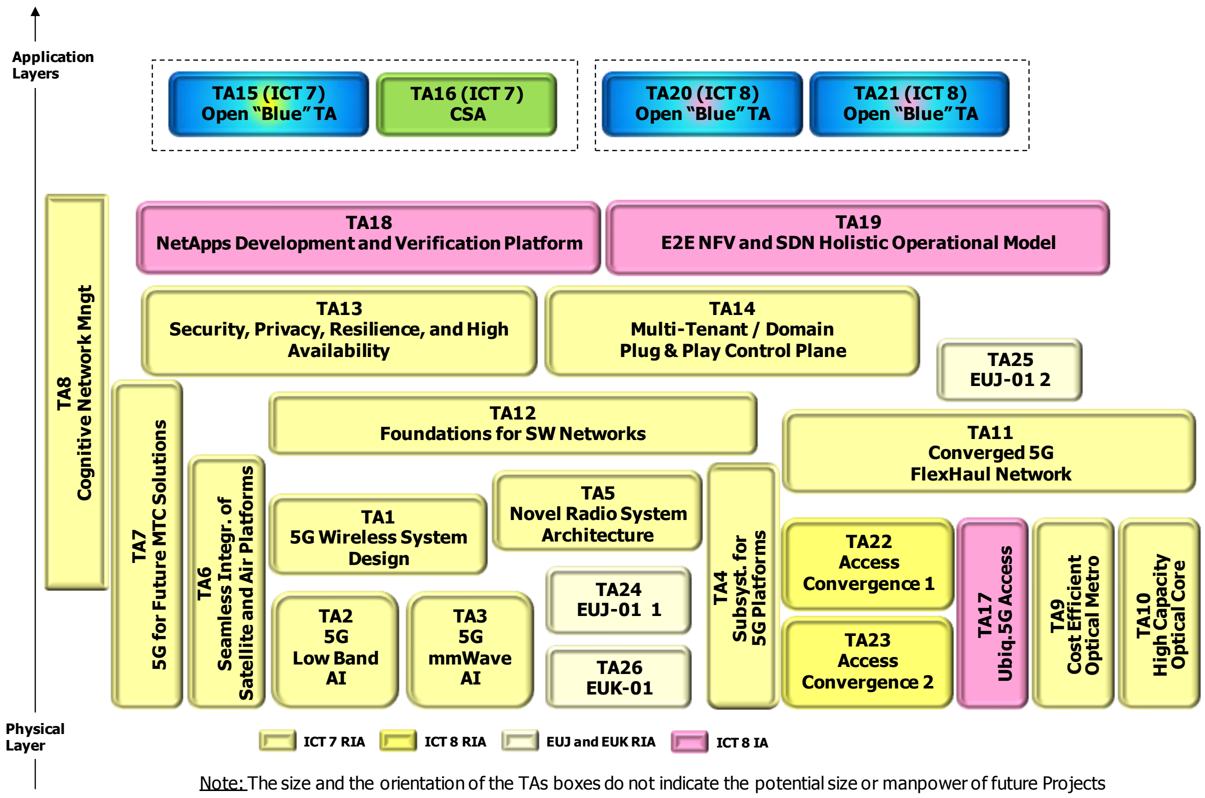


Figure 3: 5G PPP Phase 2 Pre-structuring Model version 2.0

In order to mobilise the research community in Europe to prepare and submit project proposals, 5G-IA and Euro-5G organised four additional 'Information Days' (after the first Info Day in Brussels in January 2016), in cooperation with the EU Commission at which the model version 2.0 was presented and discussed. These events took place on:

- 17/03/16 in Bologna,
- 18/05/16 in Warsaw
- 01/07/16 in Athens
- 26/09/16 in Bratislava

More details on these Info Days are available in Euro-5G Deliverables D2.3 and D2.7.

3.2 Brokerage Platform

As part of the preparation for Phase 2 of the 5G PPP, the brokerage service from Phase 1 was re-introduced. The 5G Infrastructure Association in cooperation with Euro-5G implemented a Brokerage Platform for 5G PPP Phase 2 project proposals. The goal was to support the creation of consortia and the identification of partners with the right expertise.

On 10 May 2016, the Brokerage Platform was made available on the 5G PPP website. The Platform facilitated connections between proposals under preparation and organizations expressing interest in participating to proposals.

The service allowed people to submit either proposal ideas or expertise offer profiles to the Brokerage Platform. Each submission was published after approval by the brokerage platform moderator team from Euro 5G. Proposal ideas could be posted without publishing the idea owner's identity if they only wished to be contacted via the Brokerage Platform.

The platform offered also search and contact request forms which allowed idea proposers to find matching partners for a project consortium and companies to find interesting proposal ideas to cooperate in.

There were 37 expertise offers posted on the site and these were searchable via expertise, interest areas or type of organisation (e.g. SME). There was only one project idea posted. This low number was already expected because proposal leaders generally are secretive about their proposals. However, they do use the search facility to find complementary resources for their proposals.

3.3 Selected 5G PPP Phase 2 Projects: presentation and kick off

A total of 101 proposals were received for the 5G PPP call objectives ICT 7 & ICT 8 2016 with a budget of 148M Euro.

After the selection process, 24 projects were retained of which 21 were obliged by Article 41.4 of their grant agreements to join the 5G PPP collaboration agreement (13 RIA, 6 IA and 2 CSA). The other three projects were the support action for the EuCNC event "EuConNeCts3", and two EU-Taiwan projects: 5G-CORAL & Clear5G.

ICT-07-2017-CSA	global5g.org
ICT-07-2017-CSA	EuConNeCts3
ICT-07-2017-CSA	To-Euro-5G
ICT-07-2017-RIA	5G ESSENCE
ICT-07-2017-RIA	IoRL
ICT-07-2017-RIA	5G-MoNArch
ICT-07-2017-RIA	METRO-HAUL
ICT-07-2017-RIA	BlueSpace
ICT-07-2017-RIA	ONE5G
ICT-07-2017-RIA	5G-PICTURE
ICT-07-2017-RIA	5GCAR
ICT-07-2017-RIA	5G-TRANSFORMER
ICT-07-2017-RIA	5G-Xcast
ICT-07-2017-RIA	NRG-5
ICT-07-2017-RIA	SLICENET
ICT-07-2017-RIA	SaT5G
ICT-08-2017-IA	5G-PHOS
ICT-08-2017-IA	5G-MEDIA
ICT-08-2017-IA	NGPaaS
ICT-08-2017-IA	MATILDA
ICT-08-2017-IA	5GCITY
ICT-08-2017-IA	5GTANGO
ICT-08-2017-RIA	5G-CORAL
ICT-08-2017-RIA	Clear5G

Figure 4: Retained projects in 5G PPP call H2020-16 in ICT 7 & ICT 8

Call	Proposals	Retained	% success
ICT-07-2017-CSA	5	3	60%
ICT-07-2017-RIA	72	13	18%
ICT-08-2017-IA	17	6	35%
ICT-08-2017-RIA	7	2	28%

Figure 5: Statistics on % success in 5G PPP call objectives H2020 ICT 7 & ICT 8

The table below shows Phase 1 projects that had a follow up project in Phase 2

Phase 1	Phase 2 follow up.
5G-Crosshaul	5G TRANSFORMER
5G-NORMA	5G-Monarch
5G-Xhaul	5G-PICTURE
SELFNET	SLICENET
Sesame	5G ESSENCE
SONATA	5GTANGO
EURO 5G	To-Euro-5G
FANTASTIC 5G	ONE5G

Figure 6: Follow up of 5G PPP Phase 1 projects in Phase 2

Information on Phase 2 projects is available:

- on the 5G PPP website [9]
- in the ad hoc brochure prepared by Euro-5G with details on main objectives, use cases (or applications), technical and research challenges, expected impact, included in Appendix B of this document.
- in the slides that were presented by Phase 2 projects during two special sessions at EuCNC 2017 on 14 and 15 June 2017, co-organised by Euro-5G, available on the 5G PPP web [10].

3.4 Governance of Phase 2 projects

The governance model of 5G PPP foresees that R&I actions resulting from relevant calls of the Horizon 2020 LEIT ICT actions (and beyond where appropriate) should be implemented *as a programme* to reach high industrial impact. A particular requirement for new projects coming from ICT-07 and ICT-08 Call objectives is to leverage work and results of Phase 1 projects and to accelerate on proof of concepts and demonstrators.

From that perspective, 5G PPP R&I Phase 1 and Phase 2 projects are encouraged to collaborate around issues of common interest for the definition of future 5G systems and provide access to results. The 5G PPP collaboration agreement related to Article 41.4 of the Grant Agreement defines a number of horizontal issues e.g. Steering Board, Technology Board, Working Groups and others.

Against this background, Euro-5G, the 5G-IA and the European Commission organised a full day meeting on 1 June 2017 at DG CONNECT in Brussels to kick off the collaborative process with Phase 2 projects. This covered identification of issues of common interest, identification of project Working Groups per theme, update of current structures and roadmap of the collaboration process. The Phase 2 projects cooperative work is currently ramping-up, with first actions developing in the context of the 5G Initiative SB and TB, supported by Euro-5G.

- The first SB meeting where Phase 1 and Phase 2 projects jointly met was organized on 15/06/17 collocated with EuCNC 2017, followed by a first telephone conference on 03/07/17. The next SB meeting will be organised on 20/09/17 in Brussels.
- The first TB meetings where Phase 2 projects were involved were organised as telephone conferences on 06/07/17 and 23/08/17, next calls to be organized on 07/09/17 and 22/09/17. The next TB meeting will be organised on 13/10/17 in Brussels.

Three of the immediate actions (among others) engaged at TB level to develop rapid awareness and interactions between projects are:

- Release of the document summarizing the Phase 2 projects Deliverables, including the cross-projects interests on these Deliverables.
- Release of the Phase 2 projects / WGs “champions” document, summarizing the projects experts participating to the different WGs.
- Release of the TB WG plans document including the PPP Working Groups plans and achievements (5G Industry Association WGs and Initiative WGs) and the TB feedbacks on these plans. The WGs plans are addressed at TB level and TB members provide feedbacks and recommendations towards the WGs to ensure the WGs plans are complementary and avoid duplications.

3.5 Initial assessment of 5G PPP Phase 2

To better analyse the project portfolio, facilitate coordination and timely fill-in possible gaps, Euro-5G prepared the following tables providing a strategic overview of Phase 2 projects:

- Phase 2 projects time plan
- Relevance and expected contribution to 5G PPP Performance KPIs
- Relevance and interest in 5G PPP Working Groups

Details are shown in below figures.

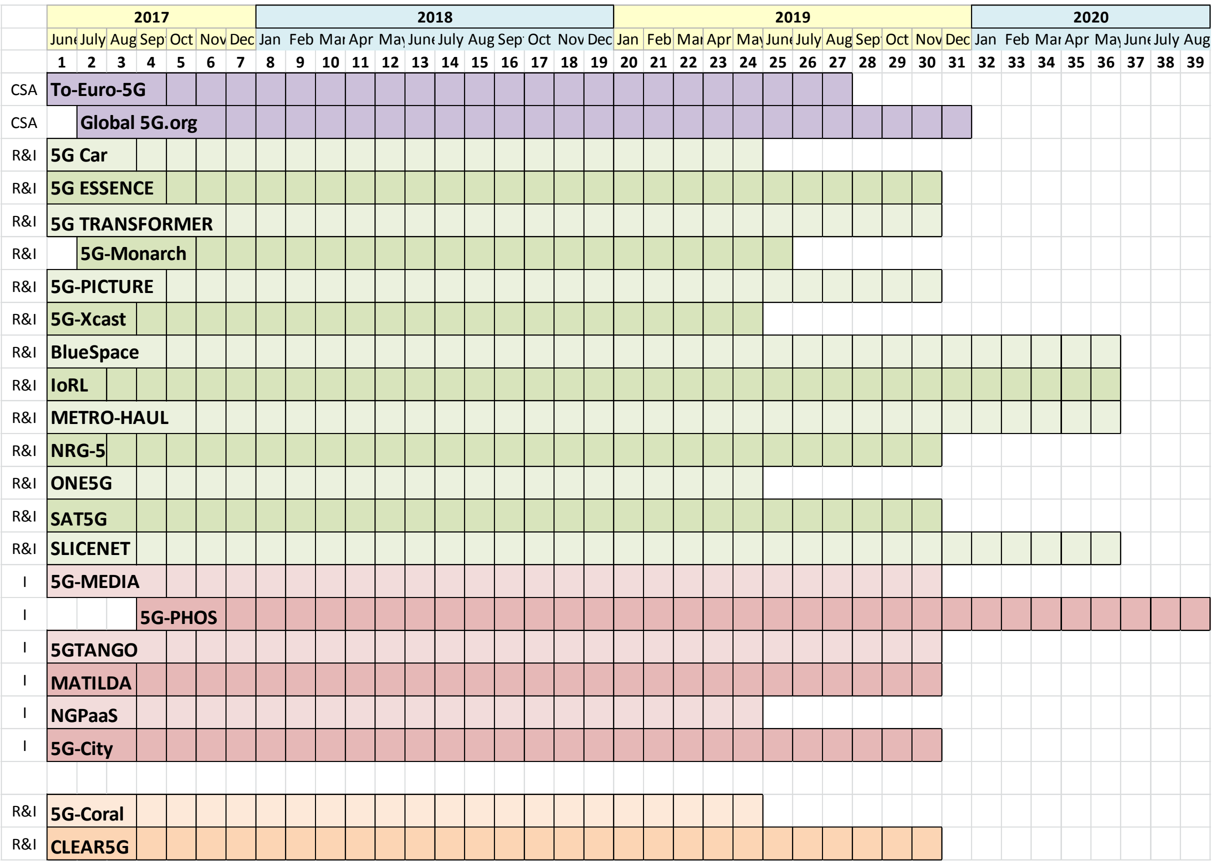


Figure 7: 5G PPP Phase 2 projects timeline

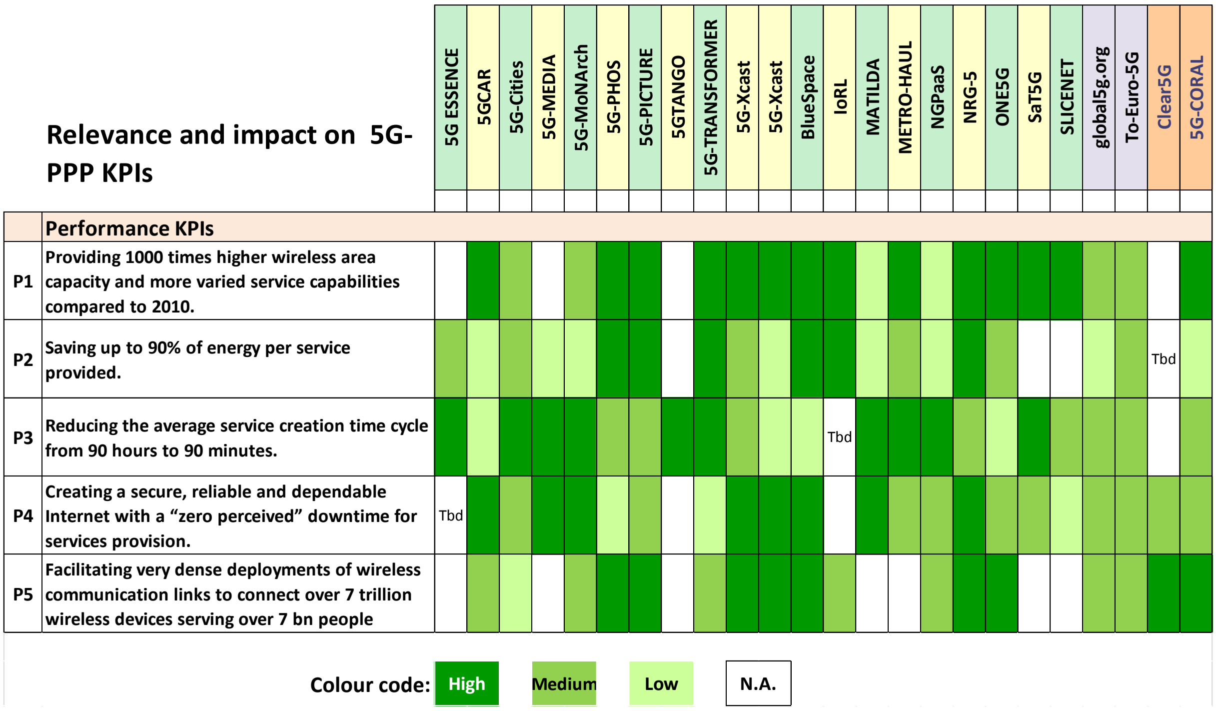


Figure 8: Relevance and contribution of Phase 2 projects to 5G PPP performance KPIs

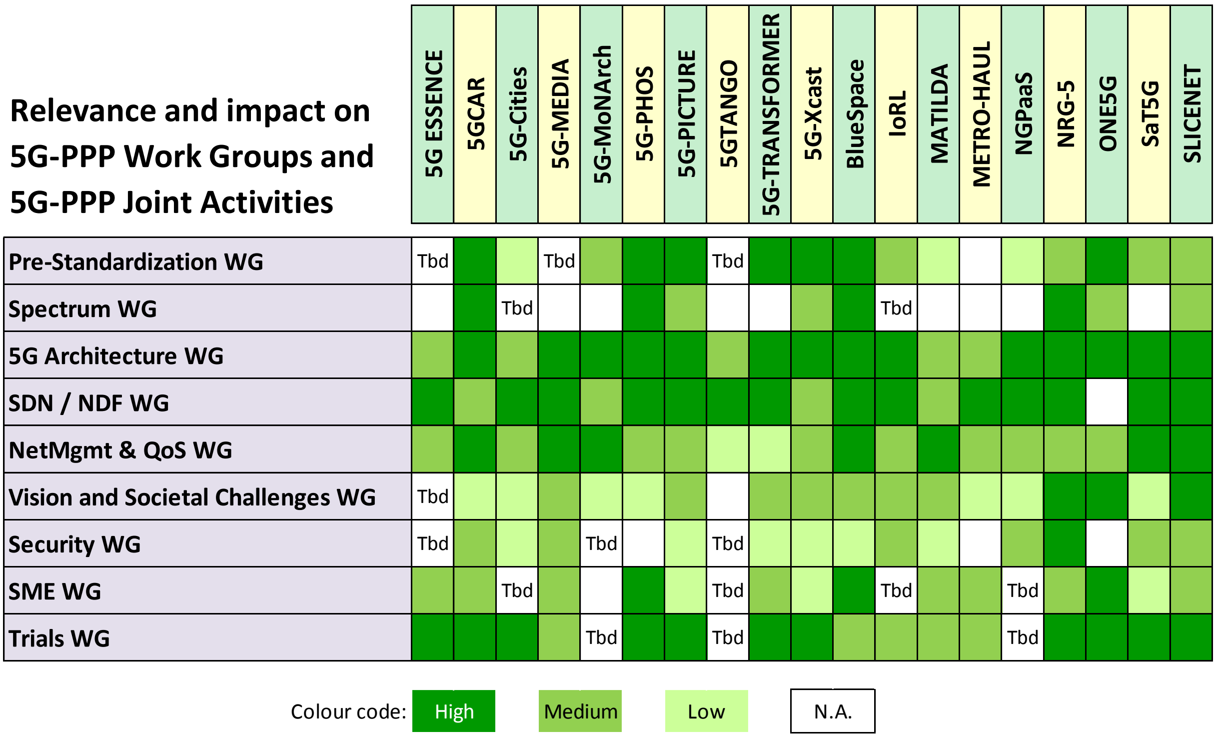


Figure 9: Relevance and interest of Phase 2 projects in 5G PPP Working Groups

In the framework of the 5G PPP Partnership Board, the EC has shared with the 5G-IA some findings of its initial analysis of the evaluation of 5G PPP Phase 2 portfolio, including the following table presenting the coverage of technical areas by the retained Phase 2 project proposals.

PROPOSALS	TA1: 5G Wireless System Design (RAN arch, multi RAT)	TA2: Air Interface ; low frequency bands	TA3: Air Interface , mmwave bands	TA4: Subsystem for 5G platform HW/SW integration	TA 5: Novel Radio syst.architecture, cloud core.	TA6: Integration of satcom, HAPs	TA7: 5G for mMTC, URLL, all Verticals	TA8: Cognitive Network Management	TA9: Optical Metro for 5G backhaul	TA10: High capacity optical core	TA11: converged 5G flexhaul
ONE5G	X	X									
5G-MoNArch					X		X				
5G ESSENCE					X			X			
SaT5G						X					
5GCAR							X				
SLICENET								X			
METRO-HAUL									X		
5GTRANSFORMER							X				X
BlueSpace					X						X
5G-PICTURE											X
NRG-5											
5G-PHOS											
5GCITY											
5G-MEDIA											
5GTANGO											
MATILDA											
NGPaaS											
5G-Xcast											
IoRL											
5G-CORAL											
Clear5G											
To-Euro-5G											
EuConNeCts3											
global5g.org											

PROPOSALS	TA12: Foundations/tools for SW networks, NetOS	TA13: Security, privacy, resilience, availability	TA14: multi-tenant / domain Plug & play Contr.Pl.	T17: 5G access integrating optical techs	TA18: platforms and tools for NetApps	TA19: Operational support to E2E NVF/SDN	TA15: Open RIA	TA20/21: Open IA	Taiwan: ICT08 RIA	TA16: ICT-07 CSA
ONE5G										
5G-MoNArch										
5G ESSENCE										
SaT5G										
5GCAR										
SLICENET										
METRO-HAUL										
5GTRANSFORMER										
BlueSpace										
5G-PICTURE										
NRG-5		X								
5G-PHOS				X						
5GCITY					X					
5G-MEDIA					X	X				
5GTANGO					X	X				
MATILDA					X					
NGPaaS						X				
5G-Xcast					X		X			
IoRL							X			
5G-CORAL									X	
Clear5G									X	
To-Euro-5G										X
EuConNeCts3										X
global5g.org										X

Figure 10: 5G PPP Phase 2 'Portfolio Assessment' (Source: European Commission)

The Phase 2 projects portfolio analysis has been triggered in 5G Initiative SB and TB, with the support of Euro-5G. One of the dimensions of the analysis includes the addressed vertical use-cases and engaged stakeholders.

The 5G-IA, in cooperation with Euro-5G, is also working on an initial assessment of the project portfolio in order to determine the projects' impact on 5G PPP's KPIs and, if necessary, to consider possible remedial actions.

The European Commission provided information about the **participation of SMEs** in 5G PPP Call 1 and Call 2. Euro-5G, in the framework of WP5, analysed the data available and produced two notes reporting on the figures related to the participation of SMEs:

- The first report, available in the "5G PPP Progress Monitoring Report 2015" that was prepared by 5G-IA, covers the participation of SMEs in 5G PPP Call 1, while
- the second one, published in Euro-5G Deliverable D5.5 "5G innovation potential and SME participation", analyses the SMEs participation in Call 2, and provides information about the total SME share in budget in the 5G PPP (i.e. Phases 1 and 2).

4 Conclusions

Euro-5G has successfully contributed to the analysis of the portfolio of 5G PPP Phase 1 and Phase 2 projects, and the results are presented in this Deliverable.

The performed work highlighted the strong need for adequate coordination and consistency of the projects:

- between Phase 1 and Phase 2,
- within Phase 2, and
- between Phase 2 and Phase 3 and access to Phase 1 results.

The time-wise overlap between ending Phase 1 and starting Phase 2 projects implied a significant increase in Euro-5G's workload (e.g. 30 to 40 projects participating in the Steering Board and Technology Board meetings; support to projects' participation in events; general management).

Euro-5G is successfully managing this "transition period" between Phase 1 and Phase 2 ensuring the smooth running of projects and the 5G PPP.

The activity of analysing project portfolios in 5G PPP will after the end of Euro-5G be continued in the follow-up CSA To-Euro-5G.

References

[1] https://ec.europa.eu/digital-single-market/en/news/horizon-2020-call-advanced-5g-network-infrastructure-future-internet-assessment-report-selected

[2] https://5g-ppp.eu/wp-content/uploads/2014/03/5G-Infra-PPP_Pre-structuring-Model_v2.0.pdf

[3] https://5g-ppp.eu/5g-ppp-phase-1-projects/

[4] https://bscw.5g-ppp.eu/pub/bscw.cgi/d117642/Euro%205G%20Annual%20Journal%202016.pdf

[5] https://www.youtube.com/watch?v=pvmyWD3KLyw

[6] https://5g-ppp.eu/5g-ppp-phase-2-pre-structuring-model/

[7] https://5g-ppp.eu/wp-content/uploads/2015/11/160304_5G-Infra-PPP_Phase2-Pre-structuring-Model_v2.0.pdf

[8] http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-leit-ict_en.pdf

[9] https://5g-ppp.eu/5g-ppp-phase-2-projects/

[10] https://5g-ppp.eu/eucnc-2017-oulu-presentations/

Appendix A Phase 1 projects input to The European 5G Annual Journal, 2017 edition

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 edition

Disclaimer

Copyright notice

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

1 H2020 5G projects

1.1 5G-CROSSHAUL

Contribution of the 5G-Crosshaul project to the European 5G Annual Journal

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 optimisation 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 is 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 Fiber (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.

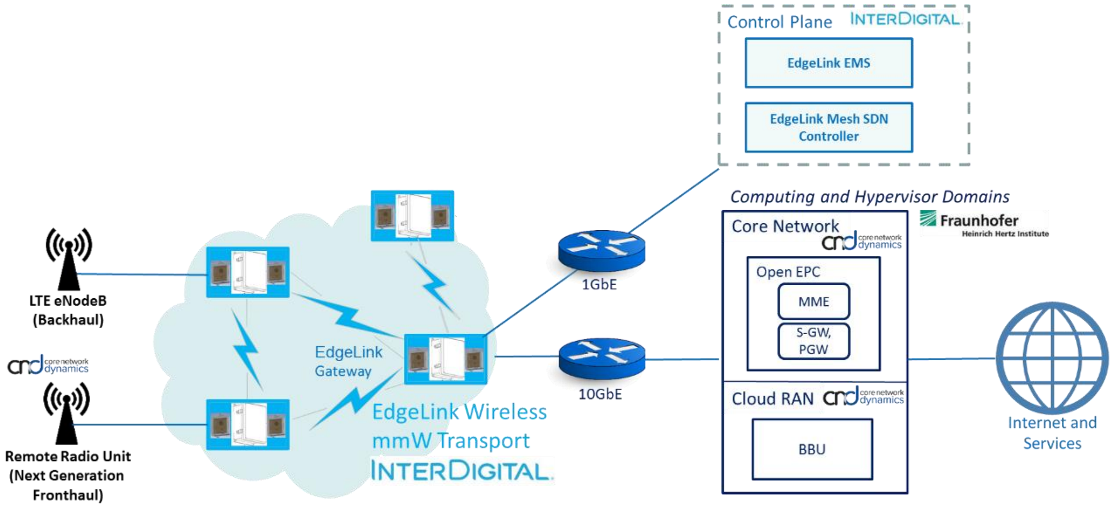


Figure 1 The topology of an mmWave-based transport network integrating backhaul/fronthaul traffics in Berlin Trial

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.

1.2 5G-ENSURE

5G Enablers for Network & System Security & Resilience

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 done towards the accomplish 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 theirs 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 specifications 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 fulfillment 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.

1.3 5G Ex

1.3.1 Motivation and Goals

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

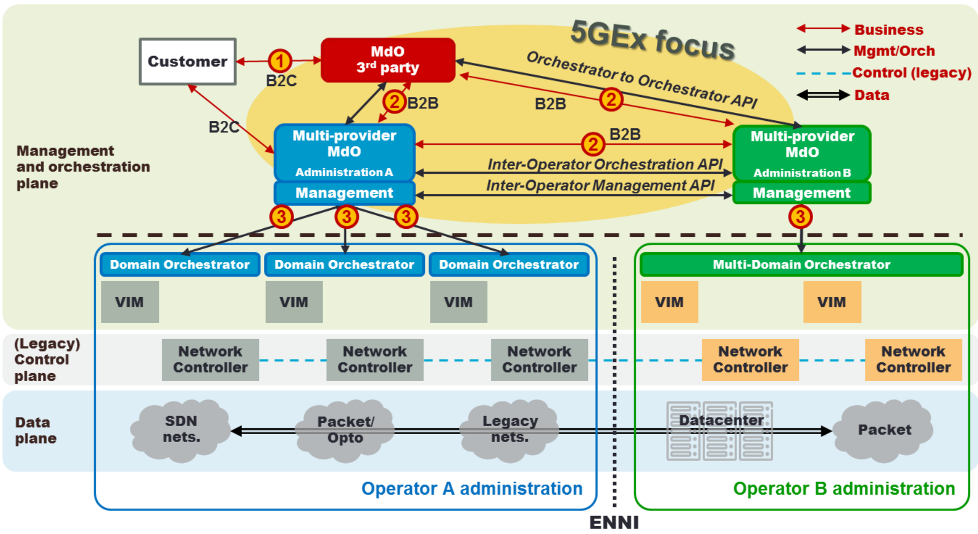


Figure 2. 5GEx reference architectural framework

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

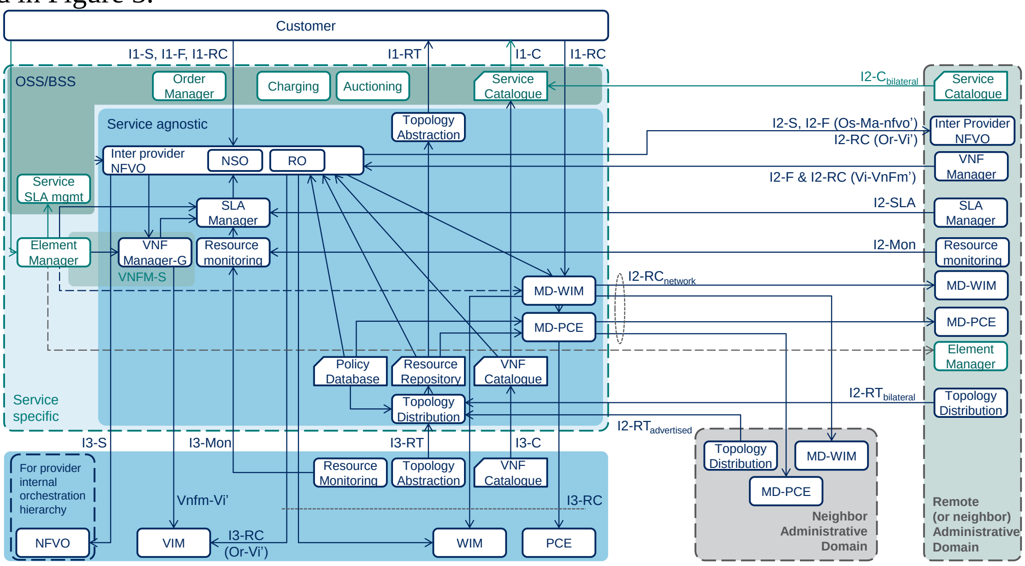


Figure 3. Functional model of multi-domain orchestration architecture

1.3.2 Major achievements and innovations during the second year of the project

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 standardization 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.

1.3.3 Demonstrations

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).

1.4 5G NORMA

5G NORMA is an EU funded project within the 5G PPP initiative with focus on adaptive and future-proof 5G mobile network architecture. In the following, we describe the major achievements of the second year of the project.

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 softwarisation. 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 softwarisation*, *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 with 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 standardization 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 Achievements: The architecture designed by 5G NORMA relies on the concept of network softwarisation 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[2] in all their aspects. The overall framework is given by the 5G NORMA MANO architecture (See Figure 1), which is an extension of the ETSI NFV MANO architecture that considers the requirements introduced by the network slicing paradigm.

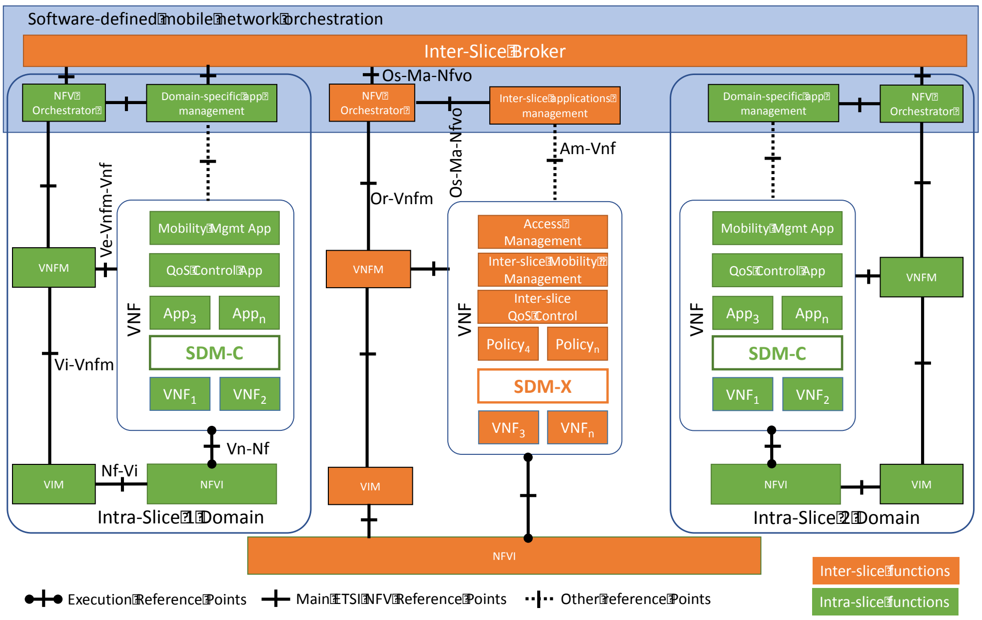


Fig. 1: Network slicing aware architecture.

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

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

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[3].

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[4]. 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

More information at:

https://5gnorma.5g-ppp.eu/

Contact: 5G-NORMA-Contact@5g-ppp.e

1.5 5G-XHAUL

5G-XHaul overarching objectives

The 5G-XHaul project aims at building up an ambitious converged optical and wireless network solution that relies on a flexible infrastructure able to support backhaul and fronthaul 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.

Main Achievements/Innovations in Year 2

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 fiber attachment points, whereas macro-cells are

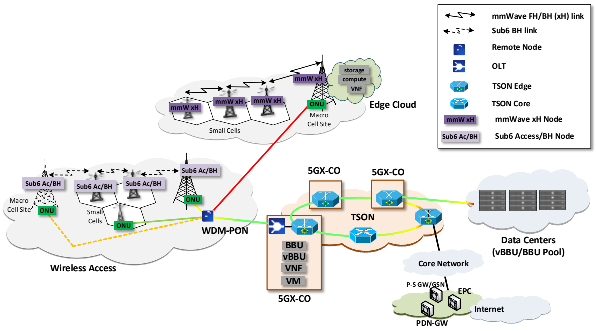
[3] 5G NORMA, D5.2, "Definition and specification of connectivity and QoE/QoS management mechanisms – final report," Jun 2017

[4] 5G NORMA, D6.1, "Demonstrator design, implementation and initial set of experiments," Oct 2016

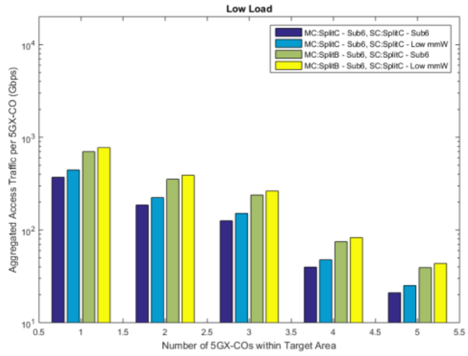
directly connected to a fiber attachment point. As the optical access technology, 5G-XHaul proposes a passive solution based on WDM-PON, which can transparently carry backhaul and fronthaul traffic through different wavelengths. In the metro-domain WDM-PON interfaces with TSON, an active optical technology 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 4.



5G-XHaul Data Plane Architecture



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

Figure 4. Evaluation of 5G-XHaul data-plane architecture

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 5). 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.

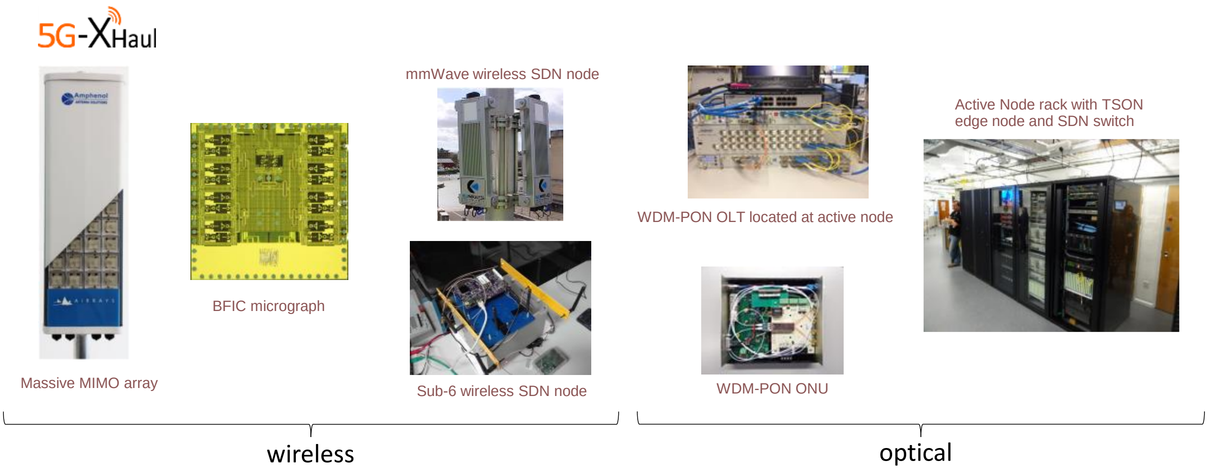


Figure 5. 5G-XHaul technological components

Planned next steps

Facing the third and last year of the project, 5G-XHaul is now preparing to demonstrate its transport architecture in a city wide testbed 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.

1.6 CHARISMA

CHARISMA Contribution for 2nd Edition of European 5G Annual Journal

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 (Fig.1), realized the enabling technologies, and developed a field-trial show-case demonstrator (based on a 5G mobile bus use case scenario) in Centelles, Spain. Fig.1 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 Fig.1.

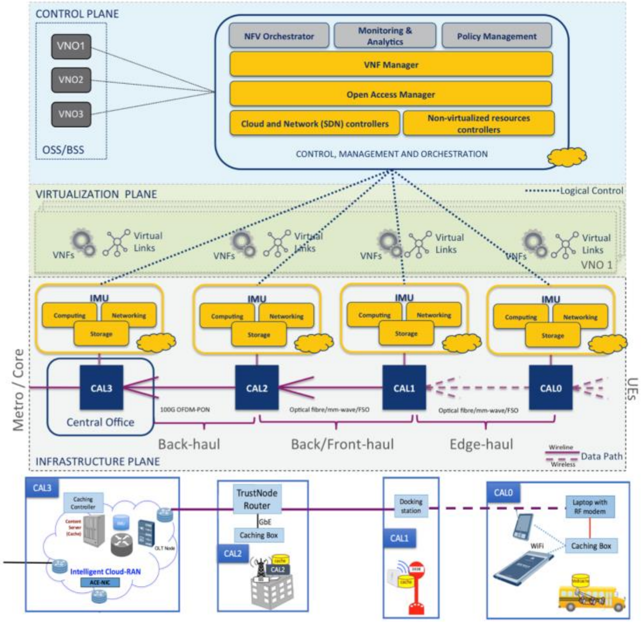


Figure 1: CHARISMA architecture with integrated PHY, virtualized infrastructure, and CMO planes, with the mapping of bus use case scenario onto the CHARISMA PHY infrastructure shown at the bottom.

CHARISMA's distributed control, management & orchestration (CMO) architecture features hierarchical intelligence nodes located at points where aggregation of access, backhaul and core networks occurs: 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 centralised M&O system is located. The Control Plane above the virtualised 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); Virtualised Infrastructure (VI) security; VI monitoring and virtualized security functions (VSFs). CHARISMA achieves virtualised 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	×1	×0.1

For the bus use case concept, Fig.2 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 virtualised Packet 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 Fig.2, 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.

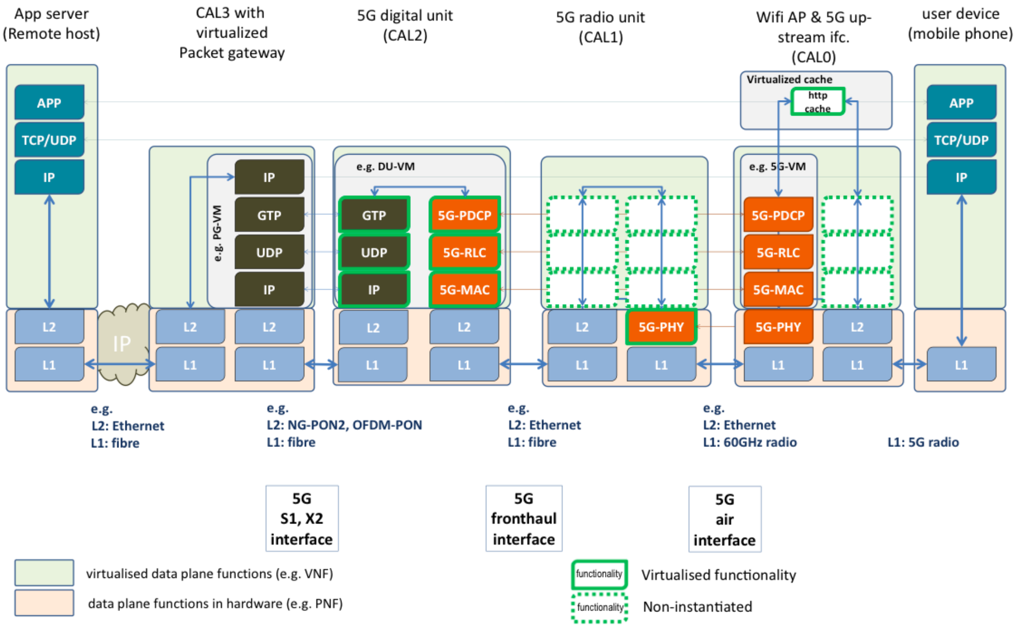


Figure 2: CHARISMA data plane architecture and VNF instantiations for bus use case.

1.7 COGNET

Overall Goals

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 Virtualisation (NFV) which virtualises 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

Architecture Advances

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.

Demos and Validation

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

1. *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 include:

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

2. *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 antennas 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 optimises the dynamic management of network physical resources based on vehicle traffic demands.

KPIs include:

- 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

3. *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 optimise 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 include:

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

CogNet concludes in December, 2017.

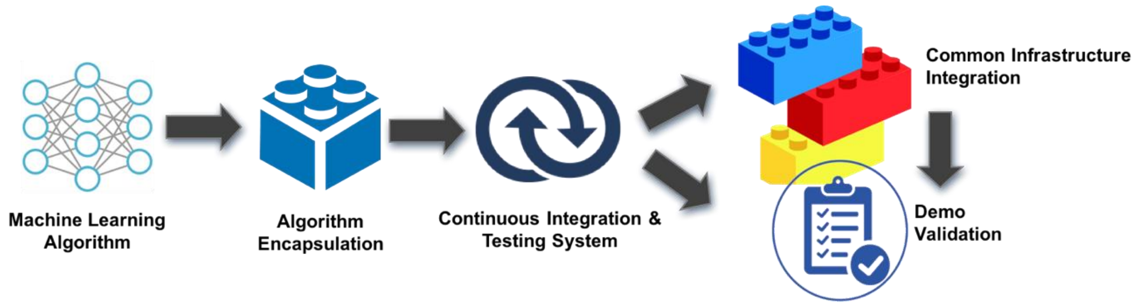


Fig.1: CogNet's procedure and assets for integration and validation

1.8 COHERENT

Coherent

COHERENT project 2nd year achievements and demos

The COHERENT project (www.ict-coherent.eu) 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.

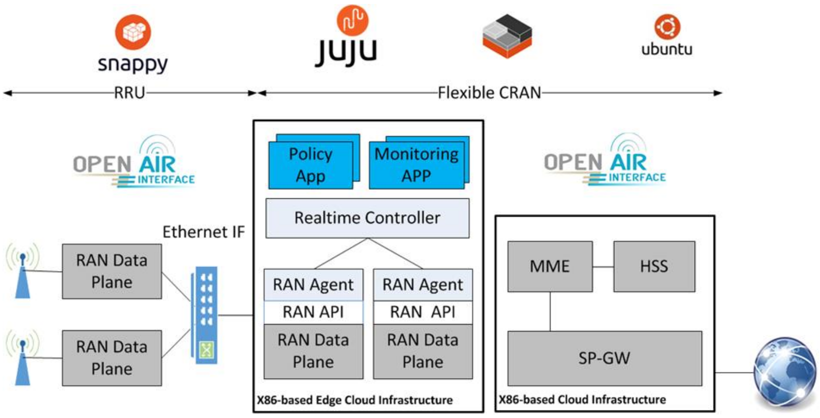
Based on the main results from the first year, and particularly following the proposed flexible RAN control and coordination architecture, in the second year COHERENT has concentrated on RAN programmability and SDK, RAN coordination algorithms, RAN slicing, flexible spectrum sharing, and demonstration development. The results have been reflected in the contributions submitted to 3GPP and ETSI BRAN. COHERENT partners has 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[5], OpenAirInterface[6,7], and Mosaic-5G[8].

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.

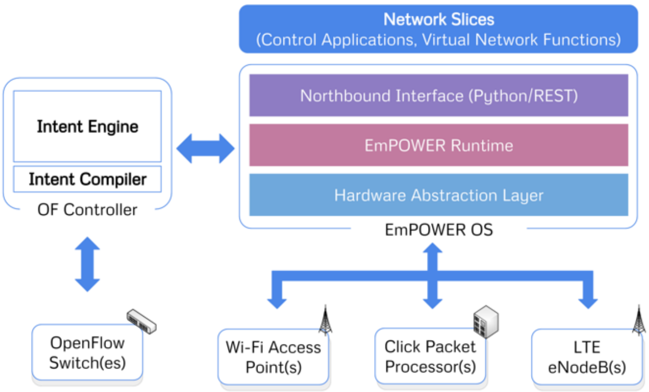
In the 2nd year, COHERENT has the particular focus on the SDN for RAN slicing and RAN virtualization. The demos for RAN slicing have been built based on OpenAirInterface and 5G-EmPOWER platforms. The objective is to show the novel concept of the heterogeneous RAN slicing developed in the project. The 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.

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:



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 the figure below:

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



1.9 FANTASTIC-5G

Flexible air interface for scalable service delivery within wireless communication networks of the 5th generation (FANTASTIC-5G)

Goals of the project

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. 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)[9]. 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/).

Major achievements/innovations of the project

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 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 subband 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

[9] Within the project we initially have 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.

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-subcarrier 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 antennas 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 of 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 are 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 extend 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.

System level evaluation
Beside the component specific research as described above, the project has spent significant effort 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.

Demonstrations
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 to various events showcasing its proof-of-concepts.

1.10 FLEX5GWARE

Flex5Gware: Flexible and efficient hardware/software platforms for 5G network elements and devices.

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 antennas 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 1 for a picture of the integrated antenna and PA.

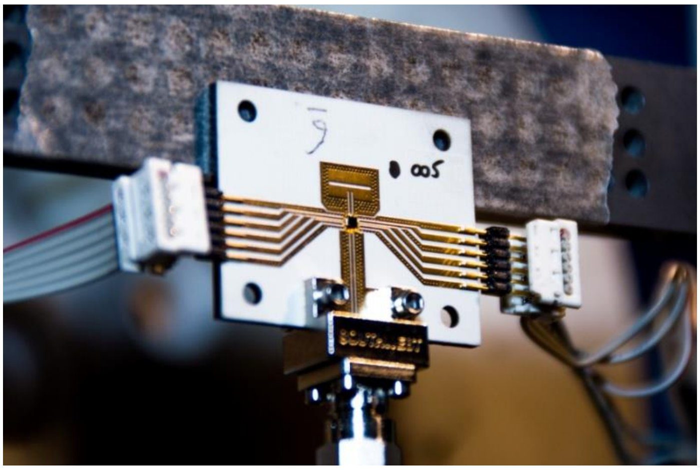


Figure 6: Assembled prototype of the integrated antenna and CMOS PA [1]

- **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.
- **PAPR 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 realize 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 reducing 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 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 behavior 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 a group of eNBs and multiple LTE commercial terminal, 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.

[1] Flex5Gware D6.2 "Final PoC evaluation in Flex5Gware", available online www.flex5gware.eu

1.11 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 standardization. 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 system, 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 1 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.

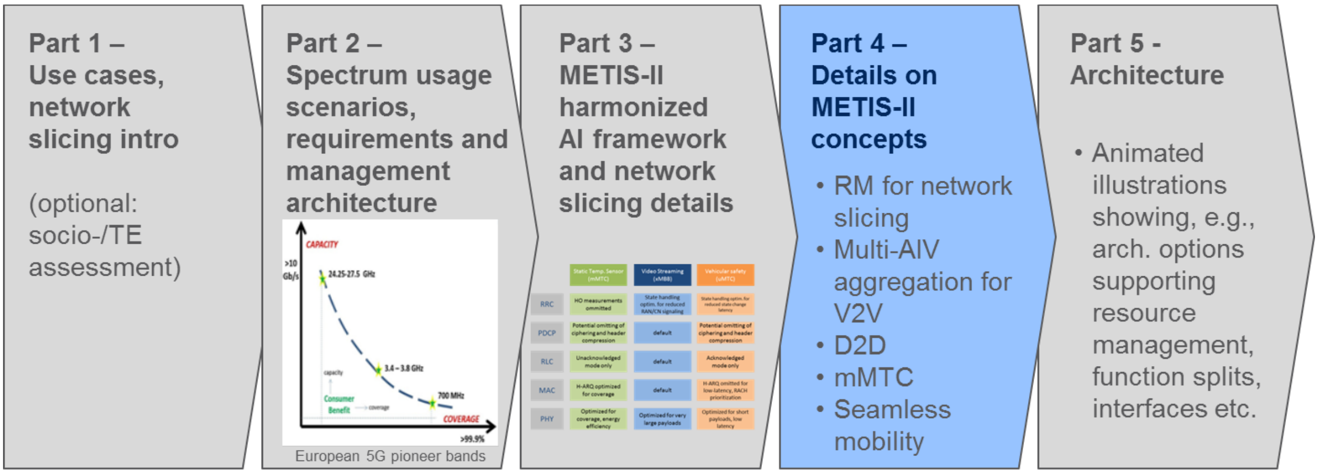


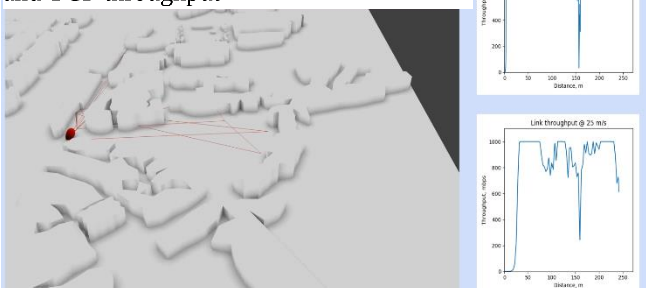
Figure 7 METIS-II achievements represented in the Visualization Platform based on Unity3D.

1.12 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 standardization and industry alignment of new 5G technologies at the mm-wave bands. The mmMAGIC visualisation 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 visualisation 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 optimisation metrics that enable multi-RAT deployments within heterogeneous network indicators. Exemplary video footages have been produced, where the mm-wave 5G capabilities, with visualisation of beam tracking, performance evaluation and mobile user throughput as well as of significant metrics, have been demonstrated.

Figure 1. Snapshot of the visualisation video footage illustrating, beam tracking and TCP throughput



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.

Chanel Measurement and Modelling: The availability of reliable and accurate channel models is crucial for the design, deployment, standardization 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.

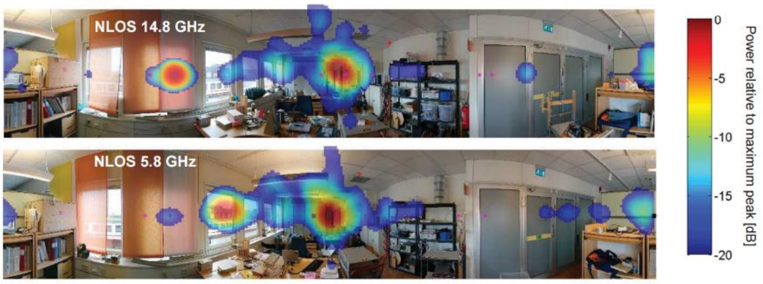


Figure 21. Directional power distribution in an office environment

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.

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.

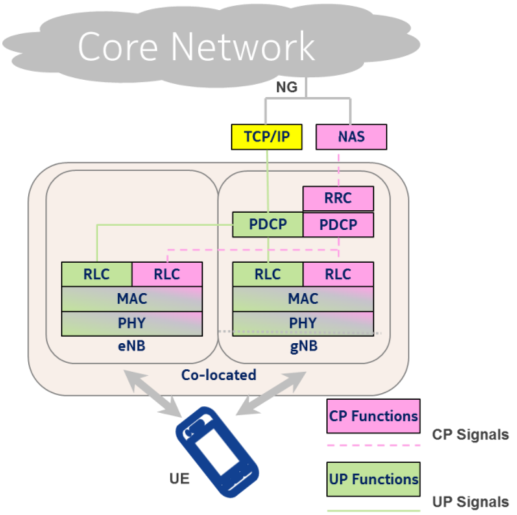


Figure 3. Access architecture with LTE-NR co-location

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.

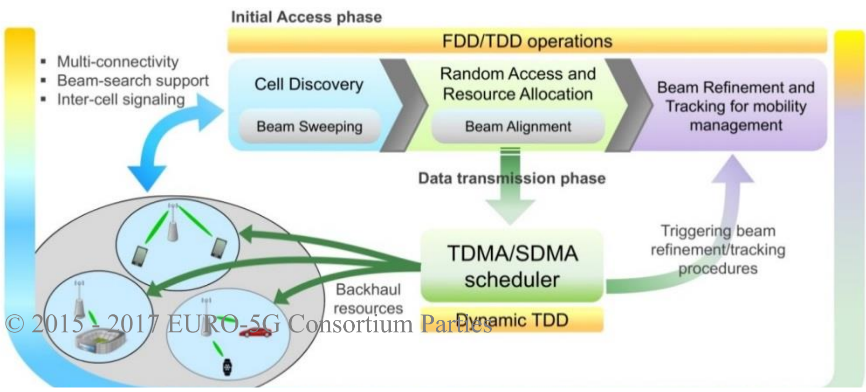


Figure 4. Initial access and multiple access concept for mm-wave system

Five subframe structures have been defined, with extensions to support Integrated Access and Backhaul (IAB) operations. Some subframes allow fully dynamic TDD operation for 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.

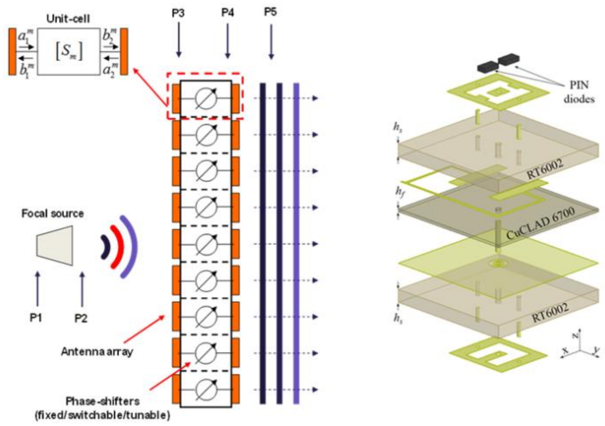


Figure 5. The Transmitarray configuration

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.

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 will be detailed in a holistic manner in our final deliverable D6.6.

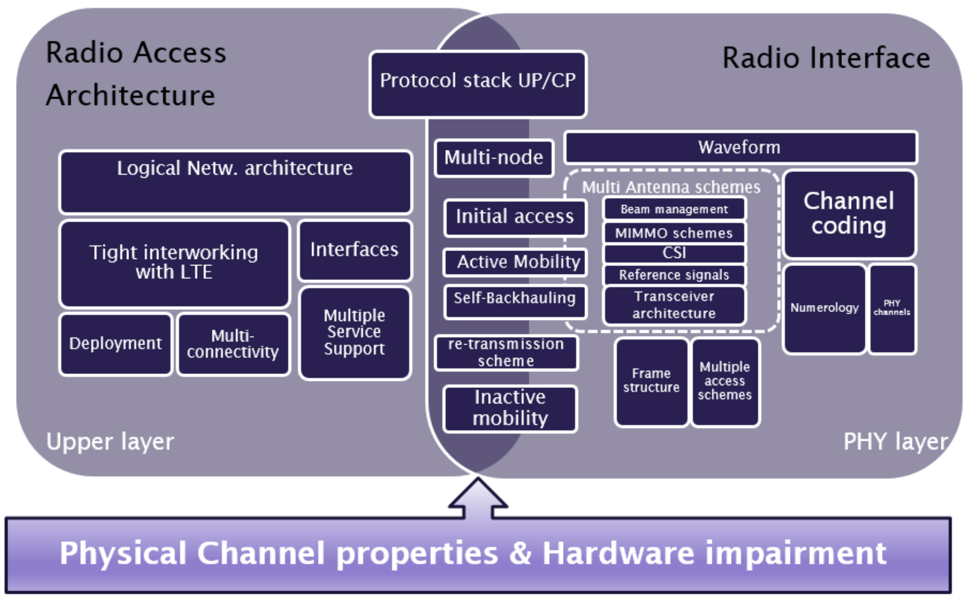


Figure 6. mmMAGIC system concept

1.13 SELFNET

SELFNET: Framework for Self-Organized Network Management in Virtualized and Software Defined Networks

1.13.1 Objectives of the project

SELFNET is a project focusing on 5G network management, with the main objective of developing an efficient self-organizing 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.

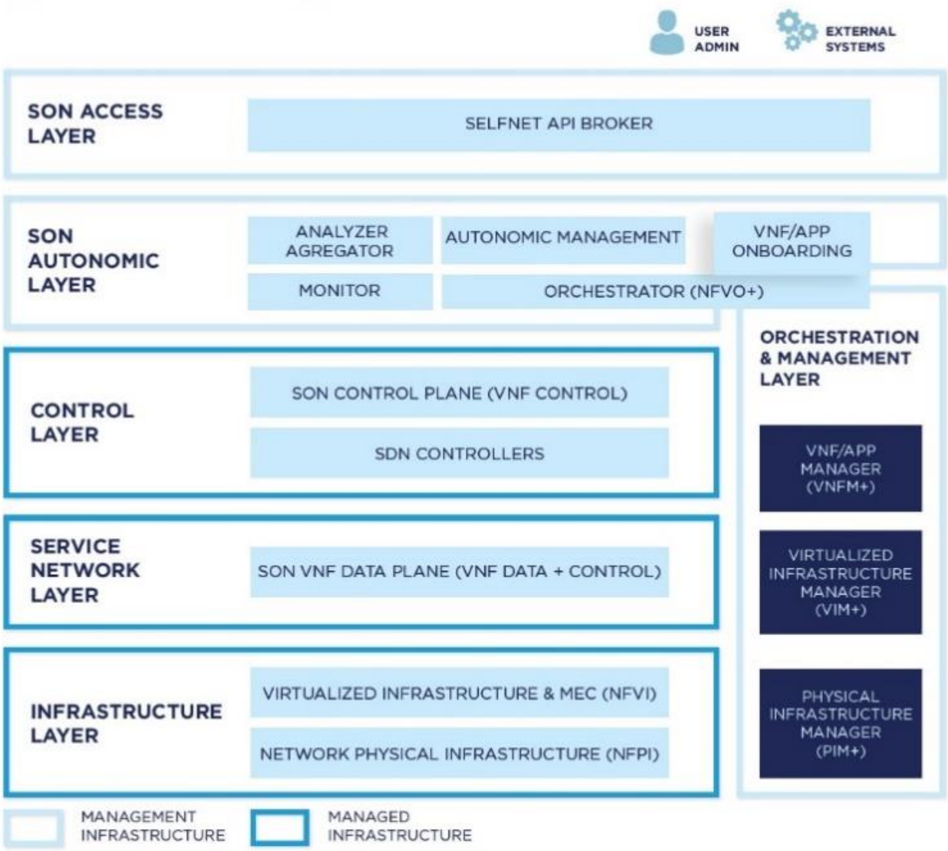


Figure 8 SELFNET Architecture

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 virtualised 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-optimisation to maintain or improve video application performances.

1.13.2 Major achievements/innovations during the second year of the project

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.

1.13.3 Description of demos

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 prioritise 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.

1.14 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 1:

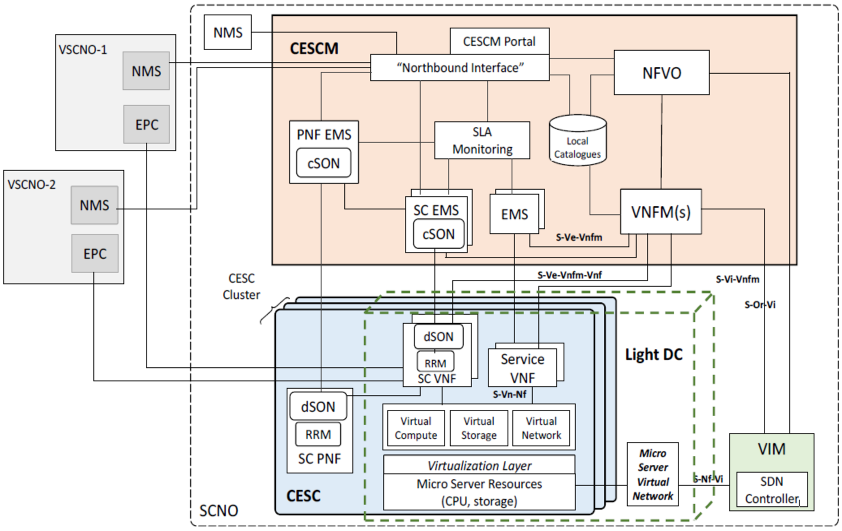


Figure 1: SESAME Conceptual architecture

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

Service 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.

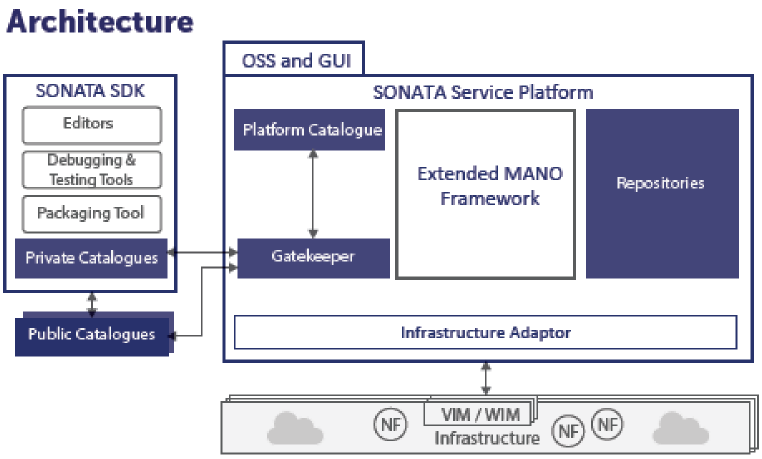
Programmable open small cell prototype: A prototype network hosting virtualization was developed for in-lab testing with the purpose of developing new network applications, services, algorithms and technologies. The lab system is based on components with open source software. The in-lab system prototype 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.

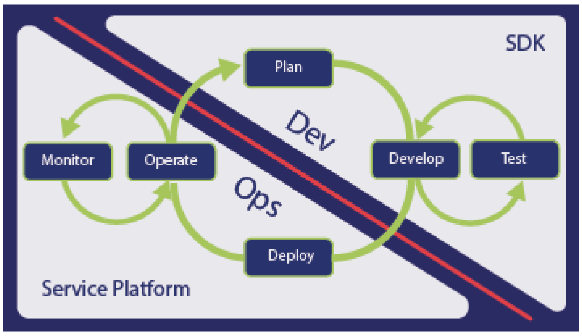
1.15 SONATA

SONATA: Agile Service Development and Orchestration in 5G Virtualised Networks

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.





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.

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.

Major achievements/innovations during the second year of the project

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 debugging 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.

Demos

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.

SONATA´s channels

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

1.16 SPEED-5G

Main project goals:

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

Benefits from the SPEED-5G solution

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 1:

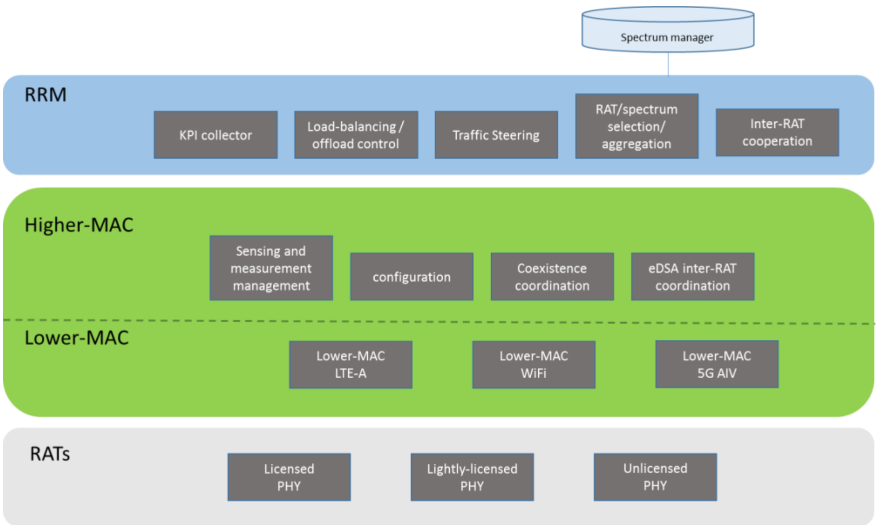


Figure 1: SPEED-5G Conceptual architecture

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 centralised) 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 centralised solutions in dense environments. However, in cases where the distributed approach does not provide satisfactory solutions, a centralised 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 centralised) 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

Proof of Concept (PoC) and planned demonstrations

The SPEED-5G testbed deployments and trials are intended to validate the innovative solutions developed in SPEED-5G and to assess their effectiveness and performance in terms of the predefined KPIs through trials via a testbed deployment (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 testbed, for final demonstrations and trials. PoC 6 will showcase the main project innovations relating to capacity improvement, aggregation and offload. Figure 2 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.

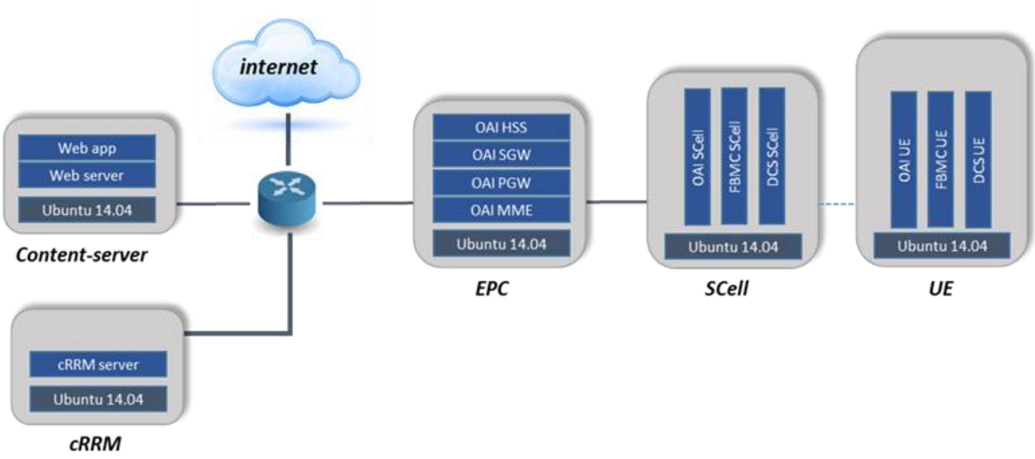


Figure 2: Logical view of the PoC demonstrator

Figure 3 below 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.

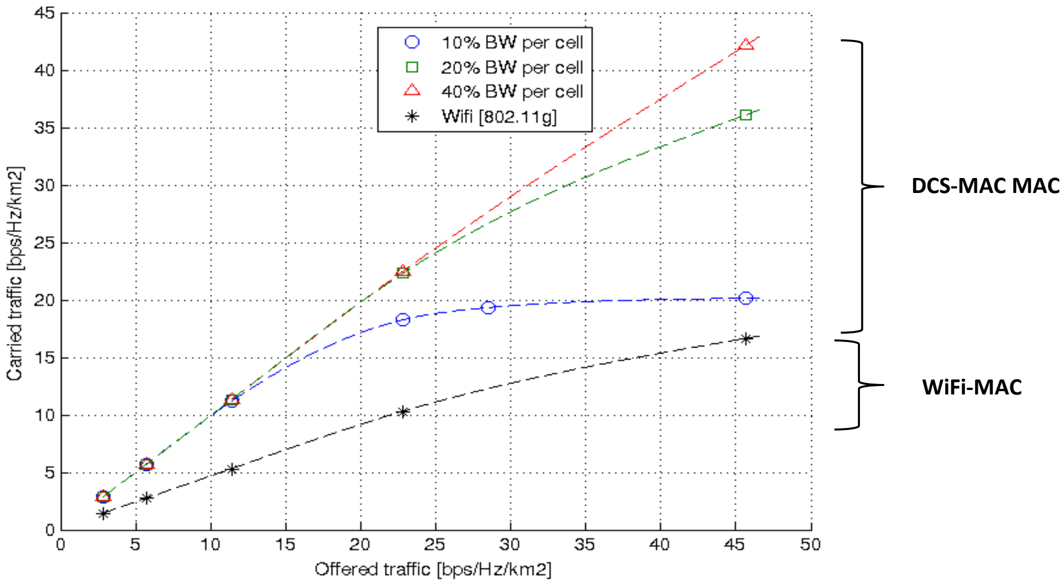


Figure 3: Comparison of network capacity - DCS-MAC vs WiFi

1.17 SUPERFLUIDITY

the caption for the figure is:

"RFB, REE and RDCL abstractions proposed by Superfluidity"

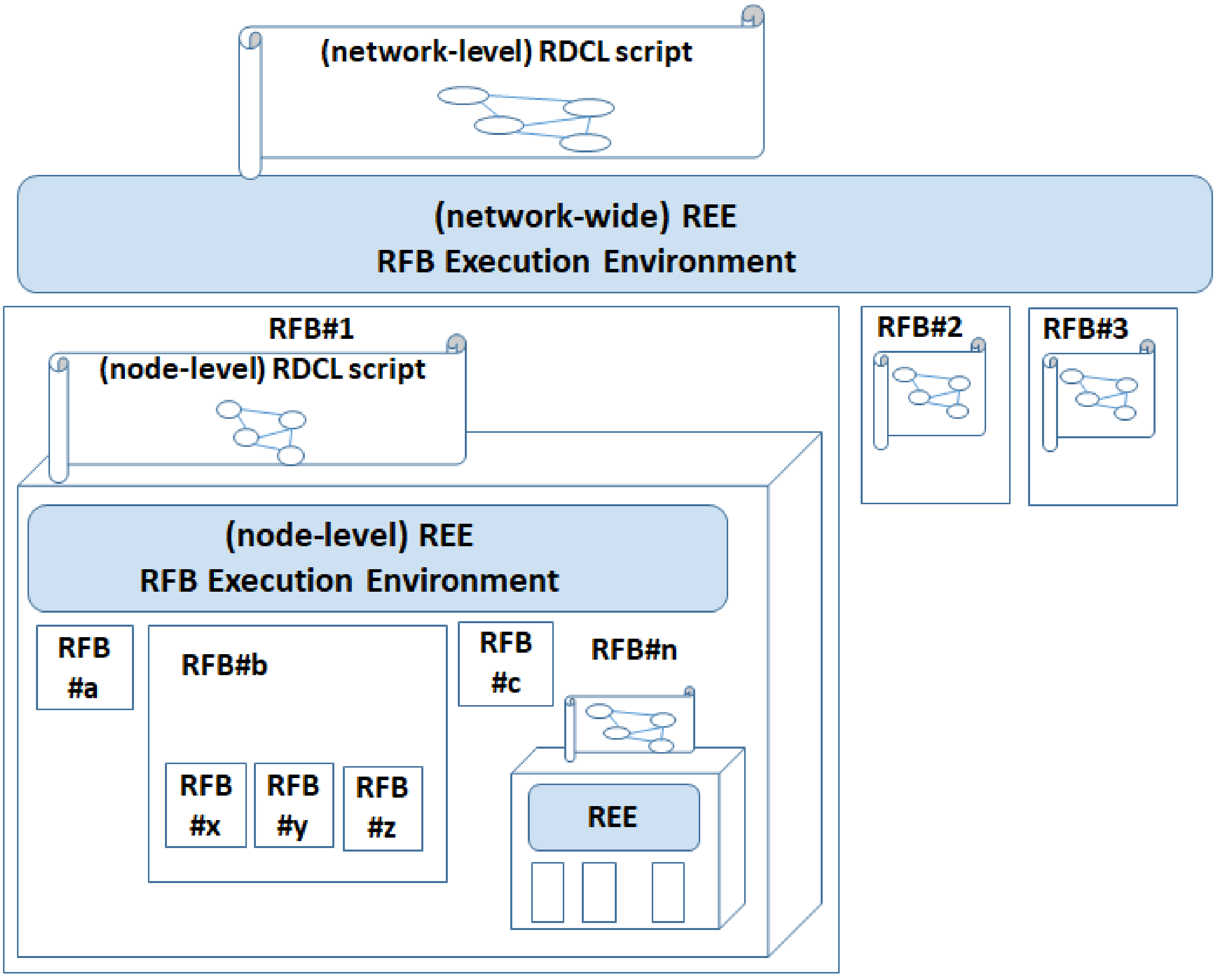
and the figure should be inserted after the sentence "as RFBs can be decomposed in RFBs resulting in a "nested" composition model."

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 modeled 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.

the caption for the figure is:

"RFB, REE and RDCL abstractions proposed by Superfluidity"



and the figure should be inserted after the sentence "as RFBs can be decomposed in RFBs resulting in a "nested" composition model."

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 virtualisation 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 virtualisation 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 virtualised environments i.e. VMs/containers and bare metal (non-virtualised environments). To address this challenge, the project has adopted standalone telemetry agents to provide a wide range of metrics across different virtualisation 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 (**T**hrough, **A**nomalies, **L**atency, **E**ntropy), which leverages a full stack monitoring approach for the collection of metrics. Collected metrics relate to both the physical and virtualised compute/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 allows 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 testbed. 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 testbeds (connected using a VPN), which are geographically dispersed and host different elements of the end-to-end demonstrator. Testbed #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. Testbed #2 is a hardware platform located at BT’s UK premises, consisting of 5 servers and a switch, which supports flexible virtualisation experiments and demonstrations. It acts as Central Cloud.

1.18 VIRTUWIND

Virtual and programmable industrial network prototype deployed in operational **Wind**park

Goals of the project:

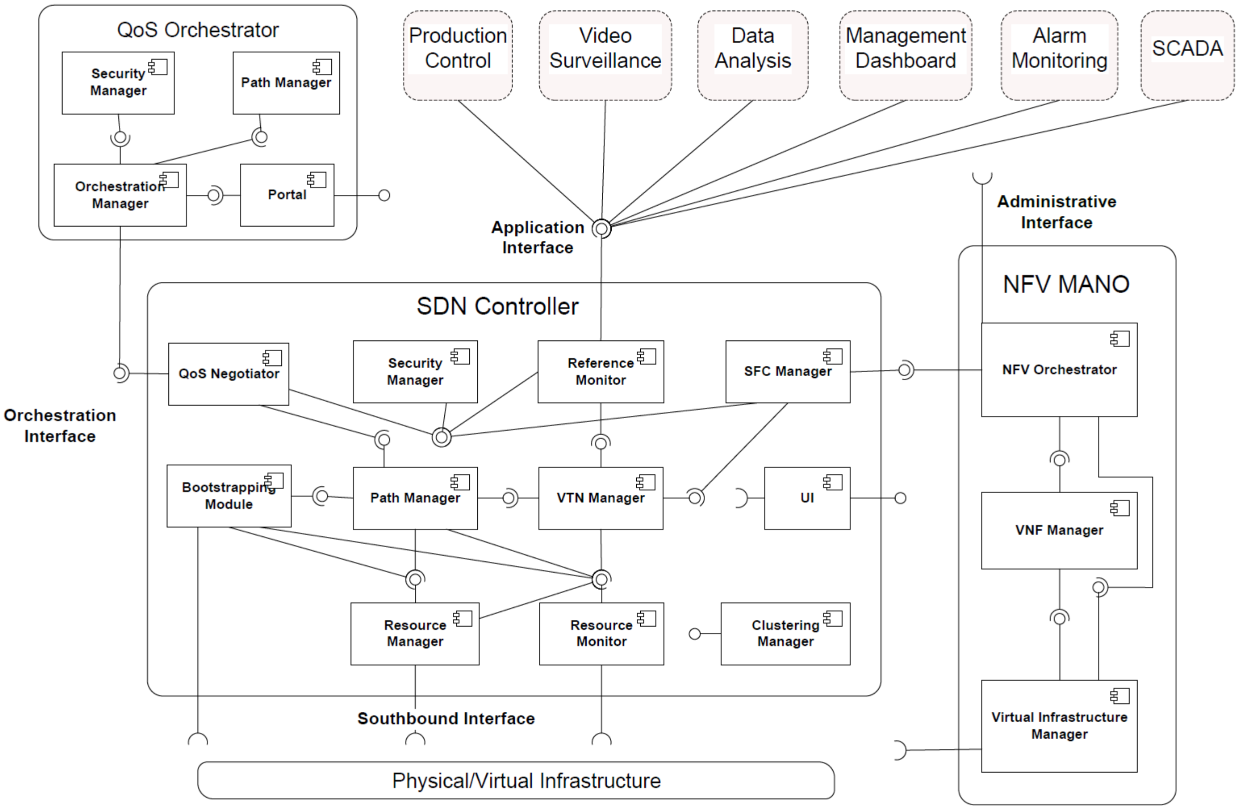
Today's industrial communication network infrastructure consists of different and discrete sets of decentralized networking protocols designed to deliver high performance and reliability, broad connectivity, and stringent security. However, these different protocols have been developed in isolation, 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 Virtualisation (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:

1. Realize industrial-grade Quality of Service (QoS) for intra-domain SDN solution: VirtuWind aims to extend SDN and NFV with industrial-grade QoS capabilities and to validate the intra-domain solution through prototyping and lab testing.
2. Guarantee inter-domain QoS for SDN based multi-operator ecosystem: VirtuWind will develop mechanisms that allow access to SDN-enabled network infrastructure in different operator environments to enforce a QoS path through multi operator domains.
3. Reduce time and cost for service provisioning and network maintenance: VirtuWind will specify and develop a suitable SDN northbound interface allowing applications to easily request communication services. 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.
4. Assure security-by-design for the SDN and NFV ecosystem: Introducing concepts like SDN and NFV for critical infrastructures requires careful investigation of the new security risks, as new threats may arise which never before existed in legacy systems. VirtuWind will establish a comprehensive threat and risk framework for industry-grade SDN networks.
5. Field trial of intra- and inter-domain SDN and NFV prototype: The developed SDN and NFV solution will be set up and demonstrated at a field trial in the "Floe" Wind Park located in Brande, Denmark.

In order to maximise the impact of its results, VirtuWind 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.

Major achievements so far:

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.



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.

Dissemination activities:

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

a) 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.

b) Standardization: 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.

c) 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.

Appendix B 5G-PPP phase 2 projects overview brochure

5G-PPP phase 2 projects

Introduction:

The 5G-PPP is a 7 year partnership leading to the introduction of 5G infrastructure and the roll out of 5G services in Europe from 2020. The Public-Private-Partnership was created by a contractual agreement between the European ICT Industry, represented by the 5G-Infrastructure Association and the European Commission signed at the end of 2014.

In phase 1 from July 2015 to date 18 collaborative projects were launched and the results are emerging continually with many of these projects completing their work by mid-2017. Some will continue and finish in mid-2018.

Phase 2 of the 5G-PPP will start on the 1st June 2017 and 21 new 5G-PPP projects have been selected. In addition there are 2 complementary projects dealing with international relations on aspects of 5G and information on these has been included in this brochure.

Index:

5G-PPP Phase 2 projects:

Complementary EU-Taiwan Projects:

Embedded Network Services for 5G Experiences

5G ESSENCE

MAIN OBJECTIVES

5G ESSENCE addresses the paradigms of Edge Cloud computing and Small Cell-as-a-Service (SCaaS) by fuelling the drivers and removing the barriers in the Small Cell (SC) market, forecasted to grow at an impressive pace up to 2020 and beyond and to play a key role in the 5G ecosystem.
5G ESSENCE provides a highly flexible and scalable platform, able to support new business models and revenue streams by creating a neutral host market and reducing operational costs by providing new opportunities for ownership, deployment, operation and amortisation. 5G ESSENCE leverages knowledge, SW modules and prototypes from various 5G-PPP Phase-1 projects, SESAME being particularly relevant.
Among the fundamental 5G ESSENCE objectives are: Full specification of critical architectural enhancements; definition of the baseline system architecture and interfaces for the provisioning of a cloud-integrated multi-tenant SC network and a programmable RRM controller; development of the centralised SD-RAN controller to program the radio resources usage in a unified way for all CESCs (Cloud-Enabled Small Cells); exploitation of high-performance and efficient virtualisation techniques for better resource utilisation, higher throughput and less delay at the network service creation time; development of orchestrator's enhancements for the distributed service management; demonstration and evaluation of the cloud-integrated multi-tenant SC network; conduct of a market analysis and establishment of new business models, and finally, maximisation of impact to the realisation of the 5G vision.

USE CASES (or APPLICATIONS)

5G ESSENCE will accommodate a range of use cases, in terms of reduced latency, increased network resilience, and less service creation time. One of its major innovations is the provision of E2E network and cloud infrastructure slices over the same physical infrastructure, so that to fulfil vertical-specific requirements as well as mobile broadband services, in parallel. The project focuses on three real-life use cases associated to vertical industries: 5G edge network acceleration for a stadium, with local video production and distribution; mission critical applications for public safety (PS) communications providers; and next-generation, integrated, in-flight connectivity and entertainment services for passengers.

TECHNICAL AND RESEARCH CHALLENGES

The technical approach exploits the benefits of the centralisation of SC functions as scale grows through an edge cloud environment based on a two-tier architecture: a first distributed tier for providing low latency services and a second centralised tier for providing high processing power for computing-intensive network applications. This allows decoupling the control and user planes of the RAN and achieving the benefits of Cloud-RAN without the enormous fronthaul latency restrictions.

EXPECTED IMPACT

5G ESSENCE introduces innovations in the fields of network softwarisation, virtualisation, and cognitive network management. It provides a highly flexible and scalable platform, capable of supporting new business models and revenue streams by creating a neutral host market and ultimately, reducing operational costs by providing new opportunities for ownership, deployment, operation and amortisation.

Project Coordinator:
Hellenic Telecommunications Organization S.A. – OTE (EL) – Dr. Ioannis P. Chochliouros
Partners:
NEC Europe Ltd. (UK), INTEL R&D Ireland Ltd. (IE), TriaGnoSys GmbH (DE), ATOS Spain S.A. (ES), Pietrzyk Slawomir (IS-WIRELESS) (PL), WIND TRE S.p.A. (IT), Athonet S.R.L. (IT), Fundacio Privada i2CAT, Internet i Innovació Digital a Catalunya (ES), Fondazione Bruno Kessler (IT), Smart Mobile Labs GmbH (IT), National Center for Scientific Research "Demokritos" (EL), Capritech Limited (UK), Bapco LBG (UK), Universitat Politècnica de Catalunya (ES), Thales Communications & Security SAS (FR), Italtel S.p.A. (IT), Orion Innovations Private Company (EL), Universidad del Pais Vasco/ Euskal Herriko Unibertsitatea (ES), Eight Bells Ltd. (CY) and Municipality of Egaleo (GR)
More information at:
https://5g-ppp.eu/5G-ESSENCE/
Contact 5G-ESSENCE-Contact@5g-ppp.eu

Fifth Generation Communication Automotive Research and innovation
5GCAR

MAIN OBJECTIVES

Main objectives within the 5GCAR project are:

- Develop an overall 5G system architecture providing optimized end-to-end V2X network connectivity for highly reliable and low-latency V2X services, which supports security and privacy, manages quality-of-service and provides traffic flow management in a multi-RAT and multi-link V2X communication system.
- Interworking of multi-RATs that allows embedding existing communication solutions and novel 5G V2X solutions.
- Develop an efficient, secure and scalable sidelink interface for low-latency, high-reliability V2X communications.
- Propose 5G radio-assisted positioning techniques for both vulnerable road users and vehicles to increase the availability of very accurate localization.
- Identify business models and spectrum usage alternatives that support a wide range of 5G V2X services.
- Demonstrate and validate the developed concepts and evaluate the quantitative benefits of 5G V2X solutions using automated driving scenarios in test sites.

USE CASES

5GCAR will define a constitutive set of 5G V2X use cases, buildning on other EU projects as well as organisations like ETSI-ITS and 5GAA. The detailed use case descriptions are intended to span the relevant 5G V2X space by representing a much broader set of scenarios. In 5GCAR there will also be three live demonstration use cases: Lane merge, Cooperative perception for manoeuvres of connected vehicles, and Vulnerable road user protection.

TECHNICAL AND RESEARCH CHALLENGES

5GCAR will clarify use cases and requirements for future connected vehicles and then perform evaluations and demonstrations on 5G V2X technologies and solutions to find and promote suitable end-to-end performance of the entire system. Some foreseen challenges to highlight are: the tackling of technical approaches that turn out to be complex, and to implement the three independent testbed platforms in a suitable way.

EXPECTED IMPACT

5GCAR is for instance expected to contribute to WRC-19, and to impact methodologies and models in 3GPP and 5GAA. The consortium will also collaborate and integrate the 5G V2X radio access network concepts of the project into the overall 5G RAN framework, e.g. through participation in 5G PPP initiatives and interaction with other projects.

Project Coordinator:
Dr. Mikael Fallgren – ERICSSON

Partners:
ERICSSON / HUAWEI / BOSCH / Centre Tecnològic de Telecomunicacions de Catalunya / Centro Tecnológico de Automoción de Galicia / Chalmers University of Technology / King's College London / MARBEN / NOKIA / ORANGE / PSA Group / SEQUANS / VISCODA / VOLVO CARS

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

Contact
5GCAR-Contact@5g-ppp.eu

5GCity

MAIN OBJECTIVES

The ultimate goal of 5GCity is to maximize the return on investment for the whole digital market chain (users, application, cloud providers, i.e., the municipalities themselves, telecom providers, and infrastructure providers). To do so, 5GCity's main aim is to build and deploy a common, multi-tenant, open platform that extends the (centralized) cloud model to the extreme edge of the network, with a demonstration in three different cities (Barcelona, Bristol and Lucca), and thus advance the state of the art to solve the main open research challenges in the 5G-based edge virtualization domain, including the neutral host perspective in dense deployment environments such as cities. Thus, 5GCity will design, develop, deploy and demonstrate, in operational conditions, a distributed cloud and radio platform for municipalities and infrastructure owners acting as 5G neutral hosts.

USE CASES (or APPLICATIONS)

The use cases targeted by 5GCity consist of:

Neutral host (Telecom Use Case): 5GCity will leverage its virtualization platform in order to enable the cities to create dynamic end-to-end slices containing both virtualized edge and network resources and lease it to third-party operators.

Media (Industry Vertical): 5GCity consortium includes different media-related partners, a television channel, a national broadcaster, and a SME focused on content acquisition and production in the Cloud or an association of media companies. Three different media use cases will be deployed and evaluated (mobile real-time transmission, UHD video distribution, and real-time video acquisition and production in the Edge & Cloud).

Unauthorized waste dumping prevention (City Services): The city of Lucca holds some yearly events that are highly disproportionate to the city size, resulting in a number of issues including illegal waste dumping. 5GCity will use the cities' surveillance cameras and deploy (multiple instances of) a virtualized service that can process video streams near cameras automatically to identify illegal dumping.

TECHNICAL AND RESEARCH CHALLENGES

From a technical perspective, evolving cloud architectures and adapting them to the edge of the network within the 5G ecosystem brings a number of open challenges: (i) **Deployment and run-time management** of densely interconnected and decentralized cloud and network infrastructures; (ii) **Tight-loop interactions** between the computing and networking infrastructures at the edge of the network; (iii) **Performance issues** arising from the use of resource-constrained devices (e.g., Single Board Computers with ARM processors) placed at the edge of the network to perform workloads that have been traditionally carried out by powerful servers in centralized data centers; and (iv) **Slicing and neutral hosting** support at the wireless edge, where bandwidth needs to be guaranteed for different slices (e.g. media), and tenant-specific counters need to be added to support elastic usage and billing of resources.

EXPECTED IMPACT

5GCity will directly impact a large and varied range of actors: (i) telecom providers; (ii) municipalities; and (iii) a number of different vertical sectors utilizing the city infrastructure. The real strength of 5GCity, in terms of real-world impact, lies in the envisioned deployment of its 5G-based edge platform in three distinct smart cities: Barcelona, Lucca and Bristol, which is foreseen as a concrete first step towards 5G trials. Other expected impacts include, i) Open environments for creation of network apps, ii) Open repository of network apps that may be validated and leveraged by third party developers, and iii) Validation at scale of VNF aggregation capability of the proposed environment. The project will also impact 5G PPP Performance KPIs related to reduced e2e latency, reduced average service creation time, multiple times higher mobile data volume and number of connected devices.

Project Coordinator:
Dr. Sergi Figuerola - Fundacío i2CAT
Partners:
NEC Europe LTD / Virtual Open Systems SARL / PrimsTech France / Retevision I S.A. / University of Bristol/Bristol Is Open / Nextworks s.r.l /Commune di Lucca / Italtel s.p.a / Institut Municipal d'Informàtica de Barcelona / MOG Technologies SA / WIND TRE S.p.A / Rai-Radiotelevisione italiana spa / Ubiwhere lda / Informació i Comunicació de Barcelona TV / Incites consulting SARL / Accelleran / Comunicare Digitale
More information: https://5g-ppp.eu/5GCity/
Contact: 5GCity-Contact@5g-ppp.eu

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

5G MEDIA

MAIN OBJECTIVES

The focus of 5G PPP H2020 remarkable research so far has been largely on the required advances in network architectures, technologies and infrastructures. Less attention has been put on the applications and services that will make use of and exploit advanced 5G network capabilities. 5G-MEDIA aims at innovating media-related applications by investigating how these applications and the underlying 5G network should be coupled and interwork to the benefit of both. In this respect, 5G-MEDIA addresses the objectives of 1) capitalizing and properly extending the valuable outcomes of the running 5G PPP projects to offer an agile programming, verification and orchestration platform for services, and 2) developing network functions and applications to be demonstrated in large-scale deployments.

USE CASES (or APPLICATIONS)

5G-MEDIA will be based on three well-defined use cases (in the areas of immersive media and VR, smart production and user-generated content, and UHD over CDN) of diverse requirements and particular interest for the consortium partners. Based on the adoption of the open innovation approach, 5G-MEDIA platform will be offered to third parties to develop, combine, verify, deploy and validate media applications by utilizing the SDK capabilities and Service Platform offerings.

TECHNICAL AND RESEARCH CHALLENGES

It can be argued that media applications have the most to gain from the promised vision of 5G network capabilities and hence early innovation activities are required into how 5G networks can be exploited by advanced media applications to realise the benefits of low latency, high bandwidth and flexible dynamic configuration.
5G-MEDIA plans to innovate specifically in this area by investigating how media applications and the underlying 5G network should be coupled and interwork to the benefit of both: to ensure the applications allocate the resources they need to deliver high quality of experience and so that the network is not overwhelmed by media traffic.

This will be achieved by applying SDN and NFV concepts to media applications to flexibly and dynamically embed them as virtual network functions (in the form of virtual machines, containers or unikernels) within the 5G network and cloud infrastructure using a serverless computing paradigm, close to traffic sources and sinks, and by configuring network paths and virtual slices to deliver the required network capacity and performance levels at the network edge. 5G-MEDIA will create a DevOps environment for media applications which will hide the complexity of service development and deployment on the underlying 5G network and distributed cloud infrastructure, allowing developers to concentrate on media application details; and a service virtualisation platform that will orchestrate the deployment and scaling of the media applications, interacting automatically with the underlying network for the dynamic control of the network paths and forwarding graphs by applying machine learning and cognitive optimisation techniques.

EXPECTED IMPACT

5G-MEDIA plans to create an ambitious business impact with the introduction of Streaming as a Service concept, built on top of a well-defined, consortium-wide exploitation plan and supported by the complementarity of expertise of its consortium, representing key industrial sectors in the network and media domains.

Project Coordinator:
Francesco Saverio Nucci – Engineering Ingegneria Informatica S.p.A.

Partners:
ENGINEERING INGEGNERIA INFORMATICA SPA, IBM ISRAEL, SINGULARLOGIC, HELLENIC TELECOMMUNICATIONS ORGANIZATION S.A., CORPORACION DE RADIO Y TELEVISION ESPANOLA SA, UNIVERSITY COLLEGE LONDON, TELEFONICA INVESTIGACION Y DESARROLLO, UNIVERSIDAD POLITÉCNICA DE MADRID, INSTITUT FÜR RUNDFUNKTECHNIK GMBH, NEXTWORKS, ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS, NETAS TELECOMMUNICATIONS INC., INTERINNOV SAS, BITTUBES GMBH

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

Contact 5g-media-Contact@5g-ppp.eu

5G Mobile Network Architecture for diverse services, use cases, and applications in 5G and beyond

5G-MoNArch

MAIN OBJECTIVES

The expected diversity of services, use cases, and applications in 5G requires a flexible, adaptable, and programmable architecture. While this has been addressed in 5G-PPP Phase 1 at a conceptual level, it must be *brought into practice* in Phase 2, taking into account progress in Standards and providing experimental results.

In this regard, the main objectives of 5G-MoNArch are summarized below.

1. Detailed specification and extension of 5G architecture.
2. Extension of existing architecture design with key enabling innovations
   - Inter-slice control and cross-domain management
   - Experiment-driven modelling and optimization
   - Native cloud-enabled protocol stack
3. Functional innovations for the key technologies required for the identified use cases
   - Resilience and Security
   - Resource elasticity
4. Deployment and experimental implementation of the architecture in two use cases
   - Sea port use case
   - Touristic city use case
5. Evaluation, validation, and verification of the architecture performance

TECHNICAL AND RESEARCH CHALLENGES

Following the above motivation, 5G-MoNArch will apply the architecture devised by 5G-PPP Phase 1 to specific and representative 5G scenarios with diverse requirements, and will evaluate the resulting architecture based on experimental results. In order to achieve this goal, 5G-MoNArch's key challenges are (1) evolving 5G-PPP concepts developed in Phase 1 to a fully-fledged architecture, (2) complementing the architecture with key innovations, some of which may be specific to the considered scenarios, (3) providing an implementation in experimental prototypes, (4) applying this implementation to representative scenarios, and (5) refining the architecture and implementation based on experimental results. To address these challenges, 5G-MoNArch will select two representative scenarios that exemplify the architecture. These scenarios will be implemented and evaluated experimentally in order to demonstrate that the relevant KPIs are satisfied, while paying attention to a cost-efficient implementation.

USE CASES

The devised architecture will be deployed in two testbeds: (i) the sea port, representative of a vertical industry use case, and (ii) the touristic city, representative of a mobile operator deployment. For each testbed, 5G-MoNArch will instantiate the architecture and complement it with use case specific functionality. This will result in the two functional innovations of 5G-MoNArch, one for each of the use cases addressed: (i) resilience and security, needed to meet the sea port requirements, and (ii) resource elasticity, to make an efficient use of the resources in the touristic city.

EXPECTED IMPACT

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

Project Coordinator: Dr. Peter Rost, Nokia
Technical Manager: Prof. Albert Banchs, UC3M
Innovation Manager: Isabelle Korthals, DT
Partners:
ATOS, CEA, CERTH, DT (Innov. Manager), Hamburg Port Authority, Huawei, Mobics, Nokia-DE (PM), Nokia-FR, Nomor, Real Wireless, Samsung R&D, TIM, UC3M (TM), Univ. Kaiserslautern
More information at: https://5g-ppp.eu/5g-monarch/
Contact: 5G-MoNArch-Contact@5g-ppp.eu

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

5G-PHOS

MAIN OBJECTIVES

5G-PHOS aims to develop novel 5G broadband fronthaul architectures and evaluate them for Ultra-Dense and Hot-Spot areas exploiting the recent advances in optical technologies towards producing a powerful photonic integrated circuit technology toolkit. It aims to capitalize on novelties in InP transceiver, Triplex optical beamformers and multi-bitrate optical communications into next generation fronthaul in order to migrate from CPRI-based to integrated Fiber-Wireless packetized C-RAN fronthaul supporting mm-Wave massive MIMO communications.

APPLICATIONS

5G-PHOS expects to release a seamless, interoperable, RAT-agnostic and SDN-programmable FiWi 5G network that supports 64x64 MIMO antennas in the V-band and offers a) up to 400 Gb/s wireless peak data rate in ultra-dense networks, adopting optical Spatial-Division-Multiplexed solutions on top of the emerging 25 Gb/s PON infrastructures, delivering a packetized integrated FiWi fronthaul network and b) 100 Gb/s wireless peak data rate in Hot-Spot areas, showcasing the benefits of WDM technology and packetized fronthauling in private C-RAN solutions. These blocks will be integrated towards architecting 5G networks for Ultra-Dense and Hot-Spot use cases, evaluating their performance in lab and field experiments at the Orange Labs in Lannion, France, the deployed network of Cyprus telecom operator MTN and at the stadium of P.A.O.K. F.C. in Thessaloniki, Greece.

TECHNICAL AND RESEARCH CHALLENGES

5G-PHOS addresses the challenging ultra-dense 5G framework encompassing a range of environments with different traffic density and coverage needs. To this end, 5G-PHOS aims to meet the following technical and research challenges: 1) Release a cost-effective ultra-dense fronthaul specification with immediately commercially exploitable perspectives, 2) Meet the respective User Experience and System Performance Key Performance Indicator (KPI) metrics, 3) Synergize mm-wave wireless radio and massive MIMO antennas to provide increased capacity and link reliability and 4) Demarcate from CPRI-based schemes towards bandwidth-scalable Ethernet-friendly fronthaul solutions.

IMPACT

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

Project Coordinator:
Prof. Nikos Pleros-Aristotle University of Thessaloniki

Partners:
Aristotle University of Thessaloniki/Orange S.A./ Fraunhofer Gesellschaft zur Förderung der angewandten Forschung e.V./ Mellanox Technologies/ Institute of Communications & Computer Systems-National Technical University of Athens/ LIONIX International B.V./ INTERUNIVERSITAIR MICRO-ELECTRONICACENTRUM VZW/MTN Cyprus Ltd/ Iquadrat Informatica S.L./ Eindhoven University of Technology/III-V Lab/INCELLIGENT/ P.A.O.K. F.C./ Siklu Communication Ltd/ Ericsson Telecomunicazioni SpA/ COSMOTE KINITES TILEPIKOINONIES A.E.

More information: https://5g-ppp.eu/5gphos/
Contact: 5G-PHOS-Contact@5g-ppp.eu

5G Programmable Infrastructure Converging disaggregated neTwork and compUte Resources

5G PICTURE

MAIN OBJECTIVES

5G-PICTURE will design and develop an integrated, scalable and open 5G infrastructure with the aim to support operational and end-user services for both ICT and “vertical" industries. This infrastructure will rely on a converged fronthaul and backhaul solution, integrating advanced wireless access and novel optical network domains. To address the limitations of current solutions, 5G-PICTURE will adopt the novel concept of Disaggregated-Radio Access Networks (DA-RANs), allowing any service to flexibly mix-and-match and use compute, storage and network resources through HW programmability. It will also rely on network softwarisation to enable an open reference platform instantiating a variety of network functions and adopt slicing and service chaining to facilitate optimised multi-tenancy operation.

USE CASES (or APPLICATIONS)

In the context of 5G-PICTURE several use cases will be examined focusing on a variety of telecom and vertical industry services. More specifically, 5G-PICTURE will demonstrate: (a) converged fronthaul and backhaul services in a smart city environment hosted by the state-of-the-art 5G “City of Bristol” network infrastructure, (b) seamless service provisioning and mobility management in high speed railway environments exploiting a real 5G-railway testbed located in Barcelona, Spain, and (c) media services supporting large venues in a 5G-stadium testbed located in Bristol, UK to address scenarios with increased density and static-to-low mobility.

TECHNICAL AND RESEARCH CHALLENGES

5G-PICTURE proposes to integrate network and compute/storage resources in a common infrastructure. This involves a hierarchical compute & storage structure supported by a network hierarchy exploiting integrated programmable wireless technologies at the edge and a hybrid passive/active optical transport network. To address the limitations of current distributed RAN and Cloud-RAN approaches, 5G-PICTURE will develop flexible functional splits that can be dynamically selected, based on transport network and service characteristics. This will be achieved through the notion of DA-RAN relying on a disaggregated resource pool. To enable this approach, 5G-PICTURE proposes a set of novel technology solutions as well as control and management platforms offering enhanced network and compute HW and SW modularity and flexibility. Another key enabler of the proposed approach is the creation and deployment of programmable network functions as well as intelligent orchestration schemes.

EXPECTED IMPACT

Currently, services with very high bandwidth and low latency requirements are supported through multiple application-specific platforms having significant installation, operational and administrative costs while advanced features vital for efficient operation of these services are not supported and the majority of existing implementations are not truly open. 5G-PICTURE addresses these inefficiencies adopting the concept of DA-RAN that allows to form any service under a common programmable open infrastructure. This will offer significant performance cost and energy efficiency benefits.

Project Coordinator:
Eckhard Grass, IHP

Partners:
IHP, University of Bristol, ADVA Optical Networking SE., Airrays GmbH, Blu Wireless Technology LTD., Consorzio Interuniversitario per le Telecomunicazioni, COMSA Industrial, COSMOTE Kinites Tilepikoinonies AE. Eurecom, Ferrocarrils de la Generalitat de Catalunya, Huawei Technologies Duesseldorf GmbH, Fundació Privada I2CAT Internet i Innovació Digital a Catalunya, Mellanox Technologies LTD., Telecom Italia SPA, Transpacket AS, Technische Universitaet Dresden, Universitaet Paderborn, Panepistimio Thessalias, Zeetta Networks LTD.

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

5Gtango

5G Development and Validation Platform for global Industry - specific Network Services and Apps

5GTANGO

TECHNICAL AND RESEARCH CHALLENGES

5GTANGO addresses the emerging challenges associated with both the development and validation of vertical services and applications. The following technologies are envisioned:

1) A modular, dependable service platform with a modular orchestration framework that will support vertical sector needs. A key evolution is a more profound separation of concerns by factoring out the verification and validation (V&V) steps to the V&V store role.
2) A store for Verification and Validation expertise. The V&V component is key to 5GTANGO and not present in existing NFV architectures
3) A NFV-specialized Software development kit (SDK) to support the development of NFV services.
4) An adapted DevOps methodology and associated tools that will help connect stakeholders to a modern, agile workflow that supports the rapid development cycles of software-driven networks, and helps tackle the inter-organizational challenges

MAIN OBJECTIVES

5GTANGO puts forth the flexible programmability of 5G networks. The main objectives within the 5GTANGO project are:

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

APPLICATIONS

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

- Smart manufacturing with deployment and orchestration of network services to control machinery or factory-wide networking system processes, address network security issues and deal with operational verification and validation.
- Immersive media, introducing a solution that relies on virtualisation technologies to implement a virtual Content Delivery Network (vCDN) architecture and adaptive streaming technologies.

EXPECTED IMPACT

5GTANGO will help to open the telecom market and to create business models adapted to the new paradigm: 5GTANGO's NFV-enabled SDK will encourage the creation and growth of start-ups in the sector; the V&V store will be an experimental innovation environment for 5G services where collaboration from different industries will enrich service portfolios; the Service Platform with its modular orchestration framework will alleviate some of the CSPs´ pain points related to the NFV transition.

Its open source results will be made available for their use in industrial and other open source initiatives and as well as future 5G PPP projects and will be discussed with the community and by promoting and actively driving standardization.

Project Coordinator:
Josep Martrat ATOS
Partners:
ATOS/ NEC/ Altice Labs/ Nokia/ Telefónica/ Huawei/ U. of Paderborn/ NCSR Demokritos/ CTTC/ IMEC/ Wiedmüller/ Nurogames/ Synelixis/ U. Pireus Research Center/ Easy Global Market/ Ubitech/ Quobis
More information at:
https://5g-ppp.eu/5gtango/
www.5gtango.eu
Contact
5gtango-Contact@5g-ppp.eu

5G-Transformer: 5G Mobile Transport Platform for Verticals

5G-Transformer

MAIN OBJECTIVES

5G-Transformer aims to transform today's mobile transport network into an SDN/NFV-based Mobile Transport and Computing Platform (MTP), which brings the "Network Slicing" paradigm into mobile transport networks by provisioning and managing MTP slices tailored to the specific needs of vertical industries. The technical approach is twofold:

(1) Enable vertical industries to meet their service requirements within customised MTP slices; and

(2) Aggregate and federate transport networking and computing fabric, from the edge all the way to the core and cloud, to create and manage MTP slices throughout a federated virtualized infrastructure.

The goal of 5G-Transformer is to design, implement and demonstrate a 5G platform that addresses the aforementioned challenges.

USE CASES

The project will demonstrate several vertical industry use cases:

- *Automotive:* Autonomous Cruise Control (ACC) enforcement application, Collaborative Advanced Driver Assistance Systems (ADAS) application and Remote Vehicle Interaction (RVI) application.
- *eHealth:* Improvement of the municipal emergency communication network and development of a new technological solution for health workers and volunteers.
- *Media & Entertainment:* Media applications for stadia and the Olympic Games.

TECHNICAL AND RESEARCH CHALLENGES

5G-Transformer defines three novel building blocks that will be developed and demonstrated integrating the aforementioned three vertical industries:

(1) *Vertical Slicer* as the logical entry point (i.e., one stop shop) for verticals to request the creation of their respective transport slices in a short time-scale (in the order of minutes).

(2) *Service Orchestrator* for end-to-end service orchestration and federation of transport networking and computing resources from multiple MTP domains and for management of their allocation to slices.

(3) *Mobile Transport and Computing Platform* as the underlying unified transport stratum for integrated fronthaul and backhaul networks, hence building on the foundations of 5GPPP Phase 1 projects.

EXPECTED IMPACT

5G-Transformer targets several 5GPPP KPIs, such as reduced service deployment times or OPEX and CAPEX reduction.

The 5G-TRANSFORMER project is an ambitious initiative that will certainly have strong impact in industry. In fact, the project implements a plan for communication, dissemination, and exploitation to maximise its impact, which includes products and standardisation (e.g., ETSI, IETF and ONF). Therefore, innovation management is also a key component.

The technologies developed in 5G-TRANSFORMER are expected to strengthen the position of European companies in the upcoming 5G Mobile Network market, both in Europe and Worldwide, for the whole value chain (Verticals, Operators, Service Providers, Manufacturers, SMEs, and Complementary Industries).

Project Coordinator:
Arturo Azcorra
Universidad Carlos III de Madrid (UC3M)
Partners:
UC3M, NEC, Ericsson, Atos, Nokia, InterDigital, Telefónica, Orange, CRF, SAMUR, B-COM, Nextworks, MIRANTIS, CTTC, Politecnico di Torino, EURECOM, SSSA, ITRI
More information at:
https://5g-ppp.eu/5G-Transformer/
Contact 5G-Transformer-Contact@5g-ppp.eu

Broadcast and Multicast Communication Enablers for the Fifth Generation of Wireless Systems

5G-Xcast

MAIN OBJECTIVES

5G-Xcast will devise, assess and demonstrate a conceptually novel and forward-looking 5G network architecture for large scale immersive media delivery. The project objectives are to:

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

USE CASES (or APPLICATIONS)

5G-Xcast will be the first 5G-PPP project to focus on the holistic implementation of multicast/broadcast as a critical technology element in 5G systems in addition and as a complement to unicast. 5G-Xcast technologies will be also fundamental to progress towards the vision of a converged 5G infrastructure for fixed and mobile accesses, including terrestrial broadcast, to audio-visual media content. The project will take a holistic approach to harmonize the media delivery among the three considered types of networks and to provide an optimised and seamless media user experience. In order to highlight practical applications, three demonstrations of use cases will be developed: "Hybrid Broadcast Services", "Object-based Broadcast Service" and "Public Warning Messages".

TECHNICAL AND RESEARCH CHALLENGES

Audio-visual media services generate large volumes of data traffic on networks which is unevenly distributed over time and geographical areas. At the same time, Quality of Experience (QoE) is strongly dependent on sustained minimum data rates and low latencies to all regardless of the total number of concurrent users. This is particularly challenging for very popular live content (e.g. sports) or unpredictable events (e.g. breaking news) that tend to cause large traffic spikes.

The increasing bit-rate demands of 4k UHDTV and, in the future 8k UHDTV, and the emerging new interactive services (e.g. augmented reality, virtual reality and 360° visual media) will further increase the demand on network capacity and performance. None of the existing networks, whether fixed, mobile or broadcast, has the capability to support this type of future demand on their own due to limitations associated with capacity, delay and cost of deployment. Furthermore, the fractured landscape of protocols and APIs across them severely limits their ability to cooperate in addressing this demand. 5G-Xcast will develop a solution that targets such limitations and therefore addresses future demand, based on the key capabilities of 5G that by far exceed those of the legacy systems.

EXPECTED IMPACT

- Provide efficient, scalable and sustainable solutions for a large-scale distribution of media services fully consistent with the core 5G specifications, contributing to the definition of 5G and its standardization in 3GPP.
- Facilitate seamless integration of fixed, mobile and terrestrial broadcast networks into a unified heterogeneous and flexible 5G infrastructure, enabling better use of network resource, easier evolution paths to future functionalities and services and improved QoE.
- Enable new sustainable business models, new applications and services, and a graceful migration of M&E services from the legacy networks to 5G.
- Bring the M&E vertical into 5G-PPP, bringing together for the first time major and small and medium size players from mobile/fixed/broadcast industries.

Project Coordinator: David Gomez Barquero, UPV

Partners: Universitat Politècnica de València (UPV), Nokia Solutions and Networks Oy, Nokia Solutions and Networks Management International GmbH, British Broadcasting Corporation (BBC), British Telecommunications Public Limited Company (BT), Broadpeak, BundlesLab Kft, Expway, Fairspectrum Oy, Institut für Rundfunktechnik GmbH, LiveU Ltd., Nomor Research, One2Many, Samsung Electronics (UK) Limited, Telecom Italia Spa (TIM), Turku University of Applied Sciences (TUAS), Union Européenne de Radio Télévision (EBU), University of Surrey.

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

Contact 5gxcast-Contact@5g-ppp.eu

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

Bluespace

MAIN OBJECTIVES

The core concept of BLUESPACE is to exploite the added value of Spatial Division Multiplexing (SDM) in the Radio Access Network (RAN) with efficient optical beamforming interface for the pragmatic Ka-band wireless transmission band. Both being seamlessly integreable in next generation optical access networks infrastructures with massive beam steering capabilities and with flexible network management control. The main objectives targeted by the **BLUESPACE** project are BlueSpace are: to develope a truly viable and efficient path for 5G wireless communications with a 1000-fold increase in capacity, connectivity for over 1 billion users, strict latency control, and network software programming.

USE CASES (or APPLICATIONS)

The BLUESPACE architecture will serve 5G service provision in millimeter-wave regions of the spectrum. Proof-of-concept validations and a test-bed will be realized to demonstrate the merits and application of the BLUESPACE concept.

TECHNICAL AND RESEARCH CHALLENGES

- The adaptation of DRoF schemes in parallel with ARoF techniques and their adaptation to SDM network with increased degree of integration and full compatibility among the two schemes
- Development of advanced hardware solutions and modules for cost efficient ARoF transceivers, remote power distribution over SDM network for the independent powering RRUs from the CO, spatial optical beam forming schemes with simplified design requirements and direct compatibility with ARoF transceivers at the RRU, and compact SDM splitter and MCF adapters enabling advanced SDM-based ODN designs.
- The optimum allocation of the BBU pool at the CO and the design of its switching and interconnection hardware to enable SDM-compatible DCA, controlled strict latency and CoMP for both DRoF and ARoF paradigms.
- Design of optimized interfacing elements between the SDM media and the radiating elements in the RRU/RRH sites to enable advanced massive MIMO and beam steering solutions for both DRoF and ARoF architectures
- The evaluation and design of SDN control to support SDM and NFV orchestration to deploy virtual base-band units (vBBUs) in the CO, as well as network slicing to support de virtualization of the network resources and multi-tenancy (e.g. verticals).

EXPECTED IMPACT

BlueSpace proposition offers unrivalled characteristics whose impact include:

a) Increased bandwidth provision by naturally enabling and supporting massive multiple Input Multiple Output (MIMO) in the Ka-band with seamless starting/ending interface with the fiber medium by exploiting space diversity in the RF domain with efficient beamsteering in the photonic domain,

b) A compact infrastructure that is reconfigurable by means of Software Defined (SDN) and Network Function Virtualization (NFV) paradigms and with

c) full integration with existing approaches for access networks such as Passive Optical Networks (PONs).

Project Coordinator:
Idelfonso Tafur Monroy-Eindhoven University of Technology
Partners:
TU/e, AIT, UPV, CTTC, UC3M, ADVA, ICOM, THALES, CORNING, OPT, LIONIX, OP, OTE, NXW, EULAMBIA
More information at:
https://5g-ppp.eu/project/bluespace
Contact
Bluespace-Contact@5g-ppp.eu

European Commission

Internet of Radio Light

IoRL

MAIN OBJECTIVES

Wireless networks in buildings suffer from congestion, interference, security and safety concerns, restricted propagation and poor in-door location accuracy.

The Internet of Radio-Light (IoRL) project develops a safer, more secure, customizable and intelligent building network that reliably delivers increased throughput (greater than 10Gbps) from access points pervasively located within buildings, whilst minimizing interference and harmful EM exposure and providing location accuracy of less than 10 cm. It thereby shows how to solve the problem of broadband wireless access in buildings and promotes the establishment of a global standard in ITU.

USE CASES (or APPLICATIONS)

IoRL project designs a Remote Radio-Light Head (RRLH), so that it can easily be installed in a wide range of different types of properties and Network Management & Operations Plane API for buildings where third party application developers can develop and exhibit their innovative network services in homes, businesses and public space buildings using open source development environment. Example services will be developed in the project such as one that ameliorates the need for using HeNB/HgNB or WLAN in buildings and eliminates the uplink interference that they induce. This will have the effect of incentivising all building construction companies to install an RRLH throughout their new build developments. Building landlords will be incentivized to find funding to realize this solution for their properties to increase their value resulting in a stimulated market for broadband networking products in buildings, benefiting society and stimulating the world Gross Domestic Product. Thus there are four use case scenarios for the most important type of buildings: homes, public spaces – museums, shopping malls and metro stations.

TECHNICAL AND RESEARCH CHALLENGES

The challenges are to (i) Develop broadband communication solutions for buildings by integrating VLC, mmWave and SDN/NFV technologies to exploit the pervasiveness and accessibility of the existing electric light access points, the broadband capacities of mmWave and VLC technologies and the flexibility of SDN/NFV; (ii) Industrially design a remote radio-light head solution that can be integrated into the myriad of form factors of existing electric light systems and consumer products.

EXPECTED IMPACT

The main benefit is that the IoRL architecture meets all the relevant 5G PPP KPI's for networks in buildings, namely: 1000x capacity, less than 1ms latency, 90% energy savings, 10x battery lifetime, service creation in minutes, better/increased/ubiquitous coverage, 10 times to 100 times higher typical user data rate and lowered EMF levels compared to LTE solutions, whilst also providing a further benefits that user equipment can be located to an accuracy of less than 10cm. Designing the radio-light communication system to fit into the confined space of a light rose requires a Network Function Virtualisation (NFV) solution, whose cloud computers can be variously located remote from the radio-light access points elsewhere in the Home Cell Site or in the external Cloud network, and a Software Defined Network (SDN) to intelligently manage and route data to the different parts of the radio-light network. Consequential benefits of this architecture are that its common building electric light network resources can be more easily shared between MNOs by slicing and that the NFV solution provides an API, which allows third party service providers to write specialized network applications to manage multi-MNO in buildings.

Project Coordinator:
Adam Kapovits, Eurescom

Partners:
Brunel University London, Cobham Wireless, ISEP, MostlyTek Ltd, Issy Média, BRE Group, Fraunhofer Institute for Integrated Circuits IIS, National Centre for Scientific Research Demokritos, Viotech, Warsaw University of Technology, Arçelik A.S.,RunEL NGMT Ltd, Holon Institute of Technology, Ferrovial sa, Oledcomm, Tsinghua University, Leadpcom, Shanghai-Feilo / Yaming, Centre for Innovation in Smart Infrastructures (CI3)

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

Contact
IoRL-contact@5g-ppp.eu

A HOLISTIC, INNOVATIVE FRAMEWORK FOR THE DESIGN, DEVELOPMENT AND ORCHESTRATION OF 5G-READY APPLICATIONS AND NETWORK SERVICES OVER SLICED PROGRAMMABLE INFRASTRUCTURE

MATILDA

MAIN OBJECTIVES

MATILDA aims to devise and realize a radical shift in the development of software for 5G-ready applications, as well as virtual and physical network functions and network services, through the adoption of a unified programmability model, the definition of proper abstractions and the creation of an open development environment that may be used by application as well as network functions developers.

Intelligent and unified orchestration mechanisms are going to be applied for the automated placement of the 5G-ready applications and the creation and maintenance of the required network slices. Deployment and runtime policies enforcement is provided through a set of optimisation mechanisms providing deployment plans based on high level objectives and a set of mechanisms supporting runtime adaptation of the application components and/or network functions based on policies defined on behalf of a services provider.

Multi-site management of the cloud/edge computing and IoT resources is supported by a multi-site virtualized infrastructure manager, while the lifecycle management of the supported Virtual Network Functions Forwarding Graphs (VNF-FGs), as well as a set of network management activities, are provided by a multi-site NFV Orchestrator (NFVO).

Network and application-oriented analytics and profiling mechanisms are supported based on real-time as well as a posteriori processing of the collected data from a set of monitoring streams.

USE CASES

In MATILDA, a set of use cases are going to be realised for validation and evaluation of the proposed solution, in the following domains:

- 5G Emergency Infrastructure and Services Orchestration with SLA Enforcement;
- High Resolution Media on Demand;
- Smart City Intelligent Lighting Systems;
- Remote Control and Monitoring of Automobile Electrical Systems;
- Industry 4.0 Smart Factory.

TECHNICAL AND RESEARCH CHALLENGES

To come up with a holistic approach for enhancing 5G with intelligent orchestration platforms able to support end-to-end 5G-ready applications and services provision over a programmable infrastructure, a set of challenges that should be tackled have been identified, as follows:

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

EXPECTED IMPACT

The vision of MATILDA is to design and implement a novel holistic 5G end-to-end services operational framework tackling the overall lifecycle of design, development and orchestration of 5G-ready applications and 5G network services over programmable infrastructure, following a unified programmability model and a set of control abstractions.

Project Coordinator: Prof. Franco Davoli, CNIT
Partners:
CNIT, ATOS, ERICSSON, INTRASOFT, COSMOTE, ORO, EXXPERT, UBITECH, ININ, INCELLIGENT, SUITE5, NCSRD, UNIVBRIS, AALTO, UPRC, ITALTEL, BIBA.
More information at: https://5g-ppp.eu/Matilda/
Contact MATILDA-Contact@5g-ppp.eu

METRO High bandwidth, 5G Application-aware optical network, with edge storage, compUte and low Latency

METRO-HAUL

MAIN OBJECTIVES

The overall Metro-Haul objective is to architect and design cost-effective, energy-efficient, agile and programmable metro networks that are scalable for 5G access and future requirements, encompassing the design of all-optical metro nodes (including full compute and storage capabilities), which interface effectively with both 5G access and multi-Tbit/s elastic core networks.
Metro-Haul has taken the 5G KPIs and already determined their implication for the optical network with these 5 targets: (i) 100 x more 5G capacity supported over the same optical fibre infrastructure, (ii) 10 times less energy consumption, (iii) Latency-aware metro network in which latency-sensitive slices are handled at the metro edge ensuring the metro network adds no additional latency, (iv) End to end SDN-based management framework enabling fast configuration time to set up or reconfigure services handling 5G applications, specifically 1 minute for simple network path set-up and 10 minutes for full installation of a new VNF and 1 hour for setting up a new virtual network slice and (v) reduction in CAPEX of a factor of 10, plus a reduction in OPEX of at least 20%.

USE CASES (or APPLICATIONS)

The two main Use Cases in Metro-Haul are: (i) Video Security for Smart Cities and (ii) Crowdsourced Video Streaming.
The first Use Case will showcase intelligent video security based on automatic object/person identification and tracking. The demo implements a video-based automated security system relying on stationary and mobile cameras (e.g. body cams, or cameras mounted on drones) with wired and/or wireless access. As a basis for the infrastructure, the demo will use the 5G Berlin testbed coupled with DT's Berlin metro infrastructure.
The second Use Case shows the simultaneous sourcing of video from different individuals in an event with a large crowd. The different video sources need synchronising and clustering to be usable for broadcast, and the role of a dynamic and controllable metro network is indispensable.
Additional portable demonstrations will be planned to be showcased in relevant events.

TECHNICAL AND RESEARCH CHALLENGES

Challenges are many and in multiple areas. There is a significant optical challenge, focused on making metro optical transport simultaneously cost effective and agile, involving both the optical architecture and also innovative new optical component technologies.
There is also a challenge around network management. Metro-Haul will design and implement an SDN/NFV control framework and architecture supporting 5G operational and both end-user and vertical oriented services, including slicing. Coupled to that is a challenge around monitoring – both implementation and AI-based tools for interpreting the vast amount of data.

EXPECTED IMPACT

The impact of the project should be felt in different directions. Europe has some large optical vendors who will get a head-start in their plans to support 5G, based on Metro-Haul know-how. The 5G KPIs, applied usually to the radio access end of the network, will be compromised without an optical metro-haul support, and the project will provide all that is needed for this.
Metro-Haul will take advantage of its close links into the standards community to press for wide=spread adoption of its concepts and solutions.

Project Coordinator: Andrew Lord - BT
Partners: BT, Telecom Italia, CTTC, Telefonica, University of Bristol, UPC, CNIT, NAUDIT, OpenLightComm, Lexden Technologies, Zeetta Networks, Fraunhofer HHI, Tech University Eindhoven, Coriant Portugal, Ericsson, Politechnic University of Milan, ADVA, Nokia, Old Dog Consulting, SeeTec

More information: https://5g-ppp.eu/metro-haul/

Contact: metro-haul-contact@5g-ppp.eu

European Commission

5G PPP

NGpaas

Next Generation Platform as a Service NGPaaS

MAIN OBJECTIVES

An ideal 5G Platform-As-A-Service (PaaS) should not only facilitate building, shipping and running classical virtual network applications (VNF) with "telco-grade" quality, it should also combine all sorts of third-party applications with those VNF for creating new more versatile and powerful cloud objects, breaking silos between connectivity and computing. Such a 5G PaaS does not exist today. The **main goal** of NGPaaS is to build it:

1. *Telco-grade PaaS* to support different configurations and a large set of deployment options such as FPGA/ARM/x86, private/public cloud in a scalable and unifying manner.
2. *Dev-for-Operations model* to remove silos not only between different teams of the same organisation, organisations of the same industry but also between different industries (vendor, IoT/Vertical, operator).
3. *High quality and high performance development and operational tools* based on same ones used in telecom environment for ensuring same quality and SLA.
4. *OSS/BSS model* for interfacing with the cloud resources supporting the Telco-grade PaaS optimised for cost and performance in a highly dynamic environment.

USE CASES

To illustrate the platform performance and the "build-to-order" principle, several use-cases will be supported in the telco and the vertical domains. These uses-cases should be highly representative of the advanced capabilities of the platform. The telco use-case demonstrates the '*X-as-a-Service*' Where X ∈ {RAN, EPC, xHaul}. The second use-case is related to IoT through two scenarios: energy monitoring and intelligent agriculture. The third use-case shows a mix of telco and 3rd party IoT components (e.g. local analytics). Heterogeneous IaaS will be considered.

TECHNICAL AND RESEARCH CHALLENGES

Specificities to 5G systems require innovations not yet available in current PaaS.

- **Adoption of a 'cloud stack'** based on a layered approach: infrastructure/platform/ business layers.
- **Components modularity to implement** "build-to-order" principle and to support recursion principle to build efficiently complex PaaS structures.
- **Unstructured and flexible stack** disrupting current approach today where a fixed combination of options in each layer is imposed.
- **Carrier-grade enhancements** implement--ted directly and natively in the control, the orchestration, the virtualisation and the operational frameworks.

EXPECTED IMPACT

NGPaaS's ambition is to:

- build a reference stack for future 5G networks, ready to be deployed for industrial usage.
- create a new ecosystem and the opportunity for all players to collaborate and develop new business models they can each benefit from.
- deliver innovative technologies enabling and accelerating the telco-grade PaaS transformation across the industry (operator, IoT/verticals and vendors), increasing the market scale and improving market economics.

Project Coordinator:
Dr Bessem Sayadi – Nokia Bell-Labs France

Partners:
NOKIA Bell-Labs France (FR) / NOKIA Israel (IL) ONAPP (UK) / Virtual Open Systems (FR)/ ATOS (ES)/ ORANGE (FR)/ BT (UK)/ Vertical M2M (FR)/ Technical University of Denmark (DK)/ University of Milano-Bicocca (IT)/ IMEC (BE)/ B-COM (FR)

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

Contact: ngpaas-contact@5g-ppp.eu

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

NRG-5

MAIN OBJECTIVES

The NRG-5 project aims to contribute to the 5G PPP/5G Initiative research and development activities and participate at the relevant 5G Working Groups, by delivering a novel 5G-PPP compliant, decentralized, secure and resilient framework, with highly availability, able to homogeneously model and virtualize multi-homed, static or moving, hardware constrained (smart energy) devices, edge computing resources and elastic virtualized services over communications' and energy utilities' infrastructures.

The ultimate project objective is to make the deployment, operation and management of existing and new communications and energy infrastructures (in the context of the Smart Energy-as-a-Service) easier, safer, more secure and resilient from an operational and financial point of view.

Furthermore, NRG-5 will investigate on extensive modelling and virtualization of electricity and gas infrastructure assets combined with the telecommunications infrastructure covering the full spectrum of the communication and computational needs.

USE CASES (or APPLICATIONS)

The NRG-5 project is based on the concept of short iterative cycles of work, with highly parallel streams of activities brought together by a mutual focus on developing 5G technologies driven, by a set of Smart Energy three defined use cases and a well-defined time to market context.

In collaboration with 5G initiative, NRG-5 will develop, validate, promote, standardize and exploit 5G results on the smart energy vertical demonstrators to be used by Telcos, Utilities and service providers. NRG-5 will examine how already defined 5G radio features (e.g. from METIS II) could be used in the Critical Infrastructure use case, while NRG-5 results (e.g. security solutions, 5G prototypes, VNFs and xMEC) will be available for 5G services provisioning.

TECHNICAL AND RESEARCH CHALLENGES

Technological advances, political visions and market liberation are transforming the energy network from a closed, monolithic and highly predictable infrastructure to an open, multi-owned, decentralized ecosystem, posing huge challenges, both in functional (i.e. stability, resiliency and highly availability) and in non-functional (i.e. sustainability, security, privacy and CAPEX/OPEX) directions. In this new and time varying energy landscape, NRG-5 and 5G initiative are challenged to guarantee optimal communications of the energy grid, which is believed to be the most complex, heterogeneous and gigantic machine ever made in human history.

EXPECTED IMPACT

NRG-5 balances innovation and development activities, simultaneously exposing concrete and targeted dissemination, communication and standardization plans in close collaboration with 5G PPP Initiative. NRG-5 will demonstrate progress towards core 5G PPP KPI's, novel business models through innovative sharing of network resources across multiple actors and eventually NRG-5 will define 5G network architecture and core technological components.

Project Coordinator:
Massimo Bertoncini – Engineering Ingegneria Informatica S.p.A.

Partners:
Ericsson GmbH, Thales Communications & Security. SingularLogic S.A., Ineo Energy & Systems , Romgaz S.A. , ASM Terni SpA , British, Telecom, Wind, Telecomunicazioni S.P.A., Hispasat S.A., Power, Operations Limited, Visiona Ingenieria De Proyectos SL, Optimum S.A., Emotion s.r.l. , Rheinisch-Westfälische Technische Hochschule Aachen, Jozef Stefan Institut, TEI of Sterea Ellada Electrical Engineering Department, University Pierre et Marie Curie, Centro Romania Energy, Rutgers State University of New Jersey

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

Contact NRG-5-Contact@5g-ppp.eu

E2E-aware Optimizations and advancements for the Network Edge of 5G New Radio

ONE5G

MAIN OBJECTIVES

- To propose the necessary 5G extensions, [...] to address the two selected scenarios ('megacities' and 'underserved areas')
- To build consensus on new features [...] and provide technical recommendations for moving 5G towards '5G advanced (pro)'
- To propose advanced link technologies and enhancements beyond release 15 to enable multi-service operation and practical implementation of '5G advanced (pro)', with future-proof access schemes, advanced massive MIMO enablers and link management.
- To research and deliver highly generic performance optimization schemes [...], in order to achieve successful deployment and operation, including optimizations for both the network operator and the E2E user-experienced performance.
- To identify the cost driving elements for the roll-out and operation and to propose adaptations to allow sustainable provision of wireless services in underserved areas under constrained circumstances.
- To validate the developed extensions and modifications through different approaches: analytically, by means of extensive simulations and with the help of proof-of-concepts for selected aspects.

USE CASES

Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC), massive Machine Type Communications (mMTC).

TECHNICAL AND RESEARCH CHALLENGES

- Future proof multi-service access solutions
- Massive MIMO enablers
- Advanced link management based on multi-cell processing
- Optimized multi-link management for improved E2E performance
- Network and user-experienced E2E performance optimization and context awareness

EXPECTED IMPACT

Standardization: release 16 and 17 of 5G New Radio.
Commercial and market impact: Empower traditional operators and vertical industries to efficiently exploit the opportunities of 5G New Radio
Scientific and technological impact: Drive forward technical advances in the areas given above.
Socio-economic and environmental impact: Enrich both private life and business/industrial activities with enhanced wireless communication services.

Project Coordinator:
Frank Schaich, Nokia Bell Labs
Partners:
Alcatel-Lucent Deutschland AG (coordinator, part of Nokia), Orange SA (technical management), Aalborg University, B-COM, Centre National de la Recherche Scientifique, HHI, Freie Universität Berlin, Huawei Technologies Düsseldorf GmbH, Intel Deutschland GmbH, Nokia Denmark, Samsung Electronics UK, Telefónica I+D, Universidad de Malaga, WINGS ICT Solutions
More information at: https://5g-ppp.eu/one5g/
Contact: one5g-Contact@5g-ppp.eu

European Commission

5G PPP

Satellite and Terrestrial Network for 5G

SaT 5G

MAIN OBJECTIVES

The project vision is to develop a cost effective "plug and play" satcom solution for 5G to enable telcos and network vendors to accelerate 5G deployment in all geographies and at the same time create new and growing market opportunities for satcom industry stakeholders.

The six principal project objectives are to:

1. Leverage relevant on going 5G and satellite research activities to assess and define solutions integrating satellite into the 5G network architecture;
2. Develop the commercial value propositions for satellite based network solutions for 5G;
3. Define and develop key technical enablers for the identified research challenges;
4. Validate key technical enablers in a lab test environment;
5. Demonstrate selected features and use cases;
6. Contribute to the standardisation at ETSI and 3GPP of the features enabling the integration of satcom solutions in 5G.

USE CASES (or APPLICATIONS)

The most relevant SaT5G use cases are: edge delivery for multimedia content and NFV software through multicast offloading to optimise the operation and dimensioning of the 5G network infrastructure; Macro cell backhaul to provide 5G service especially in rural areas or emerging markets; Small Cell backhaul to provide 5G service into buildings in rural areas of developed countries via hybrid broadband connections; and Mobile backhaul to support 5G service on board vessels, aircrafts or trains.

TECHNICAL AND RESEARCH CHALLENGES

The technical challenges that need to be addressed for the realisation of cost effective "plug and play" satcom solutions for 5G are:

- Virtualisation of satcom network functions to ensure compatibility with the 5G SDN/NFV architecture;
- Allowing cellular network management system to control satcoms' radio resources and service;
- Developing link aggregation scheme for small cell connectivity mitigating QoS and latency imbalance between satellite and cellular access;
- Leveraging 5G features/technologies in satcom;
- Optimising/harmonising key management and authentication methods between cellular and satellite access technologies;
- Optimal integration of the multicast benefits in 5G services for both content delivery and VNF distribution.

EXPECTED IMPACT

SaT5G will demonstrate the key role and integration of satellite in the 5G ecosystem by delivering the following impacts:

1. Integrated satellite/cellular solutions meeting 5G KPIs for unserved and underserved regions;
2. Virtualised satellite network architecture for seamless interoperability with 5G;
3. 5G testbeds integrating satcoms for the development of future 5G End to End test platforms;
4. Global standards to ease the market acceptance of satcom solutions by 5G stakeholders;
5. "Plug and play" satcom solutions established and certified to foster the 5G eMBB roll out.

Project Coordinator:
Georgia Poziopoulou-Avanti Communications Ltd

Partners:
AIRBUS DEFENCE AND SPACE, AVANTI COMMUNICATIONS, BT, BROADPEAK, I2CAT, GILAT SATELLITE NETWORKS, IMEC, TNO, ONEACCESS, OULUN YLIOPISTO, QUORTUS, SES TECHCOM, THALES ALENIA SPACE France, TriaGnoSys UNIVERSITY OF SURREY, VT IDIRECT SOLUTIONS

More information at:
https://5g-ppp.eu/SaT5G/

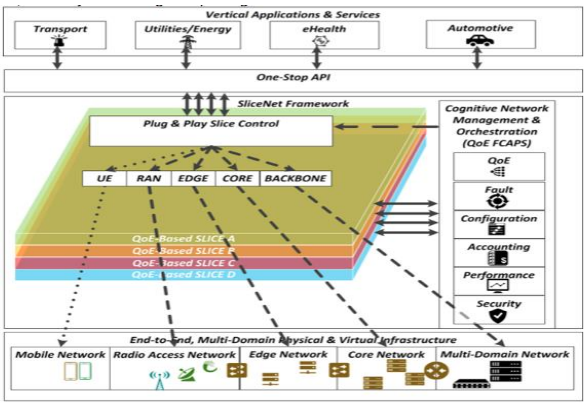
Contact
SaT5G-Contact@5g-ppp.eu

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

SLICENET

MAIN OBJECTIVES

SLICENET targets to achieve truly E2E slicing to maximise the benefits of full infrastructure sharing, and to provide a highly innovative, integrated verticals' QoE oriented slice provisioning, control, management and orchestration framework that manages to meet the diverging requirements from diverse verticals.



USE CASES

SLICENET use cases will challenge 5G slicing capabilities to its limit:

The 5G Smart Grid Self-Healing Use Case will increase automation in distribution with self-healing solutions towards a smarter grid. Altice Labs and EFACEC will jointly deploy this use case in Portugal.

The 5G eHealth Smart / Connected Ambulance Use Case will advance the emergency ambulance services using the ambulance as a connection hub (or mobile edge) for the emergency medical equipment and wearables. The use case has the support from the Irish National Ambulance Services through Irish Department of Public Expenditure and Reform.

The 5G Smart City Use Case will implement remote water metering and the Intelligent Public Lighting system in the city Alba Iulia, in Romania, and access the various technical and operational KPIs against the initial status quo in the city.

TECHNICAL AND RESEARCH CHALLENGES

SLICENET will design, prototype and demonstrate an innovative, verticals-oriented, QoE-driven 5G network slicing framework, focusing on cognitive network management and control for end-to-end slicing operation and slice-based/enabled services across multiple operator domains in SDN/NFV-enabled 5G networks.

EXPECTED IMPACT

SliceNet will advance slicing-based softwarisation of 5G systems with architectural enhancements and infrastructure integration, as well as novel enablers for the slicing control plane, management plane and cross-plane orchestration. For 5G network operators, SliceNet will enable a truly end-to-end multi-domain network management paradigm with integrated FCAPS (Fault, Configuration, Accounting, Performance and Security). For 5G service providers and users, SliceNet will achieve significantly higher service quality towards warranted perceived quality through the intelligent QoE-driven design. For 5G vertical businesses, SliceNet will facilitate them to employ 5G services in a much rapid and efficient manner through a 'one-stop-shop' approach.

Project Coordinator:
Maria Barros Weiss, Eurescom

Partners:
Altice Labs / University of the West of Scotland / Nextworks / Ericsson Telecomunicazioni / IBM Israel / EURECOM / Universitat Politècnica de Catalunya / RedZinc / OTE / Orange / Romania / EFACEC / Dell EMC / Creative Systems Engineering / CIT INFINITE

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

Contact: Slicenet-Contact@5g-ppp.eu

European Commission

5G PPP

Global5G
vision, standardisation & stakeholder engagement in 5G

Global vision, standardisation & stakeholder engagement in 5G
Global5G.org

MAIN OBJECTIVES

The overriding goal of Global5G.org is facilitating a European-led contribution to the international vision of 5G networks, addressing a large set of requirements from different vertical industries.
Global5G.org fills an existing gap in today's efforts to implement a European "5G PPP vision" in an international context, by engaging all relevant stakeholders. Global5G.org will showcase all major outputs and results of 5G-related initiatives as part of the drive towards a sustainable Global 5G PPP Vision.

USE CASES (or APPLICATIONS)

Global5G.org recognises the need to address vertical industry requirements, to limit market fragmentation, and to support standardisation as essential for ensuring interoperability, security, privacy and data protection. A set of representative use cases will be identified, starting from the most important vertical sectors in Europe: Factories of the Future, Automotive, Health, Energy and Media & Entertainment. Expert-led market trends analysis will help identify new use cases during the course of the project.
Global5G.org will facilitate EU and international initiatives with vertical use cases in communicating their requirements in relation to standardisation and spectrum. Furthermore, Global5G.org will act as a bridge across the 5G PPP and Standards Bodies internationally, by engaging with EU and international initiatives addressing horizontal issues (e.g. security, privacy, trust) to monitor progress and help increase awareness and consensus.

TECHNICAL AND RESEARCH CHALLENGES

Global5G.org will support European 5G research that address challenges of spectrum efficiency, capacity, ubiquitous coverage, ultra-high reliability, ultra-short latency, enhanced security, privacy and data protection, trustworthy interoperability across heterogeneous domains, networks and data centres, energy efficiency, network slicing, network programmability and virtualisation techniques.

EXPECTED IMPACT

The Global5G.org **technology radar** will help increase research efficiency on 5G by constantly monitoring efforts from all 5G PPP EU and international projects, supporting co-operation on horizontal issues, sharing major research findings to streamline research efforts among diverse actors in the 5G ecosystem, while sensing market needs as they arise through the Global5G.org **market watch**.

The Global5G.org **collaboration platform** will provide the ideal environment for discussions among all major 5G stakeholders, spanning the 5G industry, vertical sectors, research, spectrum experts and policy makers, enabling the creation of new synergies and partnerships in the 5G ecosystem. The platform will host a **catalogue for showcasing 5G PPP project results** to facilitate business validation from early adopters. Participation of researchers and industry from the earliest phase of the project will ensure optimal exploitation and sustainability of results in the mid-to-long term, including test facilities.

The **Strategic Research & Innovation Agendas** (SRIAs), with recommendations for 5G development plans of international breadth, and insight reports from highly relevant events, chart a course for a **Global 5G International Cooperation Roadmap** that strongly supports the "from research to standardisation" approach, covering vertical use cases and technical specifications. Interaction with standards bodies will thus play a fundamental role in the road-mapping activity, driving global harmonisation in key areas.

Project Coordinator:
Laura Baracchi – Trust-IT Services Ltd. (UK)
Partners:
Trust-IT Services Ltd. (UK), Aalto University (FI), IDC (IT), inno TSD (FR)
More information at:
https://5g-ppp.eu/global5g.org/
Contact
global5g.org-Contact@5g-ppp.eu

Supporting the 5G-PPP
To-Euro-5G

MAIN OBJECTIVES

The **To-Euro-5G** project has a prime objective to support the activities of the European 5G Initiative during the second phase of the 5G PPP from June 2017 to June 2019.

The 5G PPP Phase 2 projects will be obliged by Article 41.4 of their respective grant agreements to enact a Collaboration Agreement and participate in a number of strategic cross project horizontal activities and **To-Euro-5G** will assist with orchestrating this agreement and these activities.

The **To-Euro-5G** project will further develop and progress a strategic communications plan to ensure the best possible impact is achieved with the technical results of the 5G PPP projects and the horizontal activities of the 5G PPP programme.

The **To-Euro-5G** project will support the 5G PPP high level goal of maintaining and enhancing the competitiveness of the European ICT industry, and seeking European leadership in the 5G domain. The European 5G Action Plan[1] will require an overview of the 5G PPP projects trial/demo/showcase potential. The **To-Euro-5G** project will facilitate the new Trials Working Group, which was launched by the 5G Infrastructure Association in 5G PPP in September 2016.

The **To-Euro-5G** project also has the underlying ambition to ensure that European society, via the Vertical sectors, can enjoy the economic and societal benefits these future 5G networks can provide.

PROJECT CONCEPTS

The **To-Euro-5G** project Concept is to provide the necessary support for the operation of the 5G PPP in the most efficient and effective way possible. While the support action cannot provide the unified solutions for 5G itself, the project team realise that the support for interworking between the projects and the presentation of the combined results on the global stage can have a significant impact on the adoption and use of the European 5G solutions.

TECHNICAL AND RESEARCH CHALLENGES

At the first organisational level in the programme **To-Euro-5G** project will organise a Steering Board (SB) composed of the mandated coordinators of the all running 5G PPP projects.

The next operational level will be a Technology Board (TB) where the issues of complementary scope, consistence and interoperability, interfaces as well as the technical planning of joint demonstrations will be considered. All cross-project technical issues will be addressed here.

The third level of activity organisation will be the establishment and operation of joint Working Groups (WG) across projects and the wider community as necessary.

EXPECTED IMPACTS

- An efficient and effective 5G PPP programme
- Optimum profile for the European 5G initiative in a global context
- Widespread dissemination of 5G-PPP results
- Launch of necessary 5G standards work
- Measurable Programme Progress and KPIs
- A holistic view of 5G implementation for 2020
- Enhancement of 5G Vision
- Growth of the 5G constituency
- Supporting early exploitation of results,

Project Coordinator: David Kennedy, Eurescom

Partners:

Eurescom, 5G-Infrastructure-Association, IDATE, InterInnov, Nokia Net, University of Surrey, Università di Bologna, Orange, Martel, Telenor, Alcatel Lucent Bell Labs France (Nokia), Waterford Institute of Technology.

More info: https://5g-ppp.eu/To-Euro-5G/

Contact: To-Euro-5G-Contact@5g-ppp.eu

[1] https://ec.europa.eu/digital-single-market/en/news/communication-5g-europe-action-plan-and-accompanying-staff-working-document

5G-CORAL

A 5G Convergent Virtualised Radio Access Network Living at the Edge (EU-Taiwan Project)

MAIN OBJECTIVES

5G-CORAL aims at delivering a convergent 5G multi-RAT access through an integrated virtualised edge and fog solution that is flexible, scalable, and interoperable with other domains including transport (fronthaul, backhaul), core and clouds. The major objectives are to:

- Develop a system model that includes use cases, requirements, architecture, and business models to design and validate the 5G-CORAL solution
- Design virtualised RAN functions, services, and applications for hosting in the 5G-CORAL Edge and Fog computing System (EFS)
- Design an Orchestration and Control system (OCS) for dynamic federation and optimised allocation of 5G-CORAL EFS resources
- Integrate and demonstrate 5G-CORAL technologies in large-scale testbeds making use of facilities offered by Taiwan, and measure their KPIs
- Disseminate and contribute 5G-CORAL results into international research and innovation venues to pave the way for their successful exploitation

USE CASES (or APPLICATIONS)

5G-CORAL project will be validated in three testbeds (i) shopping mall in Taiwan, (ii) high-speed train in Taiwan, and (iii) connected cars in Taiwan and Italy.

Shopping mall: The goal of the testbed is to verify the developed technologies in dense scenarios by allowing massive connectivity, high throughput, network and computation offloading, and to provide time critical services to the users.

High-speed train: The goal of this testbed is to verify traffic offloading in the high-mobility scenario. One anticipated goal is to provision breakout and mobility functions on the on-board Fog computing devices (CDs) that could potentially mitigate the burden of passengers' mobility signalling on the backhaul.

Connected cars: The goal of the connected car testbed is to demonstrate the benefits of 5G-CORAL to V2X communications supported by Fog CDs nearby or on-board the cars.

TECHNICAL AND RESEARCH CHALLENGES

5G-CORAL project leverages on the pervasiveness of edge and fog computing in the Radio Access Network (RAN) to create a unique opportunity for access convergence. This is envisioned by means of an integrated and virtualised networking and computing solution where virtualised functions, context-aware services, and user and third-party applications are blended together to offer enhanced connectivity and better quality of experience. The proposed solution contemplates two major building blocks, namely (i) the Edge and Fog computing System (EFS) subsuming all the edge and fog computing substrate offered as a shared hosting environment for virtualised functions, services, and applications; and (ii) the Orchestration and Control System (OCS) responsible for managing and controlling the EFS, including its interworking with other (non-EFS) domains.

EXPECTED IMPACT

Through the 5G-CORAL solution, several Key Performance Indicators (KPIs) can be achieved, notably an ultra-low end-to-end latency in the order of milliseconds. Moreover, new business prospects arise with new stakeholders in the value chain, notably small players owning computing and networking assets in the local service area, such as in shopping malls, airports, trains and cars.

Project Coordinator: Antonio de la Oliva, Universidad Carlos III de Madrid

Partners: Universidad Carlos III de Madrid, Ericsson AB, InterDigital Europe, Telecom Italia, Telcaria Ideas, RISE SICS AB, Azcom Technology, Industrial Technology Research Institute Incorporated, ADLINK, FOXCONN, National Chiao Tung University

More information at: http://www.5g-coral.eu

Contact 5G-CORAL-Contact@5g-ppp.eu

Converged wireless access for reliable 5G MTC for factories of the future (EU-Taiwan Project)

Clear5G

MAIN OBJECTIVES

Clear5G aims to investigate and demonstrate some of the key enablers necessary to support Machine Type Communications (MTC) traffic in 5G networks, in particular in the Factories-of-the-Future (FoF) environment. Specific objectives include:

- Define, investigate and develop physical layer enhancements for reliable MTC supporting massive numbers of devices, achieving extreme low latency and reduced signalling and control overhead.
- Design and implement Medium Access Control layer enhancements for integrated convergent access supporting low latency, high reliability, massive connection density, and high energy and spectrum efficiency.
- Design, configure and optimize radio network architectures and management mechanisms to fulfil the needs of FoF applications in terms of latency, wireless networking heterogeneity, reliability, scalability and manageability.
- Provide security enhancements at the physical layer, contributing to the overall security solutions in a FoF environment.
- Validate and demonstrate the performance of the project use cases in a realistic environment using testbed facilities both in Europe and Taiwan.
- Support the ongoing 5G Standardization.

USE CASES (or APPLICATIONS)

The Clear5G applications focus on FoF environments employing time-critical processes, relying on timely delivered data from massive numbers of sensors, and having to make and execute decisions in less than milliseconds.

Indicative examples include:

- Remote maintenance of sensors monitoring machines' status, machine reconfiguration for product customization, goods inventory, and zero defect assembly line with continuous check quality during production.
- Closed loop control systems.
- Large factory plants covered by cellular systems.

TECHNICAL AND RESEARCH CHALLENGES

Clear5G will deliver technical solutions addressing the challenges of massive deployment of connected devices, security, ultra-low latency and ultra-high reliability in FoF applications, like remote maintenance and closed loop control systems. The requirements of these complex scenarios will be met through the convergence of different wireless technologies, enabled by protocol and architecture enhancements proposed by Clear5G.

Clear5G will focus on providing physical, medium access control, and architectural enhancements to meet the strict requirements of FoF applications in terms of KPIs: latency, reliability, connection density, spectrum, and energy efficiency, thus contributing to the ITU-R objectives (e.g., 1000 fold connection density) for the next generation mobile network.

EXPECTED IMPACT

Clear5G contributes to strengthen manufacturing capabilities of both Europe and Taiwan. More specifically, Clear5G investigates and demonstrates some of the key enablers necessary to support MTC traffic in 5G networks, in particular in the FoF environment. In addition, Clear5G will become a bridge between the 5G PPP and the FoF PPP activities, enabling their strong cooperation and synchronization in terms of factory related standardization activities.

To ensure that the highest possible impact of the project findings is achieved, Clear5G will actively contribute to the most relevant and most impacting standardization bodies and groups.

Project Coordinator:
Klaus Moessner, University of Surrey
Partners:
University of Surrey, ADLINK Technology Inc., ARGELA, Commissariat à l'énergie atomique et aux énergies alternatives, Fair Friend Enterprise Co., LTD, Hon Hai Precision Industry Co., Ltd. Hsinchu Science Park Branch Office, Institute for Information Industry National Taiwan University, Netherlands Organisation for Applied Scientific Research, Toshiba Research Europe, Turk Telekom, WINGS ICT Solutions Ltd.
More information at: https://5g-ppp.eu/Clear5G/
Contact Clear5G-Contact@5g-ppp.eu

