5G-SOLUTIONS for European Citizens

D1.3A - Leveraging and extending 5G-PPP previous work in 5G-SOLUTIONS v1.0

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Glossary of terms and abbreviations used

Abbreviation / Term	Description
3GPP	3rd Generation Partnership Project
5G	Fifth Generation (mobile/cellular networks)
5G-PPP	5G Public Private Partnership
AAA	Authentication, authorization, and accounting
AIV	Air Interface Variants
API	Application Programming Interface
AR	Augmented Reality
B2B	Business to Business

B2B2X	Business to Business to Everything
B2C	Business to Consumer
BBU	Baseband Unit
BH	BackHaul
Car2X	Car to Everything
CAPEX	CAPital EXpenditure
CBTR	Coding, Building, Testing and Releasing
CI/CD	Continuous Integration / Continuous Development
CDN	Content Distribution Networks
CLI	Command-Line Interface
CN	Core Network
CNO	Cognitive Network Optimizer
CoMP	Coordinated Multi Point
CORD	Central Office Re-architected as a Datacenter
CP-OFDM	Cyclic Prefix OFDM
CPRI	Common Public Radio Interface
C-RAN	Cloud RAN
CSI-RS	Channel Status Information Reference Signal
CSP	Communication Service Provider
CPU	Central Processing Unit
CU	Centralised Unit
DA-RAN	Dis-Aggregated Radio Access Network
DC	Data Centre
DevOps	Development Operations
DL	Downlink
DPDK	Data Plane Development Kit
DU	Distributed Unit
E-UTRA	Evolved UMTS Terrestrial Radio Access
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service

EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FaaS	Function as a Service
FDD	Frequency-division duplex
FeMBMS	Further evolved Multimedia Broadcast & Multicast Services
FH	FrontHaul
FLLR	Fast Local Link Reroute agent
FOSS	Free and Open Source Software
FPGA	Field-Programmable Gate Array
FQAM	Frequency and Quadrature Amplitude Modulation
GSM	Global System for Mobile communication
GSMA	GSM Association
GUI	Graphic User Interface
HARQ	Hybrid Automatic Repeat Request.
HD	High Definition
HW	HardWare
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IoT	Internet of Things
IPR	Intellectual PRoperty
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LL	Living Lab
LTE	Long Term Evolution
LSA	Licensed Shared Access
MAC	Media Access Control
MANO	Management and Orchestration
MAPE	Monitor-Analyse-Plan-Execute
MAPE-K	Monitor-Analyse-Plan-Execute over a shared Knowledge
MBB	Mobile BroadBand

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MCC	Mission Critical Communication
MEC	Multi-Access Edge Computing
MEC	Mobile Edge Cloud
MIMO	Multiple-input and multiple-output,
mIoT	Massive Internet of Things
MMC	Massive Machine Communication
mMTC	Massive Machine-Type Communications
mmWave	millimetre Wave
MNO	Mobile Network Operator
MTC	Machine Type Communications
MTP	Mobile Transport and Computing Platform
MVNO	Mobile Virtual Network Operator
NaaS	Network as a Service
NACK	Negative ACKnowledge character
NBI	Northbound Interface
NF	Network Functions
NFV	Network Functions Virtualisation
NFVI	Network Functions Virtualisation Infrastructure
NFV-NS	NFV Network Service
NR	New Radio
NS	Network Service
NSD	Network Service Descriptor
NUMA	Non-uniform memory access
OAI	Open Archives Initiative
OFDM	Orthogonal Frequency-Division Multiplexing
OPEX	OPerating EXpense
OPP	Open Packet Processors
OS	Operating System
OSM	Open Source MANO
OSS	Operation Support Systems
OW	OpenWhisk

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QoE	Quality of Experience
QoS	Quality of Service
PaaS	Platform as a service
PDU	Protocol Data Unit
PTM	Point-to-multipoint
RAN	Radio Access Network
RFB	Reusable Functional Block
RGB-D	Red Green Blue – Depth
RRH	Radio Remote Header
RRM	Radio Resource Management
RTT	Round Trip Time
RU	Resource Unit
SA	StandAlone
SBI	SouthBound Interface
SCTP	Stream Control Transmission Protocol
SDK	Service Development Kit
SDN	Software Defined Network
SFN	Single-Frequency Network
SLA	Service Level Agreement
SO	Service Orchestrator
SR-IOV	Single Root I/O Virtualization
SVP	Service Virtualization Platform
SW	SoftWare
TDD	Time-division duplex
TTT	Time to Trigger
TRL	Technology Readiness Level
TSON	Time-Shared Optical Network
UHD	Ultra-High Definition
UC	Use Case
UL	Uplink
UMTS	Universal Mobile Telecommunications System

URLLC	Ultra-Reliable Low Latency Communications
V2X	Vehicle to Everything
VbbU	Virtual Broadband Base Unit
VM	Virtual Machine
VIM	Virtualized Infrastructure Manager
VNF	Virtualised Network Function
VNFaaS	VNF as a Service
VNFD	Virtualised Network Function Descriptor
VPN	Virtual Private Network
VR	Virtual Reality
VS	Vertical Slicer
VSB	Virtual Service Blueprint
VSD	Vertical Service Descriptors
WDM-PON	Wavelength Division Multiplexing Passive Optical Network
XCI	5G-Crosshaul Control Infrastructure
xMBB	Extreme Mobile BroadBand

1 Executive Summary

This deliverable is an output of Task 1.3, “Leverage, build upon and extend previous and ongoing work from EU funded 5G-PPP projects and 2nd phase of 5G standardisation”, whose goal is to capitalise on 5G-PPP Phase 1 findings, 5G-PPP Phase 2/Phase 3 projects and to leverage assets and results for use in 5G-SOLUTIONS.
In particular, this document constitutes an interim version (v1.0) of the deliverable (at month 5) and contains the outputs, results and assets from previous 5G-PPP related projects that will be utilised and extended in 5G-SOLUTIONS ecosystem.

Furthermore, this deliverable outlines, validates and extends the KPIs and results of the previous 5G-PPP Projects in order to address the initial version of 5G-SOLUTIONS KPIs (as per Part B of Grant Agreement), carried out by Task 1.1, which aims to prove and validate that the 5G technology can provide prominent industry verticals with ubiquitous access to a wide range of forward-looking services with orders of magnitude of improvement over 4G.

Moreover, this deliverable can constitute a basis for other Tasks to leverage, extend, integrate and advance assets and technologies from completed 5G-PPP projects. An analysis on leveraging and extending previous results in 5G-SOLUTIONS has been carried out.

To take advantage of the fact that partners in 5G-SOLUTIONS are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects, a set of these projects, which have at least a common partner with 5G-SOLUTIONS, was identified and analysed, project by project, in terms of main achievements.
The subjects covered by this analysis are related to 5G-SOLUTIONS activities, namely transport network, control and orchestration, mobile access, network security, and media distribution over 5G infrastructure. A particular attention has been given to ICT-17 projects 5G-EVE and 5G-VINNI, which offer their platforms to implement the use cases of 5G-SOLUTIONS Living Labs.

Of particular benefit, the projects demonstrate the possibility to achieve 5G performances in terms of latency (less than 5 ms for the end-to-end and 0.5 ms for the data-plane only), user data rate up to 1Gbit/s, availability higher than 99.999% and, for the control plane, a service creation time lower than 90 sec.

In the following months the task, leveraging on the outcomes reported in this deliverable in terms of KPIs, will ensure the cooperation with the other projects in the call and with the 5G-PPP, in collaboration with Task 9.3, participating in the 5G-PPP Steering Board and Technical Boards. Additionally, in terms of Standardisation items, and in collaboration with Task 8.3, it will analyse the results obtained with 5G-EVE and 5G-VINNI to be aligned with existing and emerging standards from the relevant standardisation bodies (3GPP, ETSI, ITU, IEEE, IETF…). A tight collaboration with Task 9.1 for the organization of a pre-standardisation workshop and dissemination events will complete the task commitments.

2 Introduction

5G-SOLUTIONS Project has been conceived to be built onto the outputs and findings of completed 5G-PPP Phase 1 and Phase 2 projects and ongoing Phase 3 projects (leveraging their ICT-17 facilities) as well as other relevant projects and commercial assets to seed its technology, including incorporating interdisciplinary knowledge and expertise.

The ICT-17 projects involved, 5G-EVE and 5G-VINNI, are committed to upgrade and support their 5G facilities during and after the completion of their ICT-17 projects until the completion of 5G-SOLUTIONS. This will enable the validation of the vertical use cases to the latest available 5G 3GPP releases by the third quarter of 2021 until the second quarter of 2022 to ensure that the latest features will be supported before actual widespread 5G deployments in Europe.

This deliverable is an output of Task 1.3, which is devoted to:

- the capitalisation on 5G-PPP Phase 1 findings, 5G-PPP Phase 2 and Phase 3 projects;
- the leveraging of assets and results for use in 5G-SOLUTIONS;
- the cooperation with the other projects in the call and with the relevant entities in 5G-PPP;
- the consolidation of a common vision towards the wide deployment of 5G technologies by the analysis of the results achieved from 5G-EVE and 5G-VINNI projects and their sharing with other 5G international initiatives.

In particular, this document constitutes an interim version (v1.0) of the deliverable and contains the outputs, results and assets from previous 5G-PPP related projects that will be utilised and extended in 5G-SOLUTIONS ecosystem. The final version of the deliverable (v2.0) is scheduled in an intermediate phase of the Project itself.

Partners in 5G-SOLUTIONS are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects. This ensures knowledge, transfer of lessons learned, reuse of assets, testbeds and expertise: for this reason, this interim version of the deliverable contains a first review of results and assets achieved by previous 5G-PPP Projects and how they can be reused and extended in 5G-SOLUTIONS ecosystem.

To achieve this, in the present deliverable:

- A choice of 5G-PPP projects, whose collaborators are now partnering of 5G-SOLUTIONS, has been performed. This choice takes onto account the main aspects 5G-SOLUTIONS has to face with, in particular:
  - NFV and Orchestration, for the creation of necessary plugins to orchestrate cross-testbed provisioning and management of the various vertical applications;
  - RAN and Air Interface, in order to adopt the latest improvements for the definition functional architecture and technical specifications;
  - Security, to validate results of previous projects for possible security aspects;
  - Network slicing, which is a key component of 5G-SOLUTIONS;
  - Optical-wireless Front/backhaul, which gives an important contribution for the achievement of technical LL KPIs;
  - Multicast/Broadcast capabilities which can provide a highly efficient mean for distribution of high-quality and/or immersive content to many concurrent users;
  - 5G Facilities for field trials, for UCs related to LLs.
- An analysis of the main achievements of Projects which involve consortium partners has been carried out;
- Particular attention has been given to KPIs of previous projects, in order to relate them to the target KPIs detailed by Task 1.1 for 5G-SOLUTIONS and associated to the vertical UC scenarios;

- A preliminary analysis on leveraging and extending previous results in 5G-SOLUTIONS has been carried out.

The work done in this deliverable can constitute a basis for other Tasks to leverage, extend, integrate and advance assets and technologies from completed 5G-PPP projects.

2.1 Mapping Projects' Outputs

The purpose of this section is to map 5G-SOLUTIONS Grand Agreement commitments, both within the formal Deliverable and Task description, against the project's respective outputs and work performed.

Table 1: Adherence to 5G-SOLUTIONS GA Deliverable & Tasks Descriptions

5G-SOLUTIONS Task		Respective Document Chapter(s)	Justification
Task 1.3 – Leverage, build upon and extend previous and ongoing work from EU funded 5G-PPP projects and 2nd phase of 5G standardisation	In this task we will capitalise on 5G-PPP Phase 1 findings, 5G-PPP Phase 2 and Phase 3 projects and will leverage assets and results for use in 5G-SOLUTIONS. The cooperation with the other projects in the call and with the relevant entities in 5G-PPP is ensured by this task. The results achieved from 5G-EVE and 5G-VINNI projects will be analysed in 5G-SOLUTIONS and shared with other 5G international initiatives, including GSMA, in order to consolidate a common vision towards the wide deployment of 5G technologies. This will be realised by a continuous exchange of information among the projects, facilitated by the activities of the Working Groups in 5G- IA and 5G-PP as well as through the Steering Board and the Technical Board, where the Project Coordinator (PC) and the Technical Manager (TM) of the project are actively involved, respectively.	Chapters 4-5-6-7-8	5G-SOLUTIONS consortium partners are involved in many other 5G-PPP Projects. In Chapters 4-5-6 are listed the main achievements of Projects which involve consortium partners, respectively in Phase1, Phase 2 and Phase 3. An analysis on projects achievements has been carried out, in order to identify results and assets for use in 5G-SOLUTIONS. Chapter 7 is devoted to a listing of main KPIs from previous 5G-PPP Projects Chapter 8 is devoted to a possible extension of previous results in 5G-SOLUTIONS.
5G-SOLUTIONS Deliverable			
D1.3A: Leveraging and extending 5G-PPP previous work in 5G-SOLUTIONS v1.0 Interim (v1.0) version of report containing the outputs, results and assets from previous 5G-PPP related projects that will be utilised and extended in 5G-SOLUTIONS's ecosystem.			

2.2 Deliverable Overview and Report Structure

The project 5G-SOLUTIONS is built on the outputs and findings of completed 5G-PPP Phase 1 and Phase 2 projects and ongoing Phase 3 projects (leveraging their ICT-17 facilities) as well as other relevant projects and commercial assets to seed its technology.

A brief outline of 5G-PPP scenario is then shown in chapter 3, followed by an analysis of the main achievements of Projects which involve consortium partners. This reflects the fact that project partners are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects.

A choice of 5G-PPP projects whose collaborators are now partners of 5G-SOLUTIONS has been performed. This choice takes onto account the main aspects 5G-SOLUTIONS has to face with, namely transport network, control and orchestration, mobile access, network security, and media distribution over 5G infrastructure. Chapters 4, 5 and 6 are devoted to the analysis of the main achievements of these Projects, respectively for Phase 1, Phase2 and Phase 3.

During discussions with all the partners, a particular attention was requested on 5G-PPP KPIs, in order to relate them to the target KPIs detailed by Task 1.1 for 5G-SOLUTIONS and associated to the vertical UC scenarios: this is carried out in Chapter 7

Finally, Chapter 8 deals with leveraging and extending previous results in 5G-SOLUTIONS.

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3 5G-PPP Scenario

5G-PPP vision is that telecom and IT will be integrated towards a common very high capacity ubiquitous infrastructure, as shown in Figure 1, with converging capabilities for both fixed and mobile accesses.

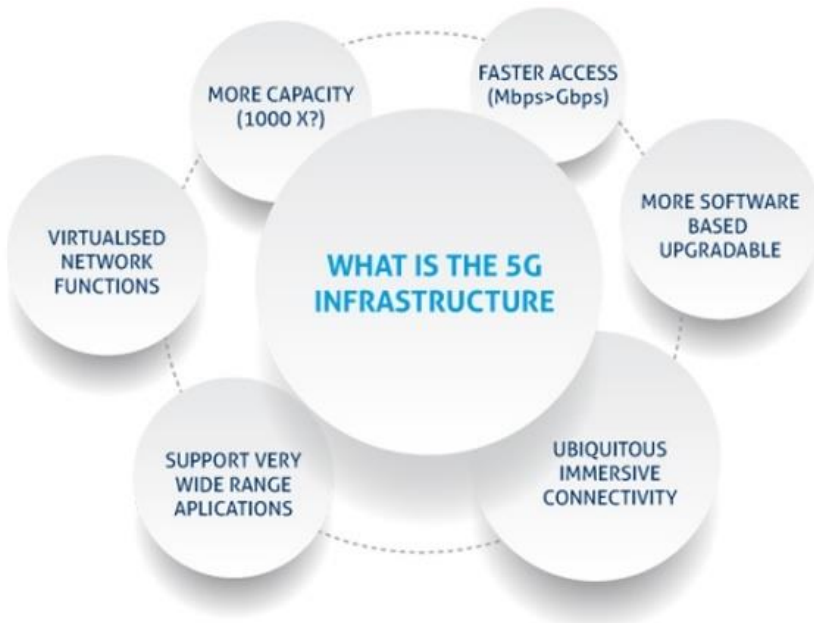

Figure 1: 5G-PPP Vision of the Future 5G Infrastructure [2]

The following parameters are indicative new network characteristics to be achieved at an operational level, within 2030:

- Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010;
- Saving up to 90% of energy per service provided. The main focus will be in mobile communication networks where the dominating energy consumption comes from the radio access network;
- Reducing the average service creation time cycle from 90 hours to 90 minutes;
- Creating a secure, reliable and dependable Internet with a “zero perceived” downtime for services provision;
- Facilitating very dense deployments of wireless communication links to connect over 7 trillion wireless devices serving over 7 billion people;
- Enabling advanced user-controlled privacy.

[2] **Source**: 5G PPP, https://5g-ppp.eu/about-us/ .

4 Phase 1 Main Achievements

Partners in 5G-SOLUTIONS are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects. In this section the main achievements of the Phase 1 Projects are listed, which involve consortium partners. An analysis of Phase 1 projects' achievements is carried out, in order to identify results and assets for use in 5G-SOLUTIONS.

4.1 SONATA

SONATA is a vendor-agnostic MANO platform that fully embraces the flexible programmability of 5G networks and the virtualization of the communication services enabled by Software Defined Networks (SDN) and Network Function Virtualization (NFV) technologies.

It follows a three-phased approach that covers the three main stages of any network service lifecycle: development, testing and operations. Its flexible architecture consists of three main modules, each of them responsible for one of the above-mentioned phases:

- **Development:** An NFV-enabled **Service Development Kit** (SDK) to support developers in the creation of innovative Virtual Network Functions (VNF) and Network Services (NS).
- **Testing:** A **Validation and Verification Platform** with advanced mechanisms for the qualification of VNFs and NSs.
- **Operations:** A modular **Service Platform,** with an innovative MANO framework for the agile management of the full lifecycle of the deployed NSs and the use of resources.

These three modules can work either in an integrated or isolated way but, in combination, they realise an extended NFV DevOps model between service developers, telecom operators and vertical industries that increases operational efficiency, fosters collaboration and facilitates the launch of innovative services.

NOKIA, now present in 5G-SOLUTIONS' consortium, was among the partners of SONATA project.

4.1.1 Flexible Open-Source Service Platform for NFV

SONATA has developed a flexible NFV MANO Service Platform for NFV that is built on a micro-service architecture and released as open-source software under the Apache 2.0 license. The Service Platform operates and manages the lifecycle of network service on top of a virtual infrastructure manager, like OpenStack. To this end, it deploys the virtual network functions as virtual machines and steers the traffic by implementing service function chains. In addition to the management, the service platform allows for extensive monitoring and analysis of network services to make smart decisions, e.g., for placement and scaling of virtual machines. One of the key innovations and outstanding features of the Service Platform is the support of so-called Service Specific Manager and Function Specific Managers. The managers are highly specialized pieces of software, which execute complex functions tailored to a network service, but run as Service Platform plugins. Thus, a service developer can ship Service Platform plugins together with their service function and modify the behaviour of the Service Platform in a standard and secure way. Obviously, this increases the flexibility of the Service Platform significantly.

4.1.2 DevOps and CI/CD for NFV

The SONATA project developed their service platform with the goal of bringing DevOps to NFV MANO platforms allowing such platforms to keep up with the rapid pace of changing NFV concepts, architectures, technologies, platforms, and standards. To that end, a continuous integration / continuous deployment pipeline has been defined that allows developers to frequently update and publish their code to platform users. Due to the DevOps approach, developers quickly receive feedback on their changes. The approach is supported by allowing service developers to create, ship and deploy service-specific management plug-ins which modify the behaviour of the MANO system. Feedback to developers is enabled by a Monitoring Framework which collects and processes data from several sources, allowing developers to dynamically activate monitoring data collection.

4.1.3 Rapid Software Development for NFV

The SONATA Service Platform is complemented by the SONATA Service Development Kit that aims at fast implementation, testing, and debugging of virtualized network functions and services. To this end, the SDK supports the creation of function and service descriptors as well as service packages which are uploaded to the Service Platform and used to manage the lifecycle of complex network service. Moreover, the SDK offers features to test, profile, and debug network services locally by using a Service Platform emulator that mimics the behaviour of the actual Service Platform locally, say on a developer's laptop. The knowledge gained by these local tests simplify the function and service development, shorten the time-to-market, and at the same time, increase the quality of the resulting product. Finally, the SDK interconnects tightly with the Service Platform and allows to monitor running services in real time. To this end, it enables the developer to collect important data and offers tools to analyse the data in order to debug or improve the service, for example in terms of performance.

More details can be found in SONATA SERVICE PLATFORM [1] and SONATA SDK [2].

4.2 SUPERFLUIDITY

The SUPERFLUIDITY project aims at achieving superfluidity in the network: the ability to instantiate services on-the-fly, run them anywhere in the network (core, aggregation, edge) and shift them transparently to different locations.

This project tackles crucial shortcomings in today's networks: long provisioning times, with wasteful overprovisioning used to meet variable demand; reliance on rigid and cost-ineffective hardware devices; daunting complexity emerging from three forms of heterogeneity: heterogeneous traffic and sources; heterogeneous services and needs; and heterogeneous access technologies, with multi-vendor network components.

The SUPERFLUIDITY solution is based on: a decomposition of network components and services into elementary and reusable primitives; a native, converged cloud-based architecture; the virtualization of radio and network processing tasks; platform-independent abstractions, permitting reuse of network functions across heterogeneous hardware platforms, while catering to the vendors' need for closed platforms/implementations; and high performance software optimizations along with leveraging of hardware accelerators.

NOKIA, now present in 5G-SOLUTIONS' consortium, was among the partners of SUPERFLUIDITY project.

4.2.1 Reusable Functional Block (RFB) Concept and Lightweight Virtualization

NFV can be used to support highly dynamic scenarios, in which the VNFs are instantiated "on the fly" following the service requests. VNFs tend to become small and highly specialized Micro-VNFs, i.e. elementary and reusable network elements. Complex services can be built through the "chaining" of these Micro-VNFs. Different virtualization approaches can be used to support these micro-VNFs: Tinified VMs and unikernels. – Added Unikernels have very important properties allowing to reduce the service deployment. They offer very good performance in terms of low memory footprint and instantiation time. The recent measurements conducted in the project using ClickOS, a Xen-based unikernel, demonstrate a small footprint (around 5 MB when running) and an instantiation time around 30 milliseconds.

4.2.2 KPI/SLA mapping and Analytics Pipeline

SUPERFLUIDITY develops a framework to automatically map service-level Key Performance Indicators (KPIs) to the platform-level parameters in the host compute environment. The framework enables the identification of platform features, which most significantly influence the KPIs for a given workload under test. Full stack monitoring is used to capture a telemetry data ranging from low-level hardware metrics to higher-level applications metrics. The data is analysed using an analytics pipeline, which identifies the most significantly correlating platforms metrics with service KPI's, based on the use of eight ranking algorithms with a reliability scoring mechanism. The eight algorithms implemented to date are a mixture of clustering and machine learning classification approaches.

4.2.3 Semantic Description and Symbolic Execution of RFBs

In 5G networks, network functions will be instantiated dynamically, and the network will run services configured not only by the operator, but also by third parties which open the door to many security risks. To enforce security in 5G networks SUPERFLUIDITY takes these directions; 1) Describe operator policies in a high-level specification language; 2) Describe RFBs in a way that is amenable to static analysis through the use of Symbolic Execution Function Language; 3) Perform static analysis of RFB configurations to ensure policy is obeyed before deployment using SymNet tool (SymNet can run reachability checks over network models by injecting symbolic packets and tracking their path through the network); 4) Ensure that the implementation conforms to the specification at deployment time. More details can be found in *Final report on Innovations & exploitation actions,* D8.8 [3].

4.3 5G-ENSURE

Security is top-of-mind for most 5G industry use cases, from automotive, high-tech manufacturing and financial services to utilities, healthcare and public safety. This is where 5G-ENSURE comes into play by driving the 5G security vision for 5G-PPP.

Key roles in this are:

- Security Architecture, a key to expanding the mobile ecosystem giving operators a platform for entirely new business opportunities;
- Security Enablers, which comes with open specifications (public and royalty free) enabling anyone interested to come up with their own implementation;
- Security Testbed, designed and set up to meet the requirements of the enablers against the threats identified by 5G-ENSURE through an extensive set of use cases.

TIM, now present in 5G-SOLUTIONS' consortium, was among the partners of 5G-ENSURE project.

4.3.1 5G Security Architecture

5G-ENSURE delivers a 5G reference security architecture with focus on a logical and functional architecture and omits (most) aspects related to physical/deployment architecture. This focus is motivated by general trends such as network de-perimetrization as well as 5G systems' strong dependency on software defined networking and virtualization in general. Specifically, the core of the 5G-ENSURE security architecture extends and revises the 3GPP security architecture from TS 33.401 [4] to integrate domain concepts derived from 3GPP TS 23.101 [5] to better support 5G trust models, going beyond "telecom" and "mobile broadband". Strata are used to characterize different functional aspects and security feature groups. Finally, they are also used to describe security objectives. More details can be found in Project Deliverable Deliverable D4.1 "5G Security testbed architecture" [6].

4.3.2 5G Security Enablers

Starting from additional use cases defined to illuminate 5G Security issues, 5G-ENSURE has advanced 5G Security Vision and initiated a Technical Roadmap on security enablers of major areas of concerns (namely AAA, Privacy, Trust, Security Monitoring and Network management and virtualization) as confirmed by Open Consultation ran publicly on 5G Security in 2016 with support of other projects. This Technical Roadmap on 5G Security was used to describe each of the enablers, on a per category basis, in terms of product vision as well as features offered and their scheduling over the two software releases planned within the project. Regarding 5G security enablers delivered by 5G-ENSURE, they come with open specifications for anyone interested to come up with their own implementation and are obviously linked to major building blocks of the 5G Security Architecture defined and to which they contribute. When 5G Security enablers software is released (either open source or closed source based on decision left to enabler owner) it comes with documentation (manuals) to integrate/deploy and also make use of them within the 5G Security testbed according to use terms and conditions that apply.

4.3.3 5G Security Testbed

The 5G testbed has been designed and set-up to satisfy the requirements of the 5G security enablers against the threats emerging from identified use cases. Launched in 2016 and based on three interconnected nodes provided by b<>com, VTT and Nokia, the testbed shows on a small scale what a 5G network could be like. It encompasses the following building blocks: (1) A cloud infrastructure providing computing, storage and network resources including Radio Access Networks, (2) An orchestrator to deploy and perform service chaining of Security Enablers and VNFs, the test bed offers a playground for identified use cases and (3) The testbed currently promotes a DevOps approach for 5G from development to Continuous Integration & Deployment. On-going work focuses on the integration of VNFs based on OpenAirInterface [7], making it a core asset of the project. With more than 30 users, 17 enablers as of today are available in catalogue.

4.4 5G-Crosshaul

The 5G-Crosshaul project aims at developing the next generation of 5G integrated backhaul and fronthaul networks enabling a flexible and software-defined reconfiguration of all networking elements in a multi-tenant and service-oriented unified management environment. The 5G-Crosshaul transport network envisioned will consist of high-capacity switches and heterogeneous transmission links (e.g., fibre or wireless optics, high-capacity copper, mmWave) interconnecting Remote Radio Heads, 5GPoAs (e.g., macro and Small Cells), cloud-processing units (mini data centres), and points-of-presence of the core networks of one or multiple service providers.

The key idea of the 5G-Crosshaul proposal is to move from a traditional transport network perspective to a novel architecture integrating both fronthaul and backhaul into the 5G-Crosshaul transport network. Figure 2 shows the physical infrastructure that 5G-Crosshaul is composed of, categorized into three differentiated layers. The bottom layer corresponds to the “Interconnection Plane” and shows the networking infrastructure, formed by heterogeneous links connecting the different elements of the planes located above.

CTTC and TIM, now present in 5G-SOLUTIONS’ consortium, were among the partners of 5G-Crosshaul project.

4.4.1 Main Concepts and Interconnection Plane

The “Interconnection Plane” makes use of **5G-Crosshaul Packet Forwarding Elements (XFE)** to **interconnect a broad set of novel technologies to create a packet-based network** that can meet the demands of 5G networks. The technologies, which have already been identified as relevant for the future of the backhauling, are represented in the figure too. They span from fibre optics to novel CPRI-over-packet technologies, also considering wireless links such as mmWave. The second plane (depicted in green in Figure 2) has been named “5G-Crosshaul General Processing Plane” and shows the different **5G-Crosshaul Processing Units (XPUs)** that carry out the bulk of the operations in the 5G-Crosshaul. The functionality provided by these XPUs is multi-faceted. It highly depends on the actual interconnection and must encompass functionality expected from the different elements in the 5G network (depicted in the uppermost layer of Figure 2. As an example, in (partially) centralized RAN implementations, the XPUs will host BBUs or MAC processors (thus enabling true Cloud RAN). Further, they might serve as end-points for services or even caches. The different functional distributions between 5GPoA and XPU relation and the different services that can be hosted in the XPUs are one of the pillars of the flexibility provided by the 5G-Crosshaul architecture. This is represented by the different connection options between the uppermost ("End-Point Plane") and the middle layer of Figure 2.

More details can be found in Project Deliverable D4.1, "Initial design of 5G-Crosshaul Applications and Algorithms" [8].

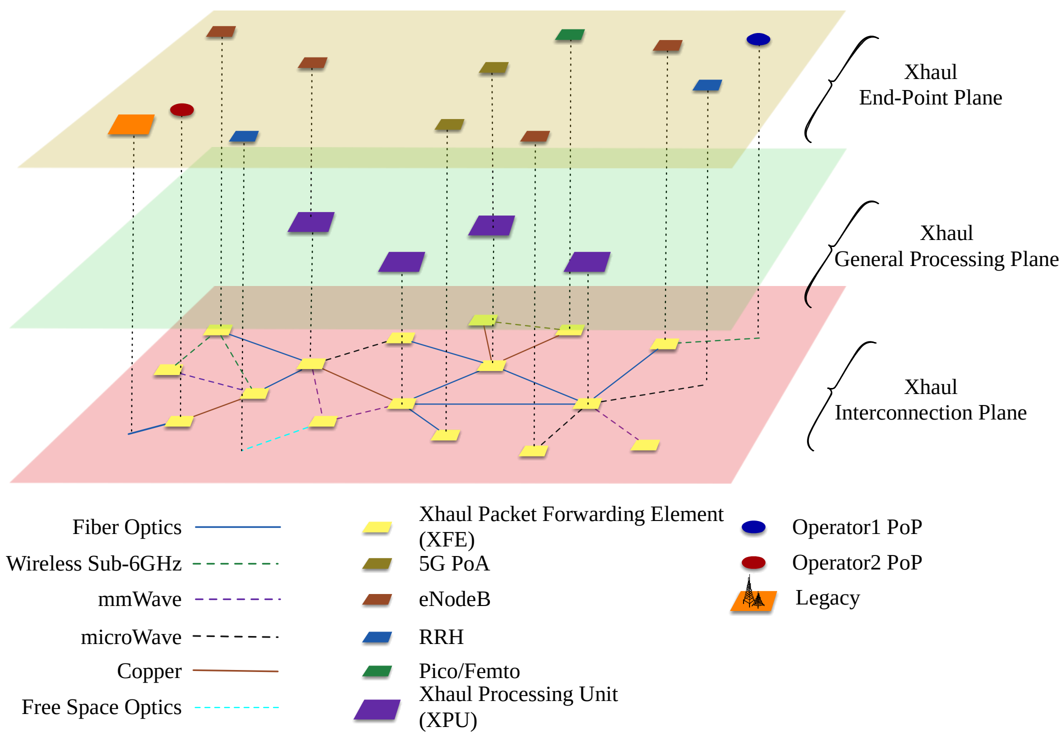

Figure 2: Physical Infrastructure of 5G-Crosshaul

4.4.2 5G-Crosshaul Control Infrastructure (XCI)

The idea is to develop a flexible frame format to allow the usage of fronthaul and backhaul on the same physical link to replace different technologies by a uniform transport technology for both fronthaul and backhaul. The result is a unified but versatile cross-technology frame format supporting all types of fronthaul (e.g., CPRI) and backhaul and their different demands on the type of payload, but also bandwidth, latency and synchronization.

Develop XCI by extending existing Software Defined Network (SDN) controllers to provide the services for novel Northbound (NBI) and Southbound (SBI) Interfaces and enable multi-tenancy support in trusted environments. Introduce new mechanisms to abstract the mobile transport network and aggregate measured contextual information.

Define interfaces to accelerate the integration of new physical technologies (SBI) and the introduction of new services (NBI) via novel or extended interfaces. In more details the work consists of:

- Specify an abstract network information model for 5G-Crosshaul technologies, including abstracted control parameters and system status metrics;

- Collect contextual information about traffic, congestion, interference of radio resources, and energy savings to provide applications (WP4) with a media-independent system status report of the heterogeneous network;
- Specify the set of southbound XCI actions (e.g., control the forwarding behaviour, configure radio parameters, deploy/migrate 5G-Crosshaul functions);
- Specify the set of northbound XCI actions (e.g., provisioning of new VPNs) to enable Service Level Agreement (SLA)-level reports, create new virtual 5G-Crosshaul slices for multi-tenancy support.

4.5 METIS II

Key objectives of METIS-II are to develop the overall 5G radio access network design and to provide the technical enablers needed for an efficient integration and use of the various 5G technologies and components currently developed. The innovation pillars that will allow METIS-II to achieve this goal are

- a holistic spectrum management architecture addressing the spectrum crunch;
- an air interface harmonisation framework enabling an efficient integration of new and legacy air interfaces;
- an agile Resource Management (RM) framework providing the dynamics required to efficiently adapt the integrated 5G air interfaces and radio concepts to the varying traffic demand and service requirements;
- a cross-layer and cross-air-interface system access and mobility framework ensuring an ubiquitous access continuum;
- a common control and user plane framework providing the means for an efficient support of the broad versatility of services expected for 5G as well as a future-proof and cost-efficient implementation of the 5G integration.

TIM, now present in 5G-SOLUTIONS' consortium, was among the partners of METIS II project.

4.5.1 Spectrum Investigations and Conclusions

METIS-II has analysed new ways to authorize use of spectrum, targeting more dynamic and local use of spectrum, adaptive spectrum resource management and the spectrum demand for its main use cases (xMBB, mMTC, Car2X, URLLC). A novel system concept for spectrum management and sharing as well as a holistic functional architecture has been designed, and enhanced by additional enablers (context awareness, QoS). The use of spectrum databases (similar to enhanced LSA) is foreseen, with interfaces to network and resource management.

Further details can be found in Project Deliverable D3.1 [9] and Project Deliverable D3.2 [10].

4.5.2 Overall Air Interface Design and Evaluation Framework

METIS-II has established an open visualization platform based on the 3D rendering engine Unity3D, which can be used to illustrate key 5G concepts and their performance and benefit to society in a detailed 3D model of a typical European urban centre. The platform is designed such that it allows for different forms of usage, from the visualization of pre-calculated simulation results, to the real-time interaction with simulation platforms, offering easy interfaces and forms of programming that allow other projects and individuals to use the platform at very reasonable effort.

4.5.3 Overall RAN Design

METIS-II has provided the design underlying the 5G air interface and the definition of a framework for the harmonization and integration of the different Air Interface Variants (AIVs) which can specialize on different services and do include LTE(-A). This integration happens at RAN level, it allows to re-use most network functions and it foresees a common RAN-CN interface. It has described the logical split between RAN and Core Network (CN) together with the interfacing options. This architecture is being complemented by a framework for agile resource management including functional, protocol and deployment perspectives.

4.6 FANTASTIC-5G

The intention of FANTASTIC-5G has been to develop, investigate and propose the air interface (AI) for 5G New Radio (NR) for the frequency region below 6 GHz. 5G NR will have to cope with a high degree of heterogeneity in terms of services, device classes, deployment types, environments and mobility levels. So, diverse and often contradicting KPIs need to be supported. To this end, the relevant technical AI components (at PHY, MAC and RRM) we have been identified, developed and evaluated. In addition, as depicted in Figure 3, they have been integrated into an overall AI framework where adaptation to the above described sources of heterogeneity can be accomplished.

CTTC and TIM, now present in 5G-SOLUTIONS' consortium, were among the partners of FANTASTIC-5G project.

4.6.1 New Waveforms Adapted for Service Coexistence Below 6 GHz

FANTASTIC-5G developed new waveforms that overcome the demerits of CP-OFDM (the 4G waveform) in terms of poor spectral containment, lack of robustness in highly asynchronous and high mobility scenarios, as well as inflexibility for the support of diverse numerology. This is obtained by applying two categories of filtering: subcarrier-wise filtered solutions and subband-wise filtered solutions. Common to all is the amelioration of spectral localization of the signal power, which improves the performance particularly for MMC, MCC and V2X services and ensures an efficient coexistence of these services with MBB service.

4.6.2 Non-scheduled Access for Massive MTC

The commercialization and deployment of 5G systems is driven by the need to support very high connection densities to make the Internet of Things serviceable. Massive connectivity is supported by new air interfaces that should optimize the available radio and infrastructure resources, spanning areas from protocol enhancements and radio resource management to waveform design. A new waveform design is proposed for asynchronous small packet transmissions in the uplink. Because of the superior spectral properties of certain waveforms, the need for tight temporal synchronization of users can be relaxed. This allows compressing or even avoiding broadcast messages, thus leading to energy and radio resource savings. In addition, new, "one-stage" access protocols are being developed, in which access notification and data delivery are performed in a single transaction by means of one or more consecutive packets or in a single transmission, thereby reducing signalling overhead for short messages.

Further details can be found in Project Deliverables D3.2 "Final report on the holistic link solution adaptation" [11] and D4.2 "Final results for the flexible 5G air interface multi-node/multi-antenna solution" [12].

4.6.3 Flexible Interference Mitigation for 5G below 6GHz – FDD & TDD

Interference is one of the most limiting factors in cellular wireless communications, especially at the cell edge. FANTASTIC-5G has investigated the statistical properties of inter-cell interference (e.g. DIR – dominant-interference-ratio) providing means to decide for the relevant dynamics of interference management/cancellation.

Furthermore, FANTASTIC-5G has developed a Framework for (massive) MIMO + CoMP in FDD/TDD downlink with hybrid beamforming. This framework makes MIMO system both efficient and effective and consists of 9 relevant techniques (e.g. 2-stage beamforming, multi-user treatment, coded CSI-RS, etc.). This framework is able to harvest on the promised gains (8-10 times higher gross spectral efficiency than LTE 8×8) while keeping overhead reasonable (5-10%). FANTASTIC-5G has investigated the ability of FQAM to shape intercell interference in an advantageous way.

Finally, FANTASTIC-5G has looked into 6 different intercell-interference coordination techniques and has identified the means required by the network and by the user equipment to implement those and has identified the required mechanisms to be included to the standard.

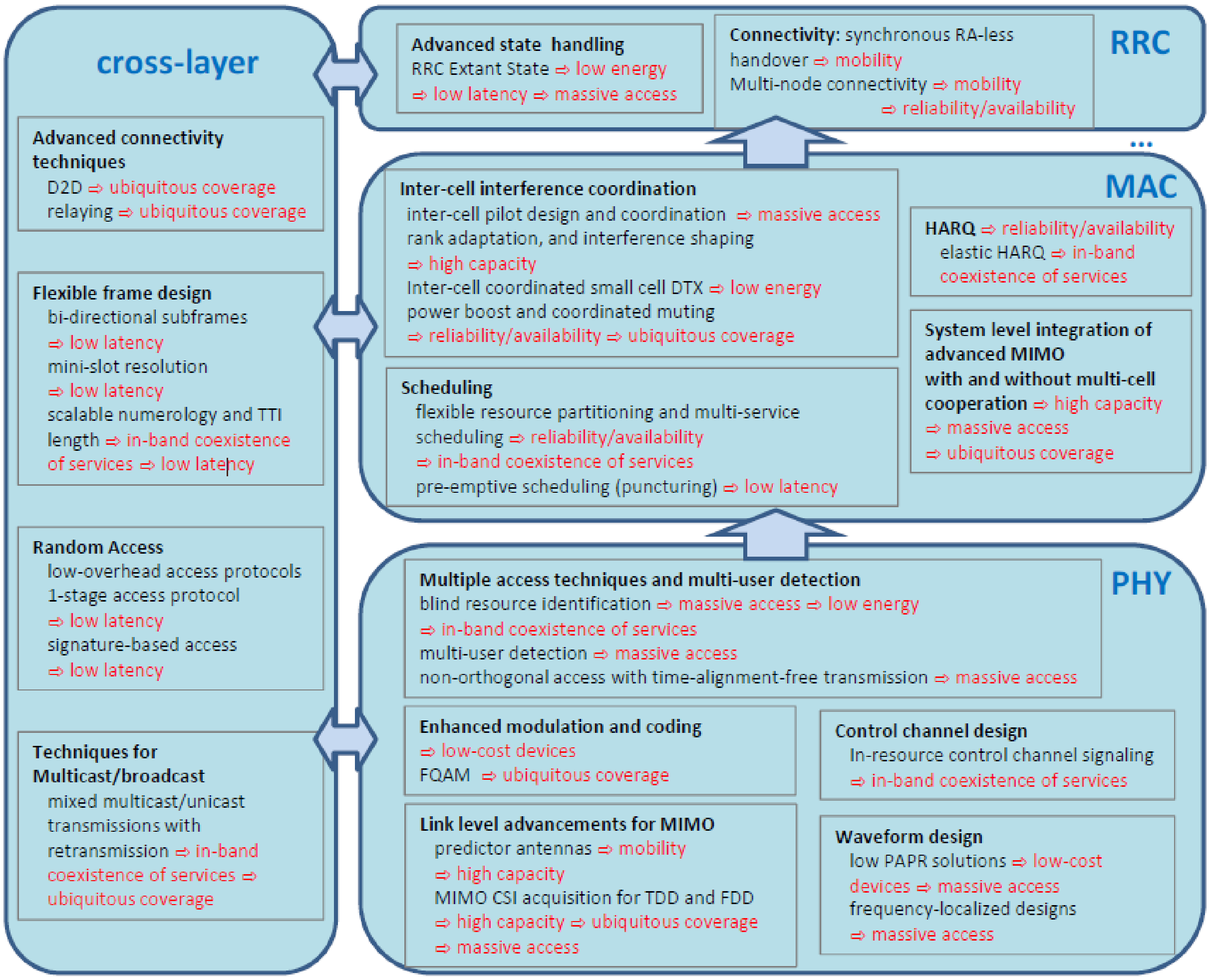

Figure 3: FANTASTC-5G Air Interface

In particular, FANTASTIC-5G:

- In terms of **flexibility, in-band co-existence of services** has developed techniques that enable the flexible operation of different service types, e.g.:
    - elastic HARQ,
    - flexible resource partitioning and scheduling,
    - flexible numerology,
    - in-resource control channels,
    - low-overhead access protocols,
    - broadcast/multicast integration.

  Some of these techniques were implemented and evaluated by system-level simulations. It was demonstrated that a multi-service air interface is feasible, but it requires a flexible design including different settings/configurations and component selections.

- In terms of **ubiquitous coverage and high capacity,** has developed and evaluated:
  - Massive MIMO is a main source of large capacity gains. It is therefore an essential component for 5G MBB use cases.
  - New access protocols, like the FANTASTIC-5G signature-based, 1-stage access, are enablers for future massive access use cases.
  - Flexible deployment of broadcast/multicast links with MBB unicast connections and retransmission is an enabler for new services.
  - Predictor antennas compensate for the channel ageing effect at high speed, enabling ubiquitous coverage and high capacity for vehicular use cases.
- In terms of **efficient energy and resource consumption, it** has contributed by developing and evaluating:
  - One-stage protocols which are more appropriate for low-power devices since they manage to minimize the total transmissions.
  - Advanced state handling schemes, requiring less measurements and messages, thus shorter awake periods.
- In terms of **future proofing,** it has demonstrated that the air interface is flexible enough to allow for inclusion of new use cases that will appear in the future. Every possible use case can be located within the triangle formed of the three services MBB (capacity challenge), MCC (reliability challenge, a.k.a. URLLC), and MMC (massive access and low-cost challenge, a.k.a. mMTC). FANTASTIC-5G has proposed a flexible design that is able to support these three main services and this makes it well prepared for future new use case, which are expected in vertical industries (e.g. V2X or "Industry 4.0").

4.7 Flex5Gware

Flex5Gware performed research to pin point specific implementation and prototyping challenges for key HW/SW building blocks in the form of proofs-of-concept (PoC). In addition, it was addressed the ability of these PoCs to provide versatile, flexible, reconfigurable, efficient operations for 5G HW/SW platforms. Accordingly, most of the performance improvement achieved by Flex5Gware in terms of increased capacity, reduced energy footprint, as well as scalability and modularity stems from experimental results extracted directly from the Flex5Gware PoCs. This constitutes a significant step towards the validation of the practical viability of 5G HW/SW platforms in comparison to other approaches where performance fulfilment is obtained primarily via simulations or analytical results.

CTTC and TIM, now present in 5G-SOLUTIONS' consortium, were among the partners of Flex5Gware project.

4.7.1 Full Duplex Transceiver

The full duplex technology developed in Flex5Gware provides gains in the user data rate of up to 50 % and in aggregated data rates (in a multiuser setting) of up to 21 %. Moreover, the main advantage of the work carried out in Flex5Gware with respect to prior art is that the proposed full duplex architecture is based on a conventional multiple-input multiple-output (MIMO) hardware architecture, which implies that no significant changes in the hardware will be required to endow MIMO transceivers with full duplex capabilities.

4.7.2 Multiband Base Stations < 6 GHz

Flex5Gware researchers have proposed an architecture design for the transceiver of medium range base stations that supports three radio bands together with a design of a multiband high-power amplifier with an output power of 53 dBm. The presented three-band transceiver solution considers radio bands defined for mobile communication (E-UTRA band 7 and 38 at 2.6 GHz and band 22 and 42 at 3.5 GHz) and one band between 2.7 and 2.9 GHz, which is in discussion to become available during the next years.

4.7.3 Dynamic HW/SW Function Split

Flex5Gware researchers have proposed a context-aware, cognitive and dynamic HW/SW partitioning algorithm for 5G network elements. This algorithm exploits knowledge (e.g. prediction of a hotspot) derived by network and sensor measurements and decides upon the HW or SW execution of functions in order to fulfil and maintain the application goals. The algorithm leads to high flexibility, performance and energy efficiency.

Further details can be found in Project Deliverable D4.2 "Final report on HW architectures" and Project Deliverable D6.2 "Proof of concept in Flex5Gware".

4.8 CogNet

CogNet project aims at making a major contribution towards autonomic management of telecoms network infrastructure through using the available network data and applying machine learning (ML) algorithms to yield insights, detect meaningful events and conditions and respond correctly to them.
Specifically, CogNet aims to develop solutions that will provide a higher and more intelligent level of monitoring and management of networks and applications, improve operational efficiencies and facilitate the requirements of the 5G.

NOKIA, IBM and WIT, now present in 5G-SOLUTIONS' consortium, were among the partners of CogNet project.

4.8.1 Policy Management Framework and Code Generator

CogNet's architecture leverages the NFV architectural framework of ETSI and adds machine learning capabilities. A data collector from the NFV/SDN-based environment gathers state and consumption records from hardware resources in real-time. The CogNet Smart Engine (CSE) processes these periodically or in (near) real-time, to generate insights or to recommend policies. Real-time analysis is a core contribution of our work. This is critical if 5G networks are to adapt quickly to changes in resource demand. The CSE also transmits scores/events to a policy engine which sends mitigating actions to the managed environment.

4.8.2 Process to Apply Machine Learning Models to Policies

To support autonomous network management, CogNet's work channels the MAPE-K autonomic loop: Monitor: information (metrics, topology, configuration parameters, etc.) is gathered from the managed system and its environment; Analyse: determine need for adaptation of managed system with respect to the adaptation goals; Plan: devise adaptation actions to achieve the system goals, with output sent to the Policy Engine; Execute: actions are executed to adapt the system as needed. Consequently, managed network resources, such as VNFs and NFVi, are adjusted though MANO and other controllers based on the recommended actions. The knowledge in the MAPE-K loop represents the knowledge shared among the monitoring, analysis, planning and execute parts. It comprises shared data, such as topology information, metrics, historical logs and policies.

4.8.3 CogNet Scenarios and KPIs

Challenges, use cases and scenarios within CogNet are presented in Figure 4. The initial work identified six use cases and eleven scenarios of CogNet based on the challenges of the future 5G network management, such as network resource utilization, network performance degradation, and energy efficiency. The final set of use cases explored in this project coincide with the initial set of use cases, and are presented in summary below:

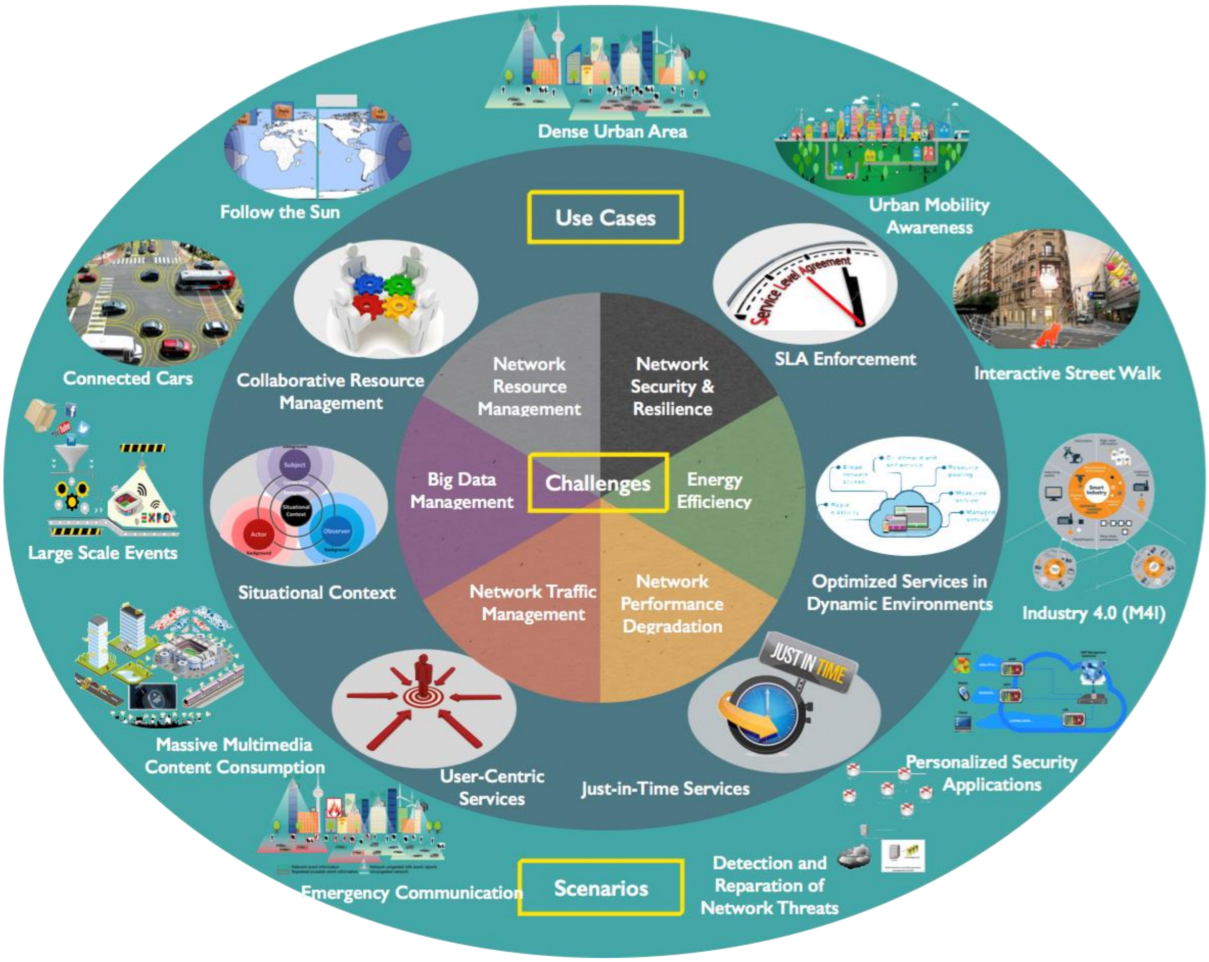

Figure 4: Initial set of CogNet challenges, use cases and scenarios.

1. Situational Context, presenting how the system will handle exceptional situations due to external environmental conditions which cannot be directly detected within telecommunication systems.
2. Just-in-time Services, referring to how cognitive network management techniques will enable the reduction of creation and deployment time for network services in 5G.
3. User-Centric Services, moving towards a richer and more complex service catalogue, with the capacity of tailoring services to the particular user's needs.
4. Optimized Services in Dynamic Environments: enabling the network to be deployed, scaled and migrated with ease and speed unheard of in today's networks, specifically by relying on the virtualization of the network functions.
5. SLA Enforcement, handling in an automated and efficient way the level of service guaranteed to a user or service by the network operator.
6. Collaborative Resource Management, where both the network and the applications at both endpoints exchange metadata about the network flows in order to improve network conditions and user experience.

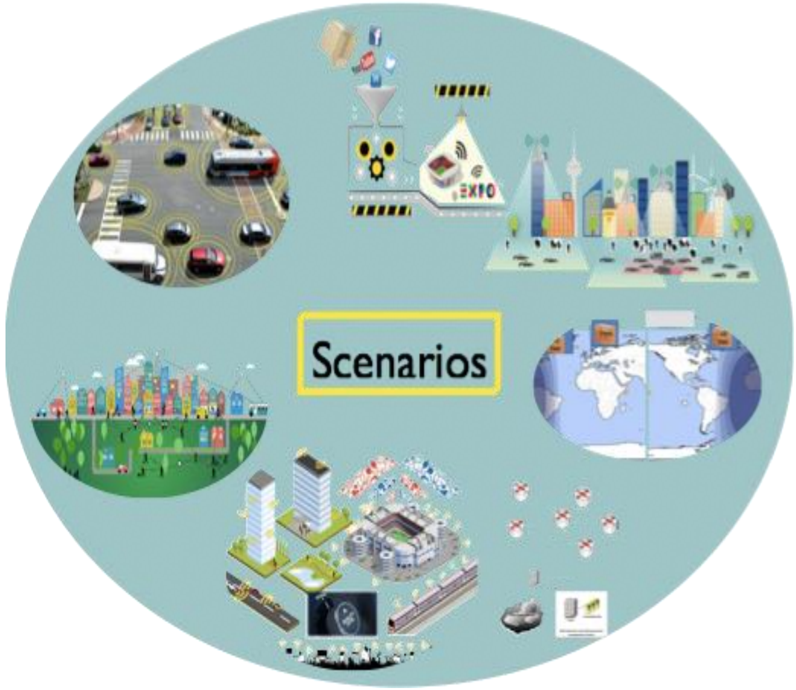

Figure 5: Final set of CogNet scenarios

CogNet initially introduced eleven scenarios pivoting around the above use cases in order to facilitate more specific research questions of high impact value in a real-life situation. Seven scenarios reached consensus for continuing work within them. These are depicted in Figure 5. The list of scenarios are as follows:

1. *Follow the Sun:* In the future 5G network, it is expected that the network management system will consider the time of the day when allocating resources to tasks. In particular, the system will consider the first wave of change, which considers typical daily patterns of resource usage. In this sense the resource provisioning will Follow the Sun to accommodate to the typically higher demand during the day for the network. Moreover, the system will further consider the second wave of change which consists of events that might affect the patterns of utilization for a period of time.
2. *Massive Multimedia Content Consumption:* Two-thirds of all internet traffic is video, and the number of smart, mobile devices in the world will double to two billion by 2017. This scenario will investigate how ML could aid by monitoring and predicting changing usage patterns and ensuring accurate resource provisioning in this complex setting.
3. *Dense Urban Area:* As it is expected that in 5G the massive number of devices connected to the network will require very different communication requirements, this scenario focuses on predicting potential congestions and determining the appropriate network adaptations operations.
4. *Urban Mobility Awareness:* This scenario focuses on assisting the users based on their location in an urban environment. It is expected that the load on the network will vary from one city region to another according to its functionality. It is very important to provide a prediction mechanism for the specific area in terms of expected subscribers; a new network density prediction mechanism has to be considered. Moreover, a second step is to investigate which are the most appropriate mitigation actions considering the specific area.
5. *Detection and Reparation of Network Threats:* In 5G, a large network of heterogeneous networks will connect many computers, mobile devices, household devices, cars, trains, industries, etc. However, their communication can be threatened and affected by malware like viruses and worms. A

management system is required for security issue detection and self-reparation in real time where ML can help to find out unusual and unwanted pattern (i.e., outliers).

6. *Large Scale Events:* This scenario proposes to additionally consider network-external data, e.g., social media data, to predict large irregular events that can potentially lead to increased traffic and impact the network performance.
7. *Connected Cars:* The transportation sector is one of the key sectors that is anticipated to benefit significantly from 5G. 5G will expand the connectivity possibilities of vehicles, which will impact not only infotainment services but also the safety of the vehicle. In particular, this scenario is related to the performance degradation detection and correction challenge. Machine Learning can be used to develop a better understanding of the vehicle mobility patterns and predict congestions that can affect to vehicles' connectivity.

Detailed list of the KPIs associated with the above scenarios and their value could be found on Deliverable 2.2 of CogNet project, "CogNet final requirements, scenarios and architecture" [15].

4.9 5G-XHaul

The overall 5G vision involves a converged heterogeneous network environment integrating a wide variety of network technologies for radio access with wireless and wired transport solutions interconnecting a huge number of vastly different end-devices and users, including compute and storage resources. These resources are called to support a combination of end-user and operational services, such as C-RAN, and the associated split options and can be hosted either by micro-Data Centres (DCs) referred to as Multi-Access Edge Computing (MEC), or at remote regional and central large scale DCs.

5G-XHaul proposes a converged optical-wireless 5G network infrastructure interconnecting computational resources (based on ETSI NFV) with fixed and mobile users, to support both operational network (C-RAN) and end-user services. The 5G-XHaul data plane considers an integrated optical and wireless network infrastructure for transport and access. The wireless domain comprises small cells complemented by macro cells. Backhauling can be supported through mmWave and Sub-6 wireless technologies or using a hybrid optical network platform combining both passive and active optical technologies. This platform can support demanding capacity and flexibility requirements for traffic aggregation and transport and, as such, a large variety of services envisaged for the 5G era.

CTTC, now present in 5G-SOLUTIONS' consortium, was among the partners of 5G-Xhaul project.

4.9.1 Unified SDN Control Plane for FH and BH

The objective of 5G-XHaul is to provide a single transport network infrastructure supporting both Fronthaul (FH) and Backhaul (BH) services under a unified SDN control plane. The technologies that were integrated included: Wavelength Division Multiplexing Passive Optical Network (WDM-PON) and the Time-Shared Optical Network (TSON) in the optical domain; to mmWave and Sub-6 technologies (BH and massive MIMO) in the wireless domain. SDN enabled 60 GHz and Sub-6 wireless nodes, connected through a fibre link up to the where the optical technologies and the C-RAN implementation using a Massive MIMO RU and a Baseband Unit (BBU) emulator are located.

Based on results shown in Project Deliverable 5.3 [16], FH and BH were all managed by a central SDN Controller, able to program forwarding paths (and backup paths using a Fast-Local Link Reroute agent, FLLR, developed within the project's WP3) across the city of Bristol leveraging multiple wireless technologies, and an optical/wireless backhaul.

5 Phase 2 Main Achievements

Partners in 5G-SOLUTIONS are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects. In this section are listed the main achievements of the Phase 1 Projects which involve consortium partners. An analysis of Phase 2 projects achievements is carried out, in order to identify results and assets for use in 5G-SOLUTIONS.

5.1 5G-XCAST

5G-Xcast is a 5G-PPP Phase 2 project focused on the design of multicast/broadcast capabilities for new 3GPP releases. Unicast has been the only mechanism in 5G-NR and 5GS to deliver content. Broadcast capabilities are only covered if using eMBMS based on 4G/LTE. From that perspective, 5G-Xcast has evaluated the main characteristics of eMBMS and FeMBMS targeting the provision of television services to massive audiences. From that point and once limitations have also been detected, a new design fully integrated in a 5G SA approach has been defined. The 5G-Xcast design covers the radio interface and RAN, the Core Network as well as a Converged Content Delivery Framework also including fixed and mobile networks.

IRT, LIVEU and TIM, now present in 5G-SOLUTIONS' consortium, were among the partners of 5G-XCAST project.

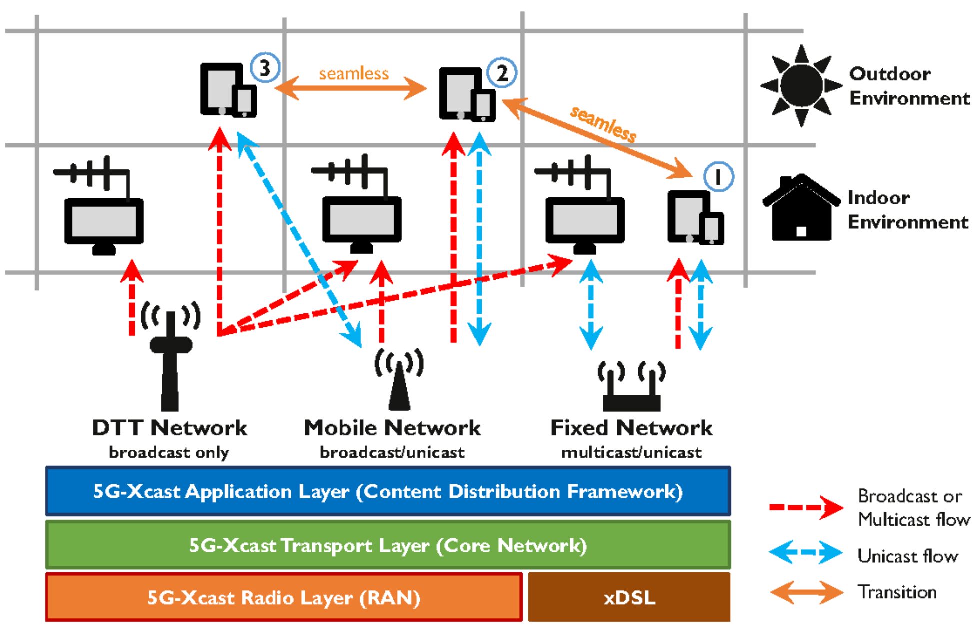

Figure 6: 5G-Xcast Content Delivery Framework including Fixed, Mobile and Terrestrial Broadcast Networks.

5.1.1 Content Delivery Network Evaluation for Multicast/Broadcast in 5G

After reviewing previous successful, and less successful attempts to enhance network technology for content delivery, 5G-Xcast has taken into account a dual approach to the problem with a content delivery framework for linear content exploiting multicast and broadcast as an internal network optimisation technology, rather than as a service to be sold in its own right, and, on top, a configuration method in order to enable the static and pre-determined delivery of TV/radio services with the Terrestrial Broadcast mode. The content delivery framework that we describe, shown in Figure 6, has minimal impact on Content Delivery Networks and Content Service Providers, which enables it to complement and exploit Internet media standards and common practice. The approach is extremely flexible, driven by content popularity, but also enabling a static allocation of network capacity to media channels.

More details can be found in Project Deliverable D5.2 “Key Technologies for the Content Distribution Network” [17].

5.1.2 Definition Converged Fixed-Mobile 5G Core Network with Multicast/Broadcast Capabilities

5G-Xcast has proposed architectural alternatives in 5G mobile core network to enable multicast/broadcast capabilities based on 5G architecture specified in 3GPP release 15. Different alternatives for converged fixed-mobile 5G core network with different convergence points applied for different deployment options were also proposed. 5G-Xcast has defined the point-to-multipoint PDU session and call flow that are aligned with the 3GPP specification in release 15. The call flow has also been extended and simplified for the provision of TV services to UEs which do not necessarily require uplink capabilities to access a particular TV service.

5.1.3 Definition 5G Point-to-Multipoint RAN

The design of a comprehensive and holistic 5G PTM RAN solution has been carried out in the 5G-XCast, to support the coexistence of PTM and point-to-point (PTP) transmissions and different PTM services with a variety of very diverse requirements. This was achieved by leveraging on the state-of-the-art point-to-multipoint (PTM) radio access network (RAN) technologies and on-going related work in different standardisation groups including 3GPP RAN.

Such design, in line with the 3GPP release 15 specifications, includes a cloud-RAN based multicast RAN architecture and interfaces, with flexible air interface configurations as well as PTM radio access technology protocols. With respect to the air interface, the design is based on a single-cell or multi-cell approach but with a careful design for the configuration of SFN modes in order to avoid complex architectures. The 5G-Xcast RAN also support the delivery of TV/radio services from a diverse set of Terrestrial Broadcast deployments including High Power High Tower and cellular networks.

5.2 5G-MONARCH

The focus of the 5G-MoNArch project has been on developing a flexible, adaptable, and programmable mobile network architecture for 5G. Inter-slice control and cross-domain management, experiment-driven modelling and optimisation, native cloud-enabled protocol stack are innovative enablers for the sliced network. The concepts and enablers have been brought into practice through prototype implementations in two testbeds instantiating slices that include the vertical use case-driven functional innovations of network reliability, resilience and security, and resource elasticity, respectively.

TIM, now present in 5G-SOLUTIONS’ consortium, was among the partners of 5G-MONARCH project.

5.2.1 Resource Elasticity

When setting up a slice without stringent service requirements, one of the key desired features will be that of elasticity; this is needed in all cases where resource overprovisioning is not a valid option either due to the actual resource availability (e.g., in the edge of the network) or to the dynamic nature of network load, which makes the efficient dimensioning of a network slice difficult. In those cases, temporal and spatial traffic fluctuations may require that the network dimensions resources such that, in case of peak demands, the network adapts its operation and re-distributes available resources as needed. We refer to this flexibility as resource elasticity, which includes the ability i) to scale resources according to the demand, and ii) to gracefully scale the network operation when insufficient resources are available.

The resource elasticity mechanisms studied in 5G-MoNArch are classified along three dimensions: (i) computational elasticity, (ii) orchestration-driven elasticity, and (iii) slice-aware elasticity. In the following, each of these dimensions and the mechanisms are further explained:

- *Computational Elasticity*: The goal of exploiting computational elasticity is to improve the utilisation efficiency of computational resources by adapting the NF behaviour to the available resources without impacting performance significantly. Furthermore, this dimension of elasticity addresses the notion of computational outage, which implies that NFs may not have sufficient resources to perform their tasks within a given time. To overcome computational outages, one potential solution is to design NFs that can gracefully adjust the amount of computational resources consumed while keeping the highest possible level of performance. RAN functions, in particular, have been typically designed to be robust only against shortages on communication resources; hence, the target should be directed at making RAN functions also robust to computational shortages by adapting their operation to the available computational resources. An example is a function that chooses to execute a less resource-demanding decoding algorithm or number of iterations in case of resource outages, admitting a certain performance loss.
- *Orchestration-driven Elasticity*: the orchestration-driven elasticity focuses on the ability to re-allocate NFs within the heterogeneous cloud resources located both at the central and edge clouds, considering service requirements, the current network state, and implementing preventive measures to avoid bottlenecks.

  The algorithms that implement orchestration-driven elasticity need to cope with the local shortage of computational resources by moving some of the NFs to other cloud servers which are momentarily lightly loaded. This is particularly relevant for the edge cloud, where computational resources are typically more limited and more cost efficient than in the central cloud.

  Similarly, NFs with tight latency requirements should be moved towards the edge by offloading other elastic NFs without such tight timescale constraints to the central cloud servers. To efficiently implement such functionalities, special attention needs to be paid to: (i) the trade-off between central and edge clouds and the impact of choosing one location for a given function, and (ii) the coexistence of MEC and RAN functions in the edge cloud.

  This may imply scaling the edge cloud based on the available resources, clustering and joining resources from different locations, shifting the operating point of the network depending on the requirements, and/or adding or removing edge nodes. Also, important, are the resources available on the network interfaces e.g. backhaul links or network segments connecting edge and central cloud servers especially in the live setup of the testbed where the traffic shares public network resources.

- *Slice-aware Elasticity*: Finally, this slice-aware elasticity addresses the ability to serve multiple slices over the same physical resources while optimising the allocation of computational resources to each slice based on its requirements and demands, a challenge earlier referred to as E2E cross-slice optimisation. Offering slice-aware elastic resource management facilitates the reduction of CAPEX and OPEX by exploiting statistical multiplexing gains. Indeed, due to load fluctuations that characterise each slice, the same set of physical resources can be used to simultaneously serve multiple slices. Adaptive mechanisms that exploit multiplexing across different slices must be designed, aiming at satisfying the slice resource demands while reducing the amount of resources required. Hence, the solutions must necessarily dynamically share computational and communications resources among slices whenever needed.

Further details are available in D4.1 “Architecture and mechanisms for resource elasticity provisioning” [18] and D4.2 “Final design and evaluation of resource elastic functions” [19].

5.2.2 Cloud-aware Protocol Stack

The aim is to provide the flexibility to shift NFs to nodes (Virtual Machines) that better fit the specific requirements of each service. As a result, NFs traditionally co-located in the same node may now be placed in

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different nodes. However, for traditional protocol stacks, placing certain NFs with heavy inter-dependencies in different nodes may incur considerable overheads or may simply be impossible. This may compromise the overall gains obtained from the flexible function allocation. To overcome this problem, one of the key innovations needed to fully leverage the benefits of the flexible function decomposition and allocation is the redesign of the protocol stack, which we call the cloud-aware protocol stack. The aim is to relax and (as much as possible) remove the logical and temporal dependencies between NFs, with the goal of providing a higher flexibility in their placement.

The approach described in above provides several advantages, as it allows heterogeneous deployments for different services (i.e., mMTC and eMBB), which are tailored to their specific requirements. For example, depending on the latency, bandwidth, and/or computational requirements of the service, it may be better to locate certain VNF towards the edge of the cloud rather than in a central location. How to place VNF across the cloud is a network orchestration problem, which is constrained by the split into modules described above. However, this typical NF decomposition for the RAN protocol stack was not designed for its cloudification, and therefore the potential gains are limited. This issue is discussed in more detail in the following. Also, the deployment of VNF in computational resources constrained environments, such as edge clouds, takes advantage of this enabler.

One key assumption of network stack designs is that certain functions are implemented in the same physical space, e.g., within the same chip (maybe on a different chip, but surely on the same HW). So, non-ideal links with non-negligible delays are a problem for physical network elements that need to be decomposed into several NFs. Interfaces among them, thus, were designed considering communication links spanning some microns of silicon, and not several miles of fibre as in the case of, e.g., C-RAN.

In this way, the possible inter-dependencies between these functions are overlooked, as the delivery of information between them is practically immediate. However, as argued above, to fully benefit from a network-wide orchestration of a cloudified stack, VNF should support their execution on different nodes. From this perspective, enabling telco-cloud aware protocol stack means to design specific interfaces that gather the resource utilisation of a given function at any time.

That is, through the controllers for RAN functions, the MANO shall be able to get precise information about the resource utilisation of each VNFs running in a specific container / VM. Information such as memory utilisation or CPU utilisation, possibly broken down into specific function utilisation (i.e., encoding or decoding functions). Also, the amount of available resources shall be communicated to the VNF itself, through system parameters that are configured by the controllers or the Element Manager of the VNFs.

5.2.3 Telco-Cloud Resilience and RAN Reliability

The term resilience refers to the ability of the network to provide an uninterrupted service, as well as to maintain its normal operation even during and after network malfunctions. Indeed, 5G shall be able to support services which ensure that the desired performance is attained for nearly 100% of operation time. The most common example is that of mission-critical services in industrial environments, where any deviation from normal network operation would result in high costs for the industry, e.g., due to an increased number of defective products, or production outages. From the network management perspective, meeting the requirements of resilient slices entails a different design methodology, comprising two fundamental elements: i) VNFs within resilient slices must be always available, and ii) resilient performance is not degradable. To ensure that resilience as an E2E concept is not subject to bottlenecks, different mechanisms are applied to distinct network domains, thereby affecting different groups of NFs, and referenced as RAN reliability and telco-cloud resilience.

Ensuring high RAN reliability is a challenging task, especially for certain use cases such as high-mobility scenarios. Reliability in RAN refers to the success probability of transmitting a certain packet to its destination within a given delay requirement. To improve RAN reliability, the two following approaches have been studied in 5G-MoNArch:

- *Multi-connectivity*: this approach uses data duplication, where the same packets are transmitted multiple times to minimise the probability of erroneous reception. A mobile terminal is connected to two macro-cell base stations and data is duplicated along both paths. Hence, this approach represents a specific case of macro-diversity using a distributed antenna system. Besides increasing the link reliability, the approach also reduces the service interruption during handover caused by the time to trigger (TTT) as well as the necessary re-connection to the target cell. Therefore, a handover in 3GPP Long Term Evolution (LTE) implies an interruption of few 10 ms, which is supposed to be reduced to less than 1 ms in the envisioned implementation. This will allow guaranteeing that no packets are lost even during handover.
- *Network coding*: this approach is a technique with high potential in improving the performance and throughput of networks. In traditional networks, signals from different nodes are treated separately, and the intermediate nodes within the network are only allowed to perform routing operations, i.e., the intermediate nodes forward their received signals to their destinations without performing any kind of processing. It could be shown that for certain networks the performance can be improved if the intermediate nodes are allowed to perform operations, where they combine their received packets and forward these combinations to their destinations, where they are decoded. Depending on the application as well as the requirements involved, this improvement in the performance can be converted into gains in terms of transmission rate, reliability, as well as transmission power.

5.3 NGPaaS

NGPaaS will 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.

In this respect, NGPaaS provides a new ecosystem and value chain and the opportunity for all players within it to collaborate and develop new business models they can each benefit from:

- **Mobile Network Operators (MNOs)**: can rapidly deploy new services for consumer and enterprise business segments which can help them differentiate their service portfolio, could increase their revenue by charging based on the virtualized resource usage (storage, network bandwidth, CPU, etc.) thanks to the new OSS model defined in NGPaaS.
- **Telecom Vendors**: can easily deal with a large number of target production systems and can deliver an update or new release of its VNFs or components in a short time and benefit from any anomaly detection in real time. It allows also to position the telecom vendors in a market with a high potential of growth where large parts of the current VNF functionality are shifting to the platform layer, which is thus gaining in importance.
- **Vertical/IoT industries**: have the chance to assess the effectiveness of 5G solutions designed to meet their requirements, and thus affect the development of 5G products tailored to their needs.
- **IT companies**: it is likely the network softwarisation will force IT companies to embrace a bigger role as software and application providers.
- **Software and application providers**: can serve the new ecosystem by developing and bringing to the market innovative services and network applications that can take advantage of the information on 5G network capabilities and conditions available at each node.

NOKIA, now present in 5G-SOLUTIONS' consortium, was among the partners of NGPaaS project.

5.3.1 5G Platform-based Built-to-order Design

To ensure maximal flexibility and meet the business and technical requirements of the different 5G use-cases, NGPaaS adopts the cloud native principles based on service-based architecture and a new modelling based on Reusable Function Block, to abstract, decompose and deploy the different PaaSes (e.g. CORD, Kubernetes, Swarm, PaaS based MANO). These latter are customized to the needs and the requirements for the supported services. Three typical use-cases are selected to be prototyped and deployed in a Paris-Saclay Pilot demonstrating a sub-set of features developed in the project like the telco-grade Kubernetes, Monitoring as a service, new OSS design etc.

5.3.2 Dev-for-Operations Model

For optimal collaboration in multi-organisational context, NGPaaS project is emphasizing the vision that 5G should be considered as a platform where many players can interact (FOSS, Third party, Vertical, Vendors, Operators). The new Dev-for-Operations model has been provided in NGPaaS. This model enhances the well-known DevOps paradigm commonly used in the IT industries making it possible to use an analogous approach in a telco-grade environment. The inner components into the Dev-for-Operations layer are grouped in three different frameworks: Monitoring, Management and CBTR (Coding, Building, Testing and Releasing). The different interfaces between that Dev-for-Operations layer and other elements in the NGPaaS architecture are provided. In addition, a typical Dev-for-Operations workflow considering different sides (vertical, vendors and the NGPaaS platform itself) is well defined.

5.3.3 Carrier-grade Orchestration and Accelerated Microservices

A set of new features of orchestration and acceleration are implemented to meet the requirements of carrier-grade microservices. Several telco grade enhancements are achieved to meet data-plane-intensive telco workload or VNFs (support of NUMA-aware CPU pinning, huge pages, DPDK and SR-IOV). The one-network-interface-per-pod limitation of the native Kubernetes network model is also addressed together with the support of the SCTP protocol that is required for the interconnection between access and core mobile networks. Besides that, the support of acceleration (e.g. FPGA) in the microservice platform is provided. In order to validate the FPGA cloud acceleration layers, a Docker plugin and a Kubernetes device plugin working on Amazon/F1 cloud have been developed enabling FPGA offloading dynamic deployment.

Further details can be found in Project Deliverable D4.1 “Telco-grade PaaS: First Results and Implementation” [20].

5.4 5G-PICTURE

5G-PICTURE designs and develops 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 adopts the novel concept of Disaggregated-Radio Access Networks (DA-RANs), allowing any service to flexibly mix-and-match and use compute, storage and network resources through HW programmability. It also relies 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.

TIM, now present in 5G-SOLUTIONS’ consortium, was among the partners of 5G-PICTURE project.

5.4.1 5G Transport Networks (FH/BH) Featuring a Disaggregated and Programmable Data Plane

5G-PICTURE advocates for an integration of heterogeneous solutions in support of joint backhaul (BH) and fronthaul (FH) services. The disaggregated and programmable data plane comprises Open Packet Processors (OPPs), Wireless transport solutions – millimetre wave (mmWave) and massive MIMO, Optical Networks – passive (Passive Optical Network – PON) and active (Time Shared Optical Network – TSON) – as well as Ethernet solutions (Flex-E). These solutions have been investigated and are being extended to more efficiently support the demanding requirements of transport in converged FH and BH environments. The resulting transport network is integrated with centralised – data centres (DCs) – and edge compute (MEC) resources adopting a hybrid model combining both general and specific purpose processors. The 5G-PICTURE transport network will be able to dynamically and efficiently support flexible functional split options, to allow a Distributed Unit (DU) and a Centralized Unit (CU) to dynamically negotiate the RAN functional split to be used under specific network conditions. An improved portability of the hardware (HW) programming languages via the specification and design of language/target-independent "intermediate representations". Physical and Virtual Functions, including support of the RAN protocol stack, virtualisation and synchronisation, have been discussed in the project, resulting in the implementation of RAN functional splits executed on programmable x86 HW, based on the OAI framework, including 3GPP splits 8, 7-1, and 6. The project also provided control plane aspects to achieve synchronisation as a service as well as specific synchronisation functions covering specific network technologies, e.g. 802.11ad mmWave and Sub-6.

The 5G-PICTURE revolution is the paradigm shift, from RAN and C-RAN to "Dis-Aggregated RAN" (DA-RAN). DA-RAN is a novel concept where hardware (HW) and software (SW) components are disaggregated across the wireless, optical and compute/storage domains. "Resource disaggregation" allows decoupling these components, creating a common "pool of resources" that can be independently selected and allocated on demand to compose any infrastructure service. Key enablers for DA-RAN are:

1. Network "softwarisation", migrating from the conventional closed networking model to an open reference platform, supported through HW programmability, as described in the following point.
2. HW programmability, where HW is configured directly by network functions, to provide the required performance. This will enable provisioning of any service by flexibly mixing-and-matching network, compute and storage resources without sacrificing performance and efficiency as is the case in today's NFV-based solutions.

The 5G-PICTURE solution enables the overall 5G vision, supporting any service, including operational and end-user services for both Information and Communications Technology (ICT) and "vertical" industries.

Given the heterogeneous compute and network infrastructure envisioned in future 5G networks, 5GPICTURE investigates and experimentally demonstrate optimal 5G functional splits for different types of infrastructure (compute and network). It will also demonstrate the concept of flexible RAN functional splits that are "adaptive" RAN implementations requiring platforms able to instantiate more than one functional split. Flexible RAN functional splits are an enabler for slicing.

Furthermore, realizing that nowadays synchronisation protocols are based on packet round trip time measurements that are subject to congestion, especially in the wireless BH, 5G-PICTURE investigates novel approaches, including the PHY layer, to deliver high accuracy synchronisation to heterogeneous wireless/optical/packet domains.

More details can be found in 5G-PICTURE D6.1 "Specification of Vertical Use cases and Experimentation plan" [21].

5.4.2 E2E Orchestration, Network Softwarisation and Programmability integrating SDN and NFV technologies

5G-PICTURE proposes the 5G Operating System (OS) to abstract the complexities of the underlying 5G infrastructure and to provide the common functionalities required for efficient and flexible service and slice management and orchestration. The components of the 5G OS are organised in a hierarchical manner, propagating service and slice management requests towards the actual infrastructure. Services are described in the context of network slices, formed from connectivity and network functions, running over heterogeneous networks divided into one or more domains (technology-based or administrative). Some important interfaces in the 5G OS are those between Orchestrator – Controller and Controller – MANO. Control and orchestration of resources is implemented through flexible service chaining. Simulation results showing the scalability of the adaptable, hierarchical design of 5G OS have been presented. The feasibility and benefits of defining and orchestrating services with a flexible structure are investigated. Each component is a virtual or programmable physical NF, provided in multiple SW versions, optimised for running on different HW platforms, e.g., a low-cost VM-based network function and a high-performance FPGA-accelerated function.

The main result of this sophisticated control is to implement tenant-based virtual networks delivery, usually managed through a dedicated SDN controller service. Its north-bound APIs allow authorized tenants to request and operate their own network instances following abstract specifications, e.g., based on intent-based network models. Access to virtual resources is wrapped by the SDN controller and it is regulated at the north bound APIs based on tenants' profiles. Physical resource partitioning is managed within the SDN controller service through resource allocation algorithms combined with procedures to map logical network concepts with their corresponding entities or traffic configurations at the physical level. Traffic separation is achieved through the creation of tagged connections.

In the example depicted in Figure 7 the SDN controller is implemented using OpenDayLight, specifically for virtual tenant network [22], while for the southbound interfaces for controlling the devices OpenFlow is adopted.

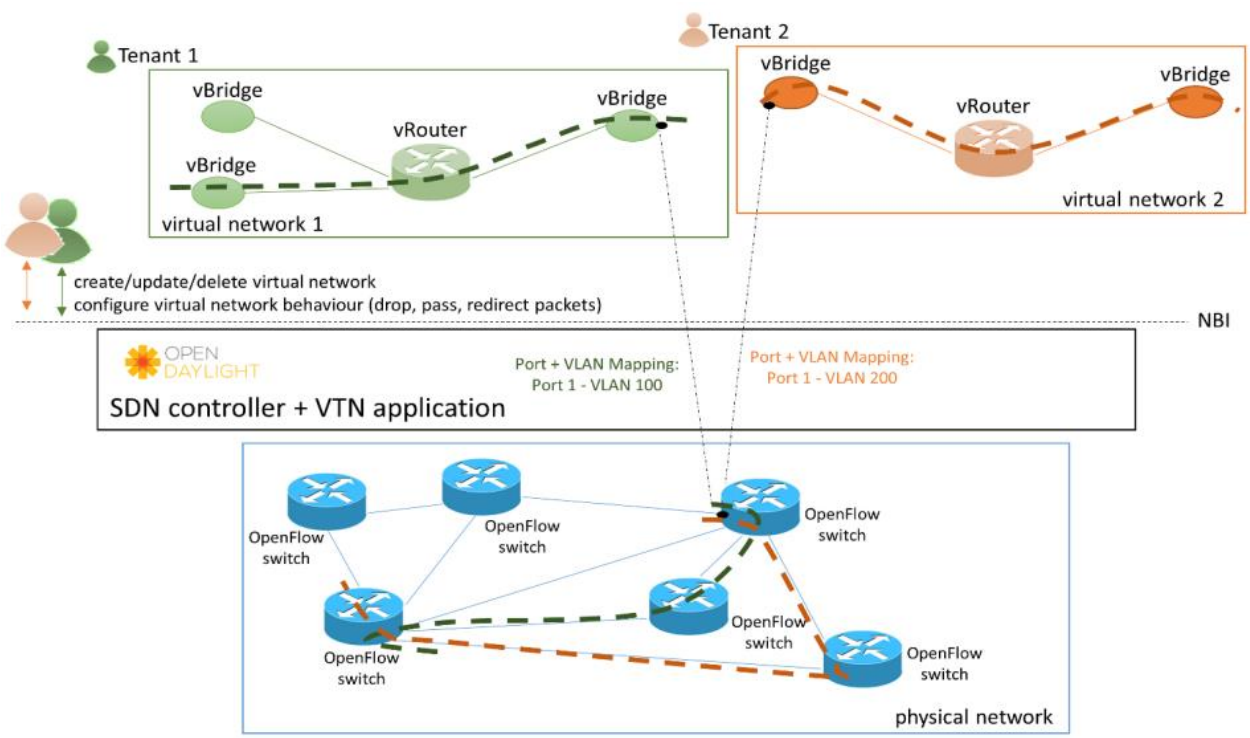

Figure 7: Control plane implementing network slicing

5.4.3 Open 5G Infrastructure Capable of Instantiating and Co-hosting Different Vertical Sectors

5G-PICTURE focuses on use cases involving railway, smart-city, and mega events. The detailed specifications of all the use case scenarios have been provided and documented in deliverable D6.1 [1]. These use cases are built up in terms of new equipment to be deployed in the current infrastructures, test scenarios and services to be executed, and a detailed time plan until the finalisation of the project (February 2020).

The 5G-PICTURE solution enables the overall 5G vision, supporting any service, including operational and end-user services for both ICT and “vertical" industries. Proof of concept demonstrators will be showcased in realistic environments including:

1. 5G-railway testbed located in Barcelona, Spain comprising three tracks covering scenarios with the rolling stock. This will be the first 5G railway experimental testbed to showcase support of seamless service provisioning and mobility management in high speed moving environments;
2. 5G-stadium testbed located in Bristol, UK to address scenarios with increased density and static-to-low mobility. In this environment media services associated with large venues will be demonstrated;
3. 5G-smart city testbed to experimentally validate the DA-RAN concept through the support of joint BH and FH services. This test-bed will be supported and hosted by the state-of-the-art 5G “City of Bristol” network infrastructure (BIO).

5.5 METRO-HAUL

METRO-HAUL involves the design and development of a novel, spectrally efficient and adaptive network solution, using dynamic elastic optical networking, including both transparent and flexible optical switching and adaptive transmission. METRO-HAUL will address the granularity mismatch between the wireless access and the optical metro domain via a new edge node design (Figure 8), and achieved through dynamic optical bandwidth allocation. This will provide metro support for increased volume of services with reduced cost and energy consumption.

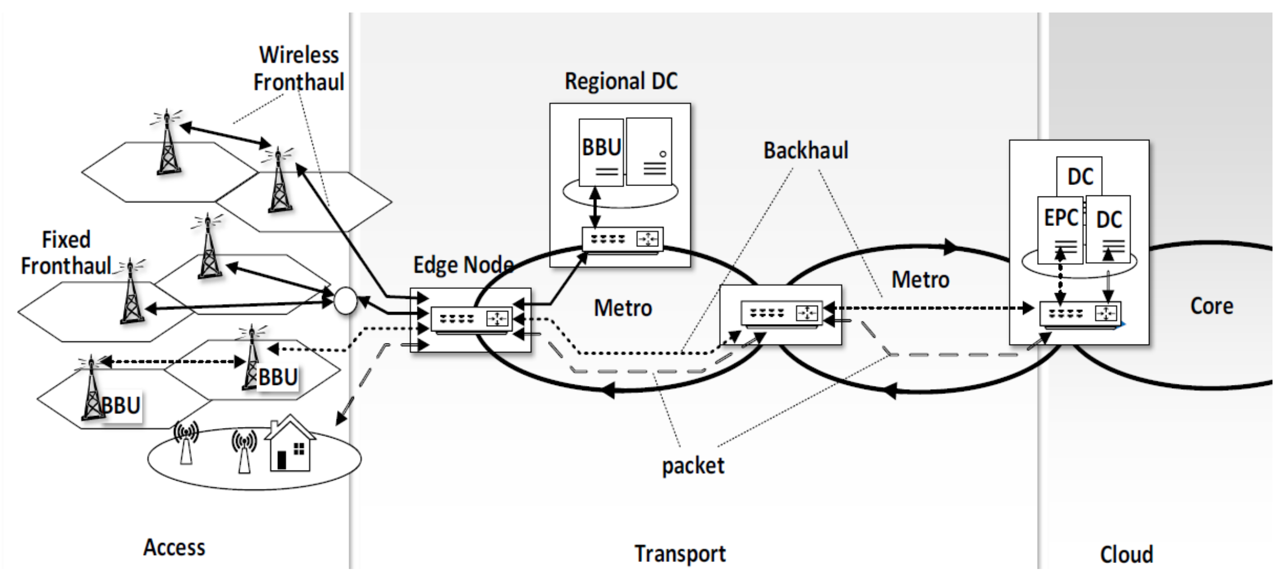

Figure 8: Metro Network Supporting RANs, with distributed DC and virtualized / pooled BBUs and EPC

To support the required dynamicity and flexibility, the METRO-HAUL architecture will be developed to integrate a wide range of optical technologies. These will be controlled using automation schemes and programmability features that will enable concepts such as HW disaggregation and virtualization, the coordination of which will be supported by a purposely designed control plane. Optical nodes will be dynamically adapted to the needs of specific services, optimally exploiting the data plane through use of relevant data monitoring and analysis schemes.

The control plane will be also responsible for the provisioning of 5G and vertical industry services that require the allocation of heterogeneous compute, storage and networking resources and ensure the required end-to-end QoS and QoE levels for each application. The METRO-HAUL control plane will leverage on the well-established SDN and NFV paradigms and exploit the benefits of a unified system, coordinating networking, computing, storage, transmission, and switching aspects, enabling abstraction at different levels.

Through the combination of improved, elastic-based optical techniques and intelligent, dynamic management of 5G applications, METRO-HAUL will support more than 100x times the capacity of current metro networks.

METRO-HAUL will perform PoC demonstrations to illustrate its network solution, metro node prototypes, novel optical transmission technologies and associated control plane / orchestration software. Detailed performance evaluation of both data and control planes will be carried out. The final project demonstrations will also involve the demonstration of real 5G and vertical services across the METRO-HAUL test-bed. Finally, the project will actively participate in the relevant standardization bodies to promote METRO-HAUL solutions to the wider community. Furthermore, the Project designed and implemented an augmented SDN/NFV control framework and architecture specially adapted for METRO-HAUL and enabling the dynamic deployment of 5G services (i.e. the operation of both end-user and corporate-oriented services). These services have requirements for resources (processing, storage and networking) that change over time considering aspects of the service life-cycle and variations in usage; the architecture will inherently support multi-tenancy, network virtualization, and slicing.

CTTC and TIM, now present in 5G-SOLUTIONS' consortium, were among the partners of METRO-HAUL project.

5.5.1 High Capacity & Flexible Metro Optical Network with Edge Computing

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

More details can be found in Project Deliverable D3.1 “Selection of metro node architectures and optical technology options” [23].

5.5.2 Real-Time Performance Monitoring & Analytics

Telemetry/monitoring framework which provides a global, real-time view of the E2E network performance. This new technology enables services configuration and reliable operation. It provides pro-active actions on early detection of issues. Machine-Learning within the decision engine allows this new Metro-Haul technology to continually learn and improve as real network data is collected. It includes state-of-the-art advanced planning, placement and re-optimization/re-configuration tools, enabling holistic (joint) optimization across heterogeneous resources.

5.5.3 Open Multi-Layer Disaggregated Network

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

5.6 5G TRANSFORMER

5G-TRANSFORMER is a 5G PPP Phase2 project that addresses the transformation of today's rigid mobile transport networks into an SDN/NFV-based 5G Mobile Transport and Computing Platform (MTP) supporting the specific needs of vertical industries. Current considered verticals in 5G-TRANSFORMER are automotive, eHealth, media & entertainment, cloud robotics and mobile virtual network operators (MVNO). In order to do so, 5G-TRANSFORMER proposes a novel architecture aligned with ETSI NFV Interface and Information Model Specifications (IFA) that defines four main building blocks: the Vertical Slicer (5GT-VS) as the vertical front-end and the common entry point for all verticals, the Service Orchestrator (5GT-SO) as the E2E service orchestration platform, the Mobile Transport and Computing Platform (5GT-MTP) as the underlying unified transport stratum for integrated fronthaul and backhaul networks, and the Monitoring platform (5GT-MON) in charge of service and performance monitoring. The key technical solutions are (1) Network Slicing to enable the provisioning and managing slices tailored to the needs of different verticals; and (2) the aggregation and federation of transport networking and computing fabric, from the edge all the way to the core and cloud using efficient contextual Virtual Network Function placement algorithms for dynamic deployment of multi-site network services while satisfying the specific demanding requirements of vertical industries.

CTTC, now present in 5G-SOLUTIONS' consortium, was among the partners of 5G-TRANSFORMER project.

5.6.1 Mobile Transport and Computing Platform

Mobile Transport and Computing Platform (5GT-MTP) to manage the underlying infrastructure of the 5G Integrated Transport Networks (FH/BH). Its functional architecture design is reported and the initial software implementation of the MTP platform is released and published as open source on GitHub: (1) Integration of heterogeneous wireless, optical and Ethernet solutions in support of joint BH and FH services, (2) Integration of transport network with centralised (DCs) and edge compute (MEC) resources, (3) Design APIs and abstractions of the infrastructure resources including networking and computing resources and (4) Cross-optimization of radio, transport and computation resources to provide efficient support for network slicing.

5.6.2 Service Orchestrator

Service orchestrator (5GT-SO) as the E2E service orchestration platform, offering orchestration of services and resources in Single and Multi-domain 5G Virtualized Networks through dynamic function placement and service chaining. Its functional architecture design is reported in Project Deliverable D4.1 [24], the initial software implementation of the service orchestrator platform is published as open source: (1) End-to-End (E2E) service orchestration along with service life-cycle management across one or multiple administrative domains (federation) and (2) Service-aware monitoring platform in charge of producing monitoring reports related to the performance or failure events associated to the managed services.

5.6.3 Vertical Slicer

Vertical Slicer (5GT-VS) as the vertical front-end and the common entry point for all verticals. The initial software implementation of the vertical slicer platform is published as open source on GitHub: (1) Offering vertical services through a high-level northbound interface to define vertical services requests and SLAs, providing a catalogue of vertical service blueprints (VSB), based on which the vertical service requests are generated by the vertical and described as vertical service descriptors (VSD), (2) Mapping vertical services to network slices and use of network service descriptors (ETSI NFV NSD) as network slice template and (3) Arbitration among vertical service instances based on their priority and resource budget.

5.7 5G-Tango

5GTANGO is a 5GPPP Phase 2 Innovation Action that enables the flexible programmability of 5G networks with:

1. an NFV-enabled Service Development Kit (SDK);
2. a Store platform with advanced validation and verification mechanisms for VNFs/Network Services qualification (including 3rd party contributions) and,
3. a modular Service Platform with an innovative orchestrator in order to bridge the gap between business needs and network operational management systems.

5GTANGO proposes an integrated vendor-independent platform applied to the three pilot scenarios where the outcome of the SDK (i.e., service packages), are automatically tested in the Verification and Validation (V&V) platform and stored in the Catalogue for their posterior deployment with the Service Platform. 5GTANGO system consists of three vertical pilots: advanced Manufacturing, immersive Media, and real time Communications.

CTTC and NURO, now present in 5G-SOLUTIONS' consortium, were among the partners of 5G-TANGO project.

5.7.1 Agile Service Orchestration Platform

The 5GTANGO project increases agility in network service management and orchestration by providing a service platform which is highly modular and supports multiple providers and infrastructures. 5GTANGO extends the service platform developed in the 5G-PPP phase 1 project SONATA with support for Service Level Agreements (SLAs), policy-based automation, and network slicing. 5GTANGO adopts a Continuous Integration and Continuous Delivery (CI/CD) approach for software development, in order to quickly create adaptive, resilient, and reusable software components. The 5GTANGO Service Platform is delivered as open source under the SONATA trademark, as SONATA is today a reference on the ETSI NFV Management and Orchestration landscape.

5.7.2 Verification and Validation for Network Services

In 5G, to reduce the time-to-market for networked services and to lower the entry barrier to third party developers of Virtual Network Functions (VNFs) and Network Services (NSs), an integrated Development and Operations (DevOps) methodology is crucial. One of the biggest challenges in NFV DevOps is the Verification and Validation (V&V) of individual VNFs and whole NSs so that providers of these services can be sure of their behaviour. 5G-TANGO creates methodology and open source software for supporting and automating functional and performance testing, validation, and verification of VNFs and whole network services.

Project Deliverable D3.1 [25] details the architecture of the V&V platform, including the main stakeholders, the list of components and the possible configurations addressing different use cases. 5GTANGO develops the components necessary for verification and validation of network services, including monitoring, policies, Service Level Agreements (SLAs), VNF/NS catalogue, and appropriate metadata and makes them available as Open Source Software.

5.7.3 Versatile Service Development Kit

The core mission of 5GTANGO is to extend the NFV model with features for verification and validation. Besides doing the actual V&V, appropriate support is needed for developing services as well as testing artefacts. Such support is provided by 5GTANGO with the implementation of a versatile service development kit. The SDK eases the life of the developer of network functions, services, descriptors and tests in an easy-to-understand, quick and robust manner. The philosophy of the 5GTANGO SDK is to provide a useful blend of independent, light-weight tools which can be used independently on their own, as well as in synergy with each other, assisting the global goal of service development for multiple orchestration systems, including SONATA and OSM.

5.8 5G-MEDIA

5G-MEDIA is a 5G-PPP Phase2 project. 5G-MEDIA aims at innovating media-related applications by investigating how these applications and the underlying 5G network should be coupled and interact to the benefit of both: to ensure the applications allocate the resources they require to deliver high Quality of Experience (QoE) while at the same time the network is not overloaded with media traffic. In this respect, 5G-MEDIA addresses the objectives of the following:

1. Capitalising upon and extending the outcomes of the running 5G-PPP projects to offer an agile programming, verification and orchestration platform for media services as shown in Figure 9 and
2. Developing network functions and applications to be demonstrated in large-scale deployments with diverse requirements, targeting three well-defined use cases:

- **Use case 1 – Immersive Media**
  This use case is based around tele-Immersive (TI) applications that enable multi-party real-time interaction of globally distributed users inside shared virtual worlds. For each user participating in a TI application, their appearance is captured via multiple RGB-D sensors and a "3D replica" is created, by utilising full-body 3D-reconstruction algorithms that produce the person's digitised 3D time varying mesh. TI applications produce a large volume of heterogeneous data, thus, creating a challenging networking scenario.
- **Use case 2 – Mobile Contribution, Remote and Smart Production in Broadcasting**
  This use case is concerned with remote and smart production in broadcasting. Traditionally, broadcast productions require large teams and long preparation times for the placement and adjustment of audio and video equipment for outside broadcasts, including the set-up and facilitation of a control room for audio/video-engineers and the directing team. The use of 5G-MEDIA technology helps to speed up the deployment through the use of virtual components implementing remote production functionality being placed more flexibly and, in an ad-hoc manner, while delivering low latency and high quality required for broadcast quality streams. A second sub-scenario investigates how broadcast-quality footage from mobile reporters can be dynamically managed and integrated into broadcasts.
  The fundamental results collected here built a good starting point for the use case on contribution in 5G-SOLUTIONS.
- **Use case 3 – Ultra-High Definition (UHD) over Content Distribution Networks (CDN)**
  This use case is about streaming of UHD media services through various personal devices, both fixed and mobile, while the user is on the move in the 5G network. The focus is on how UHD content can serve users on the go by building media distribution service chains made of software defined media functions to properly serve users attached to the 5G network. In the first scenario users move in the 5G network and aim at having a seamless media experience when migrating from fixed video/audio devices to personal mobile devices. In the second scenario of this use case the viewing experience is adapted and personalised for each viewer through interchangeable audio tracks and alternative video angles.

In addition, 5G-MEDIA plans to introduce the concept of Streaming-as-a-Service that will drive in an ambitious business impact. To slash operational costs for both customers and providers of the 5G-MEDIA platform, shorten application development cycle and making the applications highly responsive and seamlessly elastic, a serverless approach (also known as Function-as-a-Service) will be explored and serverless programming model will be provided through the 5G-MEDIA SDK.

IRT, now present in 5G-SOLUTIONS' consortium, was among the partners of 5G-MEDIA project.

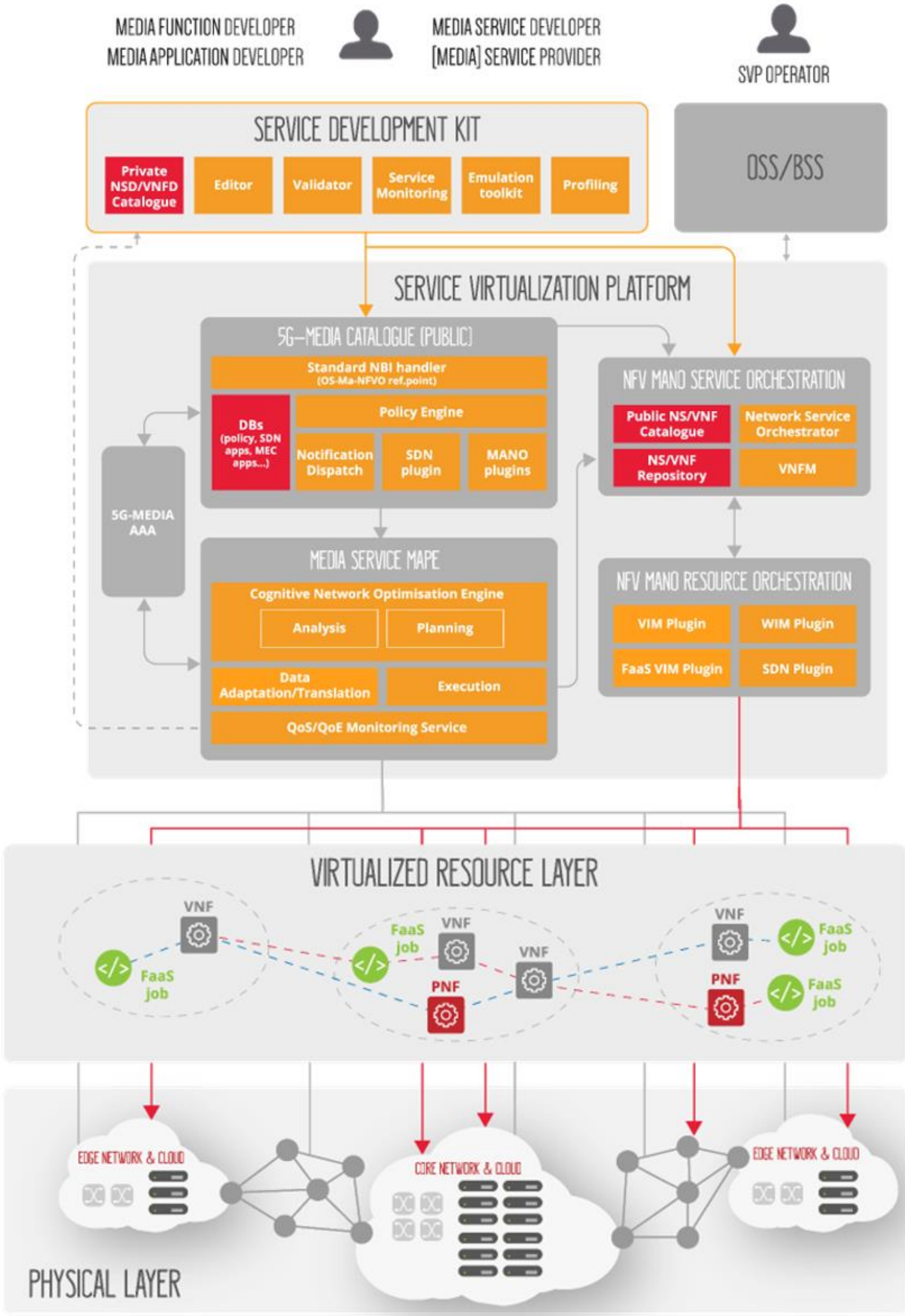

Figure 9: 5G-MEDIA Architecture

5.8.1 Service Virtualization Platform (SVP)

The 5G-MEDIA Service Virtualization Platform (SVP) is built upon the Open Source MANO (OSM) Network Function Virtualisation (NFV)—Management and Orchestration (MANO) stack and focuses on the development, adaptation and extension of the following components:

1. NFV MANO Service Orchestrator: This component will contain the Network Service Descriptor (NSD)/Virtual Network Function Descriptor (VNFD) catalogues and Network Service (NS)/Virtual Network Function (VNF) repositories customized to 5G-MEDIA project needs as well as the Network Service Orchestrator and the VNF Manager;
2. Media Service MAPE (Monitoring-Analyse-Planning-Execute): This component will realize a MAPE loop for the optimization of media services in terms of network requirements, e.g., latency, throughput etc. The 5G-MEDIA project will focus on the implementation of the Cognitive Network Optimizer (CNO), which represents the intelligence module integrated in the MAPE loop;
3. NFV MANO Resource Orchestrator: This component will contain the mechanisms for the deployment of media services on the Network Function Virtualization Infrastructures (NFVIs). The 5G-MEDIA project will provide two new Virtualized Infrastructure Manager (VIMs), in addition to those supported by OSM, i.e. the Function as a Service (FaaS) VIM, which enables the use of the so-called FaaS concept and the OpenNebula VIM, which enables the connection of OSM to OnLife NFVI provided by TID.

5.8.2 Service Development Kit (SDK)

5G-MEDIA supports the development of new media applications and services assisting the function, application and service development, emulation, testing and validation process, prior to the deployment phase and allows the use of lightweight virtualization through Docker and unikernels.

More specifically it provides an all-in-one environment to validate Network Service Descriptors (NSDs), to emulate network services, to onboard NS in the NFV catalogue and finally instantiate it on a specific Network Function Virtualization Infrastructure (NFVI)/Virtual Infrastructure Manager (VIM) through the Service Virtualization Platform (SVP). In addition, the 5G-MEDIA SDK allows FaaS Emulation using Lean OpenWhisk (Lean OW) and FaaS CLI Tools allow media application developers (NS developers) to leverage the FaaS programming model and quickly develop and evaluate value added code while relieving them from the infrastructure management concerns.

Moreover, it offers CLI tools for unikernels, to enable unikernel development, providing improved security, smaller footprint and consequent faster boot time. Finally, it provides a VNF/NS Emulation toolkit including service profiling and monitoring tools that allows doing load testing on a media application (profiling) and provides visualization of pre-defined performance metrics (monitoring) in an emulated multi – Virtualized Infrastructure Manager (VIM) environment including OpenStack and OpenWhisk (OW) emulators. This allows media application developers to test and verify their applications functionality, debug and fine-tune them before deploying to a production environment.

Further details can be found in 5G-MEDIA Publication “Programming Tools for Rapid NFV-Based Media Application Development in 5G Networks” [26].

5.8.3 5G App and Service Catalogue (5G-MEDIA)

In 5G-MEDIA, we introduce the concept of the 5G App and Service Catalogue. This new functional element is designed to be NFV MANO platform-agnostic in terms of formats and syntax for NS descriptors and VNF Package information model. The catalogue uses a novel generalized and extendible format for representing NSs and VNFs and it is capable to onboard NFV service elements as well as Mobile Edge Cloud (MEC) media applications and services and other virtual applications such as Software Defined Networking (SDN) applications and functions implementing the FaaS paradigm. In addition, the 5G-MEDIA project develops VNFs to support three media-specific use cases, i.e., Use case 1 – Immersive Media, Use case 2 – Mobile Contribution, Remote and Smart Production in Broadcasting and Use case 3 – Ultra-High Definition (UHD) over Content Distribution Networks (CDN).

6 Phase 3 Main Achievements

Partners in 5G-SOLUTIONS are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects. In this section are listed the main achievements of the Phase 3 Projects which involve consortium partners. An analysis of Phase 3 projects achievements is carried out, in order to identify results and assets for use in 5G-SOLUTIONS

6.1 5G-VINNI

The 5G-VINNI concept is to develop an (E2E 5G facility that can be used to first demonstrate the practical implementation of infrastructure to support the key 5G KPIs, and then to allow vertical industries to test and validate specific applications that are dependent upon those KPIs. However, 5G-VINNI is not intended to be simply a group of interconnected test facility sites – it is underpinned by principles that will allow for highly dynamic and flexible network architectures, service deployment and testing, that will create new technical and commercial service deployment models. These will in turn drive inter-facility interconnection to enable virtualized functions from the network and service layer to be called upon from any facility, with complete location agnosticism – a truly cloud-based network instantiation that has no functional boundaries, implemented across multiple facility sites.

Figure 10 depicts a high-level view of the 5G-VINNI conceptual E2E facility architecture by highlighting the key elements and inputs. The various building blocks that 5G-VINNI will initially include as part of its ecosystem are organized in three layers as defined in the 5G-PPP Architecture document. These are *Service Level, Network Level* and *Resources & Functional Level*.

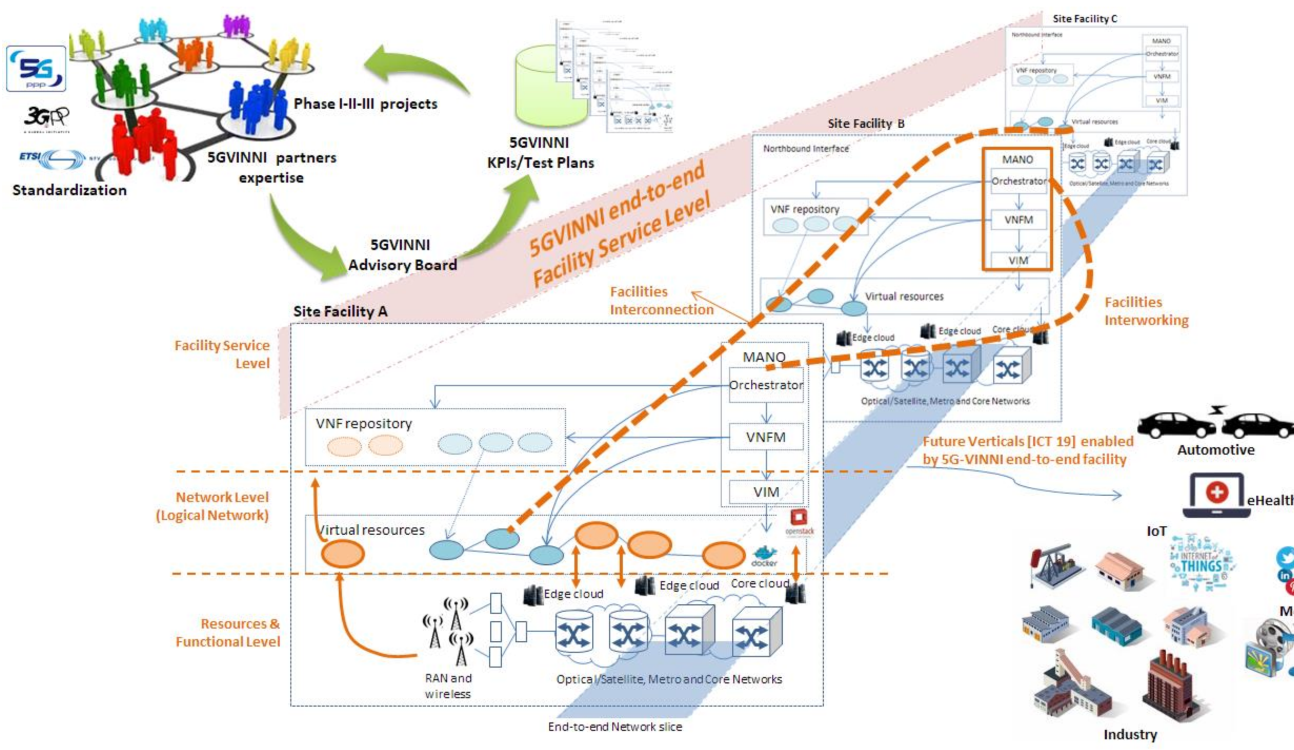

Figure 10: 5G-VINNI high level conceptual E2E facility architecture

The *Resources and Functional Level* of the 5G-VINNI E2E facility will be comprised of the RAN, Backhaul, Mobile Core and Cloud Computing facilities, the latter coming either in the form of Edge or Centralised Clouds. The *Resources & Functional Level* will provide the physical resources to host the *Service Level* and *Network Level* elements (e.g. VNFs). These are interconnected to build dedicated logical networks, customized to the respective telco services, e.g., eMBB, V2X, URLLC, mMTC. The Recursive Structure of network capability exposure is shown in Figure 11.

UOP and TNOR, now present in 5G-SOLUTIONS' consortium, are among the partners of 5G-VINNI project.

6.1.1 Testing framework

The execution of validation campaigns, as well as the vertical customer experiments, will be run through a user-friendly Testing Portal, which will be the point where tests are configured, test campaigns are executed, and campaigns results are visualised and analysed.

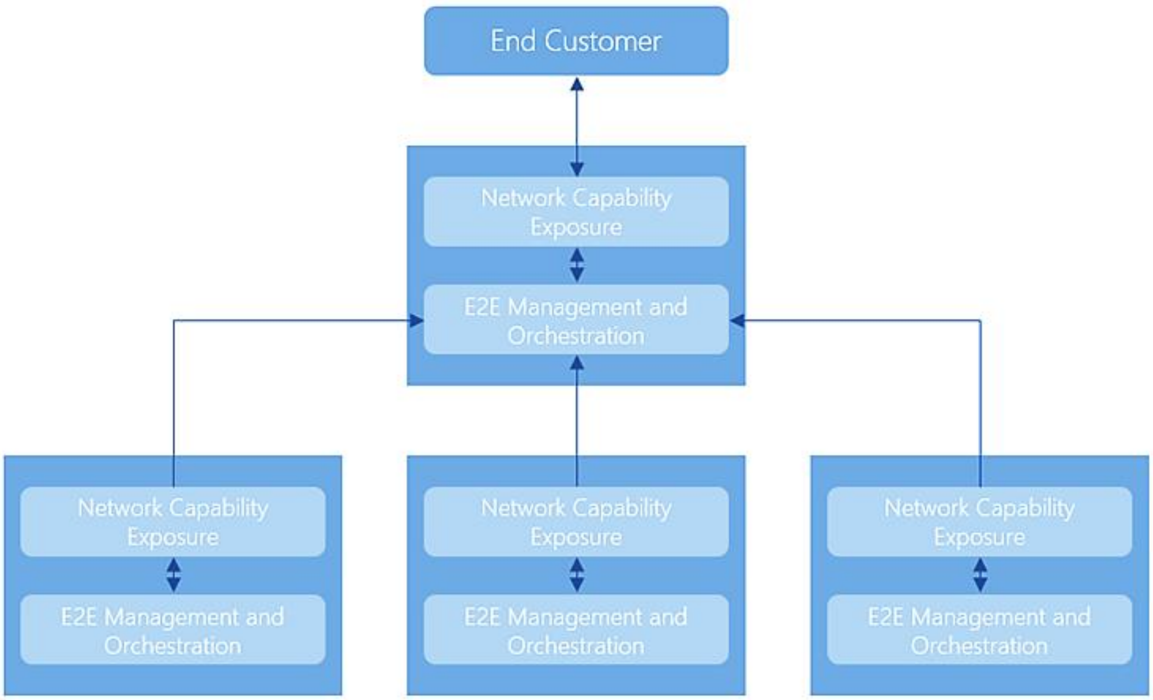

Figure 11: Recursive structure of network capability exposure and E2E Management and Orchestration

Such an advanced and radical step in networking will require a similarly advanced set of testing capabilities. The framework, displayed in Figure 12 illustrates the 5G-VINNI testing functional blocks. These are overarching across the entire 5G-VINNI set of site facilities, and is based on the presence of an Experiment and Test Executor for connecting to the appropriate infrastructure components via open APIs.

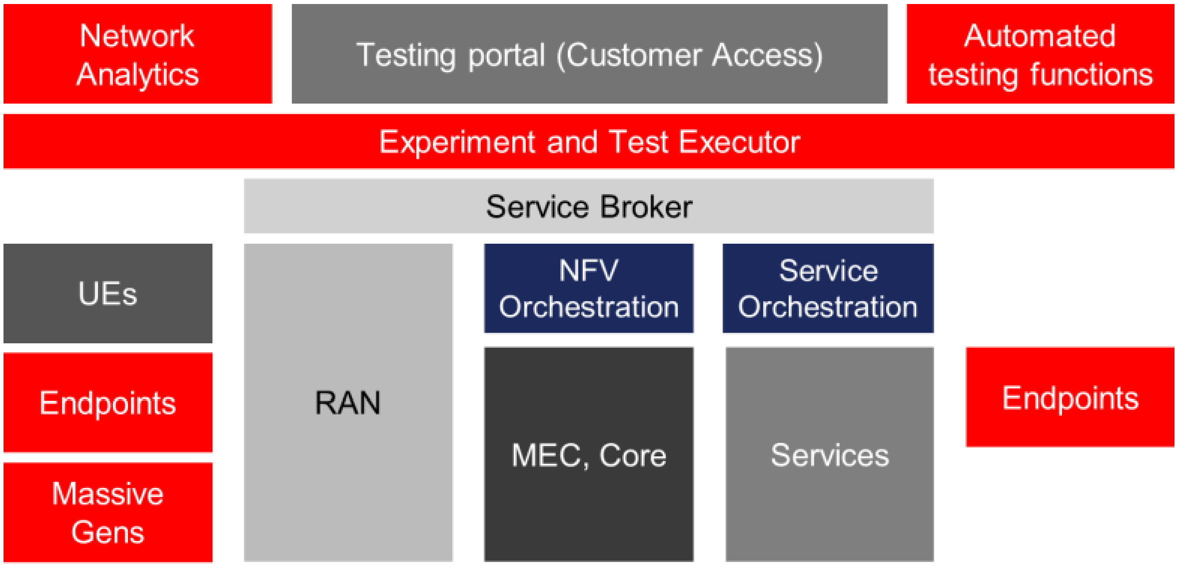

Figure 12: 5G-VINNI Test Framework

5G VINNI's combination of this comprehensive test framework, the multiple interworking 5G RAN and 5G core infrastructures, and zero-touch E2E service orchestration provides a unique platform for testing and trialling industry use cases. The platform facilitates the rapid on-boarding of verticals by exposing network slice life-cycle management functions through an open API. By using the API's, the verticals are able to create, manage and de-commission network slices. This will offer a high level of agility in the management of connectivity services and will allow verticals to shorten their innovation cycles - quickly establishing network connectivity for E2E communication services and applying different test scenarios to the connectivity using the testing portal in order to evaluate the impact upon their E2E communication services. Figure 13 illustrates the scope of the 5G-VINNI E2E facility including the test platform and its relation to vertical use cases with the example of ICT-19 projects.

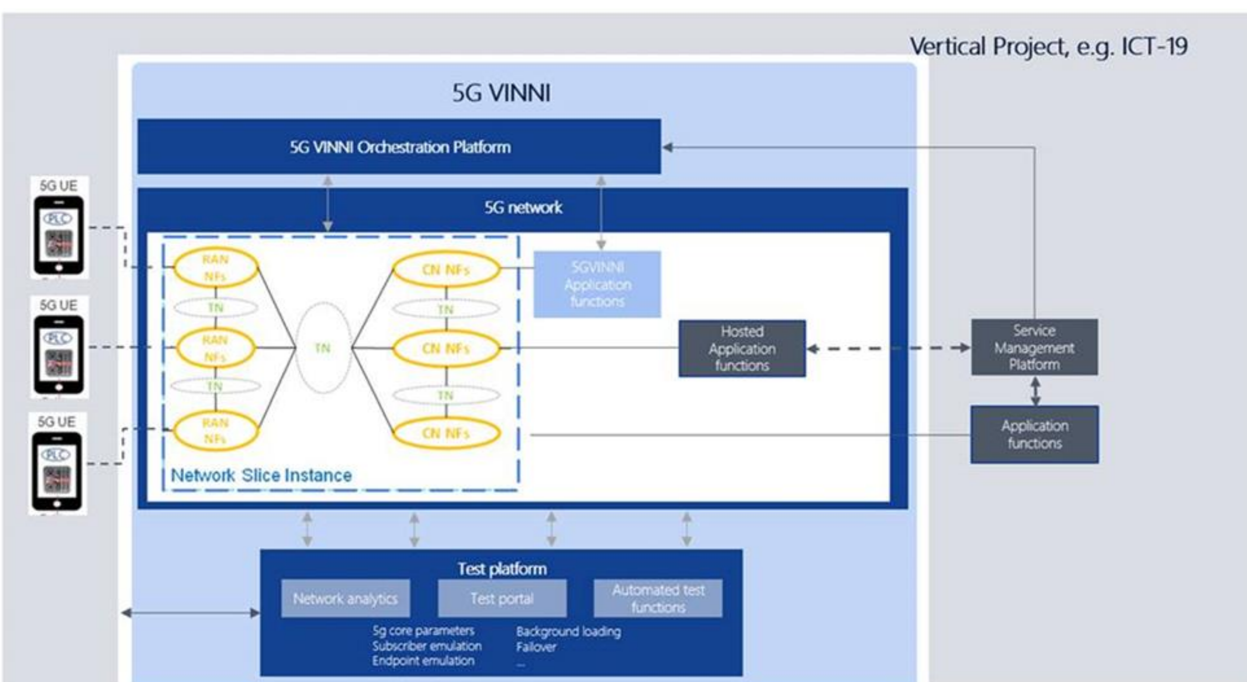

Figure 13: Basic separation of responsibilities between 5G VINNI and ICT-19 projects

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6.1.2 Architecture

At a top level, the architecture for a 5G-VINNI facility site is as shown in Figure 14.

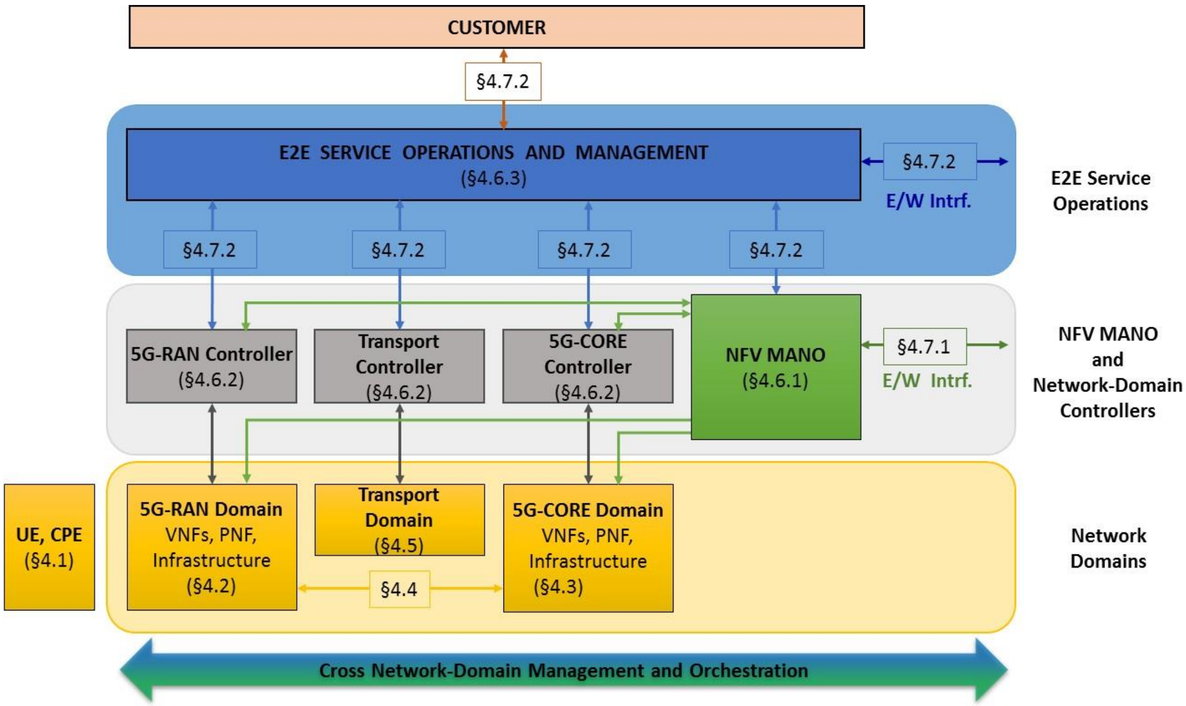

Figure 14: Architecture of a 5G-VINNI Facility Site

In the lower layer of the figure are the infrastructure, VNFs and PNFs in the RAN and CORE and the infrastructure for the transport domain.

Above the Network Domains is NFV-MANO and the respective controllers of each domain. NFV-MANO is focused on virtualization-specific tasks (i.e. management at the virtualized resource level), while domain controllers focus on non-virtualization-related operations (i.e. management at the application level). The NFV-MANO is responsible for managing VNFs, combines them in order to set up one or more network service, and in general take care of instantiation, scaling, updating, and terminating VNFs and NSs.

The Domain Controllers at the RAN and Core are in charge of managing the different NFs at the application level (independently of their deployment), and in general to provide control on all the non-virtualization-related operations. The Domain Controllers at the transport include components such as SDN controllers or Multi-Protocol Label Switching (MPLS) management and control components.

The E2E service operations and management level is in charge of coordinating the different domain controllers and the network services provisioned by the NFVO, in order to have a congruous service across RAN, transport and Core. Each section identified in the diagram contains aspects that are mandated and aspects that are optional. This allows individual facility sites to implement an architecture that can deliver a set of KPIs and use cases that are specific to that particular site, whilst adhering to the principles and architecture of 5G-VINNI as a whole.

6.2 5G EVE

5G EVE aims at implementing a platform providing innovating European Verticals and SMEs with open, easy-to-use, trustworthy and smart tools for validating their 5G-ready applications and systems.

The project will do so by offering to all 5G experimenters a 5G end-to-end facility, which enables them to validate, based on KPI's, the performance of their 5G-ready solutions prior to 5G networks being commercially rolled out.

Important representatives of European vertical industries are directly involved as participant partners of 5G EVE exactly to influence the design of the end-to-end 5G services, and to provide an early assessment.

5G EVE shall (but will not be limited to) support the requirements of the participant verticals in the project. Instead. 5G EVE's ambition is to create the common foundation for supporting more and varied innovating vertical firms wiling to engage in structured experimentation and validation tests enveloped in ICT-19, ICT-21 project proposals in collaboration with 5G EVE partners.

TIM and PIIU, now present in 5G-SOLUTIONS' consortium, are among the partners of 5G-EVE project.

6.2.1 Architecture of E2E Validation Platform

In 5G EVE framework the "**5G EVE's Integrated Portal for 5G Experimentation and Validation, with interworking capabilities among trial sites**", introduced in the centre the diagram in Figure 15, acts as the major technical interface between Verticals and the 5G technologies world, delivering these two essential benefits for Verticals' 5G validation plans:

Beyond enabling the access to the necessary 5G technologies and systems in continuous evolution, 5G EVE shall support verticals with a comprehensive, open and easy-to-use toolbox for simplifying their whole process of validation of their 5G-ready applications, from needs/intent to results/exploitation readiness.

Besides offering the possibility to perform those validations activities with one trial-site of choice (Italy, France, Spain, Greece), 5G EVE shall support Verticals with advanced interworking features allowing verticals to flexibly carry out validation activities in a homogeneous way at any 5G EVE site, and involving several 5G EVE sites in the same test case when required.

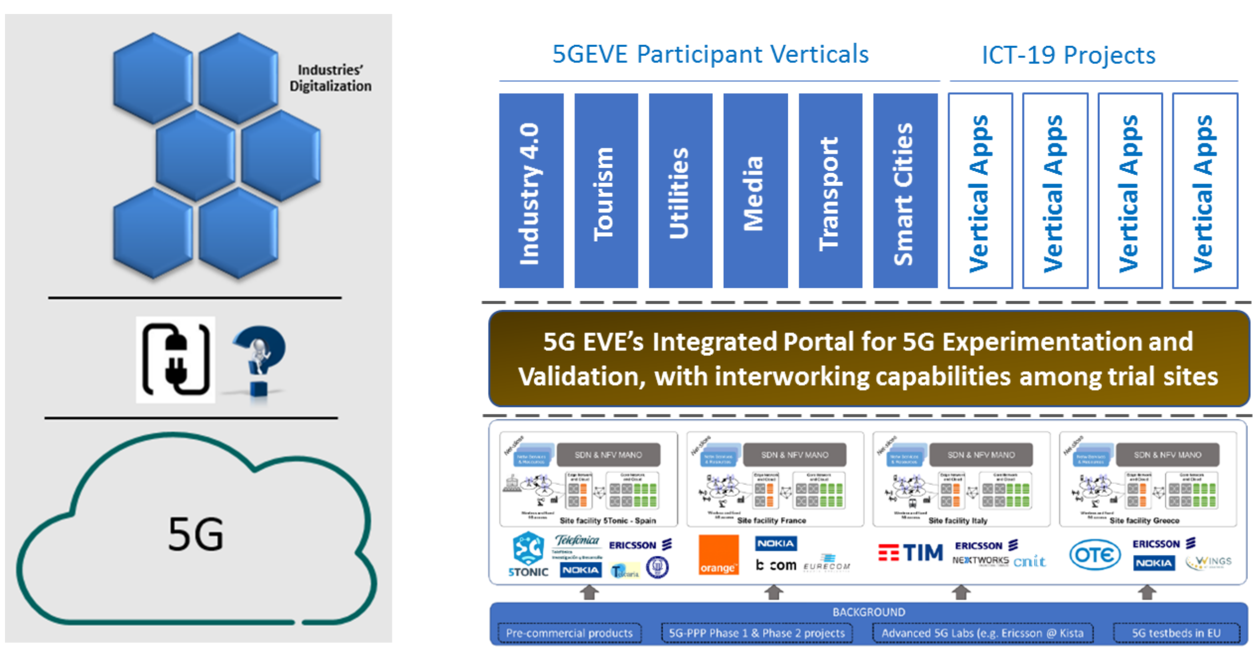

Figure 15: 5G-EVE Framework

6.2.2 What 5G-EVE Offers to Vertical Experiments

Beyond the variety of network requirements, all these verticals are calling for an immediate and intuitive access to a vast range of differentiated 5G services. The position of 5G-EVE and verticals is shown in Figure 16.

Easy-to-use APIs become one of the key facilitators of 5G, so that verticals can define or request services and functions from the 5G network through unified, intent-based APIs that can abstract from the specifics of complex network technologies. End-to-end 5G services need to be delivered as easy-to-access and easy-to-configure instances. The underlying 5G networks **need to guarantee a variety of high performances through several data plane technologies** (radio, fronthaul and backhaul, access, core), seamlessly integrated and interworking. The **portability of vertical services** needs to be guaranteed across different network domains, possibly deployed in different countries, managed by different network operators who can use technologies from different vendors. **Unified management, end-to-end orchestration** based on automation and reliable multi-domain slicing mechanisms, as well as vertical-driven service blueprints**, smart KPI monitoring and performance diagnosis are key to offer user-friendly 5G services in the market.**

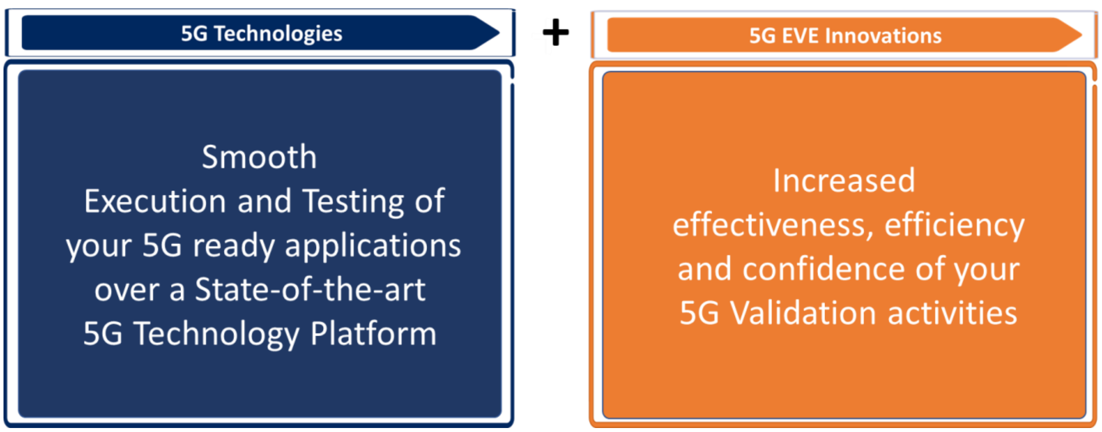

Figure 16: 5G EVE and Verticals

5G EVE will work on four specific areas of innovation which are:

- **Intent-based interfaces.** As part of the open framework that will be offered towards verticals, there will be research and realization of completely new intent-based networking concepts applied to the interfaces towards verticals and to the management of end-to-end network slices;
- **Multi-x slicing and orchestration.** As part of the means for the interworking between the 5G site facilities and in order to deliver a high degree of automation in the management of the end to end facility components, there will be creation of new slicing and orchestration mechanisms that span administrative domains, network segments and technologies;
- **Performance diagnosis.** As part of the advanced 5G testing, 5G-EVE will deliver a new, comprehensive, flexible and accurate KPI collection and measurement framework, means for technology benchmarking, and an innovative tool for performance diagnosis i.e., for delivering suggestions for the performance improvement;
- **Coexistence of proprietary and open source technologies – means for the modular replacement and chaining of components.** As part of the proposed open framework, there will be a pool of optimized 5G VNFs. The pool will comprise proprietary and open source components (i.e., OAI, programmable data plane). Moreover, there will be means allowing the replacement and chaining of the modular components, and, therefore, the coexistence of proprietary and Open Source technologies, the

comparison of different solutions and the preparation for further versions of the standards. This is supported by an innovative IPR management.

6.2.3 Platform and Architecture

The developed tools will support the following functionalities, as depicted in Figure 17:

- Browse and look up of available services in the 5G EVE platform:
    - The experimenter will have the ability to seamlessly browse through extensive lists of the available 5G EVE features, components and services.
- Definition & deployment of the experimentation service:
    - Vertical will define and deploy their experiments using an open interface (5G Portal GUI) in 5G EVE end to end facility.
    - This will be achieved thanks to the novel concept of intent-based networking.
- Monitor and maintain the experiment:
    - The experimenter will be able to monitor the progress of the experiment and (partially) interact with it in an online fashion via an intuitive GUI.

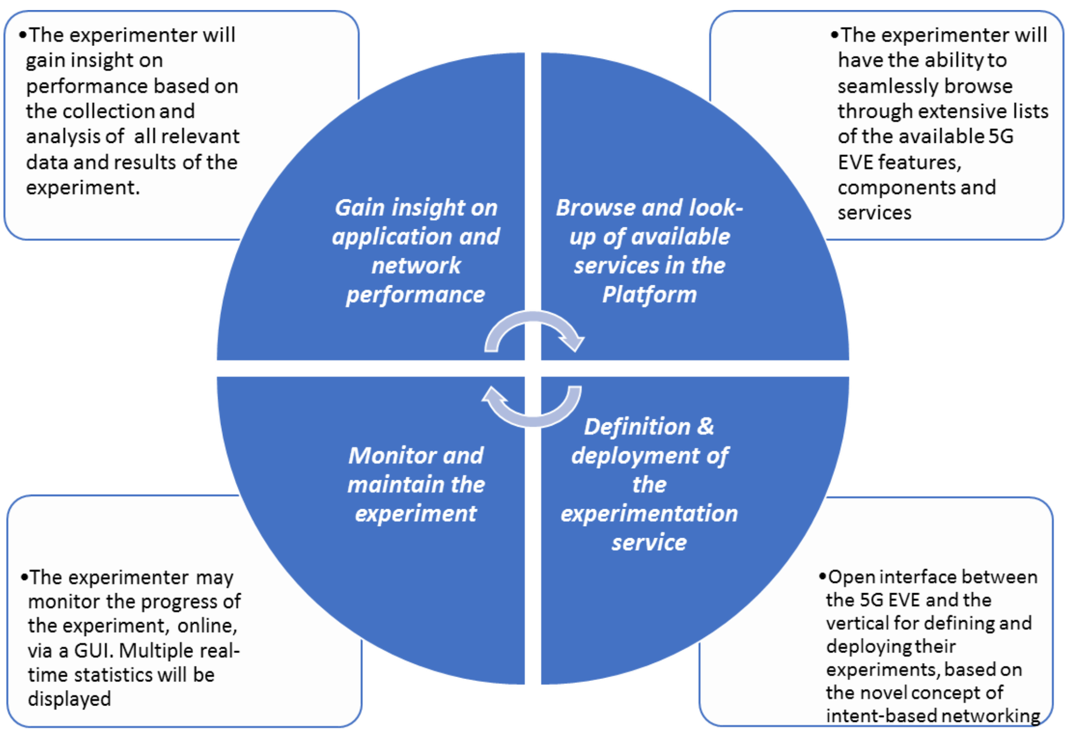

Figure 17: Validation Test as a Service

Multiple real-time statistics will be displayed in various forms (digital displays, graphs, etc.) allowing the experimenter to gain live insights during the experiment.

- *Collect experiment result data*:
    - The experimenter will also be able to collect all relevant results and data after the successful completion of the experiment.
- *Performance diagnosis*:
    - The experimenter will be supported with KPI evaluation and performance diagnosis methodology and tools ("KPI Analytics & Performance Diagnosis Tool") including identification of potential

bottlenecks of degradation and potential solutions (using post-process analytics on the collected KPIs)

- *Trouble-ticketing system:*
    - Provide a trouble-ticketing system for enabling duly support to experiments. Use of existing solutions should be prioritized over own development.

The vertical's view in 5G-EVE architecture is shown in Figure 18.

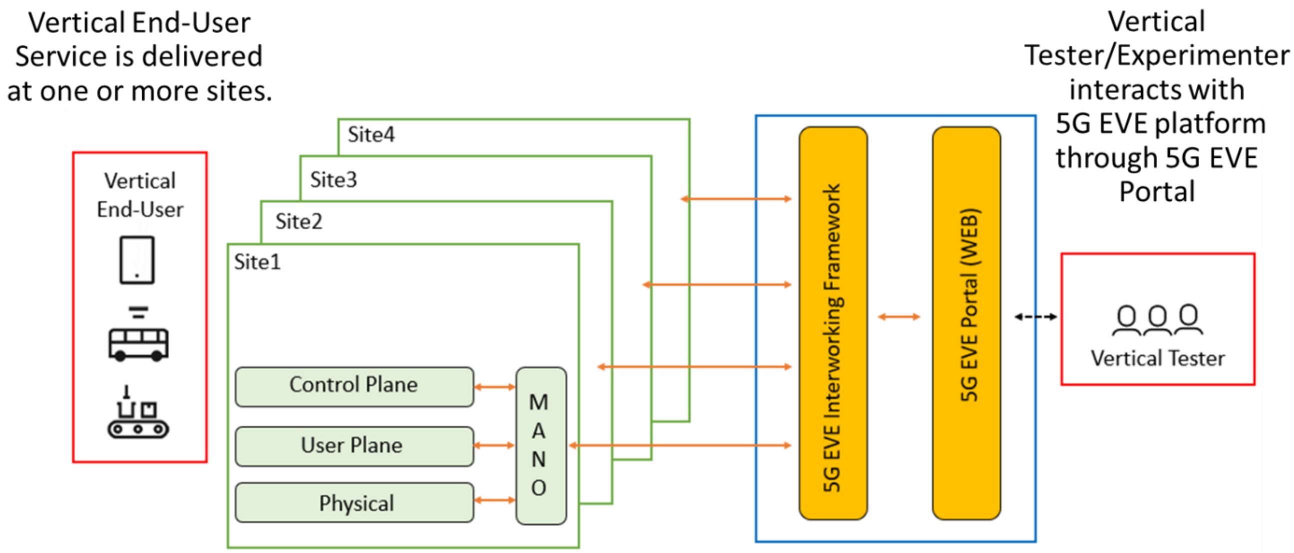

Figure 18: 5G EVE Architecture - Vertical's View

7 5G-PPP Projects KPIs

The Phase 1 and Phase 2 5G-related ICT projects which were analysed in the previous sections demonstrate the possibility to achieve 5G performances in terms of latency (less than 5 ms for the end-to-end and 0.5 ms for the data-plane only), user data rate up to 1Gbit/s, availability higher than 99.999% and, for the control panel, a service creation time lower than 90 sec.

This is shown in Table 2, which collects KPIs from these projects: this collection contains the numbers on which 5G-SOLUTIONS relies on in order to successfully carry on its own living labs. In this sense Table 2 is a reference to relate KPIs coming from previous projects to the target KPIs detailed by Task 1.1 for 5G-SOLUTIONS and associated to the vertical UC scenarios.

Table 2: KPIs from previous 5G-PPP Projects

KPI description	Reference Projects	Target value
Peak Data Rate NOTE: the data rate is a time-variable function. It might be important to define some parameters (e.g. peak, burst, average) in order to better describe the data rate	5G-EVE	20 Gbit/s DL 10 Gbit/s UL
End-to-end latency: the time it takes to transfer a given piece of information from a source to a destination, measured at the communication interface, from the moment it is transmitted by the source to the moment it is successfully received at the destination.	5G-XHaul 5G-Transformer	1-10 ms
	METRO-HAUL	• <5 s (Content delivery network) • < 5 ms (Live-TV distribution) • <1 ms (6DoF VR) • 30 ms (Crowdsourced Video)
Round trip time (RTT)	5G-Tango	< 80 ms (measured from client's side)
Area traffic capacity: this use case attempts to enable fast, high quality video consumption and transmissions from crowded spaces, such as stadiums.	5G-XHaul	DL: 3.75 Tbps/Km^2 UL: 7.5 Tbps/Km^2
	Metro-haul	• From Medium (1-10 Gbps/Km^2) to High (>10 Gbps/Km^2) • For Live-TV distribution: peak downlink 500Gbps/Km^2 • For Crowdsourced Video: >10,000 users/Km^2 • For Secure SDN Video

		Distribution: >10 Gbps/Km^2
	5G-Transformer	≥ 10.000 devices/Km^2
DL/UL data rate for mega-event Considering the peak data rate and the total, bearing in mind the statistical multiplexing.	5G-Crosshaul 5G-PICTURE	20-100Mbit/s/user, (Total ~135Gbit/s over the bowl area)
User Data Rate	5G-EVE	DL: 100 Mbps UL: 50 Mbps
Latency	5G-EVE	UP Latency (ms): 1ms (URLLC), 4 ms (eMBB) CP Latency (ms): <20 ms
Coverage. The improved coverage is expected to be needed by some MTC/IoT devices with challenging coverage conditions, for example water/gas/electricity metering devices installed in basements. The coverage enhancement is mainly achieved through repetition techniques.	5G-MONARCH	Max coupling loss 164 dB
Max Battery Life Time of battery duration.	5G-XHaul	>5 years
Jitter The **short-term variations** of a digital signal's significant instants from their ideal positions in time.	METIS II	500 us
User plane latency The time it takes to transfer a given piece of information from a source to a destination, measured at the edge of the user-plane.	5G-MONARCH	0.5 msec

Reliability Percentage value of the amount of sent network layer packets successfully delivered to a given node within the time constraint required by the targeted service, divided by the total number of sent network layer packets. The reliability rate is evaluated only when the network is available.	METRO-HAUL	99.999%
Connection availability Percentage of available time (w.r.t. total time) in a generic observation period of the connection across the transport network. A bidirectional path or connection is in the unavailable state if either one or both directions are in the unavailable state.	5G-Crosshaul 5G-PICTURE	99.999%
Communication service availability Percentage value of the amount of time the end-to-end communication service is delivered according to an agreed QoS, divided by the amount of time the system is expected to deliver the end-to-end service according to the specification in a specific area.	5G-Crosshaul 5G-PICTURE	99.999%
Packet loss or frame loss ratio Defined as the percentage of frames that should have been forwarded by a network but were not.	5G-Crosshaul 5G-PICTURE	10^-4
Stream latency Delay between the immersive camera capturing an event and the event being displayed to viewers.	5G-Tango	< 45s
Throughput per video stream	5G-Tango	~15 Mbps (~5 Mbps for secondary full HD video streams 4k)
Throughput per video stream **Packet loss measured as NACK at the client side**	METRO-HAUL	• 4K/8K User streams (per user): 25 Mbps (Content delivery network). • Uncompressed video stream (per channel, from Live-TV distribution):

		○ ~6-18 Gbps for moderated color depth 4K UHD). ○ ~48-72 Gbps for high color depth 4K-8K UHD. • For 6DoF VR: ○ 0.1-1 Gbps • For Crowdsourced Video: ○ 800 Kbps to 2.4 Mbps per user (depending on the video resolution). • For Secure SDN Video Distribution: 1.5 Gbps per video feed at least.
	5G-Tango	< 1%
Jitter	METRO-HAUL	<1 ms
User data rate	5G-Transformer	100-1000 Mbit/s
Service creation time	5G-Transformer	< 90 sec
Capacity	5G-EVE	Area Traffic Capacity (Mbit/s/m2): 10 Mbit/s/m2

8 Leveraging and Extending Previous Results

5G-SOLUTIONS envisages achieving up to Technology Readiness Level TRL 6 ('*technology demonstrated in an industrial environment*') as defined in Annex G of the work programme. The expected outcome will be functional field-trial demonstrators in the form of Living Labs, which will run in a near-operational environment (e.g. linking to isolated and production-congruent testbeds in order not to compromise operational systems for testing purposes).

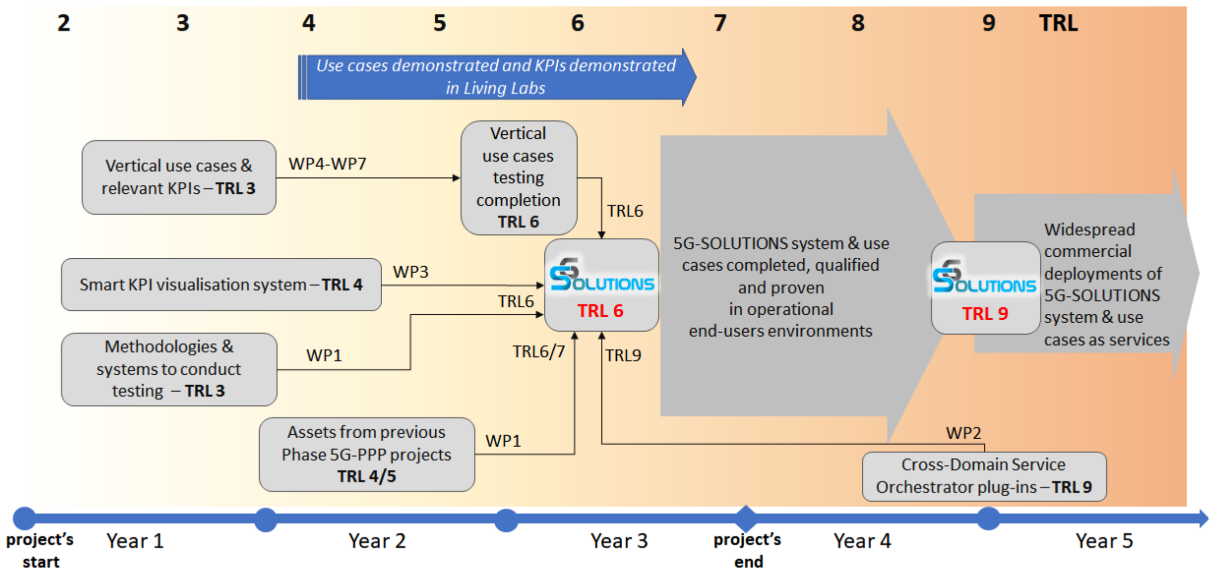

Figure 19: 5G-SOLUTIONS project positioning

5G-SOLUTIONS will leverage, extend, integrate and advance assets and technologies from completed 5G-PPP projects, as well as implement/advance commercial assets, raising their current TRL to 6-7 as listed in Table 3.

In particular, and with reference to Figure 19:

- The use cases in the Living Labs will start from TRL 3, evolve to TRL4-5 after testing Phase 3 Cycle 1, reaching TRL 6 after the completion of Phase 3 Cycle 3 by M34.
- The smart KPI visualisation system components will start from TRL 4, evolve to TRL 5 after testing Phase 3 Cycle 1, reaching TRL 6 after the completion of Phase 3 Cycle 3 by M34.
- The methodologies to conduct the validation testing (i.e. for the definition of test reports format, parameters, test points, benchmarking of results as well as for the technological and business validation of 5G E2E connectivity and management across and within the verticals) will evolve from a starting TRL 3 to TRL 5 after testing Phase 3 Cycle 1, reaching TRL 6 after the completion of Phase 3 Cycle 3 by M34.
- Assets from 5G-PPP Phases 1-3 leveraged and extended from TRL4/5 to 6/7 after testing Cycle 3 by M34.
- NOKIA's CBND, acting as the CDSO will start and remain at TRL 9 after the introduction of the plugins.

Upon the completion of the project, the validated use cases can be offered to friendly end-user customers of the vertical partners, which will allow them to be proven in the market (as extension of WP8). The technical partners who will have a commercialisation benefit will support these customers in addressing potential technical difficulties, maintain and evolve the use cases TRL to 9, to enable them to be ready for commercialisation one year after the completion of the 5G-SOLUTIONS' project.

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8.1 Linked Research Projects and Related Baseline Assets

5G-SOLUTIONS will build on the outputs and findings of completed 5G-PPP Phase 1 and Phase 2 projects (to be completed by mid-2019, coinciding with the commencement of ICT-19 projects), ongoing Phase 3 projects (leveraging their ICT-17 facilities) as well as other relevant projects and commercial assets to seed its technology, including incorporating interdisciplinary knowledge and expertise. The project partners are, in many cases, prior and/or current collaborators in 5G-PPP Phase 1, 2 & 3 projects. This ensures knowledge transfer of lessons learned, reuse of assets, testbeds and knowledge, and a strong working relationship together in support of a collaborative desire to see coherent industry impacts from the outputs of 5G-SOLUTIONS.

Table 3 provides a summary of the most directly relevant and foundational contributions to 5G-SOLUTIONS from 5G-PPP Phase 1 & 2, ongoing Phase 3 projects (ICT-17 facilities) and commercial assets, and shows how project partners will leverage and use their assets, including current and target TRLs.

Table 3: Main results from 5G-PPP Phases and 5G-SOLUTIONS extensions

Key Concepts	**Reference Projects**	**Current TRL**	**Target TRL**	**Leveraging in 5G-SOLUTIONS**	**Extending in 5G-SOLUTIONS**
NFV, orchestration	SONATA (section 4.1) SUPER-FLUIDITY (section 4.2)	4	6	Use Cloudband & NFVO and create the necessary plugins to orchestrate cross-testbed provisioning and management of various vertical applications (VNFs) being monitored as part of the KPIs validation.	Improvement of orchestration platform in order to handle a complex control of use cases, even in a concurrent usage of ICT-17 platform by several verticals.
Security	5G-ENSURE (section 4.3)	3	6	A 5G reference security architecture is ensured with focus on a logical and functional architecture. The core of the 5G-ENSURE security architecture extends and revises the 3GPP security architecture from TS 33.401 to integrate domain concepts derived from 3GPP TS 23.101 to better support 5G trust models, going beyond “telecom” and “mobile broadband”. Strata are used to characterize different functional aspects and security feature groups are used to describe security objectives	Possibility of validation of 5G-ENSURE achievements in terms of security architecture, even though 5G-SOLUTIONS does not deal in particular with security aspects.

Key Concepts	Reference Projects	Current TRL	Target TRL	Leveraging in 5G-SOLUTIONS	Extending in 5G-SOLUTIONS
Transport network	5G-Crosshaul (section 4.4)	3	6	The project results in the distribution of vBBUs, separating fronthauling and backhauling, demonstrating also the economic advantage of this solutions.	The possibility (and economic viability) of having geographic fronthauling opens the way to the providing of a plethora of services, respecting all the KPIs imposed by verticals.
5G RAN	METIS-II (section 4.5)	4	6	All the outputs are highly relevant for 5G-SOLUTIONS and will assist with the definition of a functional architecture, the technical specifications, the network service interfaces, spectrum management, 5G components integration and more.	Validation of METIS II results. 5G-SOLUTIONS does not deal with improvement of 5G RAN. The extensions resulting in other projects, forum, of working groups are deeply monitored by the project in order to adopt the latest improvements for the definition of functional architecture, technical specifications, network service interfaces, spectrum management, 5G components integration and more.
Air Interface	FANTASTIC-5G (section 4.6)	4	6	FANTASTIC-5G developed new waveforms by applying two categories of filtering: subcarrier-wise filtered solutions and subband-wise filtered solutions. Common to all is the amelioration of spectral localization of the signal power, which improves the performance particularly for MMC, MCC and V2X services and ensures an efficient coexistence of these services with MBB service.	Validation of FANTASTIC-5G results: 5G-SOLUTIONS does not deal with improvement of Air Interface, but this project can adopt the latest improvements of the Air Interface techniques developed in FANTASTIC-5G.

Key Concepts	Reference Projects	Current TRL	Target TRL	Leveraging in 5G-SOLUTIONS	Extending in 5G-SOLUTIONS
Slicing	FLEX5GWARE (section 4.7)	4	6	These developments pave the way for effective network slicing which is a key component of 5G-SOLUTIONS.	Involved 5G-SOLUTIONS partners will ensure the successful knowledge transfer and further improvements.
Methodologies to conduct testing and validation	CogNet (section 4.8)	4	6	Use Machine Learning approaches to analyse 5G KPI metrics and process results from data feeds in real-time. Deploy a testing framework to automate and boost reliable validation of network KPIs. Produce reports for homogenised evaluation based on a consistent contrast of KPIs with normalised and comparable values considering concurrent slices.	Enforce testing accountability with auditable validation reports. Practical application of CogNet smart engine in vertical environment.
Optical-wireless Front/backhaul	5G-Xhaul (section 4.9)	4	6	5G-XHaul proposes a converged optical-wireless 5G network infrastructure interconnecting computational resources (based on ETSI NFV) with fixed and mobile users, to support both operational network (C-RAN) and end-user services. The 5G-XHaul data plane considers an integrated optical and wireless network infrastructure for transport and access. The wireless domain comprises small cells complemented by macro cells.	This project's outputs related to strategies allowing the combination of several wireless access technologies. Optical-wireless Front/backhaul give an important contribution to the the achievement of technical LL KPIs. Furthermore, dynamic network path configurations leveraging SDN, and NFV are also thought to be key enablers for 5GSolutions.

Key Concepts	Reference Projects	Current TRL	Target TRL	Leveraging in 5G-SOLUTIONS	Extending in 5G-SOLUTIONS
Multicast/Broadcast capabilities	5G-Xcast (section 5.1)	4	6	The project is focused on the design of multicast/broadcast capabilities for new 3GPP releases. 5G-Xcast has evaluated the main charateristics of eMBMS and FeMBMS targeting the provision of television services to massive audiences. From that point and once limitations have also been detected, a new design fully integrated in a 5G SA approach has been defined. The 5G-Xcast design covers the radio interface and RAN, the Core Network as well as a Converged Content Delivery Framework also including fixed and mobile networks.	Validation of 5G-XCAST results. Even though 5G-SOLUTIONS does not deal with improvement of Radio Interface, this project can adopt the latest improvements of the techniques developed in 5G-XCAST in multicast and broadcast capabilities for new 3GPP releases.
NFV, Orchestration	5G-MONARCH (section 5.2)	5	7	All these project outputs are extremely relevant for 5G SOLUTIONS, especially 5G architecture, slicing, use of SDN and NFV, which will be used as guidelines for the 5G-SOLUTIONS system architecture design and the setting-up and execution of the Living Labs.	Validation of 5G-MONARCH results. Improvement of orchestration platform in order to handle a complex control of use cases, even in a concurrent usage of ICT-17 platform by several verticals.
Services based architecture, Reusable Function Block	NGPaaS (section 5.3)	5	7	NGPaaS adopts the cloud native principles based on service-based architecture and a new modelling based on Reusable Function Block, to abstract, decompose and deploy the different PaaSes (e.g. CORD, Kubernetes, Swarm, PaaS based MANO). These latter are customized to the needs and the requirements for the supported services.	5G-SOLUTIONS can exploit the fact that NGPaaS project is emphasizing the vision that 5G should be considered as a platform where many players can interact (FOSS, Third party, Vertical, Vendors, Operators).

Key Concepts	Reference Projects	Current TRL	Target TRL	Leveraging in 5G-SOLUTIONS	Extending in 5G-SOLUTIONS
DA-RAN Architecture	5G-PICTURE (section 5.4)	4	6	The main idea of the project is the novel DA-RAN Architecture, allowing a flexible transport network where different splitting options are possible	5G-SOLUTIONS inherits this concept and makes the network as most flexible as possible in order to allow the coexistence or different vertical with peculiar requirements (low latency, high reliability, massive bite rate…)
Optical Technologies	METRO-HAUL (section 5.5)	4	6	To support the required dynamicity and flexibility, the METRO-HAUL architecture has been developed to integrate a wide range of optical technologies. These will be controlled using automation schemes and programmability features that will enable concepts such as HW disaggregation and virtualization, the coordination of which will be supported by a purposely designed control plane.	Even if 5G-SOLUTIONS does not deal with photonic research, optical nodes that can dynamically be adapted to the needs of specific services, optimally exploiting the data plane through use of relevant data monitoring and analysis schemes as the ones designed by METRO-HAUL can play a fundamental role in the transport metro segment in order to guarantee latency and bandwidth requirements.
Slicing, SDN	5G-TRANSFORMER (section 5.6)	4	6	Multi-access Edge Computing (MEC) can make the difference in order to exploit in an isolated and scalable way geo-based network and QoS analytics with almost zero latency. In this regard, SDN over NFV virtualisation technologies bring new possibilities to make an efficient and dynamic setup and provision of the infrastructure.	The proposed slicing techniques will serve as a base for advanced SDN-enabled intra and inter-domain slicing schemes for validating the stringent KPIs in the Media & Entertainment Living Lab over heterogeneous NFV-based infrastructures.

Key Concepts	Reference Projects	Current TRL	Target TRL	Leveraging in 5G-SOLUTIONS	Extending in 5G-SOLUTIONS
Streaming services	5G-TANGO 5Gtango (section 5.7)	4	6	The acquired know-how on streaming service design will greatly facilitate the development of the use cases in the Media Living Lab. In addition, the VNFs will be used in other use cases, such as those in the smart cities Living Lab.	5G_SOLUTIONS can inherit these concepts to cope with increasing demand in terms of data rates, number of simultaneous users connected and/or more stringent QoS requirements.
Media production	5G-MEDIA 5G MEDIA (section 5.8)	4	6	In collaboration with broadcasters, the 5G MEDIA results will be leveraged to validate the performance of 5G infrastructures for media production and contribution scenarios.	The key concepts can be used to think new intra-slicing network schemes to handle, for instance, eMBB for streaming and URLLC for synchronised subtitles in order to optimize the media production.
5G Facilities for field trials	5G-VINNI 5G-VINNI (section 6.1)	5	7	Use of the 5G-VINNI facilities for conducting field trials for the use cases related to the Factories of the Future (Ireland, Brussels, Norway), Smart Cities (Ireland), Smart Ports (Norway) and Media & Entertainment Living Labs (Patra and Norway).	Both of these projects are committed to upgrade and support their 5G facilities during and after the completion of their ICT-17 projects until the completion of 5G-SOLUTIONS. This will enable the validation of the vertical use cases to the latest available 5G 3GPP releases.
	5G-EVE 5G EVE (section 6.2)	5	7	Use of the 5G-EVE Turin facility for conducting field trials for the use cases related to the Smart Energy Living Lab.	

9 Conclusions and Next Actions

The goal of the work reported in this document is to validate and extend the figures of KPIs and the results inherited by already finished and ongoing ICT projects, present in the Part B of 5G-SOLUTIONS grant agreement.

Among the huge plethora of EC funded projects, some of them have been analysed in detail and, through the analysis of deliverables and discussions with experts actively involved in these projects, main KPIs have been extracted.

The selection of projects followed these criteria:

- The analysed projects covered the subjects related to 5G-SOLUTIONS activities, i.e. transport network, control and orchestration, mobile access, network security, and media distribution over 5G infrastructure;
- In order to better analyse the results, the considered projects have at least a common partner with 5G-SOLUTIONS;
- Particular attention has been given to ICT-17 projects offering their platforms to 5G-SOLUTIONS (5G-EVE and 5G-VINNI).

The analysis reported in this document confirms that 5G-SOLUTIONS can benefit from outcomes for phase I and phase II 5G-related ICT projects. These projects demonstrate the possibility to achieve 5G performances in terms of latency (less than 5 ms for the end-to-end and 0.5 ms for the data-plane only), user data rate up to 1Gbit/s, availability higher than 99.999% and, for the control panel, a service creation time lower than 90 sec.

These impressive values obtained from previous projects are the numbers on which 5G-SOLUTIONS relies on to be able to conduct its own living labs, aware that 5G technology, as well as the project consortium is taking it all into its planning, and can thus be made a reality.

The KPIs defined by the 5G community are not only related to performance, but business and societal objectives are identified as well. In particular, business KPIs are related to the involvement of small medium enterprises in the research and to reach a global market share for 5G equipment & services delivered by European headquartered ICT companies at, or above, the reported 2011 level of 43% global market share in communication infrastructure.

This deliverable is issued at fifth month of 5G-SOLUTIONS project life. It should be considered as an initial version, summarizing the first results of task 1.3 “Leverage, build upon and extend previous and ongoing work from EU funded 5G-PPP projects and 2nd phase of 5G standardisation”. In next months the task, leveraging on the outcomes reported in this deliverable in terms of KPIs, will ensure the cooperation with the other projects in the call and with the 5G-PPP, in collaboration with Task 9.3, participating in the 5G-PPP Steering Board and Technical Boards. Furthermore, in terms of Standardisation items, and in collaboration with Task 8.3, it will analyse the results obtained from 5G-EVE and 5G-VINNI to be aligned with existing and emerging standards from the relevant standardisation bodies (3GPP, ETSI, ITU, IEEE, IETF…). A tight collaboration with Task 9.1 for the organization of a pre-standardisation workshop and dissemination events will complete the task commitments.

At the end of Task 1.3 lifetime, July 2021, a deliverable to be considered a final version of the present one will be issued.

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