H2020 5G-TRANSFORMER Project

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Second periodic report of the project

Abstract

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List of Acronyms

Acronym	Description
5GC	5G Core
5GT-MTP	Mobile Transport and Computing Platform
5GT-SO	Service Orchestrator
5GT-VS	Vertical Slicer
AAA	Authentication, Authorization, Accounting
AD	Administrative Domain
AN	Access Network
API	Application Programming Interface
AppD	Application Descriptor
BSS	Business Support System
CAM	Cooperative Awareness Messages
CAT	Catalogue
CIM	Cooperative Information Manager
CN	Core Network
CR	Cloud Robotics
CSMF	Communication Service Management Function
CU	Central Unit
DB	Database
DC	Datacenter
DF	Deployment Flavor
DoA	Definition of Action
DU	Distributed Unit
E2E	End to end
EBI	Eastbound Interface
EM	Element Management
EPC	Evolved Packet Core
EPCaaS	EPC as a Service
ETSI	European Telecommunication Standardization Institute
GRE	Generic Routing Encapsulation
GS	Group Specification
HSS	Home Subscriber Server
IaaS	Infrastructure as a Service
ICT	Information and Communication Technology
IETF	Internet Engineering Task Force
IFA	Interfaces and Architecture
KPI	Key Performance Indicator
LC	Lifecycle
LCid	Lifecycle Operation OccuranceOccurrence Id
LCM	Lifecycle Management
M&E	Media and Entertainment
M(V)NO	Mobile (Virtual) Network Operator
MANO	Management and Orchestration
MEC	Multi-access Edge Computing
MEO	Multi-access Edge Orchestrator
MEP	Multi-access Edge Platform
MILP	Mixed Integer-Linear Programming
MIoT	Massive Internet of Things
MLPOC	Multiple Logical Point of Contact
MME	Mobility Management Entity

MNO	Mobile Network Operator
MON	Monitoring
MVNE	Mobile Network Enabler
NaaS	Network as a Service
NBI	Northbound Interface
NF	Network Function
NFP	Network Forwarding Path
NFV	Network Function Virtualization
NFVI	Network Functions Virtualisation Infrastructure
NFVIaaS	NFVI as a Service
NFV-NS	NFV Network Service
NFV-NSaaS	Network Service as a Service
NFV-NSO	Network Service Orchestrator
NFVO	NFV Orchestrator
NFVO-RO	Resource Orchestrator
NGMN	Next Generation Mobile Networks
NS	Network Slice
NSaaS	Network Slice as a Service
NSD	Network Service Descriptor
NS-DF	Network Service Deployment FlavorFlavour
NSI	Network Slice Instance
NSMF	Network Slice Management Function
NS-OE	NFV-NS Orchestration Engine
NSSI	Network Slice Subnet Instance
NSSMF	Network Slice Subnet Management Function
NST	Network Slice Template
OLE	Onsite Live Experience
ONAP	Open Network Automation Platform
OSM	Open Source MANO
OSS	Operating Support System
OTT	Over the top
PM	Performance Management
PMON	Performance Monitoring
PNF	Physical Network Function
PNFD	PNF Descriptor
PoC	Proof of Concept
PoP	Point of Presence
QoS	Quality of Service
RAM	Resource Advertisement Management
RAN	Radio Access Network
REST	Representational State Transfer
RM	Resource Management
RMM	Resource Monitoring Management
RNIS	Radio Network Information Service
RO	Resource Orchestration
RO-EE	RO Execution Entity
RO-OE	RO Orchestration Engine
RSU	Road-Side Unit
RTT	Round Trip Time
SAP	Service Access Point
SBI	Southbound Interface
SDK	Software Development Kit

SDO	Standard Developing Organisation
SLA	Service Level Agreement
SLPOC	Single Logical Point of Contact
SLPOC-F	Single Logical Point of Contact for Federation
SME	Small and Medium Enterprises
SO	Service Orchestrator
SPGW-C	Serving/Packet Data Network Gateway Control Plane
SPGW-U	Serving/Packet Data Network Gateway User Plane
TD	Technology Domain
TETRA	Terrestrial Trunked Radio
TMVS	5G-TRANSMORMER Managed Vertical Service
TN	Transport Network
TOSCA	Topology and Orchestration Specification for Cloud Applications
TRF	5G-TRANSFORMER Resource Federation
TSC	5G-TRANSFORMER Service Consumer
TSF	5G-TRANSFORMER Service Federation
TSP	5G-TRANSFORMER Service Provider
TUVS	5G-TRANSFORMER Unmanaged Vertical Service
UC	Use Case
UE	User Equipment
UPF	User Plane Function
VA	Virtual Application
vEPC	virtual Evolved Packet Core
VIM	Virtual Infrastructure Manager
VL	Virtual Link
VLAN	Virtual Local Area Network
VM	Virtual Machine
VNF	Virtual Network Function
VNFD	VNF Descriptor
VNFFG	VNF Forwarding Graph
VNFFGD	VNFFG Descriptor
VSD	Vertical Service Descriptor
VSI	Vertical Service Instance
WAN	Wide Area Network
WBI	Westbound Interface
WIM	Wide area network Infrastructure Manager
WP	Workpackage
YAML	YAML Ain't Markup Language

Executive Summary

The present deliverable called D7.5 presents the Part B of the Second Periodic Report that will be delivered before 31st of January 2020. It mainly includes the information of the scientific work carried out between 1st of July 2019 and 30th of November 2019. It is important to highlight that the deadline of D7.5 is the 31st of January 2020, the final data for use of resources is still not available at the end of November. The full financial information will be included in the Second Periodic Report in January.

This document includes the Publishable Summary, patents and dissemination activities that will be completed in the Participant Portal too, a description of the technical work carried out by beneficiaries and overview of the progress in the 30 months of the project, including the objectives, the work performed by work package, the deliverables and milestones, the impact and finally the deviations of the project.

1 Summary for publication

1.1 Summary of the context and overall objectives of the Project

1.1.1 Project context

5G-TRANSFORMER (5GT) is a 30-month collaborative project. Its aim is to apply SDN/NFV to transform the currently rigid mobile transport networks into a 5G dynamic system able to offer network slices tailored to the specific needs of various vertical industries. To this aim, 5GT defines 3 building blocks with the following innovations:

Vertical Slicer (5GT-VS) provides a front-end for verticals.

- 5GT-VS architecture, allowing verticals with no know-how on service orchestration to: (i) describe their services via Vertical Service Blueprints (VSBs) from a catalogue; (ii) customize VSBs into Vertical Service Descriptors (VSD); and (iii) control their lifecycle.
- Arbitration among vertical service instances based on their priority and resource budget.
- Slice management and VSD/NSD Translator.
- Per-instance vertical application-level configurations.

Service Orchestrator (5GT-SO) serves as the E2E service orchestration platform.

- 5GT-SO architecture aligned with ETSI and extended to support multi-domain orchestration, and automated service management.
- E2E service orchestration along with service life-cycle management across one or multiple administrative domains (federation).
- Support of network service decomposition.
- Automated SLA management and network service scaling.
- Advanced Placement Algorithms.
- A service-aware monitoring platform.

Mobile Transport and Computing Platform (5GT-MTP) replaces current “one-size-fits-all” deployments with a customizable SDN/NFV-based transport and computing platform.

- Resource abstractions and connectivity service composition.
- Integration of heterogeneous wireless, optical and Ethernet transport solutions.
- Integration of transport network with centralised and edge compute resources.
- Providing intra-PoP and inter-PoP connectivity including the support for multi-VIM and multi-site, and federation.
- Cross-optimization of radio, transport and compute resources.

1.1.2 Project Objectives

- To develop a reference architecture and implementation for the 5GT platform, encompassing a flexible Mobile Transport and Computing Platform, a Service Orchestration platform, and a network slicing platform for verticals.
- To develop scalable algorithms for efficient 5GT service/resource orchestration.
- To support orchestration of end-to-end services across federated domains.
- Validation of key concepts and PoCs.
- Communication, Dissemination, and exploitation (incl. standardization) of 5GT.

1.2 Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

The work in the project has been divided into 5 Technical Work Packages (WPs).

WP1 was in charge of defining vertical use cases and designing the baseline architecture of 5GT. In the first period, WP1 specified the set of use cases and designed the initial architecture, which was finally completed in the second period and presented in D1.4. In addition, in the second period, we performed a techno-economic analysis assessing, through simulations in realistic scenarios, the market and business implications of 5GT for operators and service providers.

WP2 was in charge of the design and development of 5GT-MTP. In the first period, WP2 delivered its initial architecture, providing abstraction of resources and connectivity services to 5GT-SO. In the second period, 5GT-MTP introduced new features and building blocks, namely (i) local Placement Algorithms; (ii) interfaces with the monitoring platform, and (iii) support of MEC and RAN.

WP3 was responsible for the design and development of 5GT-VS. During the first period, an initial design was provided, focusing on: (i) definition of VSBs and translation into VSDs/NSDs, and (ii) initial design of arbitration algorithms. In the second period, 5GT-VS was extended with enhanced vertical support enabling (i) policy management; (ii) feedback from vertical apps; (iii) service configurations by the verticals; and (iv) vertical-driven service scaling and composition.

WP4 was in charge of the design and implementation of 5GT-SO. In the first period, an initial design of 5GT-SO was released, providing resource and service orchestration, for local and also across administrative domains (federation). To make optimal orchestration decisions, a number of placement algorithms were developed. During the second period, 5GT-SO was extended with (i) automated network service scaling; (ii) service composition and service federation; (iii) enhanced placement algorithms; and (iv)service assurance and SLA Management. In addition, WP4 developed a service monitoring platform.

The main goal of WP5 is to integrate all WP2, WP3, WP4 components and to validate the 5GT architecture design experimentally with selected use cases. The main work during the first period was the design and setup of the interconnection of the different test sites and the elaboration of an initial integration plan. The actual integration efforts were made during the second period. The final results from the demonstrated use cases are reported in D5.4, including results from automotive, entertainment, e-health, e-industry and MNO/MVNO trials.

As a result of WP2, WP3, WP4 and WP5, the final software implementation of the 5G-VS, 5GT-SO, 5GT-MTP, and 5GT-Monitoring Platform has been published as open source on github: https://github.com/5g-transformer/.

1.3 Progress beyond the state of the art, expected results until the end of the project and potential impacts (including the socio-economic impact and the wider societal implications of the project so far)

5GT targets innovations around three main components: (1) 5GT-VS: offering a powerful, yet simple and flexible, interface to verticals; (2) 5GT-SO: capable of instantiating and orchestrating network services, including federation mechanisms; and (3) 5GT-MTP, integrating compute, storage and networking resources. All these innovations are combined together into a framework that takes into account both technical and techno-economic requirements from the stakeholders of the value chain (operators, vendors, and service providers). In this way, 5GT creates a direct socio-economic impact, through lower cost and higher efficiency for the stakeholders, better service (quality and ubiquitous access) to the end users, and lower bills. The overall society will benefit from 5GT innovations through easier entry for verticals, more flexibility and cost-efficiency, whilst supporting the services envisioned in 5G and beyond.

The 5GT innovations are expected to give the industrial companies (large, medium, small) in the consortium and the extended European 5G-PPP community a privileged position and competitive advantage in the European and global markets. An exploitation plan was made to assess the possible impact on the products and services roadmaps of the vendors and operators in the consortium.

The final 5GT software platform was released as open source on github: https://github.com/5g-transformer, enabling its adoption in other European projects. Particularly relevant, 5GT has been selected as baseline for the development of network slicing and orchestration platforms in other 5G-PPP phase 2 & 3 projects.

Moreover, in order to ensure wide-reach of 5GT, the consortium has been very active in dissemination efforts. Specifically, 5GT has delivered:

- 95 scientific publications (34 journals and 61 international conferences/workshops).
- 17 organized (or co-organized) events (e.g., workshops).
- 28 demonstrations at flagship events.
- 24 adopted/agreed/accepted standard contributions.

2 Patents

In this section, we list the patents that have been filed based on 5G-TRANSFORMER research activity. Below is the list of patents:

1. “Method for restoring the connection of a telecommunications network", SSSA, (PCT/IB2019/052094), 2018.
2. “Methods for advertising and selecting network slices dual-connectivity and multi-subscriber scenarios”, IDCC (PCT/US18/46747), 2018.
3. “Multi-access edge computing, MEC, system and method for operating the same”, NECLE, 2018
4. One patent in the area of ‘IP connectivity checks’, NOK-N, to be published.
5. One patent in the area of ‘Service instance discovery’, NOK-N, to be published.

3 Dissemination activities

This section presents the work progress of the project, during Y2 and Y3 (i.e., second reporting period), regarding the dissemination activities, which follow the plan described in D6.2 and D6.5. It reports activities for Y2 and Y3 on the publication of research results (Table 2, Table 3), technology demonstration (Table 4, Table 5), academic activities (Table 6, Table 7), organization of events (Table 8, Table 9) and participation to events (Table 10, Table 11). It also includes a sub-section on the Common Dissemination Booster activities, a service offered by the European Commission towards joint dissemination and exploitation with other projects, in this case 5G-Coral and 5G-Crosshaul.

Table 1 presents a comparison between the achieved metrics on the above-mentioned activities and the targeted metrics included in the DoA and updated in D6.2 and D6.5 (Publication and Participation to events). As seen in the tables for Y2 and Y3, the project achieved the objectives, exceeding all the targeted metrics. Regarding publication of research results, the 5G-TRANSFORMER partners have published 65 scientific papers in peer-reviewed journals, conferences and workshops, in very selective venues, such as IEEE Transactions, and the IEEE INFOCOM conference. The technology demonstration activity drastically increased during Y2 and Y3, as many 5G-TRANSFORMER concepts have gained maturity, and have been demonstrated via PoCs at well-known conferences, such as EuCNC, ACM MobiHoc and IEEE INFOCOM. Several students have been enrolled on topics related to the project, at the PhD, master and Bachelor levels. 5G-TRANSFORMER has organized (or been accepted to organize) 13 events collocated with international conferences, such as EuCNC, IEEE PIMRC, and ACM CoNEXT. All these events have achieved more than 70% of attendee satisfaction in terms of scientific and technical content. Moreover, an exploitation workshop dedicated to SMEs and large companies (Emerging 5G Business Models: Opportunities for SMEs and large companies-lessons from 5G PPP) was organized in conjunction with EuCNC 2019. Finally, 5G-TRANSFORMER partners have given talks (invited) and keynotes, and participated to panels, on concepts related to the 5G-TRANSFORMER architecture and concepts, such as the Vertical Slicer, Network Slicing, Multi-access Edge Computing, etc., in several international events; this is without including the talks given at international conferences and workshops to present scientific papers.

TABLE 1: TARGETED METRICS VERSUS ACHIEVED METRICS

Activity	Targeted metric	Achieved metric
Publication of research results	10 during Y2, and 5 during Y3 (6 months)	44 during Y2 and 21 during Y3
Technology Demonstration	At least 2 per year	18 different events (up to 4 demos in some events): 7 during Y2 and 11 during Y3
Academic activities	At least 2 master thesis per academic partner over the course of the project	8 PhD and 6 Master thesis
Organization of events	One 50-people workshop co-located with a major conference with 70% satisfaction	13 events. All events with more than 70% of satisfaction

	One 30-people workshop with 70% satisfaction	Exploitation workshop (Emerging 5G Business Models: Opportunities for SMEs and large companies -lessons from 5G PPP) collocated with EuCNC 2019
Participation to events	Average of 10 talks during Y2 and 5 during Y3 (6 months)	15 in Y2 and 12 in Y3 (incl. keynotes/panels/invited talks...) Additionally, all papers presented in their respective conferences/workshops.

TABLE 2: PUBLICATIONS IN Y2 (J: PEER REVIEW JOURNAL, B: BOOK CHAPTER, C: PEER-REVIEWED CONFERENCE, W: PEER-REVIEWED WORKSHOP)

	Title	Published in
J	Characterizing the Power Cost of Virtualization Environments	Transactions on Emerging Telecommunications Technologies, 2018
J	Optimization of an integrated fronthaul/backhaul network under path and delay constraints	Elsevier Adhoc Journal, February 2019
J	Orchestrating lightpath recovery and flexible functional split to preserve virtualized RAN connectivity	IEEE/OSA Journal of Optical Communications and Networking, Nov. 2018
J	z-TORCH: An Automated NFV Orchestration and Monitoring Solution	IEEE Transactions on Network and Service Management (TNSM), 2018.
J	From Megabits to CPU Ticks: Enriching a Demand Trace in the Age of MEC	IEEE Transactions on Big Data, 2018.
J	Joint Optimization of Edge Computing Architectures and Radio Access Networks	IEEE Journal on Selected Area in Communications (JSAC) SI on Emerging Technologies in Tactile Internet and Backhaul/Fronthaul Networks
J	Cost and availability aware resource allocation and virtual function placement for CDNaaS provision	IEEE Transactions on Network and Service Management (TNSM), 2018.
J	ORLA/OLAA: Orthogonal Coexistence of LAA and WiFi in Unlicensed Spectrum	ACM/IEEE Transactions on Networking (TON), 2018.
J	The RICH Prefetching in Edge Caches for In-Order Delivery to Connected Cars	IEEE Transactions on Vehicular Technology (TVT), Jan. 2019
J	Cellular access multi-tenancy through small-cell virtualization and common RF front-end sharing	Elsevier Computer Communications, 2018.
J	VNF Placement and Resource Allocation for the Support of Vertical Services in 5G Networks	ACM/IEEE Transactions on Networking (TON), 2019

J	A Machine Learning approach to 5G Infrastructure Market optimization	IEEE Transactions on Mobile Computing (TMC), 2019
J	Modeling Mobile Edge Computing Deployments for Low Latency Multimedia Services	IEEE Transactions on Broadcasting, accepted 2019
J	Impact of Virtualisation Technologies on Virtualised RAN Midhaul Latency Budget: A Quantitative Experimental Evaluation	IEEE Communications Letters, accepted 2019
J	Latency-aware Resource Orchestration in SDN-based Packet over Optical Flexi-Grid Transport Networks	IEEE/OSA Journal of Optical Communications and Networking, 2019
J	A Blockchain-Based Network Slice Broker for 5G Services	IEEE Networking Letters 2019
J	Artificial Intelligence for Elastic Management and Orchestration of 5G Networks	IEEE Wireless Communications Magazine
J	MANOaaS: A Multi-tenant NFV MANO for 5G	IEEE Communications Magazine
J	LaSR: A Supple Multi-Connectivity Scheduler for Multi-RAT OFDMA Systems	IEEE Transaction on Mobile Computing
B	Slicing challenges for Operators	Emerging Automation Techniques for the Future Internet, IGI Editor.
C	Enabling Vertical Industries Adoption of 5G Technologies: a Cartography of evolving solutions	European Conference on Networks and Communications (EUCNC 2018), June 2018, Ljubljana, Slovenia.
C	The Vertical Slicer: Verticals' Entry Point to 5G Networks'	European Conference on Networks and Communications (EUCNC 2018), June 2018, Ljubljana, Slovenia.
C	Experimental Evaluation of Orchestrating Inter-DC Quality-enabled VNFFG Services in Packet/Flexi-Grid Optical Networks	44th European Conference on Optical Communication (ECOC), September, Roma, Italy.
C	Latency-aware Network Service Orchestration over an SDN-controlled Multi-Layer Transport Infrastructure	20th International Conference on Transparent Optical Networks (ICTON), July 2018, Bucharest, Romania.
C	Encapsulation Techniques and Traffic Characterisation of an Ethernet-based 5G Fronthaul	19th International Conference on Transparent Optical Networks (ICTON) July 2018, Bucharest, Romania.
C	Support of Safety Services through Vehicular Communications: The Intersection Collision Avoidance Use Case	AEIT Automotive 2018
C	How Should I Slice My Network? A Multi-Service Empirical Evaluation of Resource Sharing Efficiency	ACM International Conference on Mobile Computing and Networking (MobiCom), October 2018, New Delhi, India.
C	On the Impact of IoT Traffic on the Cellular EPC	IEEE Global Communications Conference (Globecom)

		December 2018, Abu Dhabi, UAE
C	Latency and availability driven VNF placement in a MEC-NFV environment	IEEE Global Communications Conference (Globecom), December 2018, Abu Dhabi, UAE
C	Mobile Transport and Computing Platform for 5G Verticals: Resource Abstraction and Implementation	IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN), November 2018, Verona, Italy
C	Overbooking Network Slices through Yield-driven End-to-End Orchestration	The 14th ACM International Conference on emerging Networking EXperiments and Technologies (Conext), December 2018, Heraklion/Crete, Greece
C	5G Traffic Forecasting: If Verticals and Mobile Operators Cooperate	15th IEEE Wireless On-demand Network systems and Services Conference (WONS), January 2019, Wengen, Switzerland
C	A Utility-Driven Multi-Queue Admission Control Solution for Network Slicing	IEEE International Conference on Computer Communications (INFOCOM) April 2019, Paris, France
C	DeepCog: Cognitive Network Management in Sliced 5G Networks with Deep Learning	IEEE International Conference on Computer Communications (INFOCOM) April 2019, Paris, France
C	Experimental Evaluation of Dynamic Resource Orchestration in Multi-Layer (Packet over Flexi-Grid Optical) Networks	23rd Conference On Optical Network Design And Modelling (ONDM), May 13-16, 2019, Athens, Greece
W	Understanding QoS applicability in 5G transport networks	WS3: Second Edition of the Workshop on Control and Management of Vertical Slicing including the Edge and Fog Systems, IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Valencia, June 2018
W	Multi-domain VNF mapping algorithms	WS3: Second Edition of the Workshop on Control and Management of Vertical Slicing including the Edge and Fog Systems, IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Valencia, June 2018
W	Towards a resilient OpenFlow channel through MPTCP	WS3: Second Edition of the Workshop on Control and Management of Vertical Slicing including the Edge and Fog Systems, IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), Valencia, June 2018
W	Orchestrating Inter-DC Quality-Enabled VNFFG Services in Packet / Flexi-Grid Optical Networks	5th International Workshop on Elastic Networks Design and Optimisation (ELASTICNETS 2018), 21-22 June 2018, Valencia (Spain).
W	Arbitration Among Vertical Services	IEEE PIMRC 2018 Workshop 5G Cell-Less Nets, September 2018, Bologna,

		Italy
W	Resource Orchestration of 5G Transport Networks for Vertical Industries	IEEE PIMRC 2018 Workshop 5G Cell-Less Nets, September 2018, Bologna, Italy
W	Wireless Interface Agent for SDN mmwave multi-hop networks: design and experimental evaluation	The 2nd ACM Workshop on Millimeter Wave Networks and Sensing Systems, October 2018, New Delhi, India
W	A Framework for Orchestration and Federation of 5G Services in a Multi-Domain Scenario	ACM CoNEXT workshop, EM-5G 2018, 1st International Workshop on Experimentation and Measurements in 5G, December 2018, Heraklion, Greece
W	Optimizing 5G networks	Informatica para todos
W	Experimental Demonstration of a Packet-based Protection for Seamlessly Recovering from a Multi-layer Metro Network Fronthaul Failure	The 5th IEEE INFOCOM Workshop on Computer and Networking Experimental Research using Testbeds 2019 (IEEE CNERT 2019), April 2019, Paris, France

TABLE 3: PUBLICATION IN Y3

	Title	Published in
J	CDN Slicing over a Multi-Domain Edge Cloud	IEEE Transactions on Mobile Computing (TMC)
J	Service Shifting: a Paradigm for Service Resilience in 5G	IEEE Communications Magazine
J	RL-NSB: Reinforcement Learning-based 5G Network Slice Broker	IEEE/ACM Transactions on Networking (ToN)
J	Resource Sharing Efficiency in Network Slicing	IEEE Transactions on Network and Service Management (TNSM)
J	A MEC-based Extended Virtual Sensing for Automotive Services	IEEE Transactions on Network and Service Management (TNSM)
J	Dynamic Latency-aware Resource Orchestration over Distributed Optical Telco Clouds in 5G Scenarios	Elsevier Computer Networks (COMNET)
J	Integrating Fronthaul and Backhaul Networks: Transport Challenges and Feasibility Results	IEEE Transactions on Mobile Computing
J	DeepCog: Optimizing Resource Provisioning in Network Slicing with AI-based Capacity Forecasting	IEEE Journal on Selected Areas in Communications (JSAC)
J	Exploiting flexible functional split in converged software defined access networks	IEEE/OSA Journal of Optical Communications and Networking
C	Exposing radio network information in a MEC-in-NFV environment: the RNISaaS concept	IEEE Conference on Network Softwarization (Netsoft), June 2019, Paris, France
C	On the Deployment of Large Scale NSaaS	European Conference on Networks and Communications (EUCNC 2019), June 2019, Valencia, Spain.
C	5G-TRANSFORMER Service Orchestrator: design, implementation, and evaluation	European Conference on Networks and Communications (EUCNC 2019), June 2019, Valencia, Spain.

C	Latency-driven Network Slices Orchestration	IEEE INFOCOM'19
C	A MEC-based Extended Virtual Sensing for Automotive Services	AEIT International Conference of Electrical and Electronic Technologies for Automotive (AEIT AUTOMOTIVE), July 2019, Turin, Italy.
C	Optical networking for 5G Xhaul and service convergence: transmission, switching and control enabling technologies	European Conference on Optical Communication (ECOC), September 2019, Dublin, Ireland.
C	Dynamic slicing of RAN resources for heterogeneous coexisting 5G services	IEEE Global conference on Communications (Globecom), December 2019, Hawaii, USA.
C	vrAIn: A Deep Learning Approach Tailoring Computing and Radio Resources in Virtualized RANs	The ACM Annual International Conference on Mobile Computing and Networking (Mobicom), October 2019, Los Cabos, Mexico
C	5GEN: A tool to generate 5G infrastructure graphs	IEEE Conference on Standards for Communications and Networking (CSCN), October 2019, Granada, Spain
C	iFUSION: Standards-based SDN Architecture for Carrier Transport Network	IEEE Conference on Standards for Communications and Networking (CSCN), October 2019, Granada, Spain
C	Towards the quest for 5G Network Slicing	IEEE CCNC2020 (accepted)
W	White paper on MANO chapter	5GArch 2019: International Workshop on 5G Architecture, held with EUCNC, June 2019, Valencia, Spain

TABLE 4: TECHNOLOGY DEMONSTRATIONS IN Y2

Title	Event
Robotic Control Leveraging a Radio Network Information Service (RNIS)	EuCNC 2018
Orchestrating entertainment network service deployment in a hybrid cloud with Cloudify	EuCNC 2018
Creating a media-oriented slice through the 5G-TRANSFORMER vertical slicer	EuCNC 2018
Overbooking Network Slices End-to-End: Implementation and Demonstration	ACM SIGCOMM 2018
Experimental Demonstration of a 5G Network Slice Deployment through the 5G-TRANSFORMER Architecture	ECOC 2018
Deploying a containerized ns-3/LENA-based LTE mobile Network Service through the 5G-TRANSFORMER platform	IEEE SDN-NFV 2018
Experimental Demonstration of a 5G Network Slice Deployment Exploiting Edge or Cloud Data-Centers	IEEE OFC 2019
Virtual CDN service deployment across multiple sites using 5G-TRANSFORMER architecture	ICT 2018
Latency-driven Network Slices Orchestration	IEEE INFOCOM 2019

TABLE 5: TECHNOLOGY DEMONSTRATION IN Y3

Title	Event
Demo of the entertainment use cases of the project	EuCNC 2019
Demos of the automotive use cases of the project	EuCNC 2019
Demos of the mvno use cases of the project	EuCNC 2019
Demos of the cloud robotics use cases of the project	EuCNC 2019
Demo of the robotic immersive teleoperation PoC (jointly with 5G-CORAL project)	EuCNC 2019
5G connected hospital use case, with radio access network and edge deployed locally and remote connection with core network hosted on BCOM NFVi central cloud	EuCNC 2019
Mobile Cloud Robotics Demonstration	Mobile Cloud Robotics Show'19 / Fronthaul & Backhaul Convergence for 5G Use Cases event
How 5G is transforming the business of Media & Entertainment	NEM 2019
5G connected hospital use case, with an on-site edge cloud as NFVi	MWC 2019
Use case in the media & entertainment vertical sector	IBC 2019
360 video service for fan engagement	PGA golf tour - Madrid
Provisioning and automated scaling of network slices for virtual Content Delivery Networks in 5G infrastructures	ACM Twentieth International Symposium on Mobile Ad Hoc Networking and Computing (Mobihoc), July, Catania, Italy.
Composing Services in 5G-TRANSFORMER	ACM Twentieth International Symposium on Mobile Ad Hoc Networking and Computing (Mobihoc), July, Catania, Italy.
Demonstration of Fault Localisation and Recovery of Optical Connectivity Supporting 5G vRAN	European Conference on Optical Communication (ECOC), September 2019, Dublin, Ireland.
Demo: vrAIn Proof-of-Concept – A Deep Learning Approach for Virtualized RAN Resource Control	The ACM Annual International Conference on Mobile Computing and Networking (Mobicom), October 2019, Los Cabos, Mexico
Experimental Demonstration of Live Migration Impact on Virtualized 5G Network using Federated Testbeds	IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN), November 2019, Dallas, Texas, USA.
Automated deployment and scaling of automotive safety services in 5G-TRANSFORMER	IEEE Conference on Network Function Virtualization and Software Defined Networks (NFV-SDN), November 2019, Dallas, Texas, USA.
eHealth event in Madrid	Evento de demostración del Sistema Automático de Emergencias 5G, 27 November 2019

TABLE 6: ACADEMIC ACTIVITIES IN Y2

Title	Level	Status
eNB split functions (Distributed Unit --- DU --- and Central Unit --- CU) virtualization and its impact on fronthaul available latency budget.	PhD	Ongoing
Resource Orchestration in Virtualized Networks through SDN-enabled OpenStack	PhD	Ongoing
Software Defined Networking based mobility management in small cells	PhD	Ongoing
Mechanisms to integrate and enhance NFV and MEC	PhD	Ongoing
Design and optimization of solutions for discovery and federation for NFV in edge & fog scenarios	PhD	Ongoing
Enhanced Connectivity in wireless mobile programmable networks	PhD	Defended
Development of an Orchestrator interface for OpenAirInterface5G (OAI)	Master	Defended
Development of a prototype 5G RAN orchestrator	Master	Defended
Graphical interface for an SDN monitoring platform	Master	Defended

TABLE 7: ACADEMIC ACTIVITIES IN Y3

Title	Level	Status
eNB split functions (Distributed Unit --- DU --- and Central Unit --- CU) virtualization and its impact on fronthaul available latency budget.	PhD	Ongoing
Resource Orchestration in Virtualized Networks through SDN-enabled OpenStack	PhD	Ongoing
Software Defined Networking based mobility management in small cells	PhD	Ongoing
Mechanisms to integrate and enhance NFV and MEC	PhD	Ongoing
Design and optimization of solutions for discovery and federation for NFV in edge & fog scenarios	PhD	Ongoing
NFV for automotive services in 5G	PhD	Ongoing
Network virtualization and 5G services	PhD	Ongoing
Design and Performance evaluation of Java based virtualized network resource Orchestrator	Master	Defended
5G for automotive applications	Master	Defended
Study of anti-congestion algorithms for autonomous and connected vehicles	Master	Defended
C-V2X Applications for a 5G network testbed exploiting OpenAirInterface framework and Multi-Access Edge Computing	Master	Defended
Connected cars and traffic flow control	Master	Ongoing
Kubernetes as a Virtual Infrastructure Manager (VIM) for MEC	Master	Ongoing

TABLE 8: ORGANIZATION OF EVENTS IN Y2

Title	Event
Workshop on Experimentation and Measurements in 5G, December 2018, Heraklion, Greece	Co-located with the 14th ACM International Conference on emerging Networking Experiments and Technologies (CoNext). Jointly organized with 5G-CORAL project.

2nd Multi-provider, multi-vendor, multi-player orchestration: from distributed cloud to edge and fog environments in 5G, June 2018, Ljubiana, Slovenia.	Co-located with European Conference on Networks and Communications (EUCNC 2018).
Workshop 'From cloud ready to cloud native transformation: What it means and Why it matters', June 2018, Ljubiana, Slovenia.	Co-located with European Conference on Networks and Communications (EUCNC 2018).
2nd Workshop on Control and Management of Vertical Slicing including the Edge and Fog Systems (COMPASS), June 2018, Valencia, Spain	Co-located with IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB)
Vertical-Oriented Service Programmability: Design and Optimization of 5G Cell-Less Networks, Bologna, Italy 2018.	Co-located with IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)
Emerging 5G Business Models: Opportunities for SMEs and large companies - lessons from 5G PPP (5G-EBM) Workshop, June 2019, Valencia, Spain.	Co-located with European Conference on Networks and Communications (EUCNC 2019).
Seventh International Workshop on Cloud Technologies and Energy Efficiency in Mobile Communication Networks (CLEEN 2019), Marrakech, Morocco, 2019	Co-located with IEEE Wireless Communications and Networking Conference (WCNC).

TABLE 9: ORGANIZATION OF EVENTS IN Y3

Title	Event
Emerging 5G Business Models: Opportunities for SMEs and large companies - lessons from 5G PPP (5G-EBM) Workshop, June 2019, Valencia, Spain.	Co-located with European Conference on Networks and Communications (EUCNC 2019).
From cloud ready to cloud native transformation, Workshop	Co-located with European Conference on Networks and Communications (EUCNC 2019).
5GArch 2019: International Workshop on 5G Architecture, Workshop	Co-located with European Conference on Networks and Communications (EUCNC 2019).
ETSI MEC Meeting #17	One of the periodic ETSI MEC Industry Specification Group (ISG) took place in Madrid (#17).
eHealth event in Madrid	Evento de demostración del Sistema Automático de Emergencias 5G, 27 November 2019
eHealth workshop in Madrid	5G y la mejora de la atención a emergencias (tentative, final title to be defined), to be held in December 2019

TABLE 10: PARTICIPATION TO EVENTS AND TALKS IN Y2

Title	Type	Event
5G Networks for Industry Verticals	Keynote	IEEE 5G Summit Tanger
Mobile Edge Computing (MEC): a 5G Enabler	Keynote	IEEE 5G Summit Marrakech (http://www.5gsummit.org/marrakesh/)
Overbooking 5GNetworks	Keynote	IEEE CSCN'18
"5G Mobile Platforms for Industry Verticals"	Keynote	IEEE Globecom'2018 (Backnets workshop)
Panelist at RAN WORLD 2018 in the Network Slicing Panel, where 5G-TRANSFORMER's vertical slicer architecture was presented	Panel	RAN WORLD 2018 (http://www.ranworldevent.com/ran-world-2018-agenda)
Panelist at GLOBECOM'18 Industry Panel on "5G Network Slice Management"	Panel	IEEE Globecom 2018 (https://globecom2018.ieee-globecom.org/program/industry-program#ip04)
Network Slicing Landscape: A holistic architectural approach, orchestration and management with applicability in mobile and fixed networks and clouds	Tutorial	IEEE Netsoft 2018 (http://netsoft2018.ieee-netsoft.org/program/tutorials/)
Cloud Native for Vertical Services	Talk	EuCNC 2018
Entry point of verticals to 5G systems: the 5G-TRANSFORMER vertical slicer	Talk	Webinar in telecomsradar (https://telecomsradar.com/webinar/entry-point-of-verticals-to-5g-systems-the-5g-transformer-vertical-
Service Orchestration and Federation for Verticals in 5G	Talk	Webinar in telecomsradar.com (https://telecomsradar.com/webinar/service-orchestration-and-federation-for-verticals-in-5g/)
5GEx concepts and how they evolve together with 5G-Crosshaul into 5G-TRANSFORMER	Talk	Webinar in telecomsradar.com (https://telecomsradar.com/webinar/5gex-concepts-and-how-they-evolve-together-with-5g-crosshaul-into-5g-transformer/)
Presentation of the 5G-TRANSFORMER Project	Talk	10ª Conferencia del Programa Marco de Investigación e Innovación de la UE en España (10th Conference of the EU Research and Innovation Framework Program in Spain)
Presentation of 5G-TRANSFORMER	Talk	"5GDay: OSM & 5GResearch", colocated with 5th OSM MANO hackfest
An Experimental View on 5G Research Projects for Edge Cloud: From the Lab to the Field	Talk	IEEE Future Network Workshop
All conference and workshop publications have been presented in their corresponding venue	Talk	Several international conferences and workshops (see publications table)

TABLE 11: PARTICIPATION TO EVENTS AND TALKS IN Y3

Title	Type	Event
Panelist in the panel session of the workshop: "5GArch 2019: International Workshop on 5G Architecture", June 20th	Panel	5GArch 2019: International Workshop on 5G Architecture, hold with EUCNC 2019.
Panelist at IEEE ICC 2019 Workshop: 5G-Trials – From 5G Experiments to Business Validation called Challenges in 5G Trials	Panel	IEEE International Conference on Communications (ICC) 2019, Shanghai, China
5G new opportunities for verticals and technology providers: an SME viewpoint	Talk	"Workshop 5: Emerging 5G Business Models", Co-located with European Conference on Networks and Communications (EUCNC 2019).
5G & OpenSource can create Unlimited Opportunities	Talk	"Workshop 5: Emerging 5G Business Models", Co-located with European Conference on Networks and Communications (EUCNC 2019).
Exploiting Programmable and Reconfigurable Hardware in 5G	Talk	IEEE Summer Tropical Meetings Summer Series, July 2019, Florida, USA.
Cooperative Information Manager (CIM) (creation and purpose)	Talk	Presentation at 5GAA, WG MEC meeting
Description of 5GT-SO module	Talk	5Growth consortium
Description of 5GT-SO module	Talk	5GEVE consortium
"Overbooking 5G Networks for Industry Verticals"	Talk	IEEE 5G World Forum 2019 (Dresden).
"Overbooking 5G Networks"	Talk	2nd Annual World 5G Summit (Barcelona, 10-11 October)
"AI-based Overbooking of 5G Networks"	Talk	European Big Data Value Forum (Helsinki, 14-16 October)
All conference and workshop publications have been presented in their corresponding venue	Talk	Several international conferences and workshops (see publications table)

3.1.1 Common Dissemination Booster (CDB)

The Common Dissemination Booster (CDB) [23] is a service from the European Commission which encourages projects to come together to identify a common portfolio of results and shows them how best to disseminate to end-users, with an eye on exploitation opportunities. 5G-TRANSFORMER formed a CDB group, named "CDB04-5G-Transformer", with 5G-Crosshaul and 5G-Coral: all projects deal with the orchestration and management of services, which may encompass different transport domains as well as services residing at the edge, the three projects also deal with federation of different administrative domains (or at least, combination of heterogeneous domains) and slicing with special focus on vertical applications. The application was approved for all the five services available in the CDB portfolio. The

original timeline is reported in Figure 1 where the initial time "0" refers to the kick-off meeting held on May 14, 2018. However, it was conveniently adapted, in particular service 5 to reach June 2019, during which EuCNC19 and the SME exploitation workshop are taking place.

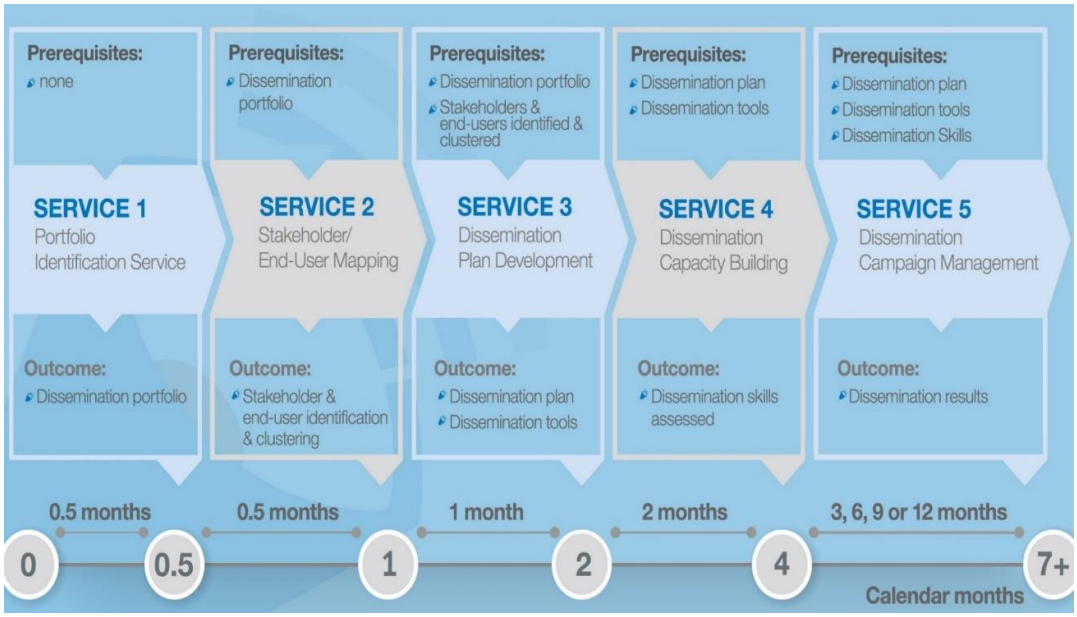

FIGURE 1: COMMON DISSEMINATION BOOSTER SERVICE RANGE AND TIMELINE

As part of the CDB, all services have been completed since CDB activities kick-off in May 2018. The following paragraphs explain the undertaken activities in each of the services.

3.1.1.1 Service 1. Portfolio Identification

Service 1 consisted in identifying dissemination activities that can be done in common among all projects of the "CDB04-5G-Transformer", which is the name for the whole CDB including all projects. A series of discussions were set up to put in common a list of such services according to the following objectives:

- Objective 1: Communication outcomes of the three projects to the widest possible audience, including non-technical audiences.
- Objective 2: Ensure technical dissemination reaches the relevant industrial and academic communities.
- Objective 3: Maximize the impact of project outcomes through coordinated exploitation activities.
- Objective 4: Plan the activities for the dissemination and exploitation of results after the end of the funding lifecycle.

The main conclusions of Service 1 "Portfolio Identification" for the CDB04-5G-TRANSFORMER Group are:

- Capitalize on the ground-breaking results of 5G-Crosshaul by strengthening the links between the projects in communications messages and common dissemination actions. Highlight the key results for 5G and the EU 5G PPP with its focus on vertical industries. Leverage partner reputations and showcase the 5G PPP collaborative spirit.

- Produce a concise joint dissemination plan that can evolve with the projects. Identify events of mutual benefit and other actions where you can leverage commonalities. Focus initially on more technical events and subsequently reach out to vertical stakeholders.
- Be prepared to evolve our communications, websites and social media campaigns towards the ultimate end-users as the on-going projects reach greater maturity. Make sure you understand their information needs and knowledge of 5G so your messages and discussions are easily understood.
- Showcase the important work being done on standardization, including the involvement of partners from the verticals. Each project can have their own visual and "boost" it with a common image that can be promoted across the 5G PPP, standards groups and other industry networks.

In this direction, a self-assessment questionnaire filled in by each of the projects was used to identify the complementary research challenges among the projects in order to look for synergies in terms of dissemination as well as the differentiators of each of the projects, their positioning, and strengths and weaknesses. As a conclusion, some recommendations were generated.

3.1.1.2 Service 2. Stakeholder/End-User Mapping

The main task of Service 2 was stakeholders and dissemination network mapping (the specific title is CDB Service 2: Stakeholder User Mapping).

The main outcomes of this service for the CDB04-5G-TRANSFORMER group are:

- Identifying priority stakeholders and gauging current levels of engagement, interest and influence.
- Defining actions to improve and increase levels of engagement. Specific actions are matched against the barriers to engagement and dissemination.
- Providing practical dissemination networks for each priority stakeholder group, thus lowering barriers to engagement.
- Offering practical tips on the most effective dissemination channels for use by the Project Group based on an analysis of current practices and appeal to the stakeholder groups.

The main conclusions of Service 2 were:

STAKEHOLDER ENGAGEMENT (influential to very influential)

Industry engagement: Dedicate efforts on direct engagement with priority stakeholders and increase this over time. Common stakeholders include: large enterprise (supply side/value chain); Start-ups and SMEs (innovators/value chain); vertical industries (large and small businesses).

5G-Transformer also indicates mainstream press and media as a target group. Engagement with local/national media outlets will benefit the Project Group directly or indirectly.

Academia and Industrial Research: The main recommendation here is to increase buy-in within the Project Group academia/industrial research partners to increase visibility and engagement across the industry to increase awareness and build branding and reputation.

Standardisation and Open Source: The CDB-team also recommends showcasing

contributions to the major standards organisations and open source communities for 5G.

They are also important building blocks towards the exploitation of results.

NEW DISSEMINATION ASSETS FOR CDB04-5G-TRANSFORMER

The dissemination networks are a core asset for facilitating and increasing engagement with the priority stakeholders, while boosting actions for strategic dissemination and exploitation of results.

The recommended dissemination channels will help the Project Group improve its approach to communicating project innovations, increase visibility and facilitate engagement with priority stakeholders outside the Project Group.

3.1.1.3 Service 3. Dissemination Plan Development

Service 3 developed a plan to increase dissemination based on the work done in previous services. The objective of this Plan is to help CDB04-5G-TRANSFORMER share results across wider geographies and variety of stakeholders detailed in the Service 2 report.

Specific objectives of the Plan are:

- Extending reach to stakeholders by leveraging the extensive network provided in CDB Service 2 and enabling the project group to boost exploitation potential. Actions include building up a community of stakeholders from relevant vertical industries and SMEs with a targeted engagement plan. Other actions seek to identify opportunities for increasing visibility with the press and media (telecommunications, national and local press). Identifying opportunities for joint demo presentations at large-scale industry events.
- Creating stronger dissemination and exploitation links between the ground-breaking research from 5G PPP phase 1 project, 5G-Crosshaul, and continued successful co-operation between industry and research experts in 5G-TRANSFORMER and 5G-CORAL.

Building on the skills development in CDB Service 4 and the implementation of the plan in CDB Service 5, this report will pave the way to increased impacts at:

- 5G events technical events, e.g. EuCNC 2019/7th Global 5G event.
- An SME workshop capturing benefits for this important stakeholder group in the 5G ecosystem.

3.1.1.4 Service 4. Dissemination Capacity Building

Service 4 consisted in providing the skills to the projects community to appropriately conduct dissemination. After a questionnaire was circulated to the key people involved in dissemination, an online course on the needed skills was prepared for them. The course consists of three modules:

- First, the strategy module consisted in learning to define objectives, the target stakeholders, the value proposition, the channels, timeline, and roles.
- Second, the implementation module focused on the tools to use, including social media, organization of events, or video preparation.
- Third, the monitoring module focused on measuring the impact.

3.1.1.5 Service 5. Dissemination Campaign Management

The goal of Service 5 was to ensure that the dissemination campaign was performed according to the dissemination plan in the targeted events, in this case, EuCNC 2019 and the SME workshop (i.e., the exploitation-oriented workshop of 5G-TRANSFORMER). The workshop was successfully organized together with several other projects (e.g., Global 5G, 5G-CORAL, 5G-EVE). As of the time of writing this deliverable, the final dissemination material is under preparation, including: a final video of the innovations of the CDB group, a joint logo for the final dissemination of results, and a social media guide to maximize communication and dissemination.

4 Explanation of the work carried out by beneficiaries and Overview of the progress

4.1 Objectives

This section is devoted to present the progress towards the fulfilment of the project objectives. For each of the objectives identified in the Description of Action (DoA), we present the details on how they have been tackled technically and by which WP.

Objective 1	5G-TRANSFORMER key concept validation and proof of concept	
Description	Demonstration and validation of 5G-TRANSFORMER technology components designed and developed in WP1, WP2, WP3 and WP4, and integrated in WP5 in an E2E 5G testbed.	
R&D Topics	WP/task	Details
Experimental validation of 5G-TRANSFORMER components and integrated platform.	WP5/T5.1	• Update on the different trial sites that compose the 5G-TRANSFORMER testbed, including updates regarding the end to end integration of the different components of the 5G-TRANSFORMER platform. Described in D5.2 [15].
	WP5/T5.2	• Implementation, integration and demonstration plans for the tests and Proofs-of-Concept (PoCs). Described in D5.2, D5.3 [17] and D5.4 [18].
	WP5/T5.3 WP6/T6.2	• 4 PoCs shown at EuCNC 2019. • 3 demos performed. • Results provided and evaluation done for all verticals involved in the project. Described in D5.3 and D5.4.
Verification	WP/task	Details
Demonstration of three verticals, namely automotive, eHealth and media distribution, over 5G-TRANSFORMER platform, having diverse requirements.	WP5/T5.1 WP5/T5.2 WP5/T5.3	• Demonstrations using the final release of 5G-TRANSFORMER platform have been performed for: ○ eHealth: on July and November 2019. ○ Entertainment: on October 2019 during the Golf Spanish Open. ○ Automotive: on November 2019 at CRF premises.
Demonstration integrating two federated domains.	WP5/T5.1 WP5/T5.2	• The federation feature of the 5G-TRANSFORMER platform has been successfully executed for the eHealth PoC. The service is instantiated using resources from CTTC and 5Tonic labs. Details, along with measurements and assessment results are collected in D5.4
Performance evaluation of algorithms in the field fulfilling vertical SLAs as well as 5G-relevant KPIs on	WP5/T5.1 WP5/T5.2	• D5.3 describes the PoCs performed, the experiments, measurements and results obtained from those PoCs and the KPIs evaluation.

throughput, latency and energy.		
Exhibiting at flagship events such as MWC 2018/19.	WP5/T5.3	• 2 demonstrations were performed at MWC'19 • At EuCNC'19 it was shown: ○ 3 proof of concepts (PoCs) based on vertical-oriented use cases. ○ 1 joint 5G-CORAL/5G-TRANSFORMER PoC (based on e-Industry).
Objective 2	Design a reference architecture for 5G-TRANSFORMER platform	
Description	Design a baseline architecture of the 5G-TRANSFORMER system that will serve as a reference for the technical work of WP2, WP3, WP4 and WP5. A first analysis of use-cases relevant to vertical sectors will set the requirements posed in the architectural design. The architecture will be validated through a techno-economic study and thorough implementation.	
R&D Topics	WP/task	Details
Analysis of 5G use-cases relevant for verticals and their requirements.	WP1/T1.1	• An analysis of the vertical scenarios from different perspectives, providing a robust and coherent set of requirements for the architecture design has been performed and reported in D1.1 [1]. The requirements are refined and complemented in D1.2 [2].
5G-TRANSFORMER reference architecture design.	WP1/T1.2	• A description of the initial system design of the 5G-TRANSFORMER architecture, including the design of the main building blocks and the interfaces among them, as well as the interface towards the verticals is reported in D1.2 [2]. Additionally, it defines the high-level workflows among the building blocks for a set of basic service operations, showing the required interactions among the different building blocks on the related interfaces.
Study on techno-economic impact of 5G-TRANSFORMER	WP1/T1.3	• A detailed techno economic analysis covering both analytical and experimental results to characterize the behaviour of the project ecosystem is reported in D1.4 [4].
Verification	WP/task	Details
Report a reference architecture design for 5G-TRANSFORMER.	WP1/T1.2	• Reference architecture design is included in D1.2 [2] and a refined version is reported in D1.3 [3].
Report on techno-economic study.	WP1/T1.3	• Detailed analytical and experimental techno economic study is reported in D1.4. The study provided an analysis of the Economic implications for the provisioning of services in 5G-T per use case per vertical domain and a model for a general Cost structure for the 5GT platform that assesses the project's impact on verticals' and providers' OPEX and CAPEX.
Implementation of the architecture and verification of the contribution to KPI.	WP1/T1.2 WP2 WP3 WP4 WP5	• Delivery of a first release of implementation including the basic features defined by the reference architecture design in D1.2 [2], and a second release of implementation including

		extended features and enhancements as reported in the refined architecture design of the platform in D1.3 [3]. A third release has also been provided in D5.5 [19], integrating all the components of the 5GT platform and fixing the bugs encountered during the PoCs. This release has been used during the final KPI assessment campaign, with results documented in D5.4 [18].
Objective 3	Design a flexible Mobile Transport and Computing Platform (MTP)	
Description	Design 5G-TRANSFORMER MTP by departing from 5G-Crosshaul MANO and adding native support for MEC along with transport control and virtualization technologies to flexibly place and move VNFs across the MTP.	
R&D Topics	WP/task	Details
Evolution of 5G-Crosshaul to encompass MEC, optimization of flexible placement of VNFs in a multi-tenant scenario.	WP2/T2.1 WP2/T2.2	• The support of MEC has been defined and implemented in the MTP platform. Specifically, algorithms for placements of VNF have been defined: Such algorithms work on the abstract views of the resources. • More details can be found in D2.1 [5], D2.2 [6] and D2.3 [7].
Multi-level, multi-criteria abstraction and network clustering for hierarchical SDN/NFV control.	WP2/T2.1 WP2/T2.2	• Abstraction algorithms have been defined for several level of details provided from the MTP to SO. A new concept for the abstraction of infrastructure that merge Radio and Transport has been defined. Moreover, novel concept of coverage area for the abstraction view has been defined in order to allow vertical to define their service in a geographical area. Extension of the MTP architecture and related interface to SO and Plug-In has been defined and implemented. • More details can be found in D2.1, D2.2, D2.3 and D1.4.
Dynamic (de-) centralization and placement of VNFs (mobile system middleware) through composition/decomposition of VNF chains.	WP2/T2.2	• Local placement algorithms have been defined; they receive as input the VNFFGs requests with different bandwidth and latency requirements from SO and place them over the infrastructure optimizing the resource usage. The algorithms have been designed, analysed and tested over different NFVI-PoPs interconnected by a packet-optical WAN. • More details can be found in D2.1, D2.2, D2.3 and D5.3 [17] for details.
Design an SDN/NFV architecture that can cope with multiple types of agents (e.g., wireless agents, packet system, optical agents).	WP2/T2.1	• Design and implementation of the SDN/NFV architecture has been done for the technology described in the following. Plug-in for Radio equipment based on commercial devices, plug in for Kuberbetes, MEC, Openstack. • More details can be found in D2.1, D2.2 and D2.4 [8].
Abstract information model	WP2/T2.2	• On the basis of the abstraction solution Defined in T2.2 for the transport, RAN, MEC and

to export parameters of MTP to the orchestrators serving the verticals (e.g., based on Transport SDN API).		application layer, corresponding information model have been defined as extension of IFA 005. Specifically, the support of MEC and Distributed Edge has been defined in an homogeneous way re-using the concept of "location info" also in case of the Radio equipment. • More details can be found in D2.1, D2.2 and D2.3.
Verification	WP/task	Details
Develop and demonstrate a proof-of-concept prototype of the MTP (TRL 3).	WP2	• MTP Software is reported in D2.2, D2.4, and D5.5. The MTP code is released in GitHub (https://github.com/5g-transformer/5gt-mtp). Moreover, it is demonstrated also in all PoC of the project (see D5.4 for details).
Objective 4	Design scalable algorithms for efficient 5G-TRANSFORMER resource orchestration: backhaul/fronthaul networking, computing, and storage	
Description	Develop and evaluate integrated management and control algorithms for resource orchestration that ensure an appropriate service delivery and optimal resource utilization, despite dynamically changing traffic loads, available computational and network resources, wireless link fluctuations, flexible functional RAN splits and heterogeneous QoS requirements.	
R&D Topics	WP/task	Details
Scalable orchestration algorithms for dynamic joint optimization of routing and RAN/MTP/Core function placement.	WP2/T2.3	• Algorithms for dynamic joint optimization of RAN/Infrastructure and Core function placement have been defined and implemented in PoC. • More details can be found in D2.2, D2.3, D5.3 and D5.4.
Novel 5G-capable routing and traffic engineering algorithms using latency and jitter, wireless transport interference, user mobility, etc.	WP2/T2.2 WP2/T2.3	• Traffic engineering algorithms have been defined and implemented. The abstract view provided by the MTP exposed such parameters independently of the specific technology. Hence the Placement algorithm makes use of that to select the more suitable resources. • More details can be found in D2.1, D2.2, D2.3 and D5.3.
Novel capacity and Quality of Experience (QoE) optimization techniques required for verticals, optimization of MEC server location and server configuration, congestion-aware caching.	WP2/T2.3	• Techniques to optimize MEC server location have been designed and are based on optimized PA algorithms. MEC server location has been designed in the MTP architecture as any Application server location with special ID to distinguish from the case of distributed edge and with specific parameters. • More details can be found in D2.2, D2.3 and D5.3.
Techniques for	WP2/T2.3	• The MTP allows to dynamically place and re-

path provisioning, mobility management, placement and re-location of VNFs based on multi-criteria optimization.		allocate the VNF. A suitable PA algorithm has been designed based on several criteria. • More details can be found in D2.2, D2.3, D5.3 and D5.4.
Techniques to support scalable and efficient distributed computing across heterogeneous vertical sectors.	WP2/T2.3	• Algorithms to support scalable and distributed computing have been defined and analyzed, such as the FluidRAN algorithm. Such solution has been designed with the objective to converge very quickly (see algorithm description in D2.3. and D5.3 and simulation analysis in D5.3). • Another technique has been designed to dynamically select the VM in a data center according to the status and traffic request. Description and analysis in D2.3 and D5.3.
Verification	WP/task	Details
Simulative or analytical proof of scalability, throughput, latency, and computational performance of resource management algorithms.	WP2/T2.3	• Verification of techniques for scalable techniques has been reported in D2.3. and D5.4 (see “Fluid RAN algorithm” and “VM placement algorithm”). Techniques for transport resource optimization, have been also verified and implemented in MTP and used for the several PoCs. • More details can be found in D2.3, D5.3 and D5.4.
Prototype at least one algorithm on top of 5G-Crosshaul data plane.	WP2	• In the e-Industry PoC, the dataplane for 5GCrosshaul is implemented. In this PoC, the algorithm for resources optimization and scalable placement is implemented. • More details can be found in D5.4.
Objective 5	Design a resource slicing platform for verticals (vertical slicer)	
Description	Design and develop slicing techniques to address heterogeneous vertical-tailored requirements in a common cloud plus MTP infrastructure, including connectivity and vertical functions.	
R&D Topics	WP/task	Details
Study of dynamic resource partitioning techniques for connectivity, computing and storage resources in an integrated core/MTP network.	WP3/T3.2	• Dynamic resource partitioning is done by the Arbitrator component within the 5GT-VS, which reassigns resources in case of dynamic resource shortage. The Arbitrator is described in D3.3 [10].
Dynamic and flexible placement of vertical functions.	WP4/T4.1	• One of the main tasks of the 5GT-SO is the optimized placement of vertical functions, once translated into a network service by the 5GT-VS. For this purpose, a number of VNF placement algorithms were developed and implemented inside the 5GT-SO to decide the most suitable

		and cost-efficient way to place the vertical functions according to the infrastructure topology and available free resources to support specific requirements of the vertical services, as reported in D4.3 [14].
Provide isolation across verticals and infrastructure provider.	WP3/T3.2	• Isolation is provided by mapping vertical services to different network slices, if required. This mapping is done by the Arbitrator component in the 5GT-VS. The Arbitrator is described in D3.3. The isolation among different network slices needs to be implemented by the MTP(s).
Definition of blueprints used to create network slices.	WP3/T3.1	• Vertical service blueprints and descriptors have been defined both in table-based info model and a JSON based data model. See D3.3 for additional details.
Automatic service decomposition from template to form service graphs and requirements associated with the services.	WP3/T3.2	• The blueprints described in D3.3 allow to express also composed services, which are described themselves in D1.3. Vertical-driven Service Composition and how it maps to the 5GT-VS architecture is described as well in D3.3.
Verification	WP/task	Details
Develop a proof-of-concept slicing platform for vertical services and demonstrate for three different verticals, automotive, eHealth, and media distribution.	WP3/T3.3	• Two releases of the 5GT-VS reference implementation were developed and shown in various demos, e.g. EuCNC 2019. The 5GT-VS reference implementation supports the automotive, eHealth, and media distribution use cases The 5GT-VS implementation(s) have been reported in D3.4 [11]. The demos have been reported in WP6 deliverables.
Objective 6	Design a Service Orchestration (SO) platform	
Description	Design a Service Orchestration (SO) platform in charge of service composition and orchestration of slices.	
R&D Topics	WP/task	Details
Service monitoring to verticals and mobile network operators.	WP1/T1.2 WP4/T4.2	• In the 5G-TRANSFORMER framework, each architectural component (i.e., 5GT-VS, 5GT-SO, 5GT-MTP) includes a monitoring service (as described in [3]) able to provide performance metrics and failure reports targeting the logical entities managed by each component: ○ The 5GT-MTP monitoring service produces monitoring data about the local physical and virtual resources. ○ The 5GT-SO monitoring service produces monitoring data about the managed VNFs and NFV-NS. ○ The 5GT-VS monitoring service produces monitoring data about network slices and vertical services. • The 5GT-SO Monitoring Service produces

		monitoring reports related to the performance or to failure events of the managed NFV network services and their VNFs. The monitoring reports can be used internally at the 5GT-SO, for example as triggers to auto-scaling procedures. The details about the service monitoring platform design and implementation are described in D4.3 and D4.4 [14][15].
Integration of resource and service orchestration by vertical slicing.	WP4/T4.1 WP4/T4.3	• One of the key functional components of the 5GT-SO is the Multi-Domain NFV Orchestrator (NFVO), including NFVO-NSO in charge of orchestrating the NFV-NS deployment along with their lifecycle management and related service federation operations; and NFVO-RO to orchestrate virtual resources across multiple domains and handle resource-related operations. They are implemented as part of the 5GT-SO platform, see D4.3 and D4.4.
Extension of homogeneous intent-based information and data models.	WP2 WP3 WP4	• To interact with 5GT-VS and 5GT-MTP, as well as to the peering 5GT-SO of other administrative domains, the 5GT-SO interfaces and references points have been designed based on ETSI NFV IFA specifications extended with information elements to express vertical applications and their requirements, e.g., location or latency constraints. This include the northbound interface towards the 5GT-VS (jointly with WP3), the southbound interface towards the 5GT-MTP (jointly with WP2), and the east/westbound interface to the federated 5GT-SOs. In addition, we also designed data models for the internal interfaces to connect different functional modules inside the SO based on REST API. Additional details can be found in D1.3 and D4.3.
Automated “plug-and-play” service composition of heterogeneous VNFs through appropriate abstraction, interfaces, and layering.	WP4/T4.1 WP4/T4.3	• Service composition is the process of joining already instantiated NFV-NS instances with new NFV-NS instances that need to be instantiated. The service composition as a joining process can be executed as concatenation of NFV-NS or composition of NFV-NS. The latter one was implemented in the 5GT-SO software prototype, also serving the base for service federation. See details in D4.3.
Verification	WP/task	Details
Develop and demonstrate a proof-of-concept 5G-TRANSFORMER SO prototype (TRL 3).	WP4	• The final release (R2) of the 5GT-SO software prototype was delivered in D4.4 [15] and published as open source on GitHub for download: https://github.com/5g-transformer/5gt-so. In this release, new features and functionalities and extensions of the interfaces were implemented on top of the initial design and first release (R1) provided in D4.2 [13]. The 5GT-SO reference implementation has been integrated in the PoC demonstrations of different

		5G-TRANSFORMER use cases in WP5. Besides, the 5GT-SO prototype has already been showcased in several public events (IEEE NFV-SDN 18, ICT 2018, MWC 2019, EuCNC 2019, MobiHoc 2019, IEEE NFV-SDN 19). • The service monitoring platform is in charge of producing monitoring data and reports related to the performance or failure events associated to the managed services. The final version of the service monitoring platform was released in D4.4 [15] and published as open source on GitHub for download: https://github.com/5g-transformer/5gt-mon.
Objective 7	Support orchestration of end-to-end services across federated domains	
Description	Design and develop interfaces and algorithms to federate independent administrative domains, leveraging results from 5GEx 5G-PPP phase 1 project, to orchestrate end-to-end services. Federation of services offered by multiple domains (horizontal federation) and/or verticals (vertical federation).	
R&D Topics	WP/task	Details
Federation across multiple service providers' domains aggregating networking and compute resources available in the infrastructure.	WP4/T4.3	• Service federation was designed and developed as an enhanced feature in the R2 5GT-SO to provide the process of establishing, consuming or providing NFV-NS by an administrative domain from/to other (peering/partner) administrative domain. The work included the definition of the federation procedures, workflows, interfaces and APIs, as well as federation algorithms to provide end-to-end services and aggregate resources across multiple administration domains.
Control interfaces between federated MANO platforms.	WP4/T4.3	• The 5GT-SO eastbound/westbound interface (EBI/WBI) was defined in the 5G-TRANSFORMER architecture as specified in D1.3 [3], and they were developed in the 5GT-SO prototype to provide the federation of services, as reported in D4.3 [14].
Verification	WP/task	Details
Experimental proof-of-concept (TRL 3) of successful federation between two independent administrative domains.	WP4/T4.3	• The service federation feature was developed and implemented in the 5GT-SO prototype final release, and this function has been validated and evaluated through the real test-bed experiments at CTTC and UC3M (5TONIC) as well as in the vertical demo (eHealth UC) in the scope of WP5.
Objective 8	Dissemination, standardization and exploitation of 5G-TRANSFORMER	
Description	Dissemination, standardization and exploitation of all concepts and technologies developed in the 5G-TRANSFORMER project.	
R&D Topics	WP/task	Details
Outreach communication to all stakeholders including the general public.	WP6/T6.1	• Throughout the project, the number of visits for various three month periods ranged from 6000 to 12000 and the most popular page reaching more than 2000 visits in three months and always staying above 1000 visits. Furthermore, for one-

		year periods, the website had around 16000 visitors and 36000 visits. • Number of interactions with the tweets steadily increased throughout the project, reaching 934 (twitter), 57 (Instagram), followers, and 1267 LinkedIn connections. Furthermore, up to 100K twitter impressions per quarter were reached. • A YouTube channel has been setup. Several videos have been uploaded (incl. overview and demonstration ones). YouTube videos reached 2100 visualizations in total. The most recent videos on the final demos are under preparation. • Promotional material prepared (e.g., leaflets, posters, video). The number of downloads of posters and leaflets was also monitored. The most popular leaflet almost reached 1000 downloads.
Dissemination to relevant industrial and academic communities.	WP6/T6.2	• Active participation in industrial events (like MWC 2019 and EuCNC 2019) and academic-related activities (such as Bachelor, Master and PhD programs). • Organization and participation in multiple technical events to present the project and its results and exchange ideas with other projects.
Maximization of the impact of project innovations through coordinated exploitation activities led by the innovation manager.	WP6/T6.2 WP7/T7.2	• The exploitation strategy was reported in the Communication, Dissemination, and Exploitation Plan (CoDEP) for Y2 in D6.2 [21]
Contributions to top-tier scientific journals, conferences and magazines.	WP6/T6.2	• Multiple submitted, accepted and published papers in top-tier scientific journals, conferences and magazines, as reported in D6.5 [22] and D6.7 [24].
Contributions to standardization bodies.	WP6/T6.2	• The standardization advisory committee (SAC), formed from 5G-TRANSFORMER experts related to the relevant SDOs (3GPP, IETF, ETSI MEC, and IEEE) continued its activities. The SAC supported partners to contribute to SDOs and to disseminate the project results. • The Standardization Activity Roadmap (SAR) described in D6.2 [21], was put into place, which resulted in the activities reported in D6.5 [22] and D6.7 [24]. • Contributions to IETF, 3GPP SA2 and ETSI NFV and MEC have been made, as reported in D6.5 [22] and D6.7 [24].
Generation of IPR.	WP6/T6.2	• Partners patented a total of 5 novel systems and/or methods related to the innovation outcomes of the project.

		• The project also contributed to Open Source, most notably, by making publicly available the code for all its software releases for the 5GT-VS, 5GT-SO, and 5GT-MTP, which is available through the GitHub of the project.
Verification	WP/task	Details
At least 8 publications per year in top-tier scientific journals and conferences such as WCNC, ICC, INFOCOM, GLOBECOM, IEEE COMMAG/WIRELESSMAG, IEEE/ACM ToN.	WP6/T6.2	• The second reporting period (Y2 ad Y3) of the project was very rich in terms of dissemination activities: 81 scientific publications have been published in peer reviewed journals, conferences and workshops; 30 in Journals, and 51 in conferences/ workshops. Some of these publications are joint publications with other projects.
File at least 5 patent applications.	WP6/T6.2	• 5 patent applications filed.
At least 10 adopted contributions to SDOs such as 3GPP, IETF, ETSI, IEEE, ITU, ONF.	WP6/T6.2	• 25 contributions to SDOs: 9 to 3GPP, and 16 to ETSI NFV/MEC. Out of these 25, 18 of them have been adopted.
Organization of at least 2 workshops.	WP6/T6.1	• 13 workshops organized during the second reporting period, including the SME-oriented technology exploitation workshop (co-located with EUCNC'19)
At least 2 demonstrations per year, including one at flagship event such as MWC.	WP6/T6.1	• 26 demonstrations at flagship events (incl. Mobile World Congress, EuCNC, ACM Mobicom, ACM Mobihoc, IEEE Infocom, IEEE NFVSDN).

4.2 Explanation of the work carried per WP

4.2.1 WP1

WP1 aims at designing the baseline architecture of the 5G-TRANSFORMER system that serves as a reference for the technical work of WP2, WP3, WP4 and WP5. The work carried in WP1 aims then at analyzing and specifying the requirements, the high-level system design and the associated business cases for the 5G Mobile Transport and Computing Platform. Our goal is to provide vertical industries with several levels of services and adapted features like, e.g., resources, isolation, QoS, mobility, etc. In Task 1.1, use cases from different verticals are analyzed to derive and classify their specific service requirements for the platform. Based on this analysis, we design in Task 1.2 the high level architecture, describing resources and services orchestration functions and their relations to the overall 5G transport architecture including RAN, flexible fronthaul/backhaul, Core and MEC network components. The designed architecture is then validated through implementation (work carried mainly by WP5) and through the techno-economic study of the envisioned system carried in Task 1.3.

This latter places a special emphasis on the benefits and costs of the solution for the vertical industries deployments. After the first implementation phase of the 5G-TRANSFORMER platform, a refinement work is also carried out as part of Task 1.2 in order to identify and plan the possible enhancements of the architecture in order to meet the objectives of the WP and the goals of the project.

The main achievements of WP1 over the second period are as follows:

- The refinements of the initial design of the 5G-TRANSFORMER architecture reported in deliverable D1.2 [2]. This refinement work included some extensions and enhancements to the main building blocks of the 5G-TRANSFORMER system architecture, namely 5GT-VS, 5GT-SO, 5GT-MTP, monitoring framework and interfaces and reference points. This is reported in D1.3 [3] with the rationale of why these extensions were required. The detailed extensions to the features of each building block can be found in their respective related deliverables.
- The techno economic analysis of the 5G-T platform. This work is part of T1.3 and is reported in D1.4 [4]. The study was conducted based on the modelling of the 5G-T vertical use cases demonstrated at the end of the project in WP5. It included both analytical and experimental studies on the 5G-T platform and its services cost for the vertical industries and the stakeholders. The study is concluded by a set of recommendations for the business models transformation of the vertical service use cases involved in the project.

4.2.1.1 Task 1.1: Vertical analysis and requirements

This task has terminated during the first period of the project. The technical work of the Task has been reported in D1.1 [1] and a summary of the main achievements during the first period was reported in D7.3 [26].

4.2.1.2 Task 1.2: High-level architecture design of 5G-Mobile Transport and Computing Platform for Verticals

This task is dedicated to the design of the overall 5G-TRANSFORMER architecture, supporting “verticals” and “legacy” networks, with regards to the requirements and analysis done in Task 1.1. The baseline architecture has been developed and fed into WP2/3/4 for their respective technology developments. The final outcome of the task is the system design of the 5G-TRANSFORMER architecture, which covers the underlying transport components, the main 5G network functions within 5G Edge encompassing MEC, and technological building blocks dedicated to resource and service orchestration for the vertical slices.
The technical output of Task 1.2 for the first period of the project has been reported in D1.2 [2] and a summary of the achieved objectives and partners contributions has been reported in D7.3. The final outcome will be reported in D1.4. Hereafter, we provide a summary of the achievements and partners contributions in Task 1.2 for the second period of the project:

- **The refinement of the 5G-TRANSFORMER baseline architecture**

During the second period of the project, we have worked in Task 1.2 on the refinements of the initial design of the 5G-TRANSFORMER architecture reported in deliverable D1.2 [2]. This refinement work included some extensions and enhancements to the main building blocks of the 5G-TRANSFORMER system architecture, namely 5GT-VS, 5GT-SO, 5GT-MTP, monitoring framework and interfaces and reference points, and has been described in D1.3 [3] with the rationale of why they were required.

The refined design of the 5G-TRANSFORMER architecture, as presented in Figure 1 (details in D1.3 [3]), follows the same concepts and design defined in the initial version of the baseline architecture in D1.2 [2], and the same function roles for the three main architecture components: Vertical Slicer (5GT-VS), Service Orchestrator (5GT-SO) and Mobile Transport and Computing Platform (5GT-MTP).

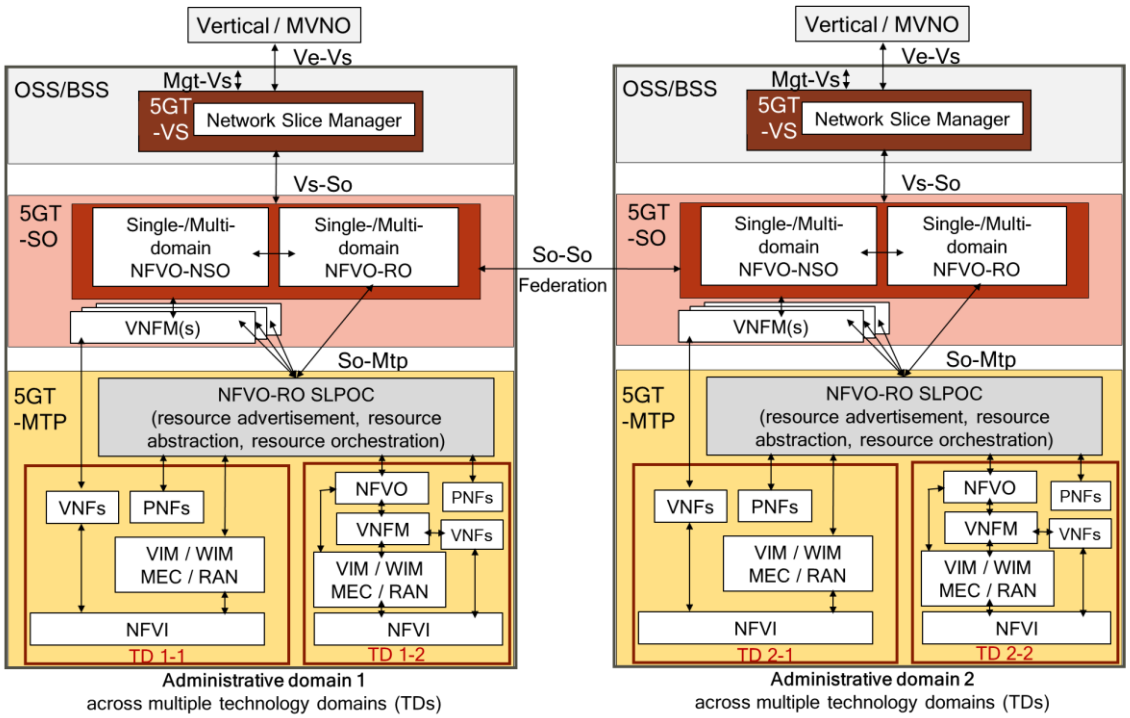

FIGURE 1: 5G-TRANSFORMER SYSTEM ARCHITECTURE

However, a number of functionalities and extended features have been added to the 5GT-VS, 5GT-SO and 5GT-MTP. These extensions were motivated by advanced research conducted in the project during the second period as well as by the ongoing development of 5G-TRANSFORMER architecture building components. They are further described in their related WP subsections of this report. Hereafter in Table 12, we summarize the main features included in the refined architecture (described D1.3 [3]) in contrast to the features available in the initial design (as described in D1.2 [2]) and in the final design (described in D1.4 [4]).

TABLE 12: SUMMARY OF FEATURES IN 5G-TRANSFORMER ARCHITECTURE DESIGN

Features in initial design	Features added in refined design	Features added in final design
Vertical Service Descriptor to Network Service Descriptor translation	Service scaling (vertical-driven, 5GT-VS driven and 5GT-SO auto-scaling)	Enhanced RAN abstraction
Initial interface towards verticals	Enhancement to vertical support with enhanced NBI towards the verticals based on the REST-based API and web-based GUI for the vertical service definition (VSB, VSD) and service configuration,	Full MEC support

	creation of new instances of vertical services at runtime directly triggered by vertical applications
Basic arbitration	Enhanced arbitration
Basic authentication and per-tenant authorization	Policy management
Basic arbitration mechanisms	Vertical service composition
Lifecycle management of simple Vertical Services and Network Slices (no service composition)	Advanced Lifecycle management of Network Slices, Network Slice Subnets with service compositions
Initial Vs-So and So-Mtp interfaces (single PoP)	Updated Vs-So and So-Mtp interfaces (also support inter-PoP and federation)
NV-NS creation, instantiation, termination and query operational status operations	NFV-NS on-boarding, NFV-NS scaling, NFV-NS service composition and federation
Resource orchestration functions	Initial RAN abstraction
Basic monitoring platform	Enhanced monitoring platform fully integrated to the system to enable: • monitor the vertical service (5GT-VS) • service assurance operations and automated SLA management (5GT-SO) • monitor the domain resources (5GT-MTP)
Cloud abstraction	Support for inter-NFVI-PoP orchestration
Resource allocation and termination for VIM and WIM domains	Enhanced placement algorithms (5GT-MTP), including functional splits
	Enhanced placement algorithms (5GT-SO) to handle the location and latency constraint
	Dynamic VNF configuration on instantiation
	Initial MEC support

All partners involved in this task participated actively to the weekly calls and the technical discussions related to the refinement of the architecture during these calls and during the WP1 dedicated sessions in plenary meetings. Many contributions were in the form of presentations during conference calls and sections in D1.3.

Orange is the leader of WP1 and was mainly leading the organization of the weekly calls of WP1 and the dedicated WP1 sessions during plenary meetings. They also contributed to the content of Annex A in D1.3 and were the host of the 5GT plenary meeting held in January 2019 in Châtillon, France.

NEC is the leader of T1.2. They led the technical discussions related to the refinement of the architecture in the WP1 dedicated weekly calls. They ensured the synchronization of the work done in WP1 with the other WPs in cross WP dedicated calls through the collection of feedback about the missing functionalities, the required improvements and interfaces gap identified in the first release implementation of the 5GT-VS, 5GT-SO and 5GT-MTP. They also contributed to D1.3.

UC3M contributed especially to the discussions related to multi-domain/federation and Scaling. They are the main editor and reviewer of D1.3 deliverable. TID participated to the discussions on the architecture refinement and contributed mainly to the multi-domain federation discussions.

NOKIA contributed especially on the scaling aspects and on the use of policies. They also contributed to the content of D1.3 and its reviewing, and presented a short paper [27] in the poster session at EuCNC 2019.

BCOM contributed on the network service federation aspects, on the composition of NS using multiple domains architecture and to the content of D1.3.

CTTC participated actively to the technical discussions of architecture refinement as they also were leading the 5GT-SO design and its interaction with other entities of 5G-T architecture, namely 5GT-VS and 5GT-MTP and design of the SO-MTP interface. They also contributed to the discussions on federation, scaling, MEC support, RAN abstraction and contributed to D1.3 sections related to 5GT-SO.

IDCC contributed to the refinement of the MTP architecture as part of the joint work between WP1 and WP2, provided inputs for standard contributions related to network slices authorization and authentication, as well as a solution that enables the network to configure and control the mutually exclusive access to network slices (submitted to 3GPP). They contributed to the discussions about federation, scaling, MEC support, RAN abstraction, and participated to the content of D1.3 and the reviewing process.

EURECOM contributed to D1.3 and led the technical discussions about MEC support. They also designed a blockchain-based broker for vertical slice composition. They also led the efforts to provide a final high-level design for MEC integration and produced a guide for MEC integration in the 5G-TRANSFORMER architecture spanning all its layers. They also updated end-to-end workflows for on-boarding and instantiation of services including MEC applications.

SSSA contributed to the SO and MTP architecture design, to discussions related to KPIs and assessment methodology. They also participated to the discussions about RAN/Radio abstraction support by the 5GT platform.

NXW contributed to the definition of detailed workflow for cross-layer monitoring and visualization of monitoring data from the verticals' graphical interface. They also were very active in architectural activities about SLAs and policy management, focusing on their implications on the interaction between Vertical Slicer and Service Orchestrator. They provided an initial analysis on the applicability of the Policy Management interface defined by ETSI NFV IFA 013 in VS-SO interface. They also contributed to the definition of the high-level workflows for service scaling and network slice subnets sharing and participated to the elaboration of D1.3 content with a focus on monitoring architecture and interfaces. They also worked on the definition of workflows for

monitoring of physical resources at MTP level and provisioning of Network Services with MEC applications.

CRF contributed to the definition of the resource scaling workflows for the automotive UC and to the definition of MEC requirements and the blueprint model refinement.

ITRI participated to the overall refinement architecture discussions. ATOS contributed to D1.3, section A 9.1.3.

Dissemination on the results of the second period has resulted in a number of publications that are reported in WP6 (see section 4.2.6). Those related to WP1 can be summarized as follows:

TABLE 13: WP1 RELATED PUBLICATIONS DURING THE SECOND REPORTING PERIOD

	Title	Published in
1	5G-TRANSFORMER. 5G Mobile Transport Platform for Verticals	5G-PPP European 5G Annual Journal 2018 https://bscw.5g-ppp.eu/pub/bscw.cgi/d257916/Euro%205G%20Annual%20Journal%202018-v1.1.pdf
2	5G-TRANSFORMER. 5G Mobile Transport Platform for Verticals	5G-PPP European 5G Annual Journal 2019 https://bscw.5g-ppp.eu/pub/bscw.cgi/d302069/Euro%205G%20PPP%20Annual%20Journal%202019-web.pdf
3	Vertical Cartography published during EUCNC'19	Available at Global 5G website: https://www.global5g.org/5g-transformer-cloud-robotics-industrial-automation https://www.global5g.org/5g-transformer-intersection-collision-avoidance-ica https://www.global5g.org/5g-transformer-emergency-health-services https://www.global5g.org/5g-transformer-emergency-services https://www.global5g.org/5g-transformer-live-streaming-0
4	Think Big Blog- Innovation blog from Telefonica	https://blogthinkbig.com/5tonic-5g-telefonica
5	"Towards the quest for 5G Network Slicing", F. Messaoudi, P. Bertin and A. Ksentini,	paper accepted for publication at IEEE CCNC2020

4.2.1.3 Task 1.3: Techno-Economic Analysis

The activity in T1.3 started at M12 and was led by Telefonica. Task 1.3 aims at analyzing the market and business implications of 5G-TRANSFORMER by identifying the business opportunities for operators and service providers in a newly constructed ecosystem leveraging on the 5G-TRANSFORMER architecture, their capability to capture value and the potential appearance of the new actors and roles.

The work in this task is based on the verticals' use cases and requirements studied in Task 1.1 and the high-level architecture components defined in Task 1.2, as well as the state of the art of Techno-Economic analysis performed in relevant phase 1 projects like 5G-Crosshaul and 5GEx.

The overall work has been conducted over two main phases: an analytical study based on modelling and an experimental study based on simulation. The followed methodology, depicted in Figure 3, takes inputs from the analytical study of the 5G-TRANSFORMER economic and technical system (including actors, scenarios of services and timeframe), injects this information into a pricing system model in order to extract information about the cost, the revenue and the profit for the 5G-TRANSFORMER services.

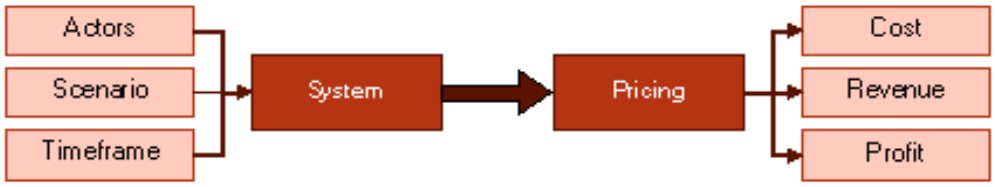

FIGURE 2: METHODOLOGY

Following the before-mentioned methodology, we started the techno economic study with the analysis of each of the 5G-TRANSFORMER vertical services by providing a model including a general description of the service, its computational resources, its connectivity assets and a network graph representing how the network functions composing the service are chained. These models and their configurations have been provided by each representative of a 5G-TRANSFORMER vertical use case, namely ATOS, CRF, ORANGE, BCOM and TEI, and served as inputs for the simulation tool that has been developed by TID for the experimental study. In order to develop this experimental study, a simulation system structure as well as a pricing scenario model has been built up using the MATLAB platform (depicted in Figure 4).

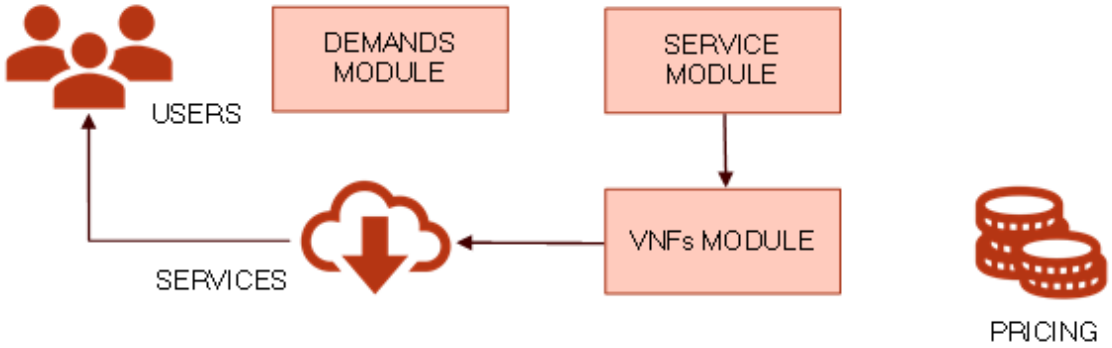

FIGURE 3: SIMULATION SYSTEM STRUCTURE

An infrastructure cost modelling has been contributed by BCOM in order to provide guidance to estimate the infrastructure cost. This guidance is especially useful for Cloud providers to estimate the budget of their platform and the benefice they may obtain from the allocation of their resources. Based on these two before-mentioned contributions, the use case modelling and the infrastructure cost modelling, we could analyse the possible demand of the 5G-TRANSFORMER vertical services and the price that should be set for them. As the services proposed in the 5G-TRANSFORMER ecosystem are novel services, it was not possible to make an estimation of the demand that they will have and therefore it was complicated to set a price for them.

Besides, a further degree of complexity has been introduced with the use of federation, as the flows of money follow a completely different approach. A sensitivity analysis has been then proposed to overcome this difficulty and study the impact of different degrees of demand on the prices and the money flows. Based on this analysis, and after simulating different scenarios, some conclusions have been reached on the

demand, service prices, the forecast utilization of the local, licenses and the negotiation of wholesale prices among overflow domains that are participating in the federation.

TID as the leader of Task 1.3 contributed actively to the work described above, by leading the techno-economic discussions during weekly conference calls and during the plenary meetings. They mainly contributed by developing the simulation tool that serves for the analysis of the Economic implications for the provisioning of services in 5G-T per use case per vertical domain and for the modeling of the Cost structure for the 5G-TRANSFORMER platform that assesses the project's impact on verticals' and providers' OPEX and CAPEX. Inputs for the modeling of the vertical use cases have been provided by the vertical representative partners.

The results of simulations using the tool developed by TID have been presented at several occasions during plenary meetings and conference calls and all the results of the work described above are reported in D1.4 [4].

4.2.1.4 Deviations

Overall, the work package proceeded as planned. No deviations have been noticed during the second period of the project.

4.2.1.5 Corrective actions

No corrective actions were needed.

4.2.2 WP2

5GT-MTP is an open source project, released with General Public License (GPLv3). From the top-down view, the 5GT-MTP is based on the Single Logical Point of Contact (SLPOC) architecture as defined in IFA028 [28] but implements additional features like abstraction, control of radio resources and control of MEC resource. The 5GT-MTP SLPOC module abstracts the resource view to the Service Orchestrator (5GT-SO) (described in D4.3 [14]) via the Northbound IFA005 interface (NBI) [29]. The SLPOC is connected to different plugins; the transport and radio Wide Infrastructure Manager (WIM) plugins, the Virtual Infrastructure Manager (VIM) plugin, Radio plugin and the MEC plugin. These plugins expose different resources view to the SLPOC via the Southbound IFA005 interface (SBI). In R2, two additional REST API are added to the SBI to handle Radio and MEC resources. Note that the MEC specific operations are handled according the ETSI MEC 010-2 [30]. Moreover, in this release two additional interfaces were added. The first is used to communicated with the Placement Algorithm (PA) to optimize the resource usage, while the second (called MON IF) is used to communicate with the 5GT Monitoring platform (based on Prometheus) and triggers monitoring tasks on the controlled resources (MEC, Radio, WIM, VIM).

4.2.2.1 Task 2.1: MTP orchestrator: architecture, procedures, API

In the second reporting period, the 5GT-MTP platform introduces new features and new building blocks with respect to the initial architecture specification, reported in D2.1 [5], and the first release (R1) of the prototype, delivered in D2.2 [6]. Moreover, integration and test have been done.
Support for the several PoCs in terms of debugging, implementation and test have been carried out also after the conclusion of WP2 in May 2019.

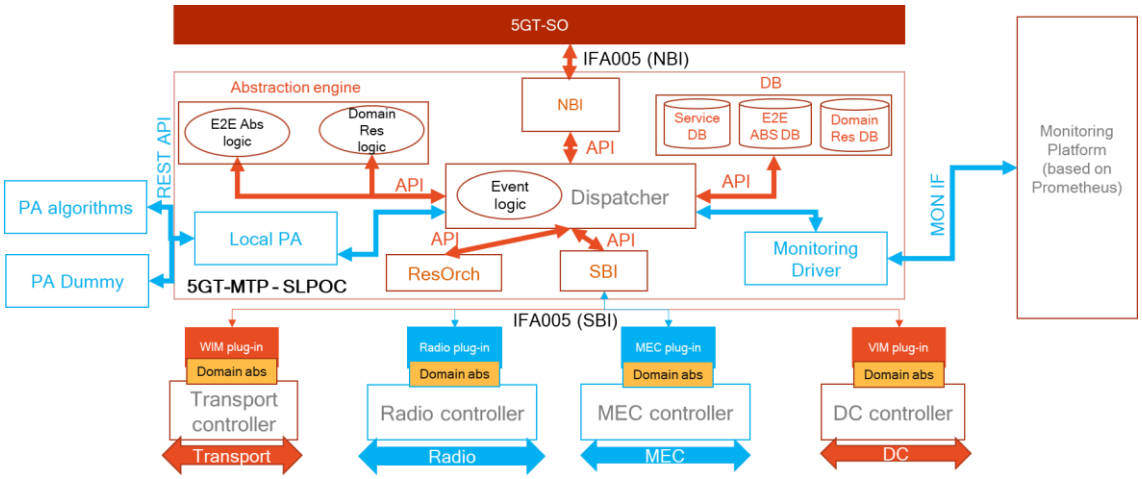

FIGURE 4: UPDATES ON 5GT-MTP ARCHITECTURE

Figure 4 reports the 5G-MTP architecture showing in blue the features with related building blocks, interfaces among the building blocks, plug-in towards the resources, and extension of North Bound Interface (NBI) towards SO.

NXW defined and developed the building block and related interface for monitoring. CTTC has implemented the local Placement Algorithm (PA) defined in T2.3 and the related interface; while EURECOM defined and implemented the MEC function in terms of building block and interface. TEI defined and implemented the radio interface. UC3M participated to the discussion on the MTP architecture evolution.

Related the 5G-MTP plug-in towards the resources, TEI defined and implemented the plug-in for Radio, EURECOM for MEC, MIRANTIS implemented the plug in for Kubernetes and BCOM realized the VIM plugin for Openstack.

UC3M studied alternatives for monitoring and data analytics within the MTP.

In collaboration with WP4 TEI, SSSA and CTTC performed the extension of NBI for the following functions:

- For Radio-Transport infrastructure abstraction has been done on the basis of the information modeling and abstraction solution defined in T2.2.
- For the MEC on the basis of the MEC solution defined by EURECOM.

Interworking with 5GT-SO has been defined in collaboration with WP4, while integration activity has been carried out in the framework of WP5.

The coordination activity for the implementation and tests has been carried out by TEI.

4.2.2.2 Task 2.2: Mobile-Transport abstraction method in support of MEC services and Slicing

T2.2 aims at defining novel method for abstraction in support in 5G scenarios based on mobility. As extension of the work done in the first period, mobility including radio resources and MEC support has been done.

Such activity included both the abstraction method and related information modeling to be used at the NBI of the 5GT-MTP for interworking with the 5GT-SO.

EURECOM focused the activity on MEC support. TEI, SSSA and NOK-N, instead focused their activity on the radio transport abstraction in order to include the mobility in a geographical area in the abstraction view. Information modeling has been done by

TEI and SSSA. Besides, BCOM, CTTC, MIRANTIS and TEI contributed to the realization of the connectivity service to manage virtual links between VNFCs deployed within a single site and across multiple sites. UC3M participated in the discussion on the MTP-MEC abstraction and on the study and analysis of abstraction models on the MTP for future releases.

On the basis of this activity, the impact on the general architecture has been carried out in the framework of WP1.

NOK-N, TEI, and SSSA defined a concept [4] how the radio access network (RAN) could be abstracted and included in the descriptions of vertical services. This was joint work among WP2 and WP3. NOK-N provided a concise summary of the relevant terms of slicing of the RAN in [7].

4.2.2.3 Task 2.3: Methods and optimization algorithms for optimal placement of virtual functions, selection of best radio splitting and transport resource to support MEC-oriented service

T2.3 aims at defining and assessing optimization algorithms for optimal placement of the virtual functions, the selection of best radio splitting and related transport resources. The MEC and edge computing scenarios have been analyzed.

In the following the methods and related algorithms are described and analyzed and part of results has been reported in D2.1 and D5.3.

POLITO developed and assessed a low-complexity, scalable algorithm for the placement of the VNFs composing a service. The algorithm has been assessed in simulation and showed the performance that can be obtained, in particular in terms of energy efficiency. Comparison of the algorithm performance with the optimum, has been done in order to highlight the close match between the two.

CTTC designed and assessed a logical link placement algorithm that allows to work on the abstracted view defined in T2.2, to optimize the placement of network resources.

NECLE proposed FluidRAN, an analytical framework for the optimized configuration of virtual RAN (vRAN) networks. They modelled the BS operation as a chain of functions that successively process the traffic to/from the users. Such framework yields the vRAN configuration (splits and paths) that minimizes the aggregated operator expenditures.

SSSA defined an algorithm for dynamic de/activation of VMs. The proposed algorithm exploits monitoring information to predict the number of active VMs required to serve the expected 5G-service requests.

UC3M studied the existing state of the art regarding VNF placement algorithms to identify key innovations on the MTP for future releases.

All partners contributed to the investigation of the constraints as well as the requirements in terms of KPIs that characterize the 5G-MTP.

4.2.2.4 Deviations

Overall, the work package proceeded as planned. No deviations have been noticed during the second period of the project.

4.2.2.5 Corrective actions

No corrective actions were needed.

4.2.3 WP3

The Vertical Slicer (5GT-VS) is the entry-point for verticals to the whole 5G-TRANSFORMER system. Within WP3 there are three tasks focusing on the description of vertical services (T3.1), algorithms within the 5GT-VS (T3.2), and implementation of the 5GT-VS and support of vertical service implementations (T3.3).

The main achievements of WP3 in the second period included:

- The final specification of the 5GT-VS in D3.3 [10]. The initial design in D3.1 [9]. was extended with mapping SLA requirements to policies and the integration of MEC application descriptors. A concept for vertical-driven service composition was developed to increase the flexibility of verticals in specifying their services. Three different approaches for scaling were identified, including the use of fallback services to save resources as an alternative to stop services completely in case of resource shortage.
- The final release (R2) of the 5GT-VS software prototype. In this release, the basic algorithms implemented in the first release (R1) [10] were extended for the complete functionality as planned. The final 5GT-VS software implementation prototype has been delivered in D3.4 [11] and published as open source on GitHub for download: https://github.com/5g-transformer/5gt-vs.

4.2.3.1 Task 3.1: Vertical service descriptors

Most importantly, the 5GT-VS allows the verticals to define vertical services – by selecting a Vertical Service Blueprint (VSB) from a catalogue and completing it to a Vertical Service Descriptor (VSD) – and to instantiate them without having to be experts in service orchestration. VSDs are translated by the 5GT-VS to ETSI NFV network service descriptors (NSD) to be processed by the 5GT-SO.

In the first period of the project we defined a table based-presentation format for VSBs and VSDs. NXW developed a corresponding data model in JSON format used by the 5GT-VS. In the second period of the project NXW extended this data model to cover as well physical network function (PNF) and e2e latency constraints. Correspondingly, in the NSDs, the e2e latency constraints are defined as additional QoS attribute on network forwarding path descriptors (NFPD), see [10].

WP3 [UC3M, ATOS, NOK-N, IDCC, CRF, BCOM, NXW, CTTC, POLITO] defined for each of the five use cases the VSB, VSD, NSD as data models in JSON format. Additional VSBs and VSDs were defined to ensure that other properties, not directly used in the specific use cases could be expressed as well. The VSBs, VSDs, and NSDs of the use cases have been reviewed and validated such that they could be processed by the 5G-TRANSFORMER system. The definition of the VSBs, VSDs, and NSDs was an iterative process, where feedback from their review and validation was used to both improve their definitions as well as to direct the development of the 5GT-VS.

Multi-access edge computing (MEC) is a suitable deployment option in several of the use cases. WP3 [EURECOM] extended the definition of NFV-NSDs and of AppDs to hold the specific information of MEC applications. A dedicated external connection point (Cp) of the AppD was associated with a SAP of the enclosing NFV-NSD. This dedicated Cp was used to express location constraints of the MEC Application, i.e. expressing that it is deployed close to the mobile edge.

WP3 [NOK-N, NXW] analysed how the SLA requirements defined for vertical services and specifically for the five use cases could be mapped to the different descriptors and eventually be ensured for the vertical service instances. We identified the need for different approaches to handle the SLA requirements. 1) Some, such as geographical constraints and priority, can be processed directly by the 5GT-VS. Geographical constraints can be mapped to the LocationInfo attribute of SAPs within NSDs (5GT-VS Translator), priority can be used directly by the 5GT-VS Arbitrator component. 2) Mobility can be translated into corresponding dimensioning by selecting instantiation levels by the 5GT-VS Translator. 3) Other SLA requirements such as availability (coverage) or cost are actually better handled in the deployment phase by the 5GT-SO. These SLA requirements can be considered as directives to the 5GT-SO to deploy a VSI in a specific way. As a technical means to get the corresponding information from the 5GT-VS to the 5GT-SO we used MANO policies as defined lately by ETSI NFV. More specifically, WP3:

- extended the 5GT-VS Translator to map SLA requirements to specific policies,
- extended the Vs-So interface to apply policies on the network services in the 5GT-VS, see Table 14,
- updated the workflows among 5GT-VS and 5GT-SO regarding the use of policies,
- contributed to ETS NFV standardization[1] allowing to associate policies with specific NSIs.

TABLE 14: POLICY MANAGEMENT OPERATIONS

Message	Direction	Description	Parameters
TransferPolicyRequest	5GT-VS → 5GT-SO	Transfer policy and retrieve reference	• designer • name • version • policy
AssociatePolicyRequest	5GT-VS → 5GT-SO	Associate policy with NSIs.	• policyInfoId • List<nsInstanceId>.

The Vs-So interface was extended with the needed operations for PNF and for policy management. Also, the Ve-Vs interface was updated allowing vertical applications to trigger scaling of a vertical service instance. The interactions among 5GT-VS and 5GT-SO were updated accordingly (UC3M, NXW, CTTC).

All five use cases of 5G-TRANSFORMER and any vertical service using mobile communication have in common the need to describe a radio access system (RAN) as part of the vertical service. WP3 [TEI, NOK-N] analysed what are the properties of a RAN that are relevant for verticals. For sure, a vertical is not interested in the myriad of parameters to configure a RAN or corresponding UE capabilities, but there are a few high-level properties such as the coverage area, the specific radio technology, and frequency bands usable by the mobile devices of the vertical. WP3 defined [3] how this information could be included in the VSBs, VSDs, and NSDs. For example, the coverage area required for a specific RAT can be described within an NSD as LocationInfo parameter of a specific SAP indicating this RAT in its layerProtocol

[1] NFVIFA(18)0001001, IFA013ed321 CR add policy associate disassociate operations, NFVIFA(18)0001002, IFA007ed321 CR add policy associate disassociate operations, NFVIFA(18)0001003, IFA008ed321 CR add policy associate disassociate operations, NFVIFA(18)0001012, IFA010ed321 CR add policy associate disassociate operations.

attribute. This mapping and corresponding interaction within the 5G-TRANSFORMER system is described in [4]

WP3 defined in the first period how to describe and process composed services in the 5G-TRANSFORMER system [2]. Such composed services were still based on VSBs provided by the operator. On a conceptual level, WP3 [UC3M, NOK-N, TID, NXW, POLITO] extended this to allow verticals to define composed services from predefined building blocks, which we call Vertical-Driven Service Composition. The target was to increase the flexibility for verticals to define verticals without increasing the complexity to do so. The complexity was kept low by identifying different domains within a vertical service that could be varied, categorizing potentially building blocks according to these domains, and by providing frameworks providing ways to compose the building blocks into a complete service. We considered that defining general building blocks and allowing to compose them in arbitrary ways would increase the complexity for the verticals too much. Technical domains were vertical services could vary are:

- **Applications**: There may be variations among the applications themselves. E.g. different kinds of content distribution systems for media applications.
- **Control-plane**: Different optimization algorithms could be used for the control plane of a communication service. E.g. handover decisions could be made with algorithms on various levels of sophistication depending on the mobility pattern of mobile devices.
- **Management-plane**: E.g. subscriber management could range from a spreadsheet-based tool for hundreds of users to a full-fledged application targeting millions of users.
- **General functionality**: There are also variations in general functions such as VPN gateways, firewall, intrusion detection systems, etc.

Categorizing building blocks along these technical domains and allowing to connect them within their domain only still provides flexibility to the verticals without increasing complexity. A diagram of the general approach is shown in Figure 5. A 5G network is the communication service within this vertical service.

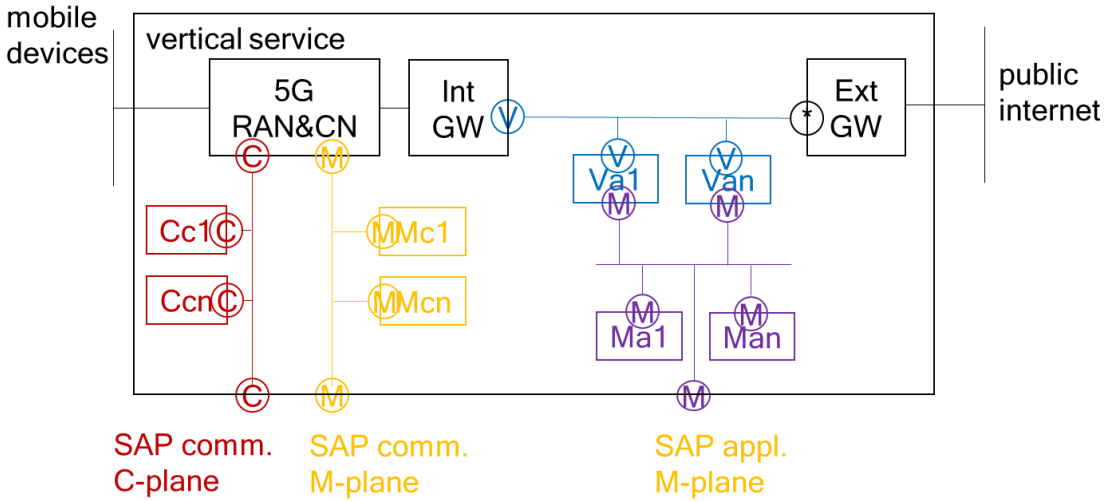

FIGURE 5: VERTICAL-DRIVEN SERVICE COMPOSITION GENERAL APPROACH

Regarding the framework to compose the building blocks we identified two approaches from other 3GPP projects, namely the service development kit (SDK) of 5G-City[2] [31] based on flow-based programming and the concept of service meshes defined by the 5G-PPP project Matilda[3] [32]. How these frameworks could be used within the scope of 5G-TRANSFORMER is described in [10].

As the 5GT-SO is capable of processing composed network services, vertical-driven service composition does not require additional functionality of the 5GT-SO or even 5GT-MTP. It is purely an extension of the 5GT-VS, providing a more generic way for the vertical to define its vertical services in addition to selecting VSBs from a catalogue.

4.2.3.2 Task 3.2: Algorithms for Verticals

Algorithms play a central role in the Arbitrator component of the 5GT-VS. The Arbitrator performs resource arbitration among VSIs and maps vertical service instances (VSI) to network service instances (NSI).

In the first phase of the project, basic algorithms have been provided in the Arbitrator component of the 5GT-VS. These algorithms have been improved in the second phase of the project [NXW, POLITO].

As a pre-study to the development of the actual Arbitrator component WP3 [POLITO] developed a simulator of the Arbitrator. The simulator allowed early to study the efficiency of the decisions of the 5GT-VS. It allowed to compare the Arbitrator against a baseline algorithm, which does not consider priorities and which assigns resources uniformly to VSIs. The simulator also allows to compare the Arbitrator against cases where priorities are considered, but where always the worst-case decision had to be made. Although the actual deployment decisions are made by the 5GT-SO, the Arbitrator considers potential deployments with lower or higher resource consumption. 'Worst-case' refers to those potential deployments with a higher resource consumption due to a more distributed deployment of VNFs and therefore higher bandwidth consumption among data centres.

Once the development of 5GT-VS had started, WP3 developed the actual Arbitrator algorithms based on the studies done with the simulator [NXW, POLITO]. A corresponding decision tree is shown in Figure 6. This example is derived from the automotive use case, with a high-priority service EVS (extended virtual sensing) and a low-priority service MS (multimedia streaming).

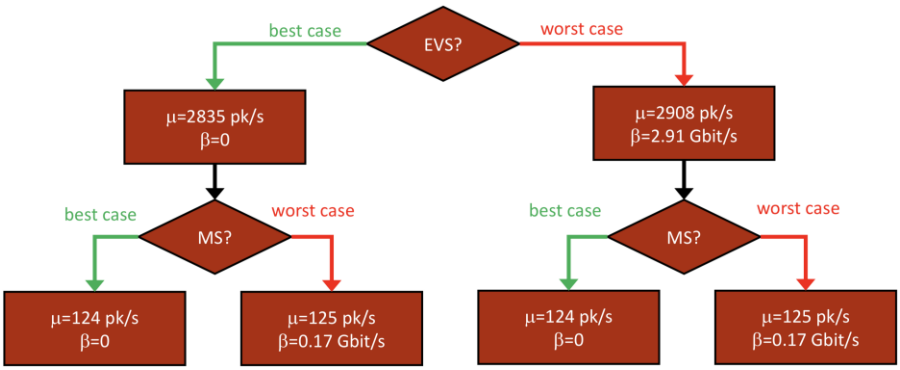

FIGURE 6: BEST AND WORST CASE ALLOCATIONS BY THE ARIBTRATOR

[2] https://www.5gcity.eu/
[3] http://www.matilda-5g.eu/

Despite the prioritization by the Arbitrator component VSIs may have to be scaled dynamically. This can be due to dynamically changing resource needs of the VSI itself, deployment of other, higher-priority VSIs, or a temporary resource shortage in the infrastructure due to failures. In all these cases, the 5GT-VS and the 5GT-SO have to interact. In some cases, the 5GT-VS is modifying the instantiation levels or deployment flavors of the network service corresponding to a VSI. In other cases, the 5GT-SO is reporting the outcome of scaling decisions it has performed or the failure of scaling operations it attempted. WP3 [UC3M, NOK-N, BCOM, NXW, CTTC, POLITO] investigated these interactions in detail and defined the corresponding workflows.

WP3 identified three different scaling scenarios relevant for 5G-TRANSFORMER:

- Vertical-driven VSI-scaling: The vertical itself or the vertical application based on some external trigger requests the 5GT-VS to scale a VSI. An example of an external trigger is the occurrence of an emergency in the eHealth use case, requiring the establishment of dedicated resources, i.e. scaling of a monitoring service, to handle also the emergency.
- Automated VSI scaling: Based on the intended deployment of additional VSI, lower-priority VSIs are scaled down by the 5GT-VS:
- Automated NFV_NS scaling: Within the defined instantiation levels and deployment flavours the 5GT-SO makes autonomous scaling decisions and just informs the 5GT-VS about the resulting actual resource consumption.

As a measure of last resort, WP3 defined the use of fallback services. Fallback services which provide basic functionality with less resources. In the example in Figure 7 a sensor monitoring and analysing service is replaced by a simpler service just raising an alarm in case thresholds are crossed. The use of fallback services can also be handled technically as scaling operation.

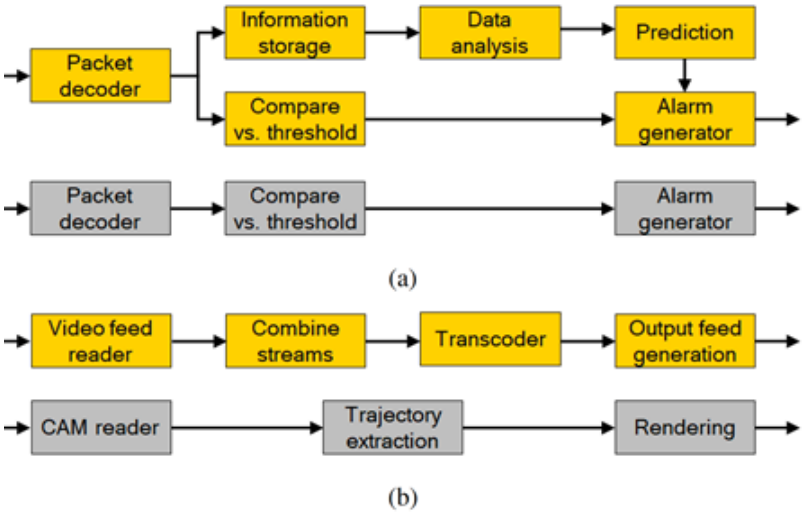

FIGURE 7: USE OF FALLBACK SERVICES

When a service is composed of several child services these child services may be reused differently. One child service might be used exclusively for the composed services whereas another child service might be used child service might be used in a shared way by several composed services. WP3 [CTTC] investigated the efficient reuse of nested service.

Also, WP3 [CTTC] maintained the NBI of the 5GT-SO, being the SBI of the 5GT-VS as well, in practical terms. Here it was ensured that the interaction workflows where kept aligned with the 5GT-VS extensions and that the NSDs used by the 5GT-VS for the different use cases could actually be handled by the 5GT-SO. WP3 [IDCC] used the 5GT-VS APIs in a direct way to check resource availability before deploying a vertical service.

4.2.3.3 Task 3.3: Vertical service implementation

In this task WP3 provides implementations of components and functionalities to support verticals in the implementation of vertical services and to integrate the vertical services in an orchestration environment and WP3 provides the implementation of the 5GT-VS.

WP3 [NXW, ATOS, IDCC] implemented two releases of a 5GT-VS reference implementation. The reference implementation corresponds to the architecture as shown in Figure 8 and includes as well an NFVO driver component among 5GT-VS and 5GT-SO. The NFVO driver allowed to decouple the implementation of 5GT-VS and 5GT-SO.

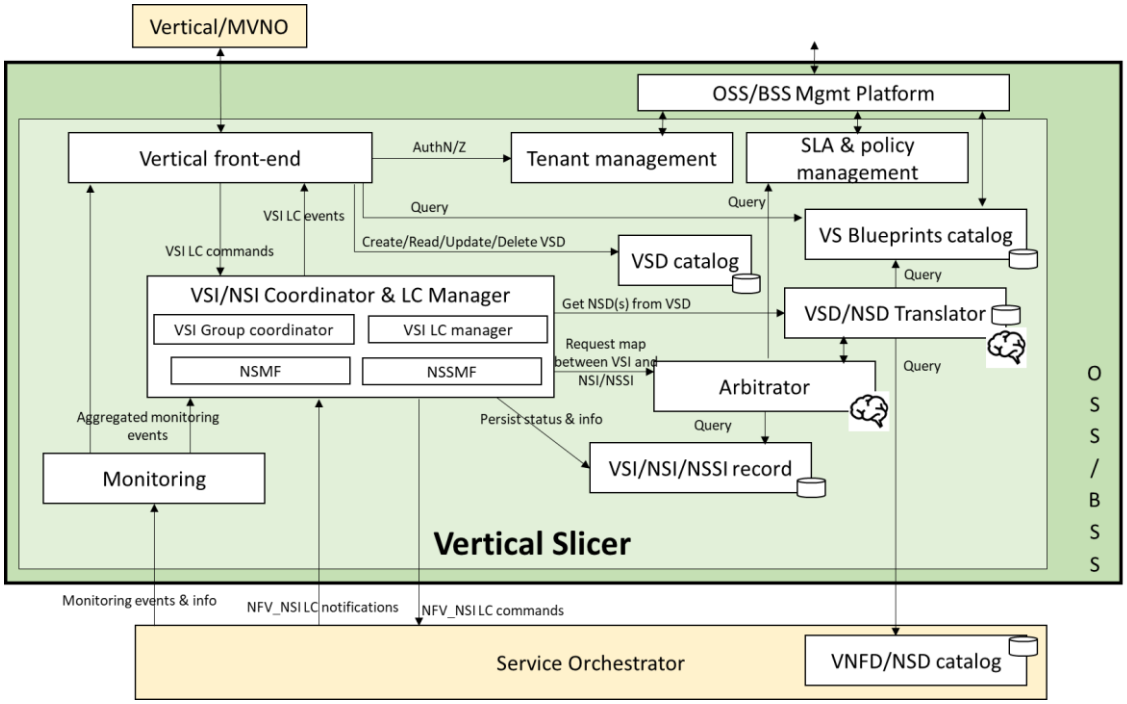

FIGURE 8: ARCHITECTURE OF THE 5GT-VS

In its first release (R1), the 5GT-VS contained already all components and interfaces, although with limited functionality and basic algorithms. Its second release provided improved functionality of the components and of the graphical user interface. The reference implementation is used by all use cases except for the MVNO one and has been demonstrated at numerous events, both as a standalone component and as part of the overall 5G-TRANSFORMER system. It is available as open source, for further detail on the implementation see [11]. The 5GT-VS reference implementation is as well used completely or in parts by other 5G-PPP phase 3 projects: SliceNet[4], blueSPACE[5], 5G-EVE[6].

[4] https://slicenet.eu/

For the MVNO use case less functionality is needed by the 5GT-VS. WP3 [BCOM, ITRI] developed 5GT-VS implementations tailored to this use cases. One implementation is focusing more on the network slice management function (NSMF) as defined by 3GPP, whereas the other is focusing more on defining services via the 3GPP defined slice and service types (SST).

For a remote robotic control service including video streaming and the robot control, WP3 [IDCC] integrated the 5GT-VS and 5GT-SO and demonstrated it. This work included the implementation of the video streaming and robot control modules and the integration with an MEC Radio Network Information Service (RNIS) implementation.

Vertical applications may require real-time or near real-time computation, yet these applications may be deployed in a virtualized manner on general purpose compute nodes, even shared with other applications. WP3 [NOK-N] conducted a study on the impact of different virtualization approaches and different optimization levels of the underlying operating system on the accuracy to meet schedules within tasks. The results were reported in [17].

4.2.3.4 Deviations

The work on Vertical-driven service extension of T1.1 extended into Q7 and was eventually described in [11], although T1.1 terminated at the end of Q6.

4.2.3.5 Corrective actions

No corrective actions were needed.

4.2.4 WP4

WP4 is devoted to the complete design and development of 5G-TRANSFORMER Service Orchestrator (5GT-SO). 5GT-SO is one of the key components of the 5GT system, in charge of instantiation and management of requested network services in the form of NFV defined Network Services (NFV-NS) and managing their life-cycles. Upon the service requests are received from the Vertical Slicer (5GT-VS), the 5GT-SO offers orchestration of services and resources in Single as well as Multi-domain 5G Virtualized Networks through dynamic function placement and service chaining.

The main achievements of WP4 in the second period included:

- The final specification of the 5GT-SO in D4.3 [14], including the final functional and software architecture design, along with new features and additional functional components extended from the initial design provided in D4.1 [12]. The new features consisted of support of automated service scaling, network service composition, service federation, enhanced placement algorithms considering location constraint and MEC support, and enhanced service monitoring platform which provides monitoring data to the 5GT-SO for automated service SLA management. The 5GT-SO related interfaces have been also refined and extended to support these new features and interactions between the 5GT-SO and the 5GT-VS, and the 5GT-MTP.
- The final release (R2) of the 5GT-SO software prototype. In this release, new features and functionalities and extensions of the interfaces were implemented on top of the initial design and first release (R1) provided in D4.2 [13]. The final

[5] https://www.bluespace-5gppp.eu/
[6] https://www.5g-eve.eu/

5GT-SO software implementation prototype has been delivered in D4.4 [15] and published as open source on GitHub for download: https://github.com/5g-transformer/5gt-so.

- The final version of the service-aware monitoring platform in charge of producing monitoring data and reports related to the performance or failure events associated to the managed services. The developed monitoring platform is also released in D4.4 and published as open source on GitHub for download: https://github.com/5g-transformer/5gt-mon.
- The 5GT-SO reference implementation has been integrated in the PoC demonstrations of the different 5G-TRANSFORMER use cases in WP5. Besides, the 5GT-SO prototype has already been showcased in several public events (IEEE NFV-SDN 18, ICT 2018, MWC 2019, EuCNC 2019, MobiHoc 2019, IEEE NFV-SDN 19) and it will be also taken as the baseline service orchestration platform to be extended and integrated into the platform for the 5G-PPP 5Growth project[7].

In the following, we highlight the above key achievements through the individual tasks and report the main contributors of the work.

4.2.4.1 Task 4.1: Service Orchestration

Functional Architecture Design

In the first period of the project we delivered the initial design of the 5GT-SO in D4.1 [12], which introduced the 5GT-SO internal design and main functionalities, its related Northbound and Southbound Interface (NBI and SBI) as well as the Eastbound and Westbound Interface (EBI and WBI), and its workflows for basic service life cycle management operations such as service instantiation and termination.

In the second period of the project, we developed in this task the final 5GT-SO architecture design with respect to the initial design from the first period. Major refinements include (i) use of monitoring services from the monitoring platform for automated service scaling and SLA assurance; (ii) service and resource federation capabilities; and (iii) interface specification toward SLA management; (iv) extending the interfaces of the 5GT-SO NBI to support the management of policies, extending SBI to support MEC and RAN functions, and support of intra-PoP connectivity in DC as well inter-PoP connectivity across DCs, and extending E/WBI to support service federation.

The final 5GT-SO functional architecture is shown in Figure 9, with the details reported in D4.3 [14]. SSSA, as the task leader, has led this work item with the partners in T4.1 (UC3M, NECLE, ATOS, NXW, MIRANTIS, CTTC, POLITO, EURECOM).

[7] http://www.5growth.eu/

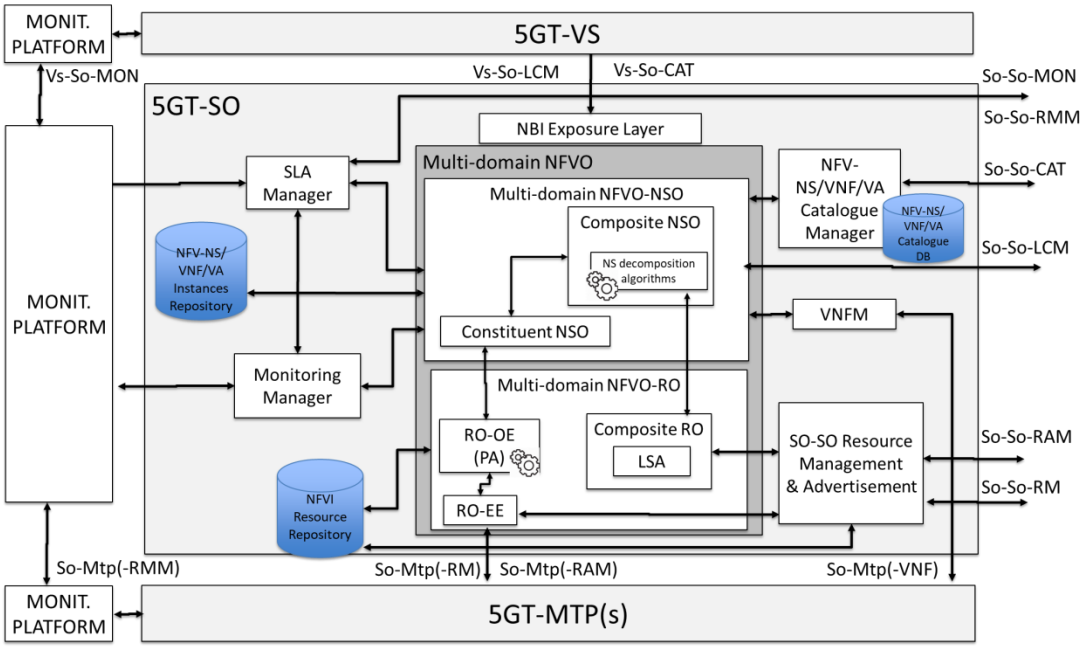

FIGURE 9: 5GT-SO ARCHITECTURE – BUILDING BLOCKS AND INTERACTIONS

5GT-SO R2 Features

Based on this architecture, the following new or extended features were implemented for the final release (R2), in the second period of the project.

- Enhanced placement algorithms to decide the most suitable and efficient way to place the services and chaining them (i.e., determining the optimal placement of VNFs/VAs along with the optimal deployment of virtual links connecting VNFs through mapping operations), support of location constraint and the specific requirements of the MEC applications/services.
- Service scaling: this feature describes the scaling of the Vertical Services to meet all the requirements for the services work and to avoid issues caused by network issues, resource shortage etc.
- Service Assurance and SLA Management: this feature is to ensure that services offered over networks and computational resources meet a pre-defined service quality level for an optimal subscriber experience.
- Service composition: enables a feature of joining already instantiated NFV-NS instances with new ones that need to be instantiated, providing the connectivity for the nested network services.

Placement Algorithms (design, implementation and evaluation)

Throughout the project, in total 4 different VNF placement algorithms (PA) that were developed at the SO level by NECLE, POLITO, CTTC, UC3M, SSSA, and EURECOM. These algorithms follow and build upon a common framework and system model (as joint work of the above partners, and presented in IEEE PIMRC 2018) that defines a set of optimization goals and constraints. Each algorithm has different features and capabilities, optimizes for potentially different criteria, and may support different constraints. Table 15 presents a qualitative comparison of these algorithms, focusing on their distinctive characteristics.

TABLE 15: 5GT-SO PLACEMENT ALGORITHM FEATURES

PA	Features	Optimization criteria	Contribution Partners
A	Genetic Algorithm (GA). Can be configured to optimize for one of three different objectives.	Either cost, latency, or service availability	EURECOM
B	Minimizes latency between VNFs placed at remote NFVI-PoPs. Also considers inter-PoP link physical distance.	Latency	SSSA and CTTC
C	Considers penalties associated with SLAs. Uses traffic forecasting. Reconfigures resource (re)allocation dynamically in timeslots.	Cost/revenue, resource utilization	NECLE
D	Clustering techniques to group VNFs and NFVI-PoPs according to VNF link requirements and inter-PoP link capacity, respectively. Heuristic to minimize cost and delay in two separate steps.	Cost vs. latency tradeoff	POLITO and UC3M

In the second period, all algorithms have been enhanced to support MEC and location constraints, evaluated through extensive simulations or experiments. The details about the individual algorithm design and evaluation results were presented in D4.3 [14]. The algorithm A, B, and D were also integrated into the R2 5GT-SO platform with a common API and information model.

Service Scaling

In 5G-TRANSFORMER three different types of service scaling have been defined, (i) Vertical-driven VSI Scaling, (ii) Automated VSI Scaling and (iii) Automated NFV-NS Scaling. Among them, the Automated NFV-NS scaling is managed entirely at the 5GT-SO level driven by the auto-scaling rules expressed in the NFV-NSDs. This feature is coordinated by the “SLA Manager”, developed by MIRANTIS, which is part of the SM, developed by CTTC. During the NFV-NS instantiation phase, the SM configures the monitoring platform and triggers the SLA Manager to configure the appropriate alerts according to the “conditions” encoded in the auto-scaling rules of the NSD. Whenever the SLA Manager is notified that one of the conditions is verified, it will send to the 5GT-SO a service scale request based on the “reaction” specified for that condition in the auto-scaling rule.

Service Assurance and SLA Management

Service assurance is the application of policies and processes with a goal to ensure that services offered over networks and computational resources meet a pre-defined service quality level for an optimal subscriber experience. Each NFV-NS is instantiated with a certain configuration, which contains scaling, monitoring and alerting rules. These configurations are controlled by the Monitoring Manager (developed by CTTC) and SLA Manager (developed by MIRANTIS), which interact with the Configuration Manager (developed by NXW) to meet certain SLA for the service, as described previously.

Service composition

Service composition is the process of instantiating services composed of different nested NFV-NS or joining already instantiated NFV-NS instances with new NFV-NS instances that need to be instantiated. The service composition as a joining process can be executed as concatenation of NFV-NS or composition of NFV-NS. CTTC implemented the latter one in the 5GT-SO software prototype. This work is the base for service federation.

5GT-SO software implementation

As one of the main outcomes of this task, we implemented the 5GT-SO software prototype based on the high-level architecture in Figure 9 and integrated all the developed R2 features introduced above. The Figure 10 presents the implemented software architecture. As for the former, a key design decision that determines the architecture of the 5GT-SO functional components is the aim of integrating widely used available MANO platforms (e.g., OSM) to be able to exploit their features and also making the 5GT-SO platform independent of which MANO platform selected or deployed. At the same time, the 5GT-SO embeds additional advanced functionality (e.g., service composition, service federation) not currently offered by these platforms, inside a building block of the 5GT-SO called **Service Manager (SM).** In this sense, the SM is the brain of the 5GT-SO and is in charge of handling service and resource orchestration, by exploiting the OSM/Cloudify functionalities when needed for the cloud part. Setting up of network paths between datacenters through Wide Area Networks (WANs) for the interconnection of VNFs involved in NFV-NSs is also carried out by the SM. The 5GT-SO integrated two MANO platforms as orchestration engines for managing compute resources, Cloudify contributed by MIRANTIS and OSM contributed by CTTC. Other MANOs can be added by implementing individual wrappers.

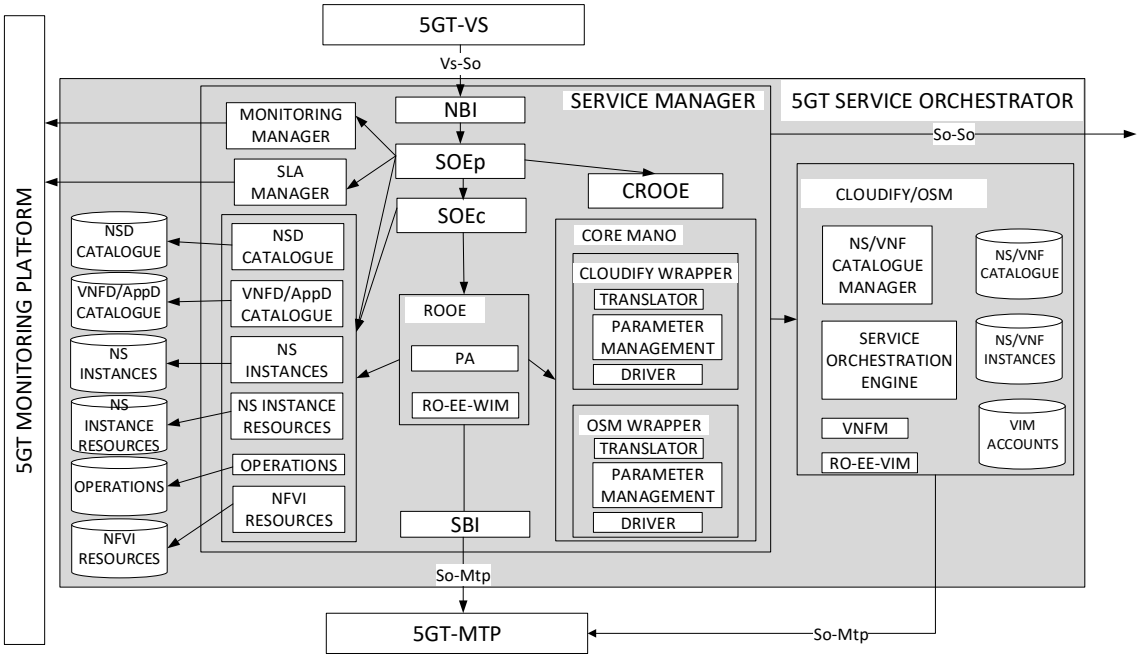

FIGURE 10: 5GT-SO IMPLEMENTED COMPONENTS

In terms of implementation work, CTTC was the key partner devoted to development the complete Service Manager (SM) component including all internal functional modules, SBI/NBI and EBI/WBI interfaces and continuously integrating and testing the different SM components. CTTC also developed the OSM wrapper to integrate the OSM with the SM.

MIRANTIS was focused on the integration with Cloudify by developing a Cloudify wrapper, and enhanced the Cloudify with adding different plugins on the Cloudify SBI to integrate with the 5GT-MTP for the cloud resources. Besides, MIRANTIS also developed the SLA manager for the automated service scaling feature.

At last, the 5GT-SO also includes the implementation of the PA module and related APIs to integrate the different placement algorithms developed by CTTC, UC3M, POLITO, SSSA, and EURECOM.

The 5GT-SO software has been published as open source on GitHub for download: https://github.com/5g-transformer/5gt-so. In addition, CTTC provided the user guide, also available on GitHub, at the following link: https://github.com/5g-transformer/5gt-so/tree/master/5GT-SO/documentation and the 5GT-SO software development guide on GitHub, at the following link: https://github.com/5g-transformer/5gt-so/tree/master/5GT-SO/documentation.

In addition to the reference implementation, one additional 5GT-SO implementation based on Tacker has been developed by ITRI, which is also aligned with the 5GT-SO functional architecture while the implementation focusing on only basic operations for deployment of communication services based on standardized Slice/Service Types (SSTs) defined in 3GPP specifications. More details are reported in D4.3 [14].

4.2.4.2 Task 4.2: Service-aware Monitoring

This task, led by NXW, is in charge of the design and implementation of a flexible service-aware monitoring platform (named as 5GT-SO Monitoring Platform) to support the management of vertical services at the run-time. The monitoring platform collects elementary monitoring data from different sources and correlates or aggregates them into reports related to the logical entities managed by the 5GT-SO, i.e. NFV network services and VNFs.

In the first period, we designed the concept and functional architecture of the 5GT-SO Monitoring Platform, which have been reported in D4.1 [4]. In the second period, we completed the prototype implementation and integration of the complete service monitoring platform to the 5GT-SO, including the configuration manager, the Grafana GUI and dashboard, integration of different exporters for the VM, VIM and WIM plugins. A number of partners have contributed to the development of the different components of the monitoring platform and providing the different exporters, including NXW, ATOS, CTTC, MIRANTIS, and SSSA.

The 5GT Monitoring platform, as shown in Figure 11 has been implemented by integrating a Prometheus backend with the 5GT-SO through the development of an adapter called Monitoring Configuration Manager (or Config Manager for short). This component was fully implemented by NXW. It acts as a unified entry point for all the configuration functionalities offered by the monitoring platform, simplifying and adapting the several APIs exposing monitoring options to the 5G-T environment.

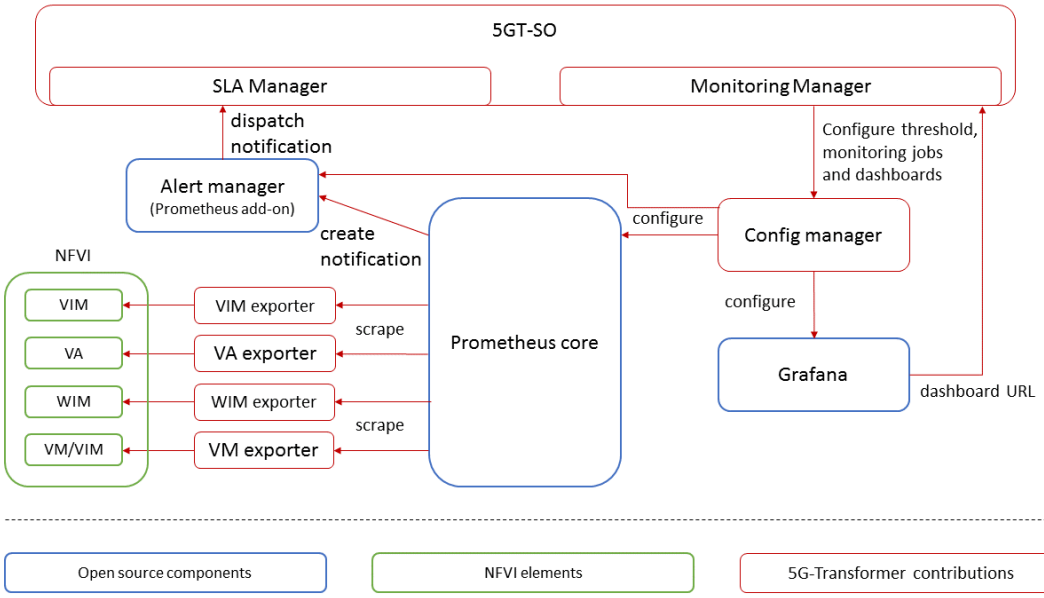

FIGURE 11: MONITORING PLATFORM ARCHITECTURE

On the 5GT-SO side, the Config Manager interacts with the Monitoring Manager and the SLA Manager. The Monitoring Manager is the component in the 5GT-SO translating requests for high-level monitoring jobs referred to NFV service instances into low-level requests related to the monitoring of resource-level parameters, which are the data actually collected at the Monitoring Platform.

The SLA Manager deals instead with SLA assurance. This component is thus interested in monitoring parameters, like Key Performance Indicators or real-time measurements mirroring the load of the resources, that may indicate potential SLA breaches or anomalous behaviours that may lead to system under-performance. The SLA Manager interacts with the Monitoring Platform following a subscription-notification paradigm, in order to promptly react to any alert associated to the target monitoring data. In particular, the SLA Manager subscribes with the Config Manager, registering monitoring parameter queries (which may include arbitrarily complex expressions on many different time series) and threshold values for notifications. Such subscription is translated into the appropriate configuration of the Prometheus Alert Manager add-on, so that whenever the given threshold is passed, a notification is sent to the SLA Manager, which will then trigger the needed reactions at the 5GT-SO.

For this task, CTTC developed the Monitoring manager including the configuration of the dashboard and tested the integration with the monitoring platform. MIRANTIS developed the SLA manager and performed jointly with CTTC the tests to validate its interaction with the monitoring platform.

The 5GT-SO monitoring platform has been published as open source on GitHub, at the following link: https://github.com/5g-transformer/5gt-mon.

4.2.4.3 Task 4.3: APIs and Service Federation

This task focuses on the design of federation mechanisms including the definition of the federation procedures, workflows, interfaces and APIs, as well as federation algorithms to provide end-to-end services and aggregate resources across multiple administration

domains. UC3M led this task with the support of a number of partners including CTTC, NECLE, TID, and MIRANTIS.

In the first period, we designed the concept for federation including related procedures and workflows, the definition of EBI/WBI towards the federated domains, which have been reported in D4.1 [12]. In the second period, the task was fully focused on the development of the federation related functional component modules and interfaces in the 5GT-SO platform. The development was driven and executed by CTTC in the support of MIRANTIS and UC3M.

Service federation is the overall process of establishing, consuming or providing NFV network services (NFV-NS) by an administrative domain from/to other (peering/partner) administrative domain. The administrative domain that requests service is referred to as consumer domain while the peering administrative domain capable of providing service is a provider domain. The service federation is the combination of establishing business/service level agreements among the administrative domains and consuming/providing federated nested NFV-NSs that are part of composite End-to-end NFV-NS. There are two types of federation:

- Service federation: this feature provides the overall process of establishing, consuming or providing NFV-NS by an administrative domain from/to other (peering/partner) administrative domain.
- Resource federation: is the overall process of consuming or providing NFVI resources from or to external federated domains.

In the project, we are focused on the implementation of the service federation feature as part of the 5GT-SO platform, as it is one of the main innovations of the project to provide network service level federation, while resource level federation has been studied in other projects like 5GEx that we can refer to their work.

For the validation and evaluation of the service federation feature, CTTC set up a test-bed at CTTC and performed experiment tests to evaluate how the service orchestrator of the 5GT platform has been enhanced to achieve network service federation by covering the gap detected in the work of ETSI-NFV. The experimental results show that the federated service under evaluation is deployed in 256 seconds, on average. Processing and operations of interconnection between administrative domains associated to the federation process do not have a great impact in the total deployment time. Overall, the proposed solution contributes to achieve the target set for 5G networks of reducing service setup from hours to minutes. The results were submitted to IEEE VTC magazine as a joint work of CTTC, UC3M and NECLE. In addition to experimentation evaluation, UC3M also has carried out theoretical study together with NECLE and CTTC on exploring the analytical gain of service federation from the network operation point of view. This work is planned to be submitted to IEEE ICC 2020.

4.2.4.4 Deviations

Overall, the work package proceeded as planned. No deviations have been noticed during the second period of the project.

4.2.4.5 Corrective actions

No corrective actions were needed.

4.2.5 WP5

The main objective of this work package has been to integrate the 5G-TRANSFORMER platform developed in WP2, WP3 and WP4 together with the different technologies available at the four test-beds available in the project and the proof of concepts (PoCs) established for the different use cases of the project. With this goal in mind, this WP has been divided in three tasks with different objectives: the definition and setup of the vertical testbeds (T5.1), the integration of the platform and demonstration of the first PoCs (T5.2), and finally a task fully advocated to experiment and evaluate the results (T5.3).

In the contest of this second periodic of the project, WP5 has had all the Tasks (T5.1, T5.2 and T5.2) alive. On this regard, the main outcomes of this activity have been detailed in the project deliverables:

- D5.2 - Integration and proofs of concept plan due to at M19.
- D5.3 – Experimentation results and evaluation of achievements in terms of KPIs due to at M25.
- D5.4 – 5GTRANSFORMER Report on trials results due to at M30.
- D5.5 - 5GTRANSFORMER Reference Implementation due to at M20.

4.2.5.1 Task 5.1: Definition and set up of vertical testbeds

In T5.1 the main goal has been to establish a planning for the integration between the four different testbeds of the project, namely: ARNO (in Pisa, Italy), 5TONIC (in Madrid, Spain), EURECOM (in Sophia Antipolis, France) and CTTC (in Barcelona, Spain), and the PoCs associated to the different UCs from the different vertical industries that are part of the project: Automotive, Entertainment, E-Health and E-Industry and the MNO/MVNOs UCs.

To achieve this goal, the work has been taken following two different directions. From one side the approach focused on describing the testbeds in terms of technologies, establish an initial plan for the integration among them and setup the physical connections that will support the integration. The other approach focused on describing the PoCs associated with the different UCs and establish a mapping between these PoCs and the technologies required from the testbeds and the functionalities required from the 5G-TRANSFORMER platform.

The result from the testbed description, as established by TEI, UC3M, NECLE, SSSA, EURECOM and CTTC, is summarized in Figure 12, Figure 13, Figure 14 and Figure 15. For further details about the infrastructure of each testbed we refer to D5.2 [16].

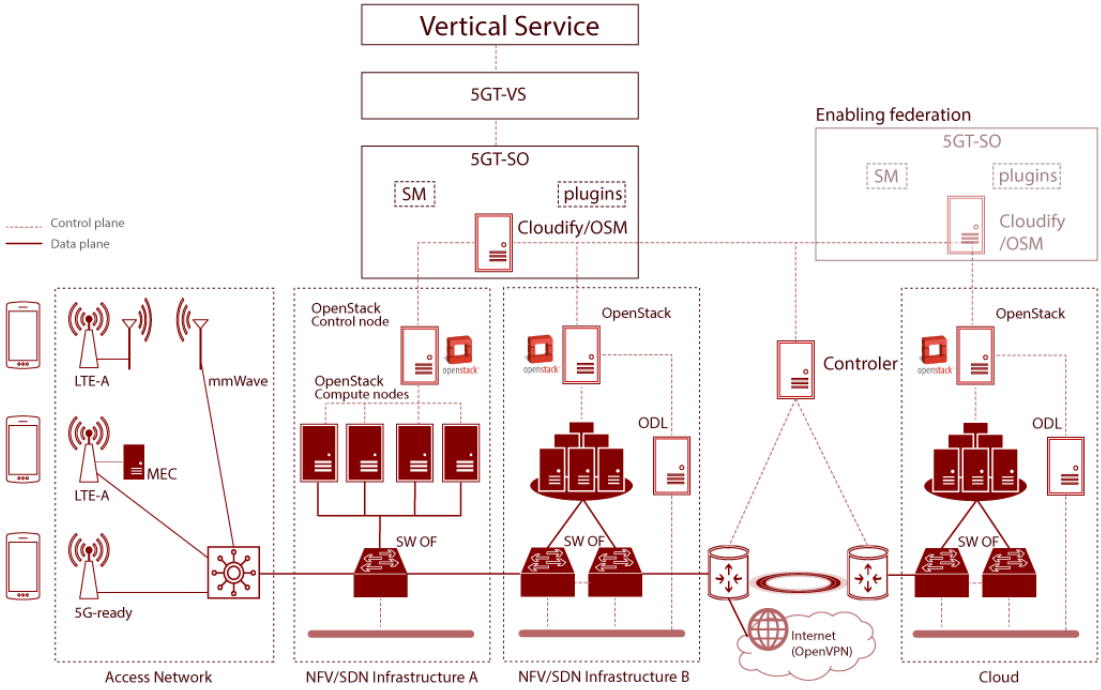

FIGURE 12: 5TONIC INFRASTRUCTURE

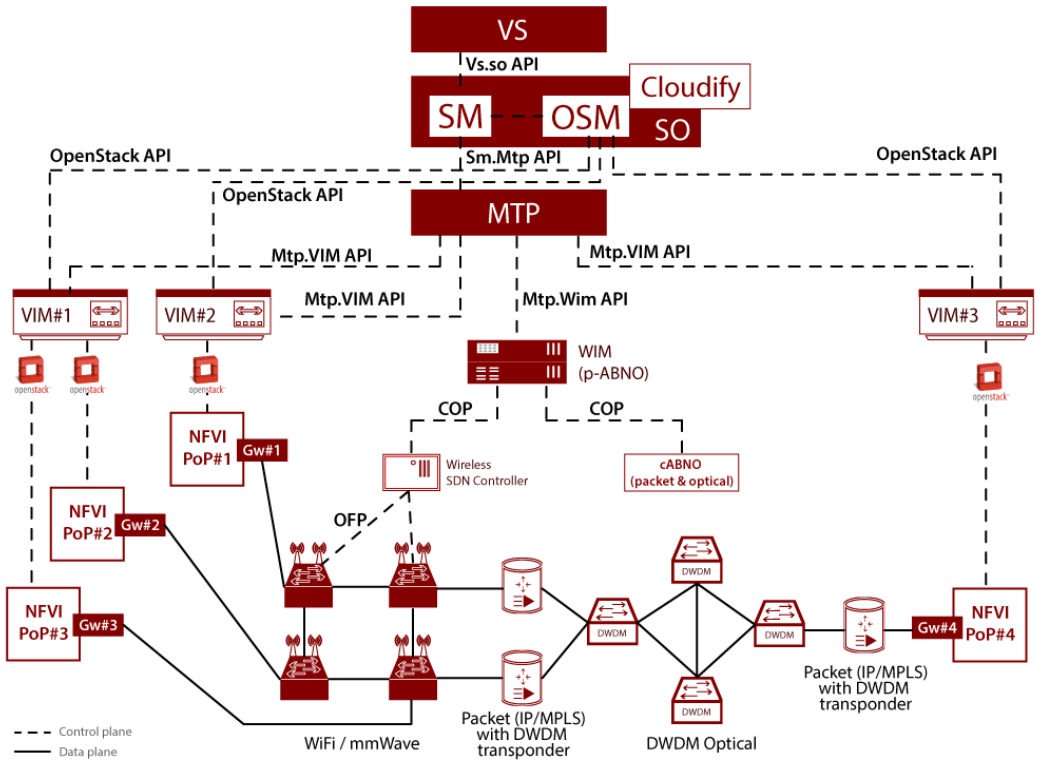

FIGURE 13: CTTC TESTBED INFRASTRUCTURE

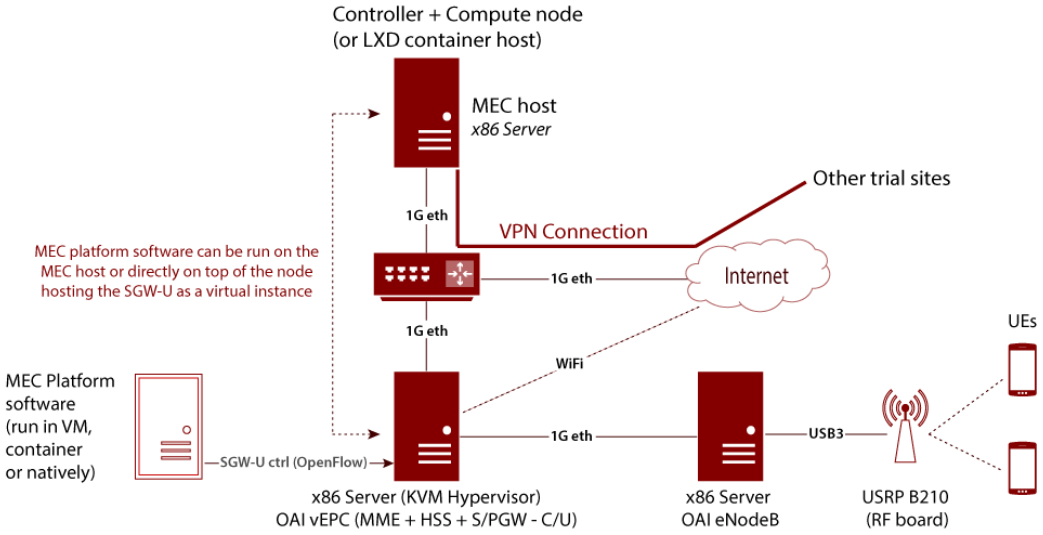

FIGURE 14: EURECOM MEC PLATFORM

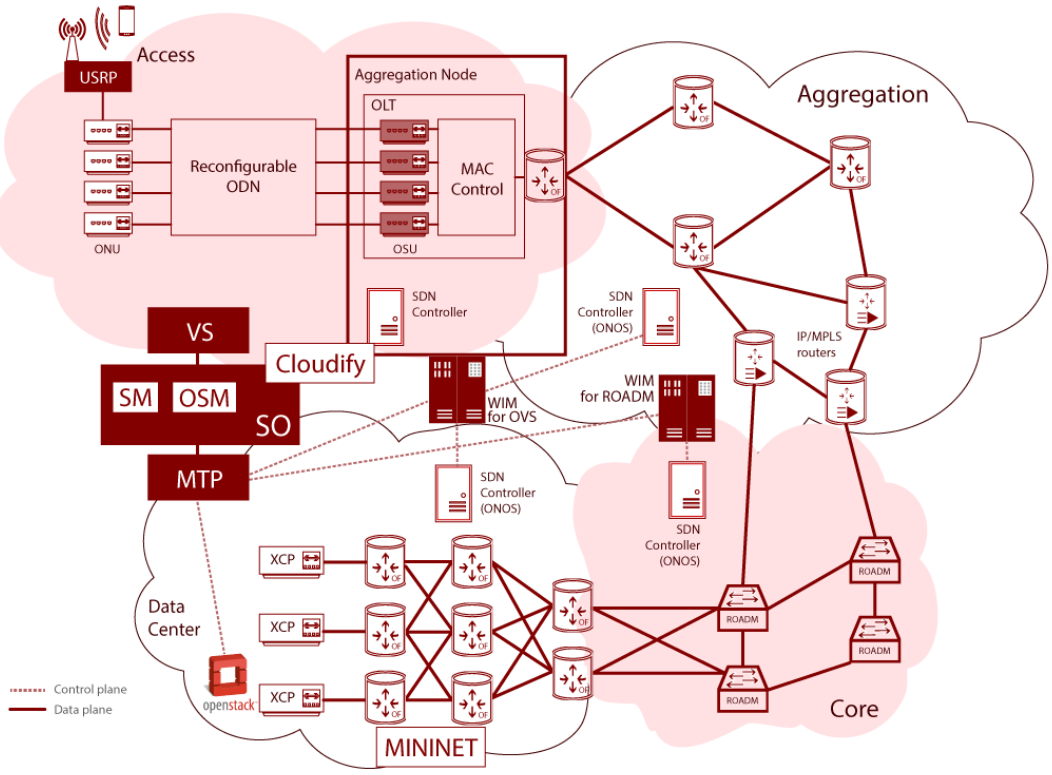

FIGURE 15: ARNO ACCESS

In terms of technologies the project obtained the set of technologies available in the integrated testbed detailed in D5.2 [16] for the technology identifiers). It has been shown several phases to detail a fully technology availability roadmap.

4.2.5.2 Task 5.2: Integration and proof of concept

In T5.2, which started on M8, the project focused on establishing and developing an implementation and integration plan which considers the five vertical PoCs and the releases of the platform. On this regard, T5.2 addresses one of the main goals of the 5G-TRANSFORMER project: demonstrating and validating the technology components

designed and developed in the project. This has been actually done in WP5 – in charge of integrating all components provided by WP2, WP3 and WP4 – by conducting different proofs of concept (PoCs) to validate the 5G-TRANSFORMER architecture. The PoCs are used to evaluate whether the solutions developed for the 5G-TRANSFORMER framework achieve the Key Performance Indicators (KPI) expected by the considered verticals. These solutions are compared to the state of the art or the used ones in common practice to evaluate the performance gain achieved in terms of KPIs. The results are extracted from the experiments' realization, focusing on quantitative and qualitative KPIs defined in 5G Public Private Partnership (5G-PPP) such as mobility, latency, energy efficiency, and service creation time. Besides that, T5.2 has been showcasing the five vertical PoCs in industrial relevant scenarios as reported in the section 4.5.2 of this document:

- The Automotive PoC has been demonstrated in Orbassano, in the CFR Test Area (Italy) and with real-cars. The PoC demonstrated the automatic deployment and scalability of the EVS/video streaming service application on edge according to priority and rules managed by arbitration and scaling functionality managed at the SO level according to monitored resources. In D5.4 the PoC assessed the Density (number of vehicles in a considered area) and Latency (from generating and sending the CAM by the vehicle, to receiving back the DENM message) KPIs.
- The Entertainment PoC has been validated in an international sport event such as The Mutuactivos Open de España". There, the consortium showed how 5G-TRANSFORMER capabilities provided an entirely new way for consumers to interact with immersive media contents in the context of a large-scale sport event. An UHD video streaming service, virtualized as a 5G-T Vertical Slicer, was orchestrated by the 5G-T Orchestrator so to be deployed at the edge with an abstraction of network and compute configuration parameters. For the Entertainment use case, there are three KPIs (Latency, User data rate and Service creation time) considered and measured. The values are compared with the current state-of-the-art showing a clear improvement by adopting the 5G-TRANSFORMER technologies.
- The E-Health PoC focused on the automation of emergency support deployment of medical services, reducing the overall reaction time, as well as providing support to AR services. The demo has been performed at 5TONIC premises. The PoC was set on two testbed sites: 5TONIC and CTTC trial sites so to show how 5G-TRANSFORMER technologies enable the management of distributed federated services and on the edge. In the context of the document the Service Creation Time has been evaluated compared with the benchmark and showing a clear improvement when the 5G-TRANSFORMER capabilities are adopted as well as the deployment on the edge.
- The E-Industry PoC has been demonstrated in a lab environment at 5TONIC lab in Spain. The PoC demonstrates factory service robots and production processes that are remotely monitored and controlled in the cloud, exploiting wireless connectivity (5G). The objective of the demonstrator was to verify the allocation of suitable resources based on the specific service requests to allow the interaction and coordination of multiple (fixed and mobile) robots controlled by remote distributed services, satisfying strict latency and bandwidth requirements. Three KPIs have been evaluated (Latency, Reliability and Service Creation Time).

- The MNO/MVNO PoC has been demonstrates in a lab testing environment. The PoC assessed the deployment of 3 network slices (echographer (URLLC), video (eMBB) and IoT devices (mMTC)). Two KPIs was selected for the MNO/MVNO PoC: Service Creation Time and Infrastructure Cost.

4.2.5.3 Task 5.3: Experimentation and evaluation

T5.3 started in M10 and aims to further detail how the different PoCs will demonstrate the KPIs established for the project. T5.3 has been providing the definitions for the considered 5G-TRANSFORMER KPIs and how they are measured, as well as their mapping to the 5G-PPP performance KPIs. Moreover, it has presented the evaluation of the 5G-TRANSFORMER KPIs conducted in WP5. A preliminary description of the experiments' realization and evaluation was provided by the deliverable D5.3. D5.4, delivered on M30, reported about the final project evaluation completing and improving the first evaluation carried out by D5.3 so developing and implementing refined evaluation procedures.

The PoCs considered in the performance evaluation are: Extended Virtual Sensing (EVS) for Automotive, On-site Live Experience (OLE) and Ultra High-Definition (UHD) for Entertainment, a heart-attack emergency use case for E-Health, cloud robotics for E-Industry, and 4G/5G Network as a Service (NaaS) for MNO/MVNO. The experiments were conducted to demonstrate and validate the benefits of adopting the integrated 5G-TRANSFORMER architecture components designed and developed in the context of the project. The evaluation was mainly performed, in two cycles, through POCs demonstrated in the 5G-TRANSFORMER testbed and via simulations.

Since the evaluation focused on assessing whether the technologies developed for the 5G-TRANSFORMER framework achieved the Key Performance Indicators (KPI) expected by the considered verticals the measurements results were compared to the state of the art (benchmark) or the used ones in common practice to evaluate the performance gain achieved in terms of KPIs. Overall, the evaluation activity demonstrated the benefits of adopting 5G-T technologies.

The Automotive PoC demonstrated with a real field trial how the 5GT platform functionalities facilitated the vertical service arbitration of a vertical offering in an automotive context involved multiple services (EVS service and video streaming service) with different priorities running in parallel according with the available resources. The adoption of the 5GT technologies demonstrated that the platform can ensure the required Low Latency KPIs of below 20ms by maintaining the Reliability (above 99.9%) also when vehicles density increases by scaling up the requested services at the edge with the application of edge computing technology. A different set of evaluation of the automotive EVS service with the aid of simulation has allowed to assess the EVS algorithm performance, from the results we can conclude that for the simulated urban scenario and for a variety of realistic urban densities and speeds, the designed EVS algorithm running over a simulated LTE network infrastructure (across LTE RAN and EPC) is able to avoid all collisions.

The Entrainment PoC demonstrated how the 5GT platform performed the automated service provisioning and orchestration of an UHD video streaming service, at the edge based an abstraction of network and compute topology and resources. The benefits achieved by using 5G-TRANSFORMER technologies in this use case were demonstrated by measuring KPIs such as E2E Latency, User data rate and Service Creation Time. For this specific use case, reducing the Service Creation time to a few

minutes is the aspect to be highlighted since, until now, deploying a service of this nature could take several hours or even days.

The E-Health PoC mainly focused on demonstrating the multi-domain service orchestration (i.e., service federation) along with service life-cycle management across one or multiple administrative domains. Thus, the PoC was set on two testbed sites: 5TONIC and CTTC test sites. Two independent 5G-TRANSFORMER platforms, acting as administrative domains on each site, show how 5G-TRANSFORMER technologies enable the management of distributed federated services and edge functionalities. KPIs measurements were mainly performed in D5.3 [1] where the service availability, latency and positioning are shown that perform better then or within the nominal KPI values. In D5.4 the E-Health PoC demonstrated the benefits achieved by using 5G-TRANSFORMER by significantly improving the Service Creation Time, in the order of minutes (other than in hours) utilizing the service federation.

The E-Industry PoC demonstrated the management of automatic allocation of network and cloud resources across 5G RAN, optical-based EXhaul (fronthaul and backhaul) and the core network functionalities (vEPC) in a factory environment for Cloud Robotic service. to the service allows the interaction and coordination of multiple (fixed and mobile) robots controlled by remote distributed services, satisfying strict latency and bandwidth requirements. Three KPIs were evaluated such as Latency, Reliability and Service Creation Time. The use case shows that the platform can reduce the service creation time in order of minutes (from several hours or even days), maintaining the reliability (99,999% of service lifecycle as recommended by ITU). In addition, thanks to 5G the latency is reduced; this allows the “migration” of several functionalities from the robots to the cloud reducing its complexity and power consumption.

Finally, the MNO/MVNO PoC assessed the deployment of 3 network slices (echographer (URLLC), video (eMBB) and IoT devices (mMTC)) considering two KPIs such as the Service Creation Time and Infrastructure Cost.

The key contributions and the associated outcomes of task 5.3 are the following:

- The description of the KPIs and the mapping between the 5G-PPP and the 5G-TRANSFORMER KPIs.
- Additional KPI evaluations provided through demos.
- Contribution of additionally developed algorithms to the KPIs.

4.2.5.4 Deviations

Overall, the work package proceeded as planned. No deviations have been noticed during the second period of the project.

4.2.5.5 Corrective actions

No corrective actions were needed.

4.2.6 WP6

As far as this project is concerned, and in accordance with common practice at the EU level [25], *Communication* includes all the activities related with the promotion of the project and its results beyond the projects own community. This includes the interaction with other research projects (e.g., H2020 5G PPP) as well as communication of its research in a way that is understood by the non-specialist, e.g. the media and the public. Notice, though, that even if collaboration with other projects is presented under communication, it also spans dissemination and exploitation. *Dissemination* includes

activities related with raising awareness of its results in a technical community working on the same research field. In general, this will be done through publications, and participation and organization of technical events. Finally, *exploitation* (in accordance with the European IPR Helpdesk) covers activities aiming at using the results in further research activities other than those covered by the project, or in developing, creating and marketing a products or processes, or in creating and providing a service, or in standardization activities.

Though a brief global overview is provided in the following paragraphs, the detailed work carried out in WP6 is reflected in various sections throughout this document according to the template. Communication activities (i.e., the outcome of task 6.1) are presented in this section, Dissemination activities (i.e., the outcome of task 6.2) are presented in section 3, and Exploitation activities (including standardization) are presented in section 0, and are also as an outcome of task 6.2. Finally, section 5 refers to D6.5 [22] for an updated communication, dissemination, and exploitation plan (CoDEP) of 5G-TRANSFORMER.

In accordance with the communication, dissemination, and exploitation plan (CoDEP) presented in the DoA (see Figure 16), the second period of the project (years 2 and 3) is devoted to present the technical results to the community and to integrate the developments into meaningful proofs-of-concept, without forgetting the actions to maximize the impact of the project results. Several actions were undertaken in these directions.

As for communication, project partners continued presenting the project in various events, participated in coordination calls with other 5G-PPP projects and generated content for the website and social media of the project. Since the project started, there has been a steady increase of the web and social media impact, for instance, reaching 33000 visits per year on the web or 109000 Twitter impressions (e.g. in the April-June 2019 quarter).

Communication actions for society at large were also carried out. Various events were also co-organised by 5G-TRANSFORMER with other H2020 projects (most of them 5G-PPP ones). More specifically, the joint work with other 5G-PPP projects was carried out in various forms. Events organized during Y2 and Y3 are: The SME workshop or “Workshop 2: From cloud ready to cloud native transformation, second edition” during EuCNC 2019, or the EM-5G workshop co-located with ACM Conext’18.

In addition to jointly organized events, the project is regularly participating in 5G-PPP working groups, and preparing joint papers. The project also regularly participates in 5G-PPP COMMS group, an activity organized by the To-Euro-5G CSA towards a joint dissemination strategy of all 5G-PPP projects, and so, regularly exploits these joint channels.

Several talks (technical and general public), publications, student supervision, etc. were also given during this period.

As for dissemination and exploitation (task 6.2), several actions were also carried out. A number of papers (28 in Journals, 37 in conferences/workshops) were accepted and presented in international journals and conferences (e.g., IEEE Transactions on Mobile Computing, EuCNC, IEEE INFOCOM).

Furthermore, the participation of the project at the Mobile World Congress (MWC’19) held in Barcelona is also relevant in this respect. Additionally, four demonstrations were

presented at EuCNC'19, in a joint booth with 5G-CORAL, and several other demos were presented in renowned international conferences, such as ACM Mobihoc'19, ACM Mobicom'19, IEEE SDN-NFV'19.

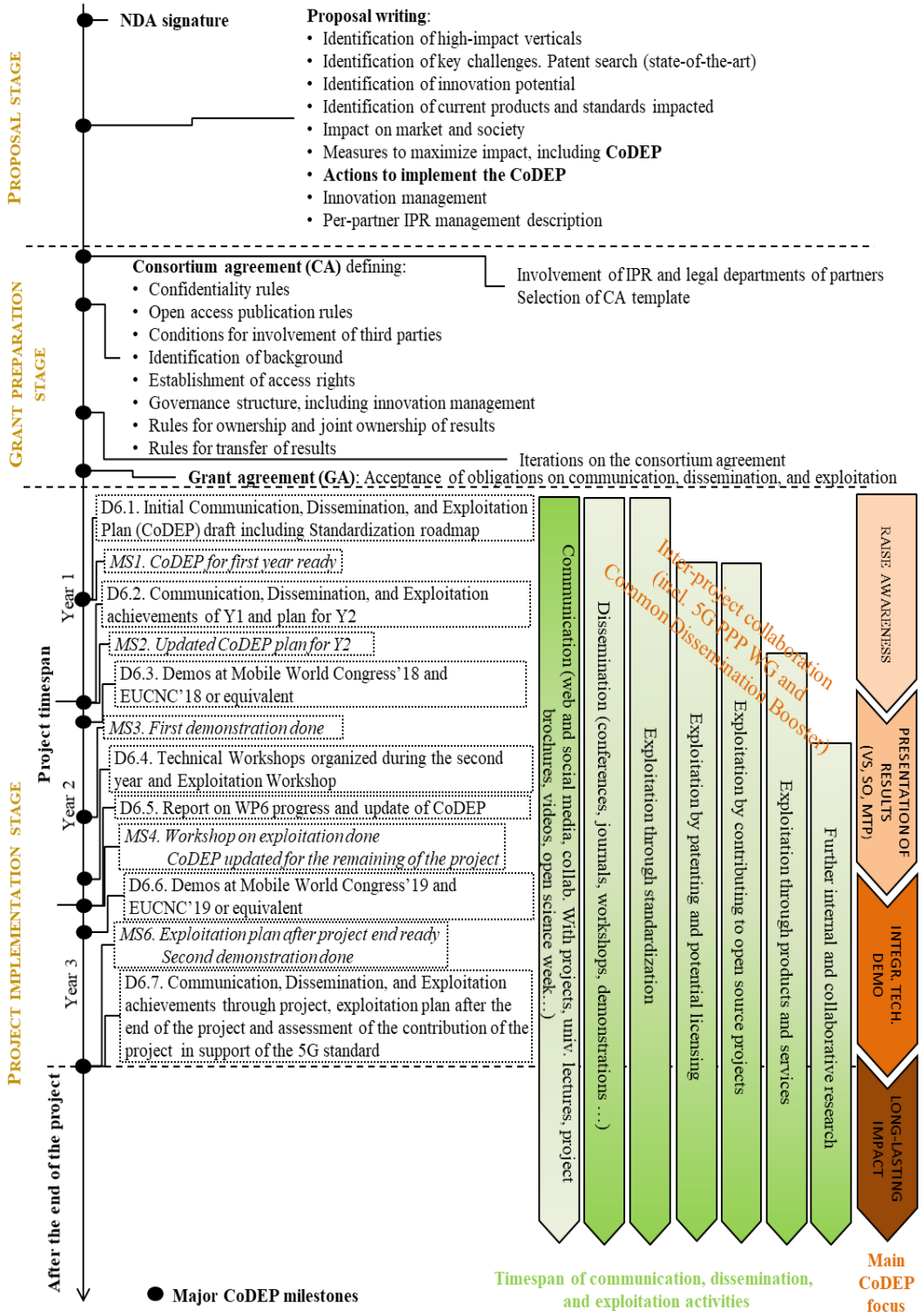

FIGURE 16: 5G-TRANSFORMER COMMUNICATION, DISSEMINATION, AND EXPLOITATION PLAN (CODEP)

A number of results in terms of standardisation were also achieved in accordance with the roadmap set up by the standardization advisory committee (SAC). As part of these roadmap, a number of contributions to ETSI MEC and NFV and 3GPP SA2 were submitted, for a total of twenty-five (9 to 3GPP and 16 to ETSI NFV and ETSI MEC).

Furthermore, in other to maximize its impact and to disseminate the work to the community, the project released as open source code for each the building blocks of the 5G-TRANSFORMER architecture, in addition to contributing to other open source code that were used by this project.

Finally, let us also highlight that the project was granted all five services requested for the Common Dissemination Booster, jointly with other projects (5G-Crosshaul and 5G-Coral), which started its operation in May 2018 and whose actions were mostly undertaken during this reporting period.

As mentioned above, the following subsection focuses on communication activities since dissemination and exploitation ones have their own one.

4.2.6.1 Communication activities

The 5G-TRANSFORMER communication plan is devoted to outreach activities to academia, industry, and society at large and to highlight the major achievements of the 5G-TRANSFORMER project, vision, concept, objectives, and results among the various stakeholders. All 5G-TRANSFORMER partners promote the 5G-TRANSFORMER project to the general public, and through different kinds of activities. In the following subsections, we will report all the activities, such as the Web, social media and project communication material, leaflet and poster, video, press releases and news, articles, presentation/lectures and collaboration with other projects for the whole project lifetime.

4.2.6.1.1 Web, social media, and project communication material

In order to achieve the objectives of the 5G-TRANSFORMER activities defined in D6.5, partners have continued contributing by issuing news about the project and utilizing their internal and external communication tools. In the last six months of the project, 5G-TRANSFORMER made a big effort on the generation of news around the presence of the project in demonstration-oriented events, showcasing the benefits of the technology developed, as shown in Section 4.2.6.1.4. More details can also be found on the project website (http://5g-transformer.eu/). Also, the statistics of 5G-TRANSFORMER social media are presented in Annex II. Throughout the project, the number of visits for various three month periods ranged from 6000 to 12000 and the most popular page reaching more than 2000 visits in three months and always staying above 1000 visits. Furthermore, for one-year periods, the website had around 16000 visitors and 36000 visits. The number of downloads of posters and leaflets was also monitored. The most popular leaflet almost reached 1000 downloads.

The social media accounts of 5G-TRANSFORMER were also set up, and are the following:

- Twitter: https://twitter.com/5g_transformer
- LinkedIn: https://www.linkedin.com/in/5g-transformer
- Instagram: https://www.instagram.com/5g_transformer/
- YouTube: https://www.youtube.com/channel/UCIQXD0ICxTK9eh_mQzMweww

Again, in the last 6 months of the project, 5G-TRANSFORMER has kept the steady impact increment of the website and of social media according to the CoDEP execution phase of the project.

4.2.6.1.2 Communication leaflets and poster

In Y2, 5G-TRANSFORMER generated several communication leaflets, available on the web, for the promotion of the 5G-TRANSFORMER project. For example, the 5G-TRANSFORMER leaflet (Figure 2) was presented in various booths during Mobile World Congress 2019. Besides, Netmgmt-WG Brochures and 5G-TRANSFORMER leaflet for MWC'19 were used to promote the project in Y2. Additionally, a number of communication brochures and posters presented at various venues (e.g., EuCNC, Mobile World Congress) were also generated. In the last 6 months of the project, 5G-TRANSFORMER generated several communication materials, available on the web, for the promotion of the 5G-TRANSFORMER project. For example, demo-specific posters were used to aid in the presentation of the project outcomes during EuCNC 2019 They are all available for download at: http://5g-transformer.eu/index.php/communication/

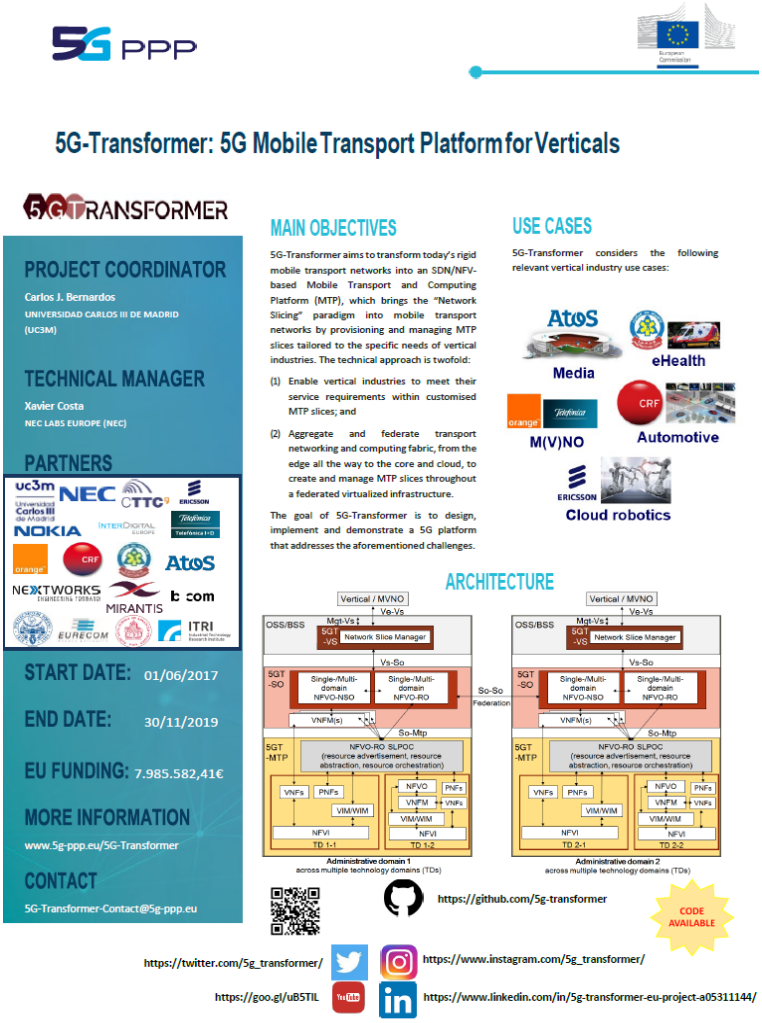

FIGURE 2: MOBILE WORLD CONGRESS 2019 5G-TRANSFORMER LEAFLET

4.2.6.1.3 Communication videos

Table 1 and Table 2 present the generated videos during Y2 and Y3, respectively. In Y2, 5G-TRANSFORMER generated several videos, which in addition to being uploaded to our YouTube channel, were exhibited in various events (Table 1).

TABLE 1: VIDEOS IN Y2

	Title	Link
1	New general video of 5G-TRANSFORMER	https://www.youtube.com/watch?v=DfhWEoMc4bU
2	Interview with 5G TRANSFORMER project coordinator, Arturo Azcorra @ EuCNC'18	https://www.youtube.com/watch?v=Rkrmcn4FgFM
3	5G network slices for mobile communication services, demo @ EUCN'18	https://www.youtube.com/watch?v=0QxeZerDZKQ
4	5G network slices for media vertical services, demo @ EuCNC'18	https://www.youtube.com/watch?v=sRH4m_eQ6NM
5	Using cloudify and public & private clouds to deploy and entertainment, demo @ EuCNC'18	https://www.youtube.com/watch?v=MhxpLNuTOEE
6	Edge Robotics	https://www.youtube.com/watch?v=aNv6BwB-JRE
7	5TONIC Projects (incl. 5G-TRANSFORMER)	https://www.youtube.com/watch?v=QNq1YL_h4v0

TABLE 2: VIDEOS IN Y3

	Title	Link
1	EuCNC 2019: Booth 40 - Carlos J Bernardos (5G-TRANSFORMER) and Antonio de la Oliva (5G-CORAL)	https://www.youtube.com/watch?v=Ug9f3-Nzg_I
2	5G-TRANSFORMER Demo MobiHoc 2019	https://www.youtube.com/watch?v=QYe1iNZIh3E
3	5G-TRANSFORMER DEMO at NEM SUMMIT 2019	https://www.youtube.com/watch?v=90ZYURuTId4

4.2.6.1.4 Communication. Press releases and news

In the 5G-TRANSFORMER website, various press releases were posted as well as distributed through a variety of channels. Table 3 and Table 4 present the summary of press releases and news during Y2 and Y3, respectively. It is important to highlight the impact of the news about different vertical oriented demos. Additional news, including impact on TV, is expected during the last months of the project and shortly after its finishes, related to the demonstration and validation of the main features of the 5G-TRANSFORMER platform.

TABLE 3: PRESS RELEASES AND NEWS IN Y2

	Activity
1	News about 5G-T Workshops at EuCNC http://5g-transformer.eu/index.php/2018/05/03/new-co-organized-workshop/
2	MEC Seminar at UC3M http://5g-transformer.eu/index.php/2018/05/09/multi-access-edge-computing-seminar/
3	Imagine Digital & Connect Europe, ICT2018 http://5g-transformer.eu/index.php/2018/05/18/5g-transformer-at-ict2018/

4	5GPPP Activities at EuCNC https://5g-ppp.eu/5g-ppp-at-eucnc-2018/
5	New Submitted Deliverables http://5g-transformer.eu/index.php/2018/06/02/new-submitted-deliverables/
6	News about CDB service http://5g-transformer.eu/index.php/2018/06/05/5g_in_cbd/
7	News in Linkedin about the participation of 5G-T in IEEE BMSB'18 conference 5GPPP group of Linkedin reports the participation of 5G-T in IEEE BMSB'18
8	5G-T activities at IEEE BMSB'18 http://5g-transformer.eu/index.php/2018/06/10/ieee-international-symposium-on-broadband-multimedia-systems-and-broadcasting/
9	News about 5G-PPP European Journal 2018 @ 5G-TRANSFORMER website http://5g-transformer.eu/index.php/news/
10	Press release: 5G-TRANSFORMER presence at EuCNC'18 http://5g-transformer.eu/index.php/news/
11	News about EC visit to 5GT booth @ EuCNC18 http://5g-transformer.eu/index.php/2018/06/22/the-european-commission-representatives-visited-the-5g-coral-5g-transformer-and-5g-ex-joint-booth-at-eucnc-2018/
12	New Submitted Deliverables http://5g-transformer.eu/index.php/2018/07/02/new-deliverables-available/
13	5GT in a tutorial at IEEE NetSoft2018 http://5g-transformer.eu/index.php/2018/07/05/5g-transformer-network-slicing-at-the-iee-netsoft-2018-conference/
14	News about a talk of 5GT at IEEE 5G Summit Tanger given by Xavier Costa (NEC), June 2018 http://5g-transformer.eu/index.php/2018/07/06/579/
15	News about Edge Robotics http://5g-transformer.eu/index.php/2018/07/13/edge-robotics/
16	News about 4th plenary meeting http://5g-transformer.eu/index.php/2018/07/23/4th-plenary-meeting/
17	News about 5GTONIC new projects http://5g-transformer.eu/index.php/2018/07/27/a-e50m-eu-sponsored-5g-programme-gives-5gtonic-a-key-role/
18	News about episodes of 5GCrosshaul http://5g-transformer.eu/index.php/2018/09/24/new-series-of-episodes-of-5g-crosshaul-integrated-backhaul-and-fronthaul-transport-network/
19	News about participation of 5G-TRANSFORMER in 2nd International Robotics Festival 2018 http://5g-transformer.eu/index.php/2018/09/28/2o-international-robotics-festival-2018/
20	News about participation of 5G-TRANSFORMER in the EuMW2018 http://5g-transformer.eu/index.php/2018/09/27/940/
21	News European Researchers Night 2018 http://5g-transformer.eu/index.php/2018/10/01/5g-transformer-participated-at-european-researchers-night-2018/
22	News about 5GCrosshaul Success Story http://5g-transformer.eu/index.php/2018/10/04/taming-the-avalanche-of-mobile-data-the-5g-crosshaul-sucess-story/

23	News about presence of 5GT in Ran World 2018 http://5g-transformer.eu/index.php/2018/10/15/5g-transformer-in-ran-world-2018/
24	Press Release: "Towards the interactive digital fan experience" https://atos.net/content/mini-sites/look-out-2020/assets/pdf/ATOS_LOOK%20OUT_SPORTS.pdf ; Also available at: https://5g-transformer.eu/svn/5g-transformer/execution/WP6/T6.1-Communication_activities/Press%20Releases/181016_ATOS_LOOK%20OUT_SPORTS.pdf
25	News: The 5G PPP Newsflash October 2018 https://5g-ppp.eu/newsflash-october-2018/
26	News: 5G-TRANSFORMER project participates in the 23rd edition of the Science Week 2018 http://5g-transformer.eu/index.php/2018/11/26/5g-transformer-project-participates-in-the-23rd-edition-of-the-science-week-2018/
27	News: ETSI MEC meeting at UC3M http://5g-transformer.eu/index.php/2018/11/28/etsi-mec-meeting-in-uc3m/
28	Press release: Major milestone: Release 1 of 5G-TRANSFORMER software http://5g-transformer.eu/index.php/2018/12/02/1025/
29	News about Release 1 of 5G-TRANSFORMER software https://5g-ppp.eu/release-1-of-5g-transformer-software/
30	News about participation of 5GT in 10th Conference of Framework Program of the EU in Spain http://5g-transformer.eu/index.php/2018/12/06/1015/
31	News about using OSM MANO in 5GT http://5g-transformer.eu/index.php/2018/12/13/5g-transformer-using-osm-to-allow-service-providers-to-automatically-deploy-5g-network-services/
32	News about Plenary meeting Paris January 2019 http://5g-transformer.eu/index.php/2019/01/16/5g-transformer-plenary-meeting-in-paris/
33	News about 5G-TRANSFORMER presence at 5th OSM Hackfest http://5g-transformer.eu/index.php/2019/02/07/5g-transformer-in-the-5th-osm-hackfest/
34	Press release: 5G-TRANSFORMER presence in MWC19 http://5g-transformer.eu/index.php/2019/02/25/5g-transformer-presence-in-mwc2019/
35	News about 5G-TRANSFORMER presence in IEEE workshop Future Networks http://5g-transformer.eu/index.php/2019/03/01/5g-technology-workshop-during-mwc19-in-barcelona/
36	News: Arturo Azcorra: “How to deploy and run Connected Industry 4.0” (MWC19) http://5g-transformer.eu/index.php/2019/03/06/arturo-azcorra-how-to-deploy-and-run-connected-industry-4-0-mwc19/

TABLE 4: PRESS RELEASES AND NEWS IN Y3

	Activity
1	5G-TRANSFORMER’s participation in IETF104 http://5g-transformer.eu/index.php/2019/04/11/5g-transformers-participation-in-ietf104/
2	FrontHaul & BackHaul Convergence for 5G Use Cases:

	http://5g-transformer.eu/index.php/2019/04/12/fronthaul-backhaul-convergence-for-5g-use-cases/
3	Visit of Juan Carlos García, from Telefonica GCTIO: http://5g-transformer.eu/index.php/2019/04/17/visit-of-juan-carlos-garcia-from-telefonica-gctio/
4	Special Issue “Beyond 5G Evolution”: http://5g-transformer.eu/index.php/2019/04/25/special-issue-beyond-5g-evolution/
5	NEM Summit 2019: http://5g-transformer.eu/index.php/2019/05/24/nem-summit-2019/
6	White Paper "Validating 5G Technology Performance - Assessing 5G architecture and application scenarios: http://5g-transformer.eu/index.php/2019/06/07/white-paper-validating-5g-technology-performance-assessing-5g-architecture-and-application-scenarios/
7	5G-TRANSFORMER summary of participation at EuCNC 2019: http://5g-transformer.eu/index.php/2019/06/18/5g-transformer-summary-of-participation-at-eucnc-2019/
8	Ericsson activates 5G NSA technology at 5Tonic Open Innovation Lab: http://5g-transformer.eu/index.php/2019/06/21/ericsson-activates-5g-nsa-technology-at-5tonic-open-innovation-lab/
9	ACM MobiHoc Conference 2019 – Demo 1: http://5g-transformer.eu/index.php/2019/07/06/acm-mobihoc-conference-2019/
10	ACM MobiHoc Conference 2019 – Demo 2: http://5g-transformer.eu/index.php/2019/07/16/acm-mobihoc-conference-2019-demo-2/
11	Boletin Informativo Samur Julio 2019 (Spanish): http://5g-transformer.eu/index.php/2019/07/23/boletin-informativo-samur-julio-2019-spanish/
12	SAMUR, UC3M and Telefonica perform an eHealth use case demo: http://5g-transformer.eu/index.php/2019/07/30/samur-uc3m-and-telefonica-perform-an-ehealth-use-case-demo/
13	‘Cloud-Native and Verticals’ services – 5G-PPP projects analysis’: http://5g-transformer.eu/index.php/2019/09/15/cloud-native-and-verticals-services-5g-ppp-projects-analysis/
14	5G-TRANSFORMER in Madrid Golf Open 2019: http://5g-transformer.eu/index.php/2019/10/15/5g-transformer-in-madrid-golf-open-2019/
15	SAMUR-Protección Civil colabora en el desarrollo de un dispositivo 5G de aviso automático de pacientes en parada cardiorrespiratoria: https://diario.madrid.es/blog/notas-de-prensa/samur-proteccion-civil-colabora-en-el-desarrollo-de-un-dispositivo-5g-de-aviso-automatico-de-pacientes-en-parada-cardiorrespiratoria/

4.2.6.1.5 Communication articles

Table 5 and Table 6 show the activities related to communication articles during Y2 and Y3, respectively. The communication articles target a wider audience than that strictly specialized in the topics of the project.

TABLE 5: COMMUNICATION ARTICLES IN Y2

	Title	Published in
1	5G-TRANSFORMER. 5G Mobile Transport Platform for Verticals	5G-PPP European 5G Annual Journal 2018 https://bscw.5g-ppp.eu/pub/bscw.cgi/d257916/Euro%205G%20Annual%20Journal%202018-v1.1.pdf
2	5G-TRANSFORMER. 5G Mobile Transport Platform for Verticals	5G-PPP European 5G Annual Journal 2019 https://bscw.5g-ppp.eu/pub/bscw.cgi/d302069/Euro%205G%20PPP%20Annual%20Journal%202019-web.pdf

TABLE 6: COMMUNICATION ARTICLES IN Y3

	Title	Published in
1	Vertical Cartography published during EUCNC'19	Available at Global 5G website: https://www.global5g.org/5g-transformer-cloud-robotics-industrial-automation https://www.global5g.org/5g-transformer-intersection-collision-avoidance-ica https://www.global5g.org/5g-transformer-emergency-health-services https://www.global5g.org/5g-transformer-emergency-services https://www.global5g.org/5g-transformer-live-streaming-0
2	Think Big Blog- Innovation blog from Telefonica	https://blogthinkbig.com/5tonic-5g-telefonica

Table 8 and Table 7 list the presentations and talks targeting a wide general audience during Y2 and Y3, respectively. They all describe the project general ideas and scope without entering too much into technical details.

TABLE 7: COMMUNICATION PRESENTATIONS AND LECTURES IN Y2

	Activity
1	Demo on Cloud Robotics at Festival Internazionale della Robotica (International Festival on Robotics).
2	Internet Festival Pisa 2018 Internet Festival 2018: Workshop “Internet in the Era of 5G, demo on “5G-Enabled Services”
3	Bright Researchers night 2018 Sant’Anna School celebrates the European “Bright” researchers’ night 2018 in Pisa, Pontedera and Livorno
4	23rd edition of Science Week 2018 5G-TRANSFORMER project participates in the 23rd edition of the Science Week 2018
5	Nokia Discovery Day co-organized with IHK Industry and Commerce Chamber

6	5G-TRANSFORMER at the I Jornadas de investigación EPS

TABLE 8: COMMUNICATION PRESENTATIONS IN Y3

Activity	
1	Proyecto 5G-TRANSFORMER “salvar vidas ahorrando tiempo”, eHealth description use case at the Boletin Information Samur-Protección Civil (in Spanish), July 2019
2	“Diversity Drives Societal Change”, 7th ACM Celebration of Women in Computing: https://womencourage.acm.org/2019/panels/
3	Panel about “5G, mobility and the automotive use case of 5G-TRANSFORMER”, Tendencia Movilidad en Smart Cities (in Spanish): https://eventos.uc3m.es/38171/detail/movilidad-en-smart-cities.html

4.2.6.1.6 Collaboration with other projects

A series of activities have been carried out together with 5GPPP projects in the framework of the various 5GPPP working groups. In Y2, Table 9 summarizes the collaboration with other projects in these WGs as well as joint papers or joint organization of events. Activities for Y3 are reported in Table 10.

Furthermore, most meetings (face-to-face or through audioconferences) were attended by the project representatives. As an example, in the software networks working group, meetings took place at a pace of at least one per month, and often two. Among others, this resulted in various white papers, as reported below. The architecture working group meetings was also regularly attended, as well as all the rest of working groups, which makes a total of around 20 meetings attended per year.

TABLE 9: ACTIVITY WITHIN 5G PPP WGS IN Y2

	Activity
1	5G-T Architecture Presentation for 5GPPP Arch WG
2	5G-PPP Software Networks WG white paper
3	WS3 Workshop @ EuCNC 18, joint with 5G-Exchange, 5G-CORAL, 5GCirty, 5G-Picture, Matilda, RECAP
4	Joint booth and Demos @ EuCNC18, with 5G-Exchange, 5G-CORAL
5	Netmgmt-WG Brochures
6	Special Session @ EuCNC'18
7	5G PPP PRE-STANDARDISATION WG - Mapping of Contributions to standards May 2018
8	Edge Robotics Demo in collaboration with 5G-Coral and 5G-Ex
9	Conext Workshop, joint with MONROE and 5G-CORAL
10	Joint paper with 5G-Monarch project for Mobicom'18 entitled "How Should I Slice My Network? A Multi-Service Empirical Evaluation of Resource Sharing Efficiency"
11	Joint paper with H2020-MSCA-ITN-20155G-Aura project @ ACM CONEXT'18 entitled “Overbooking Network Slices through Yield-driven End-to-End Orchestration”
12	PIMRC Workshop, joint with ITN H2020 5GAura
13	Joint paper with 5G-EVE project at IEEE Transaction on Big Data entitled: “From Megabits to CPU Ticks: Enriching a Demand Trace in the Age of MEC”
14	7th CLEEN workshop at WCNC19
15	Collaboration with NECOS project in the context of T1.3
16	Joint paper with 5G-EVE project at ACM/IEEE Transactions on

	Networking entitled: VNF Placement and Resource Allocation for the Support of Vertical Services in 5G Networks
17	Joint paper with 5G-Monarch project for INFOCOM'19 entitled: "A Utility-driven Multi-Queue Admission Control Solution for Network Slicing"
18	Joint paper with 5G-Monarch project for INFOCOM'19 entitled: “DeepCog: Cognitive Network Management in Sliced 5G Networks with Deep Learning”
19	Joint paper with 5G-Monarch project for IEEE Transactions on Mobile Computing entitled: "A Machine Learning approach to 5GInfrastructure Market optimization"
20	Presentation of an update of 5GT system architecture design to the 5G PPP Arch WG
21	Contribution to 5GIA Pre-Standardization WG
22	Contribution to 5GPPP Arch WG White Paper 3.0
23	Joint Demo with blueSPACE and 5G-Media projects for ACM MobiHoc 2019 Conference
24	Joint Demo with H2020-MSCA-ITN-2015 5G-AURA project
25	Joint Paper with 5G-Carmen project @ IEEE Communications Magazine (Telecom Software, Network Virtualization, and Software Defined Networks Series) entitled: “MANOaaS: A Multi-tenant NFV MANO for 5G Network Slices”
26	Joint Paper with 5G-MoNArch @ IEEE Wireless Communications Magazine entitled: “Artificial Intelligence for Elastic Management and Orchestration of 5G Networks”
27	Contribution to 5GPPP Arch WG White Paper 3.0

TABLE 10: ACTIVITY WITHIN 5G PPP CSA WGS IN Y3

Activity
1	Joint Paper with projects: 6Genesis, 5G!Pagoda, MATILDA @ IEEE Transactions on Mobile Computing entitled ”CDN Slicing over a Multi-Domain Edge Cloud”
2	Joint Paper with project 5Growth @ IEEE Communications Magazine entitled "Service Shifting: a Paradigm for Service Resilience in 5G"
3	Contribution to White Paper “Validating 5G Technology Performance – Assessing 5G architecture and Application Scenarios” released by the 5G PPP Test, Measurement and KPIs Validation (TMV) Working Group
4	Joint paper with Spanish 5GCity project (TEC2016-76795-C6-3-R) @ IEEE Transactions on Networking entitled “Paper: RL-NSB: Reinforcement Learning-based 5G Network Slice Broker”"
5	Joint paper with 5G-Monarch project @IEEE Transactions on Network and Service Management entitled “Resource Sharing Efficiency in Network Slicing”
6	Contribution to 5GPPP Software Networks (SN) WG White Paper entitled “Cloud-Native and Verticals services”
7	Joint PhD with 5G-EVE, entitled “Network virtualization and 5G services” (ongoing)
8	Contribution to 5G PPP phase II KPIs - Annex to Programme Management Report
9	Contribution to Standard Impacts presentation at the 5GArch 2019: International Workshop on 5G Architecture by 5GPPP
10	Submission of a joint Paper with project 5GCoral @ IEEE Access

	entitled "Virtualization at the edge: exploiting NFV-MEC integration"
11	Participation in a published 5GPPP Software Networks (SN) WG White Paper entitled “Cloud-Native and Verticals services”
12	Joint Paper with project 5G!Drones @ Globecom19 entitled “Dynamic slicing of RAN resources for heterogeneous coexisting 5G services”
13	Joint Paper with projects: 5GROWTH, 5G-MoNArch, 5G-TOURS @ ACM Mobicom'19 entitled “vrAIn: A Deep Learning Approach Tailoring Computing and Radio Resources in Virtualized RANs”
14	Joint Demo with projects: 5GROWTH, 5G-MoNArch, 5G-TOURS entitled ”vrAIn Proof-of-Concept – A Deep Learning Approach for Virtualized RAN Resource Control”
15	Join Paper with project 5G-Coral @ IEEE CSCN 2019 entitled “5GEN: A tool to generate 5G infrastructure graphs”
16	Joint Demo with 5G-CORAL @ EUCNC'19: immersive robotic teleoperation

4.2.6.2 Deviations

During this first reporting period, the project achieved all its milestones in due time and progress was as expected. So, no deviations had to be handled.

4.2.6.3 Corrective actions

No corrective actions were needed.

4.2.7 WP7

This WP is about the management of the project, as described in the DoA, and is led by UC3M.

The main activities in this period are related to ensure that the project runs successfully, that the partners successfully and efficiently collaborate and that the technical objectives are achieved taking care of the time and the costs of the project. The project coordinator (PC) administered the financial contribution, allocating it between the beneficiaries, and activities in accordance to the Grant Agreement. The payments have been done with no delay. The PC kept the records and financial accounting and informed the European Commission of the distribution of the EU financial contribution. The PC verified consistency between the reports and the project tasks and monitors the compliance of beneficiaries with their obligations.

In M19 the Deliverable D7.3 (Report on Cumulative Expenditure - 2018), was delivered on time. It provides a summary of the expenditures (per partner) of 2018, as well as the accumulated ones.

During this reporting period an amendment has been carried out. The main changes implemented in this amendment are listed below:

- Addition of a third party (Interdigital Germany, IDG) of IDCC.
- Redistribution of PM among some of the Partners and tasks they carry out in different WP without changing overall budget.
- Change in WP5 Leader; and formal swap of wap Project Coordinator and Deputy Project Coordinator.
- Some typo fixing in the DoA.

4.2.7.1 Task 7.1: Project administrative, financial, and legal management

In this period (M4-M30) seven plenary meetings were held:

- 5th plenary meeting on July 10-12, 2018 in Berlin (hosted by IDCC). This meeting focused on the preparation of the first technical review. In addition to this, a couple of smaller meetings (only involving the PMT) were devoted to the preparation of the review.
- 6th plenary meeting on October 15-17, 2018 in Madrid (hosted by UC3M). This meeting focused on the analysis of the recommendations from the reviewers after the first technical review.
- 7th plenary meeting on January 15-17, 2019 in Paris (hosted by Orange). This meeting focused technical aspects related to the second release (R2) of the 5G-TRANSFORMER platform.
- 8th plenary meeting on April 2-4, 2019 in Poznan (hosted by MIRANTIS). This meeting focused on the finalization of the R2 of 5G-TRANSFORMER.
- 9th plenary meeting on June 25-27, 2019 in Madrid (hosted by UC3M). This meeting focused mainly on the preparation of the PoCs.
- Virtual plenary meeting on October 8-9, 2019. This meeting took place on two half-days, and was devoted to the review of the status of the last round of deliverables of the project.
- 10th plenary meeting on November 5-7, 2019 in Turin (hosted by CRF). This meeting focused on the preparation of the final technical review, with a main focus on the demonstrations (including a real demo of the automotive use case at the CRF test track). In addition to this meeting, there will be a couple of smaller meetings (only involving the PMT) to prepare all the details of the review.

During the second reporting period, some technical remote meetings (per WP), using gotomeeting tool, maintained the weekly frequency, while others switched to bi-weekly frequency. A shared calendar is used to reflect and share the planned remote meetings to keep the partners informed about the date and hour.

A report of the project progress in terms of technical activities and resources allocation is planned each three months by means of the Quarterly Management Reports.

The Consortium has continued using the following tools for the management of the project (no changes compared to what was using in the first reporting period):

- Redmine: a web-based tool for the description of the activities and the coordination between the partners. A dedicated section has been created as repository of the meeting minutes. This includes a shared calendar for meetings bookkeeping.
- SVN repository: the repository where documentation and software have been stored and shared among the partners.
- Several mailing lists have been created in order to communicate with the partners: 5g-transformer-all, 5g-transformer-wp1, 5g-transformer-wp2, 5g-transformer-wp3, 5g-transformer-wp4, 5g-transformer-wp5, 5g-transformer-wp6, 5g-transformer-wp7, 5g-transformer-pmt, 5g-transformer-admin and 5g-transformer-contact.

The 5G-TRANSFORMER website has been available since the beginning of the project (http://5g-transformer.eu). Moreover, Twitter (https://twitter.com/5g_transformer),

Instagram (https://www.instagram.com/5g_transformer/), LinkedIn (https://www.linkedin.com/in/5g-transformer) accounts and a YouTube channel (https://www.youtube.com/channel/UCIQXD0lCxTK9eh_mQzMweww) also exist.

4.2.7.2 Task 7.2: Technical coordination, Innovation and Quality management

This task is led by NECLE as technical manager and UC3M and TEI participate as project coordinator and innovation manager, respectively. NECLE as the project technical manager, leads the technical innovations for the project and coordinating the work of all WPs. UC3M as project coordinator ensures the project progresses towards its objectives. TEI as the innovation manager has monitored the innovation and exploitation activities.

4.2.7.3 Task 7.3: Technical coordination, Innovation and Quality management

Within 5G PPP, the project participates in the cross-project work groups (WGs), where the work of multiple projects can converge into identifying the shared issues and developing supported program level position on technical and strategic items. 5G-TRANSFORMER actively participates in seven working groups. Table 16 only lists the main representatives of the project. Other partners may participate as well.

TABLE 16: 5G-TRANSFORMER AND 5G PPP CSA WGS

5G PPP CSA WG	Description of the activities	5G-T representative
Pre-Standardization WG	Attendance to periodic conference calls, including one with the WG Chair on including other non-3GPP activities. Reporting of 3GPP activities and 5G-TRANSFORMER.	IDCC
5G Architecture WG	Attendance to periodic conference calls, including one where 5G-TRANSFORMER architecture was presented. Participation to 5G PPP Architecture WG. The group organized a session at EuCNC 2019, where representatives of the project participated representing different stakeholders/views: Operators, Verticals, Vendors and the project as a whole.	NECLE
Software Networks WG	Active participation to the 5G PPP Software Networks WG. 5G-TRANSFORMER provided the information on software components, which can be reused by other projects or is even available as open source. 5G-TRANSFORMER contributed actively to the white paper 'Cloud-Native and Verticals services'. The white paper was presented at a workshop at EUCNC 2019, to which 5G-TRANSFORMER participated as well.	NOK-N, UC3M
Vision and Societal Challenges WG	Attendance to periodic conference calls.	TEI

Trials WG	Participation to 5G PPP Trials WG and the roadmap (5G Pan-European trials roadmap 3.0.) generated by the group (https://5g-ppp.eu/5g-trials-roadmap/).	UC3M
Network Management & QoS WG	Attendance to periodic conference calls. Input on 5G-TRANSFORMER for preparation of a brochure for EuCNC. 5G PPP Network Management & QoS WG	POLITO
Automotive WG	Attendance to periodic conference calls	CRF

Additionally, ATOS and ORANGE participate in the EC H2020 5G Infrastructure PPP Technical board on Performance KPIs.

Last, but not least, NECLE and UC3M attends the Technical Board and Steering Boards.

4.2.7.4 Deviations

Overall, the work package proceeded as planned.

4.2.7.5 Corrective actions

No corrective actions were needed.

4.3 Deliverables

Deliverable Progress			
	On Schedule	Delayed	Completed
D1.1			X
D1.2			X
D1.3			X
D1.4			X
D2.1			X
D2.2			X
D2.3			X
D2.4			X
D3.1			X
D3.2			X
D3.3			X
D3.4			X
D4.1			X
D4.2			X
D4.3			X
D4.4			X
D5.1			X
D5.2			X
D5.3			X
D5.4			X

D5.5			X
D6.1			X
D6.2			X
D6.3			X
D6.4			X
D6.5			X
D6.6			X
D6.7			X
D7.1			X
D7.2			X
D7.3			X
D7.4			X
D7.5			X

4.4 Milestones

Milestones Progress			
	On Schedule	Delayed	Completed
MS1			X
MS2			X
MS3			X
MS4			X
MS5			X
MS6			X
MS7			X
MS8			X
MS9			X
MS10			X
MS11			X
MS12[8]			X
MS13			X
MS14			X
MS15			X
MS16			X
MS17			X
MS18			X

[8] Due to the shift of deliverable D6.4 to month 25, triggered by reviewers' recommendation and changed in the Second Amendment, milestone MS12 should have been shifted to month 25 as well (as the verification means of MS12 is the delivery of D6.4), instead of month 24. This clerical error was notified to the PO when D6.4 was submitted, but was not corrected in the GA, as it required an amendment. While MS12 appears might appear as achieved late in the Participant Portal, this does not really mean that we had any delay in the completion of the milestone, as it is associated with the organization of the SME workshop that took place in EuCNC 2019 (which corresponds to D6.4, which was timely delivered).

4.5 Exploitable Results

4.5.1 Exploitation on commercial products and PoC developed internally to the companies

In view of the high importance given by the project to the exploitation activities, the project has appointed an Innovation Manager (IM) Dr. Giulio Bottari from Ericsson (TEI) to lead the work and ensure successful exploitation of the innovations from the project. The IM has continuously interacted with partners to capture exploitation achievements and to coordinate reporting plans for future impacts on partner's products, also after the project end.

An exploitation strategy has been established since the project beginning to maximize the impact of the project results on products and services of the verticals, SMEs, and manufacturer partners participating in the consortium. In addition, the two operators/service providers Orange and Telefonica (TID) have identified exploitation opportunities from the project as they have been involved in all facets of the activities, including the definition of concepts such as orchestration and federation of resources and in the evolution of the radio/transport network.

A preliminary identification activity has been reported in the Initial CoDEP D6.1 where products and services have been grouped following the three main architectural building blocks envisioned by the project: Vertical Slicer (5GT-VS), Service Orchestrator(5GT-SO), and Mobile Transport and Computing Platform (5GT-MTP). The subsequent deliverables D6.2, D6.5, and D6.7 have preserved this categorization in reporting the advancements, partner-by-partner, in commercially exploiting project results. As the project was progressing, partners have more and more clearly associated project components and modules to their specific products and services enforcing the link among 5G-TRANSFORMER outcomes.

Demos and test-beds deployed in the context of WP5 have activated a fruitful ecosystem for experimentation where verticals, manufacturers, SMEs, operators, and academia have shared requirements, constraints, feasibility of specific features and functionalities. This has increased the value of exploitation through products and services as real needs and constraints have been injected in the exploitable project outcomes.

At the end of Y2, in the context of the Innovation Radar process, WP1-4 have identified thirteen innovations presenting market opportunities in and beyond the project lifetime. Single companies, in some cases in cooperation with academia, have declared that said innovations can have an impact on their product portfolio in a time window that can span from immediate exploitation to long-term (five year) one.

Table 17 reports the final mapping between the project main building blocks and the target products, services, and solutions, indicated by the project partners.

The last deliverable of WP6, that is D6.7, reports, for each partner, a complete and detailed list of exploitation achievements in products and services through the project and the relevant exploitation plans after the end of the project. It's worth to notice that, as the project outcomes are also feeding other projects (i.e. 5Growth, Slicenet, blueSPACE, 5G EVE) the survivability of project results, like project components, could also have indirect exploitation opportunities in the context of said other projects.

TABLE 17: MAPPING BETWEEN BUILDING BLOCKS AND THE RELEVANT PARTNERS' PRODUCTS AND SERVICES

Block	PoC/Product/Service/Solution	Partner
Vertical Slicer/Vertical Services	Smart Platform/Smart Stadium/Fan Engagement Solution	ATOS
	Cloud Solutions	ATOS
	Smart T-Shirt	SAMUR
	FCA car models	CRF
	Wireless Edge Factory	BCOM
	Consultancy and training services	NXW
	Symphony	NXW
	Sealux	NXW
	NFV Mano Portfolio (Sebastian)	NXW
	Video Streaming Robotic Platform	IDCC
	Netcracker 12 (NFV Management & Orchestration)	NECLE
Service Orchestrator	Netcracker 12 (NFV Management & Orchestration)	NECLE
	TMS -Traffic Management System	NECLE
	MS5000- Integrated Network Management System	NECLE
	Mirantis Cloud Platform (MCP)	MIRANTIS
	Cloudify	MIRANTIS
	Ericsson Dynamic Orchestration	TEI
Mobile Transport and Computing Platform	Airscale 5G BTSs	NOK-N
	Airframe	NOK-N
	Airframe data center	NOK-N
	NFV-based packet core	NOK-N
	MEC Platform	NOK-N
	MS5000 - Integrated Network Management System	NECLE
	UNMS - Unified Network Management System	NECLE
	Fronthaul 6000	TEI
	Ericsson Cloud Infrastructure	TEI

4.5.2 Exploitation on the realization of common platform among the 5G-TRANSFORMER partners by means of testbed and demos

In Table 18 below, we report on the realization of public demonstration and testbed integration implemented during the lifecycle of the project.

Besides that, 5G-TRANSFORMER, in the context of EuCNC 2019 demonstrated and validated a series of 4 project vertical use cases and, importantly, the innovative components and concepts delivered by the project specifically designed and developed to meet the vertical functional and technical requirements. 5G-TRANSFORMER platform can orchestrate dissimilar PoCs based on the vertical-oriented use cases selected by the project. In depth:

- Show how an Automotive PoC will demonstrate the deployment and management of the EVS (Extended Virtual Sensing) application on MEC. EVS is a road safety application designed to alert drivers about the presence of unseen vehicles or other unexpected obstacles at intersections.
- The e-Industry (Cloud/Edge Robotics) demonstrates the automatic deployment of a robotic control application that leverages the Mobile Edge Computing (MEC) Radio Network Information Service (RNIS).
- The Entrainment demonstration describes the provision of a high definition content distribution service with very low latency and service creation time. The virtual appliances are dynamically deployed allowing the streaming service provider to deploy the different components in edge clouds close to the user.

- The MNO/MVNO PoC demonstrates the deployment of 3 network slices (echographer (URLLC), video (eMBB) and IoT devices (mMTC)).

TABLE 18: PLAN FOR DEMONSTRATION AND TESTBED

Vertical Industry	Testbeds	Partners	Description
Automotive	CTTC, ARNO	CRF, POLITO, CTTC, NXW, SSA, EURECOM	The DEMO is played in Orbassano, CFR Test Area (Italy) with real-cars. The PoC demonstrates the automatic deployment and scalability of the EVS/video streaming service application on edge. This is be done according to priority and rules managed by arbitration and scaling functionality managed at the SO level according to monitored resources. The demonstration consisted in using 5G-TRANFORMER to: a) deploy a full version of video streaming (based on 2 VMs); b) deploy EVS (3 VMs) with higher priority. So, to handle of priority by the Arbitration instantiating a new video service configuration (only one VM instead of 2). Finally scaling down of video streaming managed by arbitrator or c) eventually scaling up of EVS managed by SO when CPU consumption increases as a consequence of the increase in traffic load.
Entertainment	5TONIC	ATOS TID	At "The Mutuactivos Open de España" (3 to 6 October, Madrid: https://lnkd.in/dXRisSk), ATOS delivered a novel and engaging media solution on 5G that merges dissimilar technological concepts such as 5G technologies, cloud-native approach for edge deployments and 4K/360-degree adaptive video streaming to achieve a highly-customizable video streaming experience on an orchestrated 5G network. The demonstration showed how new capabilities brought by 5G, provide an entirely new way for consumers to interact with immersive media contents in the context of a large-scale sport event. An UHD video streaming service, virtualized as a 5G-T Vertical Slicer, was orchestrated by the 5G-T Orchestrator so to be deployed at the edge with an abstraction of network and compute configuration parameters. 5G-T technologies enabled ATOS, as media operator, to access to a whole range of multimedia processing and interaction executed in a more distributed way closer to the users while the full infrastructure stack is governed, monitored and the resources are automatically scaled.
E-Health	5TONIC, CTTC	UC3M, SAMUR	UC3M, Telefonica and SAMUR performed a demo (Madrid, 30 July 2019 in) about the eHealth use case to Korea Telecom delegates among others. The demo focused on the automation of emergency support deployment of medical services, reducing the overall reaction time, as well as providing support to AR services. The demo has been performed at 5TONIC premises. The demonstration showed how 5G-TRANSFORMER technologies enable the management of distributed services on the edge.
E-Industry	5TONIC	TEI	The DEMO is played at the 5TONIC lab in Spain. The PoC demonstrates factory service robots and production processes that are remotely monitored and controlled in the cloud, exploiting wireless

			connectivity (5G). The objective of the demonstrator is to verify the allocation of suitable resources based on the specific service requests to allow the interaction and coordination of multiple (fixed and mobile) robots controlled by remote distributed services, satisfying strict latency and bandwidth requirements.
MNO/MVNO	5TONIC, CTTC, EURECOM	BCOM, TID, ORANGE, ITRI	The MNO/MVNO PoC demonstrates the deployment of 3 network slices (echographer (URLLC), video (eMBB) and IoT devices (mMTC)).

4.5.3 Exploitation on standards

5G TRANSFORMER has devoted great effort towards the standardization activity as proven by the high number of contributions (so far 34) submitted to key SDO forums, including ETSI MEC, IETF and 3GPP.

Table 19, Table 20 and Table 21 list each contribution adopted in Year 1, Year 2 and Year 3, respectively, by the corresponding SDO and specify how the contribution maps into the project, i.e., which task or specific activity has produced the specific standard contribution.

TABLE 19: DESCRIPTION OF STANDARDS DISSEMINATION ACHIEVEMENTS IN Y1, HIGHLIGHTING THE RELATIONSHIP BETWEEN CONTRIBUTIONS TO SPECIFIC SDOS AND 5G-TRANSFORMER COMPONENTS

SDO	Contribution ID	Contribution Summary	Outcome	Relation to 5G-T	Date
First Year of 5G TRANSFORMER					
IETF (DMM WG)	Proxy Mobile IPv6 extensions for Distributed Mobility Management https://tools.ietf.org/html/draft-ietf-dmm-pmipv6-dlif-04	A solution based on Proxy Mobile IPv6 is proposed in which mobility sessions are anchored at the last IP hop router, called Mobility Anchor and Access Router (MAAR). The MAAR is an enhanced access router, also able to operate as a local mobility anchor or mobility access gateway, on a per prefix basis.	Adopted	5G Mobile Transport and Computing Platform, deliverable D2.3 [5], implements a mechanism to provide Mobility support (clause 7.3.1.3) to aggregate resource base on virtual coverage. The virtual coverage encompasses radio and Core Network resources, including information on CN gateways. The cross-abstraction manager in the MTP considers the simultaneous anchoring of flows abstracting resources from a particular coverage area composed by ordered geographical points	10/05/2018
IRTF (NFVRG)	Network Virtualization Research Challenges https://tools.ietf.org/html/rfc8568	Survey of the different efforts taking place at IETF and IRTF with regards to network virtualization, automation and orchestration in contrast with efforts taken by other SDOs	Adopted	5G Mobile Transport and Computing Platform and Service Orchestrator, in conjunction with the Vertical Slicer leverage on the concepts of network slicing and network virtualization to provide slices tailored to needs (e.g., networking	03/07/2017

				and computing requirements) of different vertical industries and to allow per-slice management of virtualized resources as described in deliverable D1.3 [6]. Furthermore, this RFC identifies multi-domain orchestration as one challenge that needs to be tackled by the IETF community. Multi-domain orchestration is one key contribution of the 5G TRANSFORMER project, as seen not just in deliverables, e.g., D4.3 [8] but alson in other standardization contributions e.g., IETF Multi-domain Network Virtualization (https://tools.ietf.org/html/draft-bernardos-nmrg-multidomain-00).	
IETF (NMRG)	Multi-domain Network Virtualization https://tools.ietf.org/html/draft-bernardos-nmrg-multidomain-00	Analysis of the problem of multi-provider multi-domain orchestration, by first scoping the problem, then looking into potential architectural approaches	Not yet adopted	The 5GT Service Orchestrator addresses the problem of multi-provider/multi-domain orchestration by providing service scaling, network service composition, service federation, enhanced placement algorithms considering location constraint and MEC support, and enhanced service monitoring platform which provides monitoring data to the 5GT-SO for automated service scaling and SLA management, as described in deliverable D1.3 [6]	05/03/2018
IETF (INTAREA)	IPv6-based discovery and association of Virtualization Infrastructure Manager (VIM) and Network Function Virtualization Orchestrator (NFVO) https://tools.ietf.org/html/draft-bernardos-intarea-vim-discovery-01	The contribution describes mechanisms allowing dynamic discovery of virtualization resources and orchestrators in IPv6-based networks. New IPv6 neighbor discovery options are defined	Not yet adopted	5G Mobile Transport and Computing Platform and in particular its Enhanced Placement feature, as described in deliverable D2.3 [5] addresses the issue of where to put VNF in multi-VIM domains	05/03/2018
IETF (COMS BoF)	COMS Architecture https://datatracker.ietf.org/doc/draft-geng-coms-architecture	The contribution defines the overall architecture of a COMS based network slicing system. COMS works on the top level network slice	Not yet adopted	At its core, the 5G TRANSFORMER project, leverages on the concept of network slicing for providing slices tailored to needs (e.g., networking and	05/03/2018

		orchestrator which directly communicates with the network slice provider and enables the technology-independent network slice management		computing requirements) of different vertical industries and to allow per-slice management of virtualized resources. Multiple enhancements and novelties have been included to satisfy the requirements to support heterogeneous network slicing as described in deliverable D1.3 [6]	
IETF (COMS BoF)	Problem Statement of Common Operation and Management of Network Slicing https://datatracker.ietf.org/doc/draft-geng-coms-problem-statement	This contribution discusses the general requirements and problem statement of supervised heterogeneous network slicing	Note yet adopted	The Vertical Slicer, through its Vertical Services Monitoring, supports monitoring of Vertical Service (VSI) their corresponding Network Slice Instances (NSI). The 5GT-VS interacts with the 5GT-SO to collect monitoring data about the established NFV network services and correlates or aggregates these data in order to produce metrics and KPIs for network slices and vertical services, as described in deliverable D3.3 [7]	05/03/2018
IETF (CCAMP WG)	A YANG Data Model for Microwave Topology https://datatracker.ietf.org/doc/draft-ietf-ccamp-mw-topo-yang/		Adopted	Definition of an information model and the related data model specified in deliverable D1.3 [6]	05/03/2018
IETF (CCAMP WG)	A framework for management and control of microwave and millimeter wave interface parameters https://datatracker.ietf.org/doc/draft-ietf-ccamp-microwave-framework	This contribution describes the required characteristics and use cases for control and management of radio link interface parameters using a YANG Data Model	Not yet adopted	5G Mobile Transport and Computing Platform, addresses the representation of network resources through Logical Links (LL) which define the link interconnecting two IP endpoints. The information model for a logical link, includes the IP address of terminating nodes and information related to the bandwidth and the latency induced by such connectivity.	05/01/2018
IETF (CCAMP WG)	A YANG Data Model for Microwave Radio Link https://datatracker.ietf.org/doc/draft-ietf-ccamp-mw-yang	This contribution defines a YANG data model to describe the topologies of microwave/millimeter	Adopted	5G Mobile Transport and Computing Platform has adopted YANG data models as information models defined to express relevant information parameters, thus enabling the exchange of this information through the adoption of a proper protocol, as described in	03/03/2018

				deliverable D1.3 [6]	
3GPP SA2	(S2-183925-S2-183923)	New Key Issue: Identify scenarios when Network Slices cannot coexist within a single PLMN	Approved	Vertical Slicer, e.g., Verticals may impose requirements on what slices should be mutually exclusive (i.e., cannot be accessed simultaneously). The Vertical Slicer should be aware of this property. E.g., when managing policies per tenant, as specified in deliverable D3.3, in particular as part of the Policy Management and Arbitrator components.	16/04/2018

TABLE 20: DESCRIPTION OF STANDARDS DISSEMINATION ACHIEVEMENTS IN Y2, HIGHLIGHTING THE RELATIONSHIP BETWEEN CONTRIBUTIONS TO SPECIFIC SDOS AND 5G-TRANSFORMER COMPONENTS

SDO	Contribution ID	Contribution Summary	Outcome	Relation to 5G-T	Date
Second Year of 5G TRANSFORMER					
ETSI NFV	IFA013	The contribution proposes a mechanism to associate specific policies to NFV NSIs	Accepted	The contribution allows the 5GT-VS to associate specific policies to NFV NSIs such that 5GT-SO could orchestrate different NSIs accordingly. Policies are needed to implement some of the SLA requirements, as described in deliverable D3.3 [7], and in particular as part of the Policy Management component	22/10/2018
ETSI NFV	IFA007ed321, IFA008ed321, IFA010ed321, IFA013ed321)	The contribution proposes a mechanism to associate specific policies to NFV NSIs	Accepted	The contribution allows the 5GT-VS to associate specific policies to NFV NSIs such that 5GT-SO could orchestrate different NSIs accordingly. Policies are needed to implement some of the SLA requirements. This is in line with deliverable D3.3 [7], and in particular as part of the Policy Management component	22/10/2018
3GPP SA2	Contribution to 3GPP SA2#127 meeting in Vilnius, LT. Technical Document (Tdoc): S2-187289	This contribution addresses KI1 "Mutually exclusive access to Network Slices" and in particular, identifying whether improvements to existing Release 15 System procedures are needed when controlling	Noted	Verticals may impose requirements on what slices should be mutually exclusive (i.e., cannot be access simultaneously). The Vertical Slicer should be aware of this property. E.g., when managing policies per	02/07/2018

		the access to mutually exclusive Network Slices, including aspects of both UE and network"		tenant, in line with deliverable D3.3 [7], and in particular as part of the Policy Management and Arbitrator components	
3GPP SA2	Contribution to 3GPP SA2#127 meeting in Vilnius, LT. Technical Document (Tdoc): S2-187248	This contribution proposes a new Kew Issue addressing system impacts when handling access to network slices, for UEs that have already been authenticated for PLMN access using 3GPP SUPI, but that require an additional level of authentication and authorization using User Identities and Credentials for specific slices	Approved	The arbitration features in the vertical slicer may need to consider slices that require Slice specific additional authentication, when selecting slices based on tenant policies as described in deliverable D3.3, [7]	02/07/2018
3GPP SA2	Contribution to 3GPP SA2#128bis meeting in Sophia Antipolis, FR. Technical Document (Tdoc): S2-188484	This contribution addresses KI1 (Key Issue) 1 "Mutually exclusive access to Network Slices" and in particular, identifying whether improvements to existing Release 15 System procedures are needed when controlling the access to mutually exclusive Network Slices, including aspects of both UE and network"	Approved	Verticals may impose requirements on what slices should be mutually exclusive (i.e., cannot be access simultaneously). The Vertical Slicer should be aware of this property. E.g., when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management and Arbitrator components	20/082018
3GPP SA2	Contribution to 3GPP SA2#129 meeting in Dongguan, China. Technical Document (Tdoc): S2-1811600	This contribution proposes and update to Solution 1.6 "Enabling access control to network slices that cannot be access simultaneously" in 3GPP. Solution 1.6 provides the evaluation of this solution	Approved	Verticals may impose requirements on what slices should be mutually exclusive (i.e., cannot be access simultaneously). The Vertical Slicer should be aware of this property. E.g., when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management and Arbitrator components	15/10/2018
3GPP SA2	Contribution to 3GPP SA2#129 meeting in Tenerife, SP. Technical Document (Tdoc): S2-1901747	This Change Request (CR) proposes normative text to implement Slice-specific secondary authentication, ensuring that the UE is first successfully registered to the Network before Slice Specific Authentication and Authorization is executed	Postponed	The arbitration features in the vertical slicer may need to consider slices that require Slice specific additional authentication, when selecting slices based on tenant policies, as per SLA agreement, within section 2.1, in deliverable D3.3 [7]	20/02/2019
3GPP SA2	Contribution to 3GPP SA2#129 meeting in Tenerife, SP. Technical	This Change Request (CR) proposes normative text to implement Slice-specific secondary authentication, ensuring that the UE is first	Postponed	The arbitration features in the vertical slicer may need to consider slices that require Slice specific additional authentication,	20/02/2019

	Document (Tdoc): S2-1901746	successfully registered to the Network before Slice Specific Authentication and Authorization is executed		when selecting slices based on tenant, as per SLA agreement, within section 2.1, in deliverable D3.3 [7]	
ETSI MEC	MEC(18)000298	MEC024 errata of use case 5.1 and exemplary figure	Accepted	The Vertical Slicer and Service Orchestrator should be aware what MEC resources are needed to be accessed when allocating resources to tenants when managing policies per tenant, as described in deliverable D3.3 [7]	24/07/2018
ETSI MEC	MEC(18)000299	MEC024 key issue on slice-awareness of the MEAO		The Vertical Slicer and Service Orchestrator deliverables D3.3 and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	24/07/2018
ETSI MEC	MEC(18)000300	MEC024 key issue on slice-awareness of the MEP	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	24/07/2018
ETSI MEC	MEC(18)000301	MEC024 key issue on slice-awareness of the MEPM-V	Presented	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	24/07/2018
ETSI MEC	MEC(18)000326	MEC024 - Some Clarifications for the use case 5.2	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants	31/07/2018

				when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	
ETSI MEC	MEC(18)000329r1	MEC024 - Use case on dedicated instances of MEC components in a network slice	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	31/07/2018
ETSI MEC	MEC(18)000339	MEC024 - Use case on multiple tenants in a single network slice	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	03/08/2018
ETSI MEC	MEC(18)000340	MEC024 - Use case on MEC applications shared among NSIs	Presented	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	02/08/2018
ETSI MEC	MEC(18)000430	MEC024 - Overview of Network Slicing Concept in ETSI NFV	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	12/10/2018
ETSI MEC	MEC(19)000038	MEC024 - Draft v2.0.6 - Editorial Changes	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and	05/03/2019

				D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	
ETSI MEC	MEC(19)000039r2	MEC024 - Section 7 - Conclusions and recommendations	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	05/03/2019
ETSI MEC	MEC(19)000067r1	MEC024 - Editorial changes and references formatting	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	29/03/2019
ETSI MEC	MEC(19)000068	MEC024 - Scope text proposal (Section 1)	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and in particular as part of the Policy Management component	29/03/2019
ETSI MEC	MEC(19)000122	MEC024 - Efficient E2E multi-slice support for MEC-enabled 5G deployments	Accepted	The Vertical Slicer and Service Orchestrator deliverables D3.3 [7] and D4.3 [8] should be aware what MEC resources are needed to be access when allocating resources to tenants when managing policies per tenant, described in deliverable D3.3 [7], and, in particular, as part of	09/04/2019

				the Policy Management component	
3GPP SA2	Contribution to 3GPP SA2#133 meeting in Reno, (NV) USA. Technical Document (Tdoc): S2-1905305, merged into S2-1906591	This Change Request (CR) proposes normative text to implement Slice-specific Authentication and Authorization, where the Network holds policies to indicated whether Slice Specific Authentication and Authorization should be run on more than one Access Network (e.g., 3GPP and Non-3GPP)	Agreed	The arbitration features in the vertical slicer may need to consider slices that require Slice specific additional authentication, when selecting slices based on tenant. In particular, whether Slice Specific Authentication should be run simultaneously for the same S-NSSAI when the UE access the system through 2 or more Access Networks. This is considered in the implementation of Service Level Agreements, described within section 2.1, in deliverable D3.3. [7]	17/05/2019
3GPP SA2	Contribution to 3GPP SA2#133 meeting in Reno, (NV) USA. Technical Document (Tdoc): S2-5306 merged into S2-1906592	This Change Request (CR) proposes normative text to implement Slice-specific Authentication and Authorization, where the Network holds policies to indicated whether Slice Specific Authentication and Authorization should be run on more than one Access Network (e.g., 3GPP and Non-3GPP)	Agreed	The arbitration features in the vertical slicer may need to consider slices that require Slice specific additional authentication, when selecting slices based on tenant. In particular whether Slice Specific Authentication should be run simultaneously for the same S-NSSAI when the UE access the system through 2 or more Access Networks. This is considered in the implementation of Service Level Agreements, described within section 2.1, in deliverable D3.3. [7]	17/05/2019

TABLE 21: DESCRIPTION OF STANDARDS DISSEMINATION ACHIEVEMENTS IN Y3, HIGHLIGHTING THE RELATIONSHIP BETWEEN CONTRIBUTIONS TO SPECIFIC SDOS AND 5G-TRANSFORMER COMPONENTS

SDO	Contribution ID	Contribution Summary	Outcome	Relation to 5G-T	Date
Third Year of 5G TRANSFORMER					
3GPP SA2	Contribution to 3GPP SA2#136 meeting in Reno, (NV) USA. Technical Document (Tdoc): S2-1912735	The contribution proposes a New key issue to study what potential enhancements in the 5GS may be needed to provide event notification capabilities when quotas are reached, and the SLA cannot longer be met	Agreed	The contribution highlights the problem of how to monitor the enforcement of an SLA outlining Slice Specific restrictions. This is considered in the implementation of SLAs, described within section 2.1, in deliverable D3.3.	22/11/2019

4.6 Impact

5G-TRANSFORMER addresses **ICT-07-2017 – "5G PPP Research and Validation of critical technologies and systems"** which covers three complementary strands: wireless access and radio network architecture/technologies, high capacity elastic - optical networks, and "software networks". The challenge is to eliminate the limitations of network infrastructures, by making them capable of supporting a wider array of requirements and with the capability of flexibly adapting to different "vertical" application requirements. This challenge includes optimisation of cost functions and of scarce resources, like spectrum, as well as migration towards new network architectures.

With respect to such challenge, Section 2.1 of the DoA has indicated the contribution of 5G TRANSFORMER in seven expected impacts. Achievements during the project, in the direction of said expected impacts, are reported in the following.

Expected Impact 1: Overarching impact: 40% of the world communication infrastructure market for EU headquartered companies (all strands).

The technologies developed in 5G-TRANSFORMER contributed to strengthen the position of EU companies in the upcoming 5G Mobile Network market, both in Europe and worldwide, for the whole value chain. The architecture and the relevant building blocks of 5G-TRANSFORMER are broad enough so that basically all actors of the ICT domain are involved in the key innovations of the project which has benefited from the presence of:

- Two leading Mobile Network Operators (MNOs), namely Orange and Telefonica. They have business interests in 11 countries in Europe (e.g., France, UK, Germany, Spain, Poland, etc.) and in more than other 30 countries across different geographical areas (mainly in Africa and America), accounting for about 22% of the EU market share (84M Orange, 84M Telefonica).
- Four manufacturers: Ericsson, Nokia, NEC, and Interdigital. They represent leading providers of mobile network equipment and solutions for Telecom Operators in Europe and worldwide. Their product portfolios cover most aspects of Mobile Broadband (MBB) deployment, including LTE and 5G NR Radio Access Networks, Transport Networks, Evolved Packet Core equipment, MEC solutions, and SDN software products. These manufacturers have declared a direct impact of 5G-TRANSFORMER outcomes on their products (see Section 4.5.1).
- Three SMEs which added novel complementary technologies to the project such as NFV and Cloud orchestration (Mirantis), Unified Gateway (BCOM), SDN control (Nextworks). The project has recognised the importance of SMEs in the economic development of Europe, hence allocating 20.9% of its budget to SMEs.

In addition, three Vertical industries partners (CRF, ATOS, and SAMUR) have provided a clear picture of all the needs that are specific of their sector of interest, identifying the key innovation areas that need to be advanced, and the relevant use-cases demanding very different requirements. D1.1 [1] reports the investigated vertical use cases and the relevant requirements also outlining the key project performance indicators and how they have been related to the 5GPPP ones.

As summarized in Section 1.2, the project activity led to the following relevant outputs:

- Definition of use cases and scenarios that have been used to challenge the system architecture and implemented building blocks.

- Design of the architecture aligned with the SDOs relevant in the area.
- Design and implementation of the 5GT-VS module.
- Design and implementation of the 5GT-SO module.
- Design and implementation of the 5GT-MTP module.
- Design and setup of the interconnection of the different test sites.
- Integration of the project modules and implementation of several proofs of concept around the vertical use cases considered in the project.

Expected Impact 2: Novel business models through innovative sharing of network resources across multiple actors (all strands).

By reducing the entry barrier through virtualization and standardized interfaces based on open APIs or protocols, 5G-TRANSFORMER has contributed to accelerate the integration of new services over existing and new networks, creating a new business model which includes Mobile Network Operators (MNO), Mobile Virtual Network Operators (MVNO), Over The Top (OTT) service providers, and providers of vertical services in different, heterogeneous, sectors.

5G-TRANSFORMER has defined a novel architecture which provides, through the Vertical Slicer (5GT-VS) block, all these actors with high-level APIs for the creation of network slices that integrate network and computing resources belonging to the physical network infrastructure of one or multiple network operators. Through said APIs, the system hides unnecessary details from the verticals, allowing them to focus on the definition of the services and the required Service Level Agreements (SLAs)

Having defined a Service Orchestrator (5GT-SO) module, a network slice is handled as a service: it is created, enforced, and managed over a shared infrastructure which includes transport and computing.

In summary, the 5GT-VS eases service definition, through blueprints, for verticals and the 5GT-SO provides a uniform view of federated infrastructures, lowering the entry barrier for new actors.

Expected Impact 3: Definition of 5G network architecture and of core technological components (strands 1 and 3).

5G-TRANSFORMER has defined a novel architecture integrating transport and core networks into a common sliceable transport stratum to provide verticals with end-to-end services, relying on SDN, NFV, and MEC as core technological components.

The architecture is based on three major components, each addressed by a dedicated working package of the project: 5GT-VS, 5GT-SO and 5GT-MTP.

5GT-VS is the logical entry point (i.e., one stop shop) for the vertical requesting a service. It handles the association of these services with slices as well as network slice management. 5GT-SO is responsible for end-to-end orchestration of services across multiple domains and for aggregating local and federated resources and services and exposing them to the 5GT-VS in a unified way. 5GT-MTP provides and manages the virtual and physical IT and network resources, both in radio and transport, on which service components are eventually deployed. It also decides on the abstraction level offered to the 5GT-SO.

Expected Impact 4: Proactive contribution to the 3GPP standardisation activity on 5G, and to other standardisation activities, e.g., ONF, ETSI-NFV, IEEE; proactive contribution to the WRC 19 preparation for 5G spectrum (all strands).

The standardization framework of 5G-TRANSFORMER is wide thanks to its mixture of enabling technologies such as NFV, SDN, and MEC, which are hot areas of standardization and open source developments in various Standard Development Organizations (SDO) and forums (e.g., 3GPP, ETSI, IETF, IEEE, ONF).

With the scope to boost the contribution to SDOs, 5G-TRANSFORMER has formed a Standardization Advisory Committee (SAC) composed of standardization experts supporting 5G-TRANSFORMER in all the key relevant SDOs. These include 3GPP, IETF, ETSI MEC, and IEEE. Members and Moderator of the SAC have been appointed from expert researchers from partners of 5G TRANSFORMER with relevant and operational involvement in each of the key SDOs, which have been identified as essential within the project. This list of experts is outlined in D6.1 [20].

A Standardization Activity Roadmap (SAR) has been produced and agreed during the 5G TRANSFORMER plenary meeting held in Rennes, France, on January 2018.

A detailed description of specific contributions that were brought to the SDOs relevant for 5G-TRANSFORMER is outlined in Table 35, Table 36 and Table 37 of D6.7 [24]. The tables provide a description of how specific standardization contributions were prepared, discussed and ultimately presented in the relevant standards fora by 5G-TRANSFORMER partners, related to specific 5G-TRANSFORMER components.

Expected Impact 5: Proof-of-concept and demonstrators beyond phase one and validating core functionalities and KPI's in the context of specific use cases with verticals closely associated to the demonstrations and validation. Indicative sectors include: automotive, connected cars; eHealth; video/TV broadcast; Energy management; very high-density locations and events (strands 1 and 3).

One of the main goals of 5G-TRANSFORMER has been the validation of the technology components designed and developed in the project through demonstrators and proof-of-concepts (PoC). WP5 has integrated all the technological components provided by WP2, WP3, and WP4 in testbeds formed by four different sites, provided by partners of the project. The testbed description is illustrated in D5.2 [16], which also includes a description of PoCs and the relevant technological and functional requirements. In summary, the 5G-TRANSFORMER has validated the architecture in the following use cases:

- The **Automotive** use case, demonstrating scalability of the Extended Virtual Sensing (EVS), previously known as Intersection Collision Avoidance Service, which will allow (thanks to the communication among the vehicles and infrastructure) to calculate the probability of collision and react accordingly. This demo leverages on the priorities and rules managed by arbitration and scaling functionality of the 5GT-SO module.
- The **Entertainment** use case, demonstrating a video streaming service to deliver an immersive and interactive experience to users attending a sports event. The demonstration consists of two PoCs regarding On-site Live Experience (OLE) and Ultra High-Definition (UHD). The objective of the demonstration is to prove that 5G-TRANSFORMER platform can deploy a video service simultaneously to multiple users in the same or in different locations.

- The **E-Health** use case, demonstrating a Monitoring & Emergency scenario in two trial sites: 5Tonic and CTTC. It has been demonstrated the successful deployment of the composite Emergency NFV-NS using the federation feature of the 5G TRANSFORMER platform for instantiating part of the service in an external domain.
- The **E-Industry** Cloud Robotics use case, demonstrating how factory service robots and production processes can be remotely monitored and controlled in the cloud, exploiting 5G. to minimize infrastructure cost, optimize processes, and implement lean manufacturing. The demo uses the complete 5G TRANSFORMER stack.
- The **MVNO/MNO** use case consisting of instantiating a 5G network by sending a 5GT-VS order to the 5GT-SO to create a network service instance. The result is the deployment of an E2E network slice which contains a vEPC network service.

Expected Impact 6: Network function implementation through generic IT servers (target) rather than on non-programmable specific firmware (today) (strand 3).

5G-TRANSFORMER has defined a programmable architecture for heterogeneous verticals to deploy their services over a common multi-domain infrastructure using virtual slices composed by VNFs running in the cloud or MEC on generic IT servers. Recent virtualization techniques for VNF composition/decomposition and orchestration algorithms to place VNFs over the transport and computing infrastructure have been used, providing business-driven a differentiated, virtually isolated view of the network (i.e. network slices).

Per-tenant RAN functions (i.e. integrated fronthaul/backhaul, flexible functional split) and core services (i.e. MME, S-GW, P-GW) runs in cloud data centres scattered through the transport network.

The deployed 5G-TRANSFORMER entities leveraged on Application Programming Interfaces (API) among components through which the system hides unnecessary details from the verticals, allowing them to focus on the definition of the services and the required Service Level Agreements (SLAs) and enabling services to be deployed on commodity hardware.

Expected Impact 7: Trustworthy interoperability across multiple virtualized operational domains, networks and data centres (all strands).

5G-TRANSFORMER has envisioned the creation of network slices by federating transport and computing resources from different network operators' domains. These can be operated, managed, and orchestrated using different VIM or transport technologies.

The 5G-TRANSFORMER architecture has deployed a common orchestration system, interoperating with the different technologies used by the network domains through well-defined interfaces, which enable service and resource federation across different administrative domains. 5G-TRANSFORMER service providers can enhance their service offerings towards their customers by peering with other providers. Project defined APIs allow a provider to become user of another provider's service towards a true multi-domain E2E service.

More details are included in D4.3 [14].

4.6.1 Progress towards the 5G-PPP Key Performance Indicators

D1.1 [1], in Section 6, presented the 5G-PPP KPIs that are related to the 5G-TRANSFORMER project, providing a first qualitative assessment of the relevance of each of these KPIs in relation to the planned contributions in the project.

D5.3 [17], in Section 2, has later reported the considered KPIs with their consolidated definitions as these KPIs may slightly differ between Verticals according to their interpretation of these KPIs in their relevant PoCs.

In Table 22, we detail such KPIs showing how they map to the ones established by the 5G-PPP [33]. Only the 5G-PPP KPIs which are relevant for the project are listed in the table. We refer to section 4.2.5.3 on the current deliverable to see progress of this in terms of implementation and demos.

TABLE 22: KPIS CONSIDERED IN 5G-TRANSFORMER

KPI	Acronym	Description
End-to-end (E2E) latency	LAT	E2E latency, or one-way trip time (OTT) latency, refers to the time it takes from when a data packet is sent from the transmitting end to when it is received at the receiving entity, e.g., internet server or another device [4].
Reliability	REL	Refers to the continuity in the time domain of correct service and it is associated with a maximum latency requirement. More specifically, reliability accounts for the percentage of packets properly received within the given maximum E2E latency (OTT or RTT depending on the what is considered by the service).
User data rate	UDR	Minimum required bit rate for the application to function correctly.
Availability (related to coverage)	A-COV	The availability in percentage (%) is defined as the ratio between the geographical area where the Quality of Experience (QoE) level requested by the end-user is achieved and the total coverage area of a single radio cell or multi-cell area times 100.
Mobility	MOB	No: static users Low: pedestrians (0-3 km/h) Medium: slow moving vehicles (3-50 km/h) High: fast moving vehicles, e.g. cars and trains (>50 km/h)
Device density	DEN	Maximum number of devices per unit area under which the specified reliability is achieved.
Positioning accuracy	POS	Maximum positioning error tolerated by the application, where a high positioning accuracy means a little

		error.
Confidentiality	**CON**	Preserving authorized restrictions on information access and disclosure, including means for protecting personal privacy and proprietary information.
Integrity	**INT**	Guarding against improper information modification or destruction, and includes ensuring information non-repudiation and authenticity
Availability (related to resilience)	**A-RES**	Ensuring timely and reliable access to and use of information
Traffic type	**TRA**	Depending on the amount of data moving across a network at a given point of time, traffic can be: • Continuous • Bursty • Event driven • Periodic • All types
Communication range	**RANG**	Maximum distance between source and destination(s) of a radio transmission within which the application should achieve the specified reliability.
Infrastructure	**INF**	• Limited: no infrastructure available or only macro cell coverage. • Medium density: Small number of small cells. • Highly available infrastructure: Big number of small cells available.
Energy reduction	**NRG**	Reduction of the energy consumption of the overall system. The most common metric that is used to characterize this KPI is the reduction in the consumed Joules per delivered bit.
Cost	**CST**	Expenditure of resources, such as time, materials or labour, for the attainment of a certain Hardware (HW) or Software (SW) module. Operational Expenditure (OPEX) and Capacity Expenditure (CAPEX) are

		important components of the overall costs.
Service creation time	**SER**	Time required to provision a service, measured since a new service deployment is requested until the overall orchestration system provides a response (a positive response implies the service has been actually provisioned).

5 Update of the plan for exploitation and dissemination of result

The communication, dissemination, and exploitation plan (CoDEP) presented in the proposal is periodically refined according to the evolution of the project and the activities considered of interest. The initial plan was presented in D6.1 [20] along with early achievements. D6.2 [21] presents the achievements during the initial period of the project as well as a refinement of the plan for the following period. This is the plan that was executed during this second reporting period, whose results were reported in the various deliverables, and more exhaustively, in D6.5 [22]. It is not repeated here for brevity. The reader is referred to these documents.

6 Follow-up of recommendations and comments from previous review

Next, we enumerate all the comments received from the experts during the 1st technical review, as included in the Review Report. We include an explanation of how we have address each of the recommendations.

Avoid unnecessary repetitions and overlapping between deliverables. Instead, make proper use of references and annexes. We encourage the consortium to maintain the high level of the deliverables also in the second period. If possible, upload pdf deliverables including markers to sections in order to facilitate navigation through the document (check D6.1 as an example).

We have taken very seriously this comment by making an effort to make the deliverables comprehensive while limiting repetitions and overlapping between deliverables to what is strictly necessary. A very concrete example of an action we have taken is the following. In the second reporting period we have several deliverables (D1.3, D2.3, D3.3 and D3.4) that are updates of the architecture and system components, that is, updates of former deliverables. In order to both make the document easy to follow for a reader that is familiar with the project (interested in the updates made and their rationale) and a newcomer that wants to get the updated picture of the complete system design (note that this also applies to a developer of our architecture), we have included in the aforementioned deliverables the updated complete design as an annex, while the main body of each of the documents just focus on identifying the main changes, explaining them and providing references to where additional details can be found. In this way, a reader familiar with the previous deliverables can just read the main body of the documents and check additional parts if needed.

Regarding the second comment about including markers, we checked and updated (on the project web site) all the deliverables to ensure they have the markers.

Provide a clear and definite list of use cases to be tested in WP5. Also, explain the procedure followed to downsize the initial long list of use cases to the selected ones.

Section 2 of D5.2 [16] includes both the list of use cases selected to be tested in WP5 as well as the procedure followed to select them.

Clarify the business model transformation of use cases.

Section 2.4.3 of D1.4 is devoted to address this very specific comment, including a subsection per use-case where we explain the business model transformation of the 5G-T vertical use cases by answering the two following questions:

- What kind of transformation has been brought by the platform to the classical model of the vertical service?
- What are the economic benefits to the Vertical industry business with the use of the 5G-T platform features?

Explain how the e-industry selected use cases might be of direct (or almost direct) use for the other three verticals, e.g. automotive, entertainment and e-health.

The eIndustry use case deployed in 5GT might be directed to the segments of the three verticals involved in the project: Automotive (CRF), Entertainment (ATOS), eHealth (SAMUR). The project envisions these beneficial applications of the eIndustry demonstrator concepts (with the appropriate modifications to meet the specific vertical needs) and in particular of the mobile cloud robotics (i.e. AGV) functionalities:

- In the automotive segment, AGVs are useful for raw material delivery, work-in-process (WIP) movement between manufacturing cells, finished goods transport toward loading bays, automated trailer loading and unloading. For this reason, also as replacement of the inflexible conveyors, AGVs are recognized as important elements of the future factories as these smart vehicles can enable quick changes and rearrangements in the assembly layout and facilitate organizing the plant with a "multi-directional" layout.
- In the entertainment segment, and in particular in video production in sport venues, smart automated trolleys can be fruitfully used to implement automated "camera dolly" carts. These carts are wheeled vehicles or similar devices used in television production to move cameras in a specific area, for example in a sport venue to follow the action of athletes. The cloud robotic vehicle developed in the project could be adapted for this scope and, in addition, the centralized robot control could facilitate the dynamic assignment of tasks and missions which is particularly important in highly dynamic scenarios. Note that 5G is essential for application is dense scenarios like the one in a stadium. Only with 5G it's possible to guarantee the appropriate stability to drive such kind of AGVs without discontinuities.
- In the eHealth segment, AGVs can be used in a healthcare setting to move materials throughout a hospital. Even if AGVs were originally developed for industrial applications, it's expected their future usage to transport hospital materials like meals, linen, drugs, laboratory specimens, waste and other medical supplies. By moving these tasks to robots, hospital employees can spend the maximum amount of their time directly on patient care. The use of AGVs with control in cloud can facilitate tracking all material movements and prioritizing some task with respect to others even changing priorities on the fly.

Improve demos to clarify and highlight the key achievements of the project, and relate them to the selected use cases and the business case. Try to focus more on higher top-level transport layers, vertical slices and service orchestration, rather than on network issues.

We have made a significant effort during the second reporting period to better highlight and disseminate the key achievements of the project, relating them to the use cases and business cases. As such, an important number of vertical-oriented demos and events have taken place during the last 18 months of the project, such as the PGA golf, tour in Madrid in 2019, EuCNC'19 demos, International Broadcasting Convention (IBC)'19, or the eHealth demo (Evento de demostración del Sistema Automático de Emergencias 5G).

Clarify the relation between contributions of the project to standards, and publications in general, and project results.

Based on this comment, the relationship with the project of each of the standard contributions was detailed in all WP6 deliverables that reported on the activities developed based on de communication, dissemination, and exploitation plan of 5G-TRANSFORMER, namely D6.5 [22] and D6.7 [24]. In the tables that report on standardization progress a new column was added for each contribution (e.g., Tables 25 and 26 of D6.5), in which the detailed explanation with the technical activities of the project is explained.

In order to foster novel business, one of the future workshops can be oriented towards SMEs with potential to become vertical developers.

Following this very good recommendation, we updated our intended exploitation workshop (D6.4, MS12) so it had a clear SME orientation. We co-organized this workshop in EuCNC 2019, together with the 5G-PPP SME WG.

In fact, the organization of this workshop became the main dissemination task that we requested as part of the activities related with the Common Dissemination Booster (CDB) offered to 5G-TRANSFORMER by the EU. The idea was discussed with the SME WG, which considered this very interesting. This generated the required traction in European SMEs involved in the topics deal with in the project. We also tried to maximize the impact, and so, we co-located it with a relevant event (EuCNC'19) in which the presence of such SMEs (and other relevant audience) was guaranteed. Furthermore, it was co-organized with several 5GPPP phase 2 and phase 3 projects, such as 5G-CORAL (also involved in the CDB) or 5G-EVE. The business orientation is also reflected in the title (Emerging 5G Business Models: Opportunities for SMEs and large companies-lessons from 5G PPP (5G-EBM)) and the program. Deliverable D6.4 reports on this workshop.

Forthcoming exploitation achievements and plans should include a table with products, similar to the one presented in the DoA, that shows the partners' progress.

Following this recommendation, the Innovation Manager interacted with partners to prepare a specific table like the one included in Section 2.2.1 of the DoA. This new table has been reported in D6.5 (Table 23) reporting a clear mapping between building blocks of the architecture (5GT-VS, 5GT-SO, 5GT-MTP) and the impacted partner's products and services. In Section 3.3 of D6.5 it has been then reported a detailed explanation of the progress in exploitation, for each product/service mentioned in the table. Later in D6.7 the table, and the related explanatory text, has been updated (Table 32) according to the achievements in the project lifetime and to the plans beyond the project end.

Exploitation plans are expected from all partners in the second period.

Updated exploitation plans for the second period have been reported in D6.5 for all partners. Updates of plans beyond the Project lifetime are reported in D6.7, including plans of operators/service providers.

7 Deviations from Annex 1 and Annex 2

7.1 Tasks

T6.1 leadership has been transferred from ITRI to UC3M.

7.2 Use of resources

As the second reporting period of the project closes on November 30th, 2019, the final information of resources (PMs) used during the second reporting period (M4-M30) will not be available before December 15th, 2019. The final version of the Periodic Report will be complete before the deadline (January 28th 2020).

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