5G-SOLUTIONS for European Citizens

D1.3 – Leverage, build upon and extend previous and ongoing work from EU funded 5G-PPP projects and 2nd phase of 5G standardisation

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Disclaimer

[1] According to 5G-SOLUTIONS Quality Assurance Process:
1 month after the Task started: Deliverable outline and structure
3 months before Deliverable's Due Date: 50% should be complete
2 months before Deliverable's Due Date: 80% should be complete
1 months before Deliverable's Due Date: close to 100%. At this stage it sent for review by 2 peer reviewers
Submission month: All required changes by Peer Reviewers have been applied, and goes for final review by the Quality Manager, before submitted

Table of Contents

List of Figures

List of Tables

Glossary of terms and abbreviations used

Abbreviation / Term	Description
3GPP	3rd Generation Partnership Project
5G	Fifth Generation (mobile/cellular networks)
5G-PPP	5G Public Private Partnership
API	Application Programming Interface
BBU	Baseband Unit
CAPEX	CAPital EXpenditure
CI/CD	Continuous Integration / Continuous Development
CDN	Content Distribution Networks
CDSO	Cross Domain Service Orchestrator
CN	Core Network

CoMP	Coordinated Multi Point
C-RAN	Cloud RAN
CSP	Communication Service Provider
CPU	Central Processing Unit
CU	Centralised Unit
DA-RAN	Dis-Aggregated Radio Access Network
DC	Data Centre
DevOps	Development Operations
DPDK	Data Plane Development Kit
DU	Distributed Unit
E2E	End-to-End
eMBB	Enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
FaaS	Function as a Service
FDD	Frequency-division duplex
FeMBMS	Further evolved Multimedia Broadcast & Multicast Services
FH	FrontHaul
FLLR	Fast Local Link Reroute agent
FQAM	Frequency and Quadrature Amplitude Modulation
GSMA	GSM Association
HARQ	Hybrid Automatic Repeat Request.
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IoT	Internet of Things
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LL	Living Lab

MANO	Management and Orchestration
MBB	Mobile BroadBand
MCC	Mission Critical Communication
MEC	Multi-Access Edge Computing
MIMO	Multiple-input and multiple-output,
mIoT	Massive Internet of Things
MMC	Massive Machine Communication
MME	Mobility Management Entity
mMTC	Massive Machine-Type Communications
mmWave	millimetre Wave
MNO	Mobile Network Operator
MTC	Machine Type Communications
MTP	Mobile Transport and Computing Platform
MVNO	Mobile Virtual Network Operator
NaaS	Network as a Service
NAF	Network Application Functions
NF	Network Functions
NFV	Network Functions Virtualisation
NFVI	Network Functions Virtualisation Infrastructure
NFV-NS	NFV Network Service
NR	New Radio
NS	Network Service
NSA	Non Stand Alone
NSD	Network Service Descriptor
OAI	Open Archives Initiative
OFDM	Orthogonal Frequency-Division Multiplexing
OPEX	OPerating EXpense
OS	Operating System
OSM	Open Source MANO
OSS	Operation Support Systems

QoE	Quality of Experience
QoS	Quality of Service
PaaS	Platform as a service
PDU	Protocol Data Unit
PTM	Point-to-multipoint
RAN	Radio Access Network
RRH	Radio Remote Header
RTT	Round Trip Time
RU	Resource Unit
SA	StandAlone
SBI	SouthBound Interface
SCTP	Stream Control Transmission Protocol
SDK	Service Development Kit
SDN	Software Defined Network
SFN	Single-Frequency Network
SLA	Service Level Agreement
SO	Service Orchestrator
SVP	Service Virtualization Platform
TDD	Time-division duplex
TTT	Time to Trigger
TRL	Technology Readiness Level
UHD	Ultra-High Definition
UC	Use Case
UL	Uplink
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra-Reliable Low Latency Communications
V2X	Vehicle to Everything
VbbU	Virtual Broadband Base Unit
VM	Virtual Machine
VIM	Virtualized Infrastructure Manager

VNF	Virtualised Network Function
VNFaaS	VNF as a Service
VNFD	Virtualised Network Function Descriptor
VPN	Virtual Private Network
VR	Virtual Reality
VS	Vertical Slicer
VSB	Virtual Service Blueprint
VSD	Vertical Service Descriptors
xMBB	Extreme Mobile BroadBand

1 Executive Summary

This deliverable is an output of Task 1.3 "Leverage, build upon and extend previous and ongoing work from EU funded 5G-PPP projects and the 2nd phase of 5G standardization".

The aim of this document is essentially to report an analysis, and of course to share it in the Project, about the results achieved by means of the interaction with 5G-EVE, 5G-VINNI, 5Genesis as well as the collaboration with other 5GPPP parallel projects.

This fruitful collaboration is obtained also thanks to the fact that most of these projects involve 5G-SOLUTIONS' partners and the related results have been considered by the Project as a basis for challenging new research activities.

The editing of this document provided the opportunity for the project management to better integrate5G-SOLUTIONS results with parallel efforts in the scientific community and in the 5G-PPP context, and for the technical staff, to use previous results not duplicating work already done, and further build upon it.

Starting from D1.3A (previous version of the document) it was decided to use a greater number of results, therefore numerous projects are analyzed.

More specifically, the topics of greatest interest are slicing, orchestration, based on NFV, Multimedia and broadcasting, the topic of cell fronthauling, disaggregation and mobile edge computing, but also security and ML.

During the life cycle of the project integration is very important, in fact our vertical solutions are 5G oriented, entirely or partially based on infrastructures developed by ICT-17 project most of the use cases of 5G-SOLUTIONS are based on the infrastructures of 5G-VINNI, others on 5G-EVE, and in few use cases use "private" infrastructures.

The work of integration of 5G-SOLUTIONS in the scientific arena and in the 5G-PPP environment, will not finish with the end of T1.3 and neither at the end of the project. In fact, the work summarized in this deliverable is a first step for the identification of themes and ideas on which to contribute to the standardization bodies, initiatives that can lead to the development of a business based on our solutions.

Particular attention is given to the involvement of external SMEs (Small and Medium enterprise) and to initiatives aimed at involving other companies, large industries, and academic realities.

2 Introduction

In Task 1.3 we set the goal to capitalize on 5G-PPP Phase 1 findings, 5G-PPP Phase 2 and Phase 3 projects: assets and results are leveraged for use in 5G-SOLUTIONS. Furthermore this effort ensures an active cooperation with other 5GPPP projects and Working Groups.

It is essential to analyse and share the results achieved by 5G-EVE and 5G-VINNI, as well as results achieved by other parallel projects that involve 5G- SOLUTIONS partners in the consortium.

The cope of this living document is also to have an overview of these results with the additional aim to share them with other 5G international initiatives such as GSMA. This can consolidate a common vision towards the wide deployment of 5G technologies.

This deliverable is an output of Task 1.3. One of the main purposes of T1.3 is to act as an amplifier within the project on the ideas and sources that all researchers draw from other activities outside the project, e.g. other ICT-19, standardization bodies, research of other initiatives.

To do this, the present deliverable shows how 5G-SOLUTIONS:

- Leverages and extends 5G EVE
    - Reaching requirements (KPIs) about end-to-end latency
    - Integrating the network with a complex commercial service orchestrator (CDSO)
- Extending the 5G-VINNI facilities:
    - Integrating the CDSO and the KPI VS with the 5G-VINNI testing framework
    - Use of the CDSO for managing and orchestrating 3rd party network application functions
    - Running concurrently multiple UCs
- Goes beyond the work done in 5GENESIS
    - Providing cross-domain analytics & live predictions
    - Introducing model store and model execution function in support of live predictions
    - Enabling runtime optimizations (involving the cross-domain orchestration feature) through zero-touch automation mechanisms

The 5G-SOLUTIONS project is deeply integrated within 5G initiatives, and collaborations between ICT-19 projects are very active: the document focuses on the main points of collaboration focusing on 5GROWTH[2] and 5GMediaHUB[3].

The strong connection between 5GPP/ 5G-IA standardization and 5G-SOLUTIONS is also highlighted in the current deliverable. The challenge is to understand the relative influence of 5G network performance indicators (KPIs) to the vertical services.

The T1.3 team adopted the usage of a living document during the last months, to register all the collaborations and, in any case, partners whenever someone must search for results from deliverables of other H2020 projects or organizations or important international initiatives. This living document has been further checked and summarized in the current document.

Furthermore, T1.3 wants to make explicit the forms of contacts with other initiatives, through what each researcher does implicitly every day. This kind of document can also facilitate an exchange of information among the projects, by interfacing with the activities of the Steering Board and the Technical Board.

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[2] https://5growth.eu/
[3] https://www.5gmediahub.eu/

2.1 Mapping Projects' Outputs

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

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

5G-SOLUTIONS Task		Respective Document Chapter(s)	Justification
Task 1.3 – Leverage, build upon and extend previous and ongoing work from EU funded 5G-PPP projects and 2nd phase of 5G standardisation)	In this task we will capitalise on 5G-PPP Phase 1 findings, 5G-PPP Phase 2 and Phase 3 projects and will leverage assets and results for use in 5G-SOLUTIONS. The cooperation with the other projects in the call and with the relevant entities in 5G-PPP is ensured by this task. The results achieved from 5G-EVE and 5G-VINNI projects will be analysed in 5G-SOLUTIONS and shared with other 5G international initiatives, including GSMA, in order to consolidate a common vision towards the wide deployment of 5G technologies. This will be realised by a continuous exchange of information among the projects, facilitated by the activities of the Working Groups in 5G-IA and 5G-PP as well as through the Steering Board and the Technical Board, where the Project Coordinator (PC) and the Technical Manager (TM) of the project are actively involved, respectively.	The entire document	The document specifies the results of previous projects used by 5G-SOLUTIONS. Furthermore, how to feed the standardization and the collaboration with 5G-IA and 5G-PPP
5G-SOLUTIONS Deliverable			
D1.3B: Leveraging and extending 5G-PPP previous work in 5G-SOLUTIONS v2.0 Final version of reports containing the outputs, results and assets from previous 5G-PPP related projects that will be utilized and extended in 5G-SOLUTIONS's ecosystem.			

2.2 Deliverable Overview and Report Structure

This deliverable has been structured in such a way so that the reader can easily have a complete view of the complex relation between 5G-SOLUTIONS and other projects and standardization.

In more details, the complete structure of the document is the following:

- **Chapter 2** “Introduction” introduces the reader into the document and presents how the deliverable fits inside the more complex project framework
- **Chapter 3** “Verification of final table of D1.3” mainly shows, in table format, a set of projects that 5G-SOLUTIONS has considered, and the level of enhancement that has been reached. The results are grouped with respect to the following features/items:
    - NFV, slicing, orchestration, cloud
    - Multimedia and broadcasting
    - VBBUs, Fronthauling, disaggregation, MEC
    - Security
    - Machine Learning
- **Chapter 4** “ICT-17 Projects” describes in more details the main areas of leveraging and extending the following ICT-17 Projects: 5G-VINNI, 5G-EVE, 5GENESIS
- **Chapter 5** “Cooperation with ICT-19” describes the most significant collaborations with 5GROWTH and 5GMediaHUB projects
- **Chapter 6** “5G-PPP / 5G-IA and standardization”, showing the relationship between standard principles/ architectures and results of 5G-SOLUTIONS verticals running over such networks, mainly focusing on features, performance and KPIs evaluation
- **Annex I** –Simulation Assumptions and Performance Evaluation of the Scenarios Based on Release 15 5G-NR System-level Simulator

3 Results leveraged and extended by 5G-SOLUTIONS

5G-SOLUTIONS is an ICT-19 project and, as such, it is part of a much broader research context that certainly includes the other projects of the Horizon 2020 program, and beyond.

The fact that some partners of the project had important roles in other H2020 realities facilitated an exchange of information and access to results. Deliverable D1.3A reported a set of projects that 5G-SOLUTIONS has considered, analyzing in detail the results, to build upon them in its own research.

Some projects did not provide substantial elements onto which to leverage, because they date back to a long time ago (in the world of communications research 3-5 years are a geological era) or because they are not perfectly relevant to what 5G-SOLUTIONS does. For this reason, rather than making an excursus on the various projects mentioned in D1.3A, it was preferred to cluster the inputs acquired in macro-themes.

At this point of the project, the situation is clearer, and we can affirm where the project really leveraged for not duplicating work already done and uses the results in subjects useful for 5G-SOLUTIONS, but not directly faced off by the project.

Of course, the main projects where 5G-SOLUTIONS leveraged are ICT-17, creating the bases and the infrastructure for the living labs experiments, namely 5G-VINNI, where most use cases are using its infrastructure, 5G-EVE, base of living lab 2 “smart energy” use cases, and 5GENESIS. This last project does not provide any infrastructure to 5G-SOLUTIONS, but the experience obtained by our partners involved in it was transferred to a certain degree to important problems in 5G-SOLUTIONS, related to service analysis.

For the other projects, we clustered some important subjects and summarized what we used from the results of previous projects. Table 2 reports this correspondence.

Table 2: Subjects already considered by previous projects taken into account by 5G-SOLUTIONS

Subjects	Projects	Relationships and used results
NFV, slicing, orchestration, cloud	SONATA, SUPER-FLUIDITY, FLEX5GWARE, 5G-TANGO, NGPAAS, 5G-TRANSFORMER	5G-SOLUTIONS is enhancing the vision of these projects of providing to the network the characteristic of flexibility (i.e., via an architectural decomposition of network components and network services into elementary, reusable primitives), adopting complex orchestration functions and using all the functionalities provided by the ICT-17 platforms. The main enhancement w.r.t. the mentioned projects is that 5G-SOLUTIONS provides an answer for most verticals of 5G, while, as an example, 5G-TANGO is only related to industry (achieved by the complex multi-living lab) and that, thanks for the results of those projects, 5G-SOLUTIONS results have a higher TRL (Technology Readiness Level), meaning that the solution is closer to commercialization.
Multimedia and broadcasting	5G-TANGO, 5G-MEDIA, 5G-XCAST	These projects were about broadcasting/multicasting media on the distribution side to end viewers. An interesting part was on the distribution side – assisting in convergence of fixed and cellular to better distribute

		video in some UCs, complementing the broadcasting. In 5G-SOLUTIONS WP6/LL4 has two UCs which focus on the media distribution side – UC4.1 & UC4.2. In this second use case (multi CDN), results from these projects have been used. One important evolution is that broadcast/multicast in the way 5GXcast developed has not even been standardized in 3GPP yet. 5G-SOLUTIONS is using 5G Rel 15-16 platforms & labs which do not have broadcast/multicast support yet.
VBBUs, Fronthauling, disaggragation, MEC	5G-CROSSHAUL, 5G XHAUL, 5G-PICTURE, 5G-TRANSFORMER	The result of these projects has been to transform traditional closed, static, and inelastic network infrastructures into open, scalable and elastic ecosystems supporting new types of connectivity, high mobility and new mission-critical services for operators, vendors and vertical industries. They designed a novel type of architecture, compatible with 5G, demonstrated the feasibility, also experimentally including some vendors, and showed the feasibility of the solution both from economic and environmental points of view. 5G-SOLUTIONS received the precious heredity to provide a more integrated and complex solution for a more innovative case study, in a larger scale, with precise commercialization roadmap. 5G-SOLUTIONS evolves the studies of 5G-PICTURE, 5G-XHAUL or 5G-CROSSHUAL in three main points: • The experimental environment provided by 5G-SOLUTIONS is much more complex and closer to the reality w.r.t. cited projects • 5G-SOLUTIONS is setting a multi-living lab where several use cases can run concurrently • Some implementations of Multi-access Edge Computing (MEC), offering application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the network (e.g. 5G-SOLUTIONS use cases 3.4. add 4.6)
Security	5G-ENSURE	5G-SOLUTIONS does not have a task directly devoted to the security of the solutions. Nevertheless, the common partners in 5G-SOLUTIONS and 5G-ENSURE allows the possibility to use 5G-ENSURE results to guarantee an adequate level of security in the solutions envisaged by 5G-SOLUTIONS for the verticals.

Machine Learning	COGNET	All the results of COGNET project, i.e. a software capable of forecasting resource demand requirements through usage prediction, recognizing error conditions, security conditions, outlier events such as fraud, and responding and taking corrective actions is considered as important in 5G-SOLUTIONS, even if not directly addressed in our solutions. A dedicated task about zero-touch automation, which considers machine learning techniques, is also designed in 5G-SOLUTIONS.

4 ICT- 17 projects

4.1 5G-VINNI

4.1.1 Introduction

5G-VINNI is based on the latest 5G standards and designs, and it is composed by 7 different facility sites around Europe, creating user friendly zero-touch orchestration, operations, and management systems to ensure operational efficiencies and optimal resource use [5]. 5G-VINNI will leverage the latest 5G technologies, including results from previous 5G-PPP projects. This means it employs Network Function Virtualisation, Network Slicing, and a rigorous automated testing framework to validate the 5G KPIs under various combinations of technologies and network loads.

5G-VINNI is composed by 4 main facilities and 3 additional experimental facilities. The main facilities will follow as much as possible the finalized standards proposed by 3GPP and ETSI, while the additional experimental facilities, as the name indicates, will have the opportunity to implement several experimental technologies which are not necessarily standardized. In the following, the 5G-VINNI Norway facility site will be presented as an example site. Note also that the Norwegian site is used in several 5G-SOLUTIONS use cases. For some of the 5G-SOLUTIONS UCs the 5G-VINNI Norway Facility will be extended into local UC-specific facilities adding RAN nodes and edge cloud nodes where applicable. These extensions might also include extending the 5G-VINNI Norway Transport Network, e.g. for backhaul purpose.

5G VINNI Norway Facility-site network is built on two Data Centres. The main one is called **Central site** and the smaller one is called **Edge site**. These two sites are shared by all deployed slices. More **Edge sites** are expected in the planning with ICT-19 projects going forward.

5G-VINNI Norway is collaborating with the Norwegian Defense Material Agency[4] for providing dedicated slices for their use, including autonomous edge deployments. The learnings from these deployments and their use cases are relevant for 5G-SOLUTIONS as well.

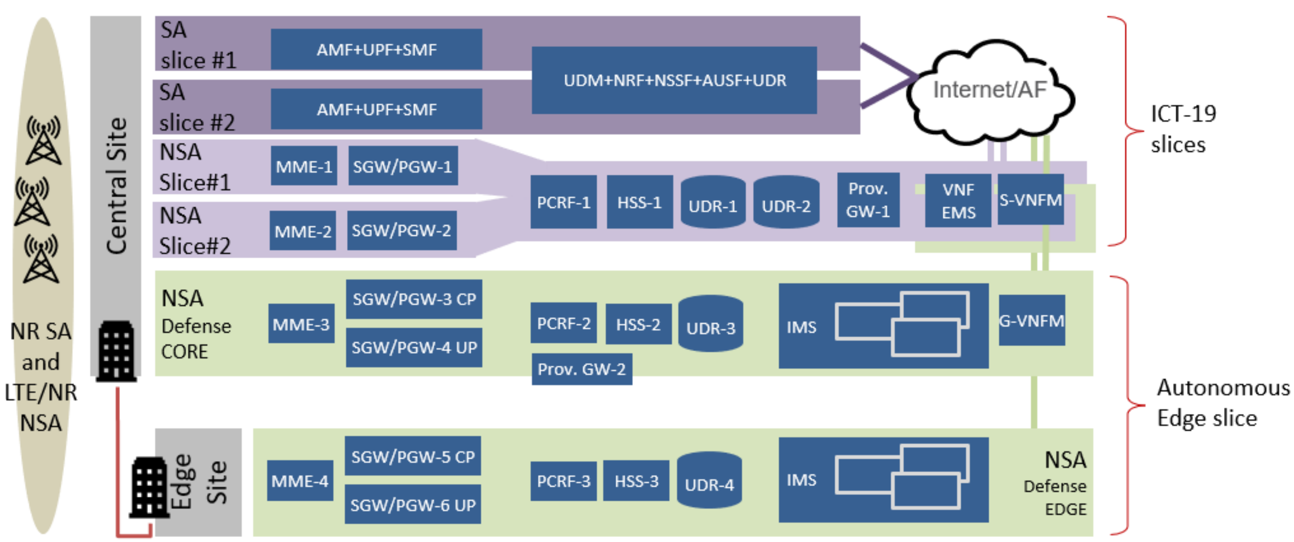

Figure 1: Norway NSA and SA slicing

[4] https://www.fma.no/en

Figure 1 above, shows how NSA and SA Networks are mapped to the ETSI NFV architecture. Slices and VNFs deployment are fully automated using S-VNFM or G-VNFM and triggered from the Service Orchestrator or NFVO.

For NSA Slices selection DECOR functionality is implemented. MME-1 from Slice #1 is default MME and in the type of slices supported are shown. This includes what VNFs are deployed and how they are shared with slices at the time of writing this document. The slice configuration and specifically which VNFs the slices are composed of can be changed as needed based on the real use case needs. For more details, please see [7].

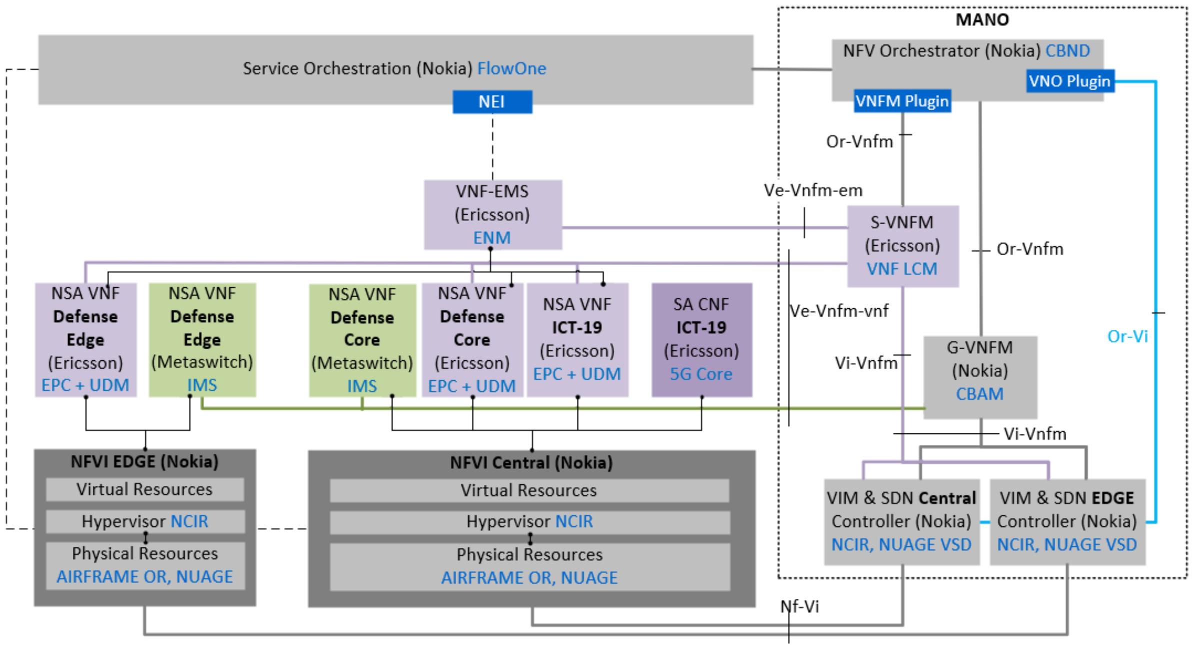

Figure 2: NFV Architectural Framework for NSA and SA

On each facility a so called *VINNI portal* will be available acting as a Customer Facing Service (CFS) to verticals, allowing the customer to order specific CFSs or managing parameters of existing predefined or pre-provisioned services. That is, it will expose available facility services based on the TMForum SID model, and specifically to TMF633 Service Catalogue Management.

A first draft architecture of the VINNI portal solution (OpenSlice) is depicted in Figure 2. For more information, see[8]. The OpenSlice portal solution will support API features to enable the CDSO of 5G-SOLUTIONS to integrate with 5G-VINNI. (See left side of figure.)

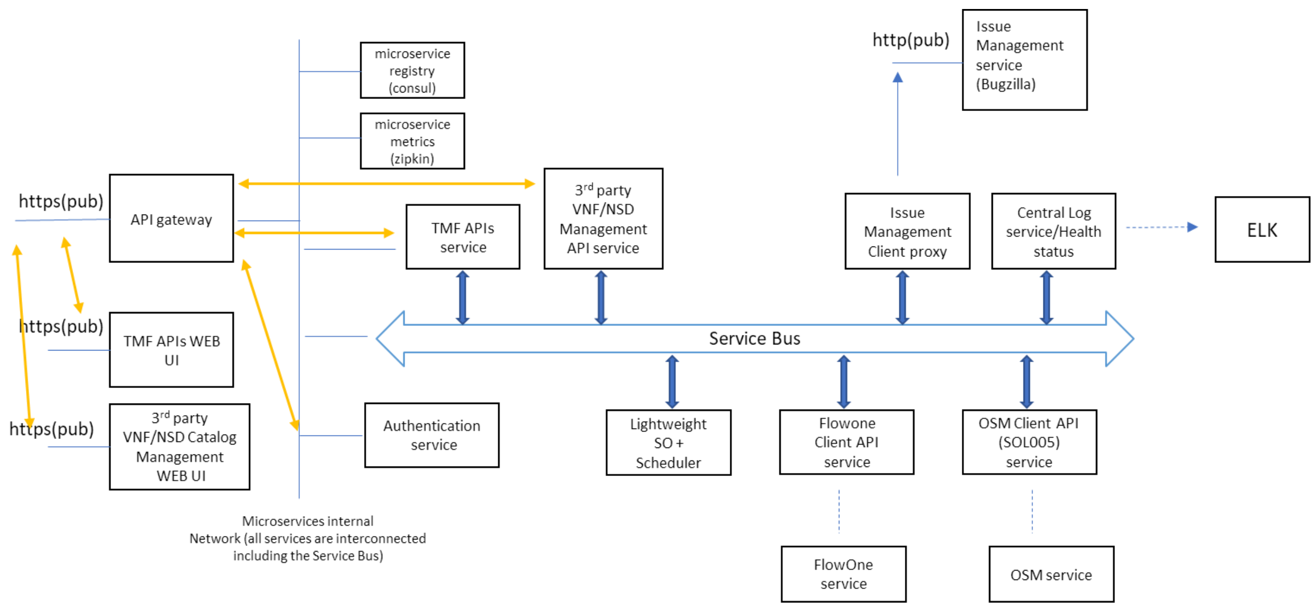

Figure 3: VINNI portal architecture

It is envisaged that the VINNI portal solution will be installed on each facility, allowing Vertical Customers to browse the available offered services of each facility. At the minimum, according to plan, the 5G-VINNI portal solution (OpenSlice) will consist of:

- A web frontend
- An API gateway that will be used by the web front end as well as any other 3rd party service
- An authentication server
- Various API services (e.g., Service Catalogue API, Service Ordering API, VNF/NSD on-boarding, etc.)
- Catalogue storage services
- Central logging
- A lightweight simple Service Orchestrator or Operations Support System solution that will transform Service Ordering requests to the equivalent Orchestrators, e.g. FlowOne in case of Norway, UK facilities and OSM in case of Greece, Spain facilities.

The VINNI portal will offer the following main functionalities:

- **Service Catalogue Management:** The CSP will have the ability to manage the Service Catalogue Items, their attributes, organise in categories and decide what to make available to Customers
- **Services Specifications:** The CSP will be able to manage Service Specifications
- **Service Catalogue Exposure:** The CSP will be able to expose catalogue to customers and related parties
- **Service Catalogue to Service Catalogue:** It will be able to consume and provide Service Catalogue items to other catalogues
- **Service Order:** The Customer will be able to place a Service Order

Next, the Test as a Service (TaaS) framework is presented, which is another key part of the 5G-VINNI platform and allows testing of both network level KPIs and application level KPIs depending on which tools are used with the TaaS testing automation framework.

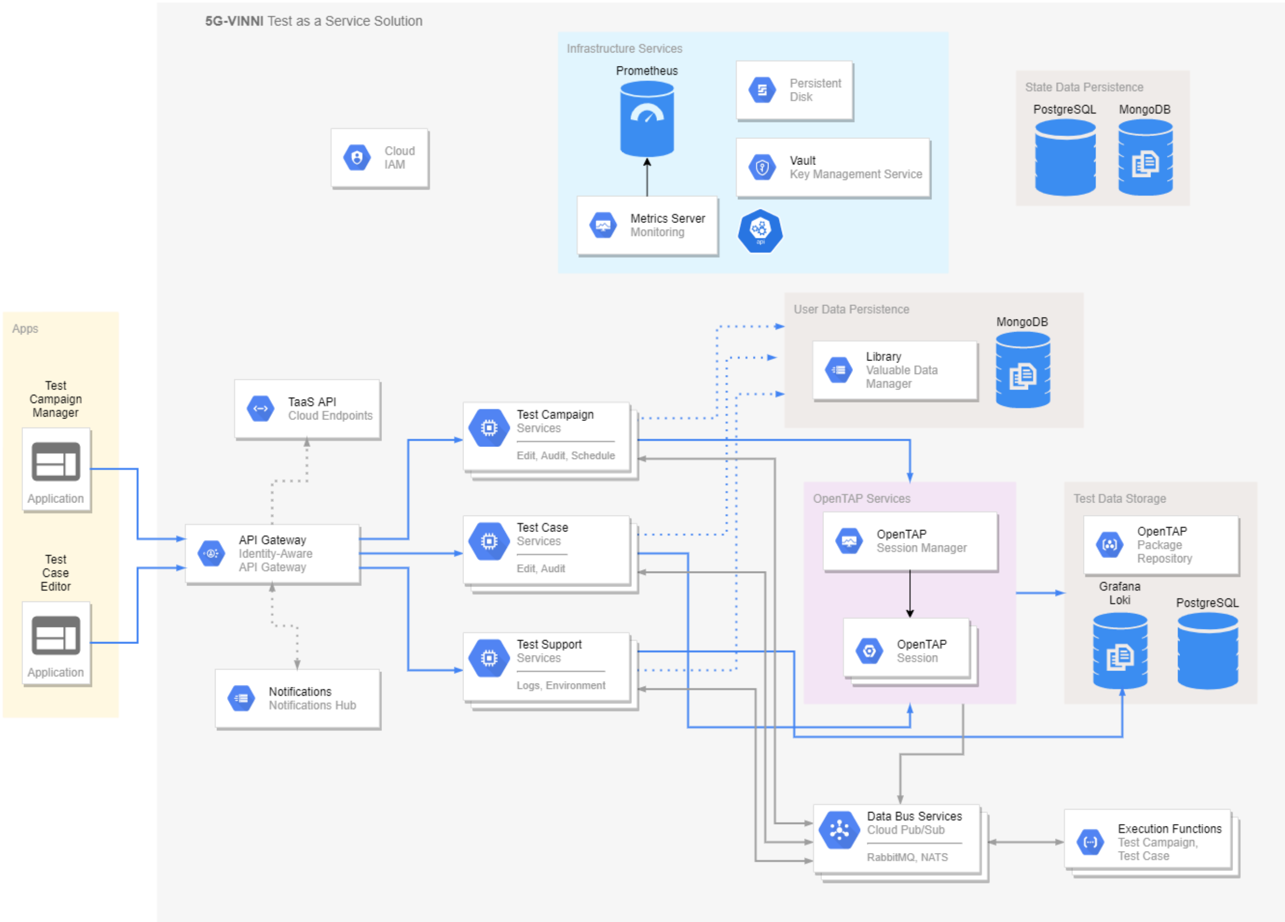

Figure 4: Testing as a Service architecture

For more information on this architecture and its components, see 5G-VINNI Deliverable D4.2 [9].

Figure 5 exemplifies how TaaS can be utilized by vertical customers in two ways: via the OSS/BSS or via the web service. In the first case, while deploying the Network Service, a set of test cases can be automatically requested by the BSS/OSS and executed after the deployment to verify the health or performance of the service. In this case, the test cases are programmatically requested via API calls to the TaaS.

In the second case, a web service (browser-based UI) is introduced to allow manual execution of the tests. The manual execution allows for a more comfortable way of configuring the tests to perform more exploratory experiments. After the tests are requested (1), the test scripts present in the TaaS repository are loaded and executed on OpenTAP, an open-source technology that is at the heart of the 5G-VINNI TaaS system. OpenTAP allows to programmatically deploy tools e.g. in an OpenStack cloud, and configure them to target the newly deployed service (5G system VNF or 3rd party VNF / NAF).

Note that before consuming the service, the vertical customers (as represented 5G-SOLUTIONS UC owner) need to go through a full onboarding process, to guarantee the effectiveness of the workflow. The onboarding process is outlined as follows:

- **Training**: a set of webinars will be offered to cover all the different aspects, from how to design effectively experiments and tests cases, to the use of specific tools.
- **Design of test cases (TCs)**: the vertical customers shall foresee a phase where the KPIs of interest, and how to stress them (the testing conditions) are formalized, before considering scripting or launching

experiments. (See information on "Test Campaign Editor" below.) Note that for test cases that are not contained in the Test Case Repository predefined by 5G-VINNI, 5G-SOLUTIONS use case owners (with support from facility owner) need to develop their own test cases (e.g., scripts) and upload into the test repo, before going through the subsequent steps, e.g., order/create test campaigns.

- **Development and onboarding of connecting plugins**: if the vertical customers wish to include their own application as part of the experiment under the control of the automation framework (strongly suggested for guaranteeing results consistency), they will need to develop the drivers for connecting OpenTAP to the application via an exposed API. Furthermore, if the KPIs of interest lay on the vertical application domain, the customers shall prepare the application for exposing specific metrics for collection.
- **Development and onboarding of Test Scripts**: finally, it will be possible to develop the automation scripts needed for executing the tests and experiments in a consistent and repeatable fashion.

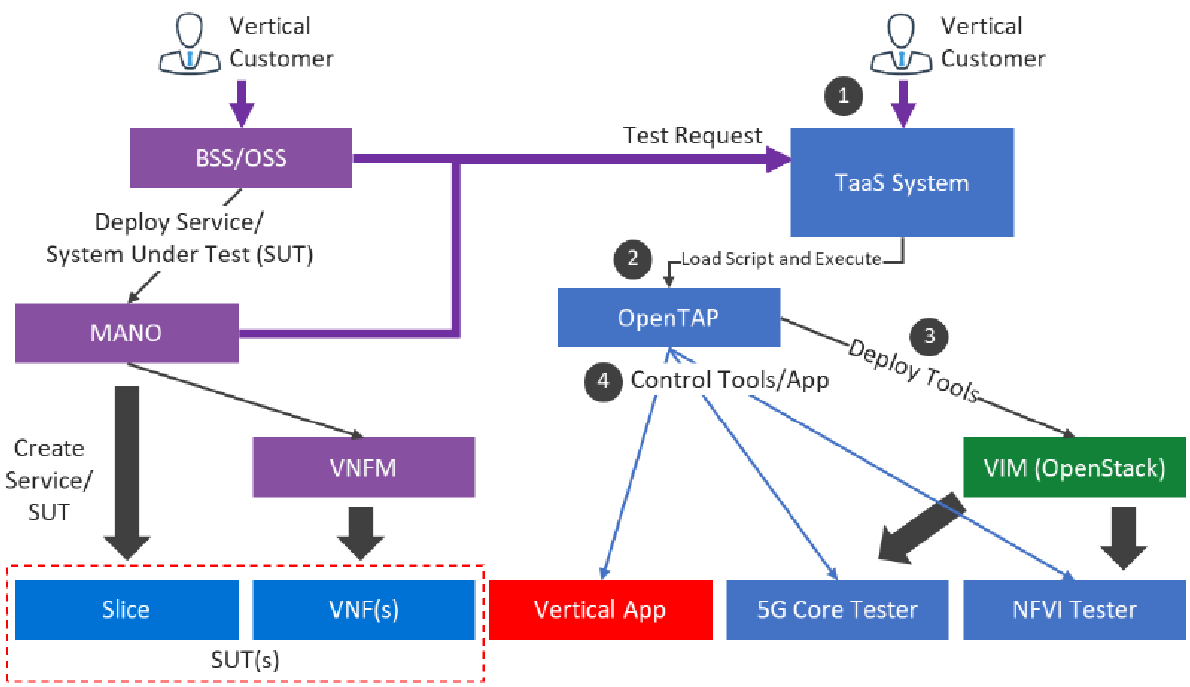

Figure 5: Vertical customers consume TaaS ([11])

Figure 6 shows the high-level design architecture of TaaS, in which there is a Test Cases Repository storing the execution scripts needed to perform the different types of tests in the 5G-VINNI infrastructure. Specifically, the following components are included (see details in reference [9]):

- **Customer Web Service**: the service is a web application that allows the human user to define, create, and execute test campaigns. The application also exposes an API that can be contacted by other applications (e.g., CI/CD pipelines) for consuming testing services. From here on it will be denoted as Automation Solution.
- **Test Case Repository**: it is a logical component used for storing and managing the available test scripts needed to execute the tests and their configuration.

- **Test Executor Service**: the service is the actual component coordinating and performing the test on the selected SUT. It oversees managing and coordinating all the different tools required to perform the tests.
- **VIM**: it is a needed third-party actor in the system. It allows the Test Executor to deploy the needed infrastructure and tools to perform the tests. In the NFV terminology, it corresponds to the VIM, and in 5G-VINNI, the most used orchestration system is Heat/OpenStack.
- **Traffic Generation Tools**: these are the actual T&M tools used to probe and stress the 5G infrastructure. They are needed for having granular control over the type and quantity of traffic present in the network, or for performing specific operations difficult to do with real application traffic (e.g. Latency and QoE measurements).
- **Results Repository**: this is a needed element for storing the results generated by the tools, but also essential status and configuration elements of the network, e.g., VNF logs. It is a logical element, since its implementation might be rather complex given the heterogeneity of the data and their quantity. It could be implemented e.g., with Big Data solutions. It provides the permanent data storage for further analytics applications.

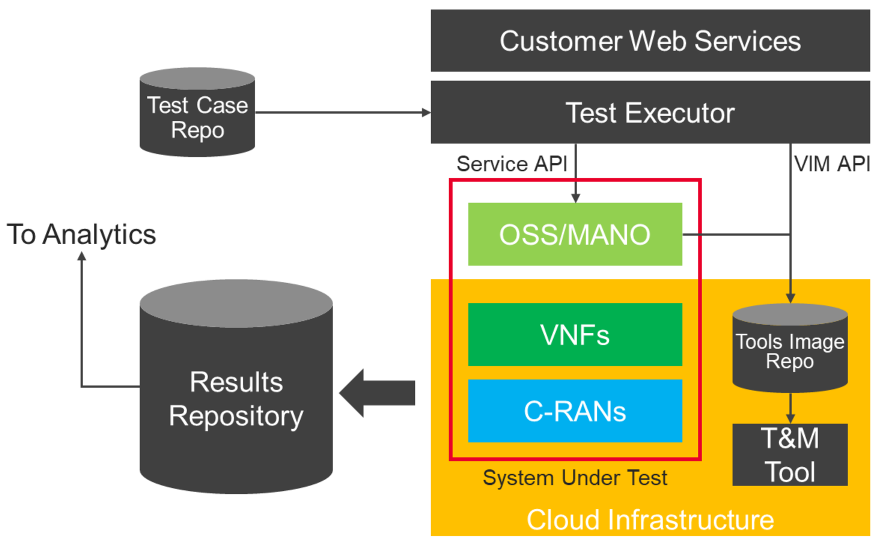

Figure 6: TaaS architecture ([9])

From a user perspective, a number of web pages have been implemented for facilitating the interaction with the TaaS system. The first entry point for the user is the Campaign Manager Dashboard, which is a summary of all the execution history (past or currently executing) of Test Campaigns visible to the specific user, as displayed in Figure 7.

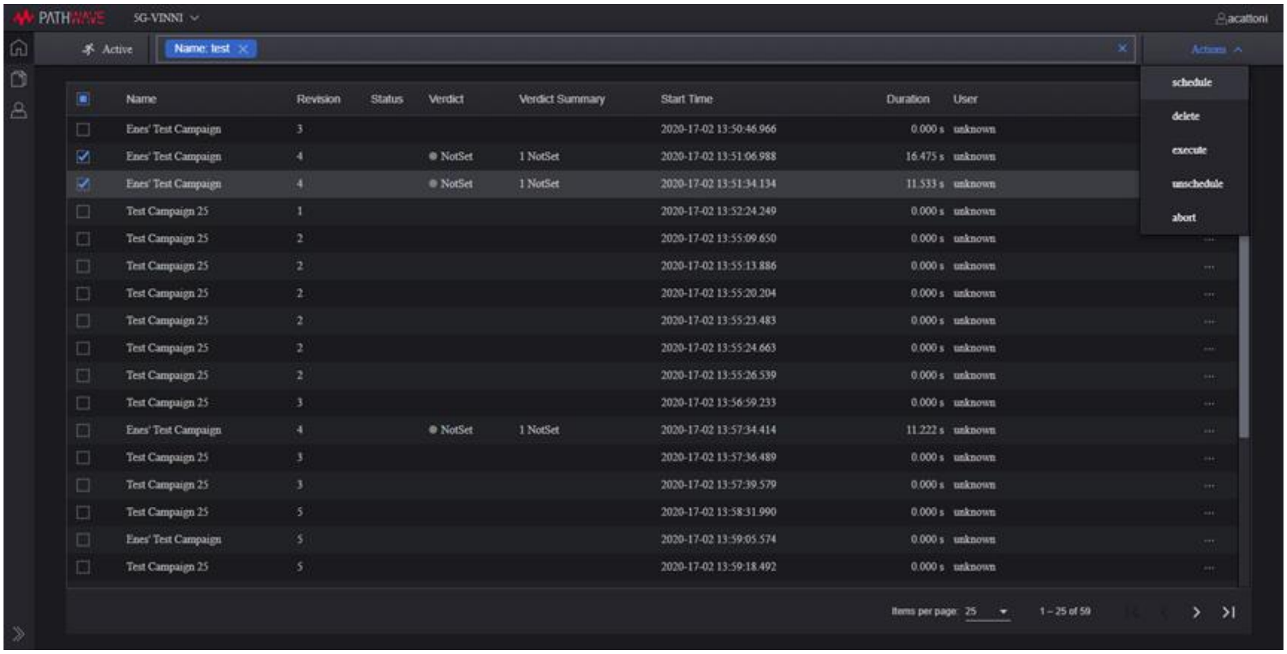

Figure 7: Campaign Manager Dashboard

From the Dashboard it is possible to visualize details of each executed Test Campaign, including how each individual Test Case performed. It is also possible to schedule a new Test Campaign or re-schedule an already executed one. Such feature is currently implemented only at client side with no backend support.

The Test Campaign Manager is complemented by the Test Campaign Editor page, shown in Figure 8. The Test Campaign Editor allows the user to compose a custom Test Campaign and freely modify the relevant parameters of each individual Test Case, including in which environment each Test Case of a Test Campaign should be executed. The web page offers the possibility to browse through all the available Test Cases and Test Campaigns visible to the specific user, or to upload new ones. Moreover, the Test Case Editor allows the user to create custom test flows.

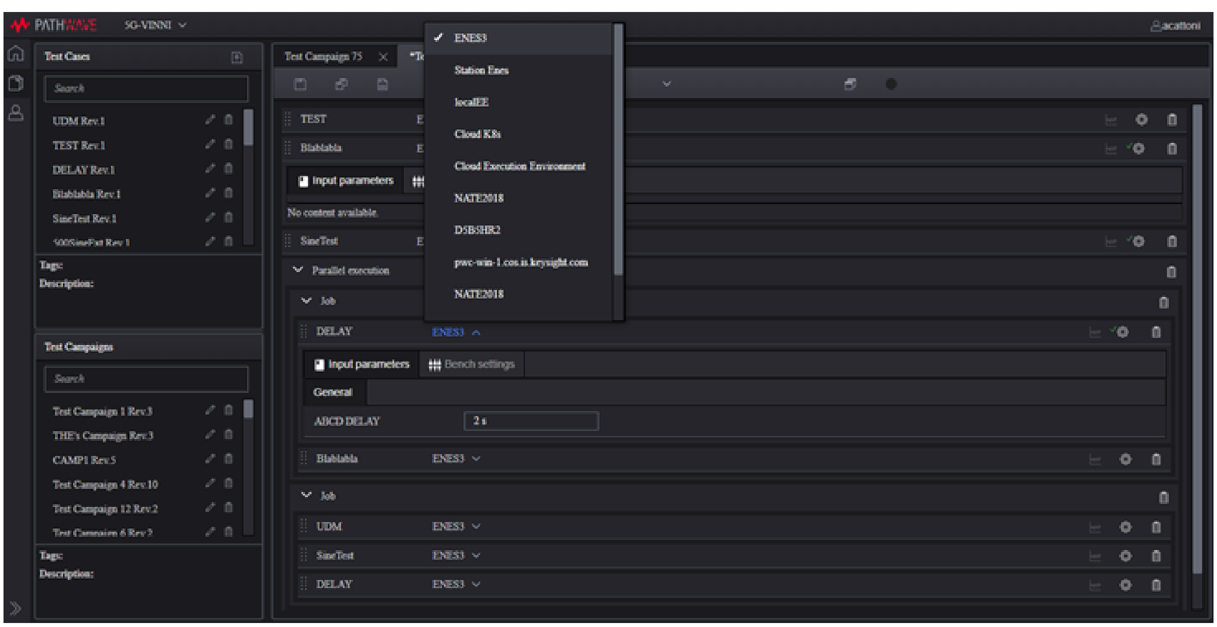

Figure 8: Test Campaign Editor

For more information on the TaaS portal features below please see 5G-VINNI Deliverable D4.2 [9].

4.1.2 Leveraging and extending 5G-VINNI

While the 5G-VINNI is now in its last phase for completing the planned capabilities and features, the main areas of leveraging and extending 5G-VINNI are going into the following main topics.

- Extending the 5G-VINNI facilities in Norway and at University of Patras, e.g., for the LL1 at NTNU in Trondheim
- Integrating the CDSO with the specific 5G-VINNI facilities, enabling support for integrating 3rd party network application functions (aka. NAF, or 3rd-pty VNFs), targeting effective service chaining, also involving edge cloud infrastructure
- Integrating the CDSO and the KPI VS with the 5G-VINNI TaaS testing framework (depending on facility components and capabilities) for effectively running test campaigns and performing technological validation according to the 5G-SOLUTIONS methodology and procedures
- Design of Test Cases and Running specific use cases for testing and KPI validation, exercising the above extended capabilities
- Running so-called multi-living-lab use case scenarios, where multiple UCs are running concurrently, to test and validate the specific UC KPIs under such concurrency, and test and validate KPIs defined in the context of running concurrent services, and where relevant concurrent services are run over multiple 5G network slice instances
- Use of Zero-Touch-Automation (ZTA) and machine learning (ML) mechanisms, in the context of CDSO and/or KPI VS to enhance the test-cases and technological validation.

In the following, in addition to what has already been covered above (e.g., in relation to the use of and extending the TaaS platform) we address specifically the extension of the 5G-VINNI Norway facility for supporting the relevant use cases and their test cases. More details per facility are presented below:

- Extending the 5G-VINNI Norway facility
  - Indoor 5G RAN for the LL1, Factory of the future, at NTNU manufacturing lab (ManuLab),
    - Cycle 1
    - Cycle 2, extended with edge cloud infrastructure
    - Cycle 3, extended with mmWave RAN
  - Outdoor 5G RAN for LL3 (Smart City Co-Creation) and LL4 (UC 4.3, Live event enhanced media) at NTNU Gløshaugen campus
    - Cycle 2 and Cycle 3, progressively adding functional capabilities and 3rd party network application functions (3rd-pty VNFs) and service chaining, involving edge cloud
  - Outdoor 5G RAN for LL3 Smart Port at YARA, Herøya Industry Park, (in collaboration with Telenor Norway)
    - Cycle 1, using Telenor Norway 5G RAN with non-stand-alone 5G (NSA)
    - Cycle 2, using Telenor Norway 5G RAN connected to 5G-VINNI stand-alone (SA) 5G Core, with edge cloud infrastructure
    - Cycle 3, still pending some decisions. Adding functional capabilities and 3rd party network application functions (3rd-pty VNFs) and service chaining, involving edge cloud
- Extending the 5G-VINNI UoP facility
  - Cycle 1 using Patras5G indoor with both 5G NSA and SA modes - MultiLL trial used also the outdoor 5G RAN
  - Cycle 2 using both indoor and outdoor 5G RAN on SA at the University Campus building

Providing some more details considering the use of the CDSO for managing and orchestrating 3rd party network application functions (aka. 3rd-pty VNFs) and service chaining, involving edge cloud, the following topics and capabilities are considered as examples:

- UE / Device onboarding (considering subscription level management)
- Management of specialized connectivity services, provisioning and handling of connectivity specifically managed on-demand according to application requirements
- Activating / de-activating of functionality, either related to the 5G system or the vertical application
- Other (pre-) configuration of customer or UC specific parameters, considering Logical Network as a Service (LNaaS), e.g. Network based Firewall policies
- Zero-Touch Automation (ZTA) is a potential topic, depending on the UC's intention and the capability of the 5G-VINNI's MANO to support the ZTA intention. In case the 3rd party VNFs will be deployed in the 5G-VINNI infrastructure and managed by 5G-VINNI MANO system, ZTA will be achieved by closing a MANO chain from CDSO to OpenSlice (instance in the 5G-VINNI Norway facility) to 5G-VINNI MANO (including FlowOne for E2E service management, CBND as NFVO, and CBAM as VNFM). A typical ZTA intention is VNF scaling, which requires monitoring the resource utilization of the VM that hosts the VNF. Realizing this ZTA intention also requires the inclusion of the TaaS and ML/AI module of the KPI-VS which offer the analytics capability and present the ZTA requests to CDSO
- Scaling adjusting application parameters of (distributed) UPF (cf. management of specialized connectivity services above)
- Scaling and adjusting application parameters of the 3rd-party NAFs/VNFs.

Moreover, a couple of Multi-Living-Lab (MLL) scenarios will be experimented in Cycle 2 and Cycle 3 in the 5G-VINNI Norway facility, including UCS 5.2 (UC3.5 by YARA with 3 concurrent slices) and UCS5.4 (UC3.1 + UC3.2 by NURO with two concurrent UCs). Experimentations of these MLL UCSs will demonstrate how the 5G-VINNI facility:

- Orchestrates multiple slices concurrently. The main concerns are: i) isolation of these concurrent slices; ii) isolation of testing data for these concurrent slices (TaaS needs to provide slice-level granularity to separate the data of different slices).
- Orchestrates multiple UCs in one or multiple slices concurrently. The main concerns are: i) resource competition of multiple UCs; ii) isolation of testing data for these concurrent UCs (TaaS needs to provide tenant-level granularity to separate data of different UCs).

More details considering the living-lab use cases in more detail will be provided in the coming 5G-SOLUTIONS Deliverable D2.1.

4.2 5G-EVE

4.2.1 Introduction

5G EVE is the European 5G validation platform for extensive trials. It is one of three 5G PPP infrastructure projects started on 1st July 2018 and finished on 30th June 2021. The goal is to implement and test advanced 5G infrastructures in Europe. The 5G-EVE concept is based on further developing and interconnecting existing European sites in in Greece, Spain, France, and Italy to form a unique 5G end-to-end facility.

The main objective of the project has been to propose a general facility architecture that could implement the approach described in Figure 9. The green part of the representation is based on the different technologies and implementations at different sites' level, whereas the orange part is common to all sites and interfaces with the green one. This orange part includes the portal, which allows a vertical player to register, deploy, execute, and monitor its use-case. Saying that, lot of functionalities, interfaces definitions and developments have been carried out in order to enable automated deployment of the virtual functions provided by the verticals, from the portal to the distant site facility, offering virtual infrastructure, management and orchestration tools, as well as KPIs performance evaluation tools which are required to collect and analyse the use-case performance evaluation.

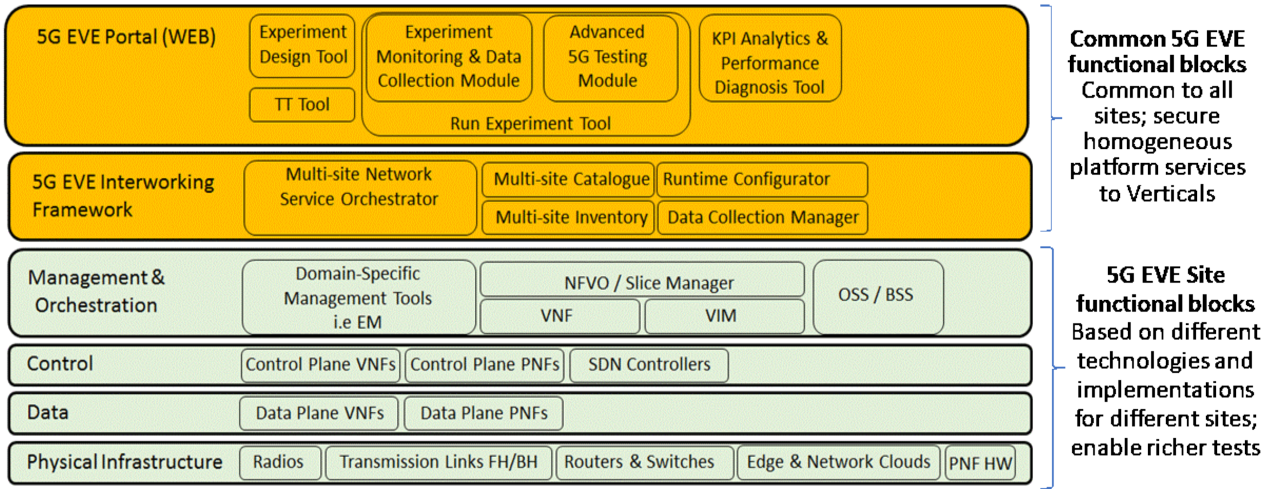

Figure 9: 5G EVE Architecture – Implementation View

Figure 10 gives the technical architecture view that has led to build the E2E 5G EVE facility. This figure highlights the addressing planes put in place for connecting the different sites, that is not important for the sake of this document. Nevertheless, it demonstrates the complexity of 5G-EVE facilities. 5G-SOLUTIONS is leveraging on Italian site, managed by TIM.

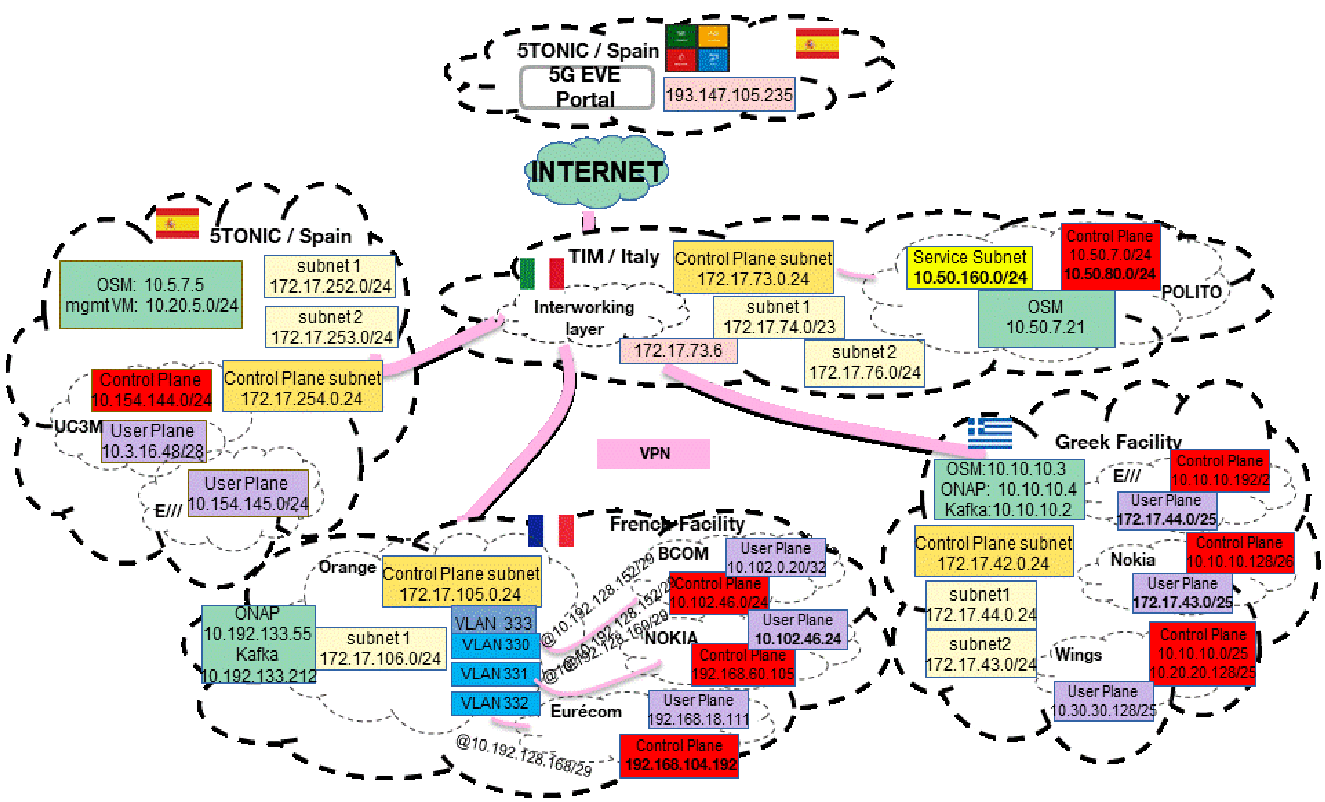

Figure 10: 5G EVE Technical Architecture view

A star network implementation was chosen as the most appropriate, given the geographical location of the sites. It was implemented by interconnecting the north bound of the sites facilities to the south bound of the InterWorking Layer (IWL) via secured VPN, the IWL being deployed in Italy at TIM premises. Then, connectivity from Italy to France, Greece and Spain was achieved and connection from site A towards site B is possible even by passing through the IWL that plays a gateway role, routing the different flows.

The main functionality of the IWL is to perform the multi-site services orchestration considering the assumption that the different sites facilities may implement different kinds of NFV orchestrator (OSM or ONAP). Consequently, specific drivers (or adaptation layers) were developed to adapt the different interfaces to the ETSI NFV SOL005 [14] standard adopted at the IWL north bound interface.

So, starting from the portal, a vertical, who has received the confirmation of its registration asked previously to the portal manager with its “vertical profile”, starts the design of its experiment following the E2E workflow, as already described in D2.4 [5]. Several tasks are linked leading to the experiment declaration, automated services deployment in distant infrastructure, experiment running and KPIs data collection and analysis. Several verticals have succeeded on this process, being able to target any of the four 5G EVE site facilities.

Figure 11 shows the uniform internal procedures of the 5G EVE Platform to collect, to process, and to evaluate the metrics and KPIs required to validate a vertical experiment.

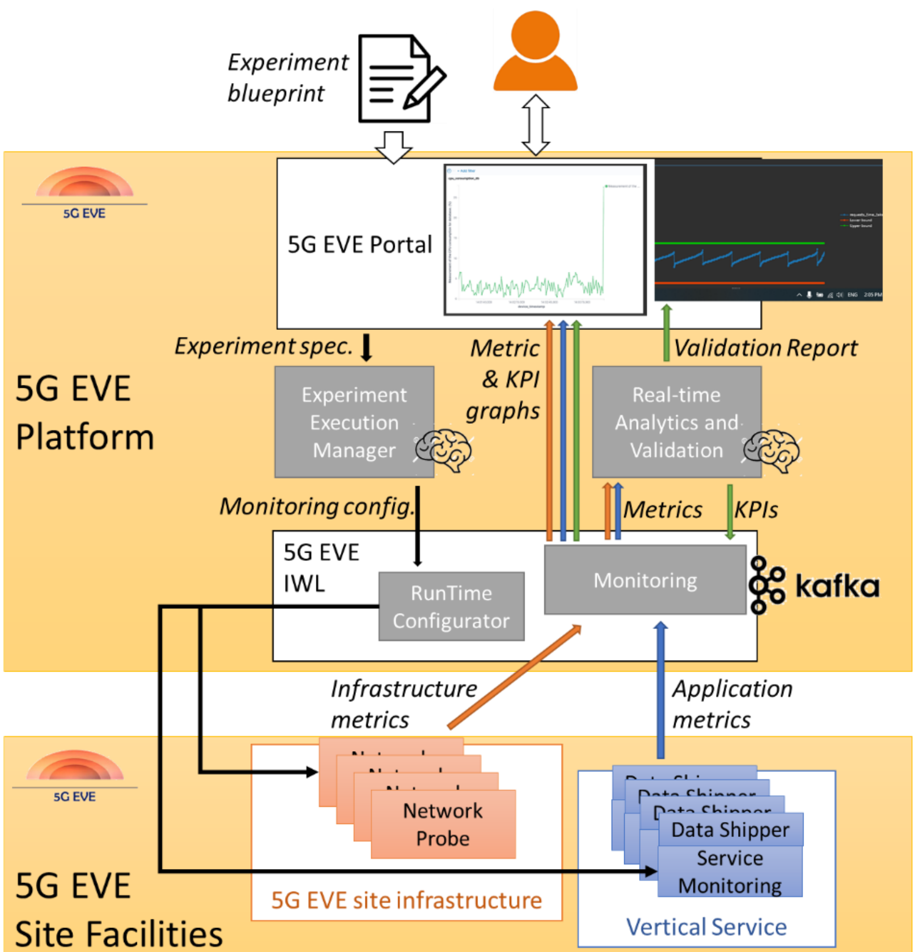

Figure 11: 5G EVE Platform - procedures for metrics and KPI collection, validation, and visualization

In reference to Figure 11, the Vertical Service is deployed and configured by the Vertical through the 5G EVE Portal. The necessary images and descriptors (*Experiment blueprint*) are onboarded on the 5G EVE Platform through the 5G EVE Portal, as well as metrics and KPIs defined by the Vertical in the *Test Case* *blueprint* for the specific experiment (namely, one test case execution). From this point of view, the Vertical Service can be considered part of the 5G EVE Site Facility as soon as it is deployed in it. Differently from the Network KPIs (defined by the Vertical as mentioned above), the Vertical KPIs can be collected directly by the Vertical Service or can be sent to the 5G EVE Monitoring system by a specific VNF in the Vertical Service. In this last case, the Use Case Developer conceived the Vertical Service and related VNFs accordingly, so as to tackle this aspect by design.

The 5G EVE portal processes the experiment blueprint retrieving the specification of the metrics and the KPIs and setting the related topics at the monitoring platform. The Kafka brokers at the monitoring platform, in the Data Collection Manager component, are thus ready to receive and exchange all the data related to the experiment on the configured set of topics. When triggering the execution of the experiment, the 5G EVE portal interacts with the Experiment Execution Manager (EEM) providing the experiment specification, including its monitoring topics. As first step of the execution, the EEM coordinates the configuration of the experiment elements. For the monitoring part, it interacts with the Run-Time Configuration (RTC) at the IWL providing the details of the monitoring configuration, like the topics, the list of infrastructure metrics, the IP addresses of the VNFs that run the data shippers for the application metrics, the scripts to configure these data shippers, etc. The RTC uses this information to configure the probes and the data shippers on the target functions. It should be noted that the list of network probes available on each facility and their capabilities is automatically retrieved from the site inventory at the IWL. In parallel, the Real-Time Analytics and Validation (RAV) component is configured with the list of topics, metrics, KPIs and thresholds, to activate the procedures for the automated analysis of the experiment results.

Once the data shippers have been properly configured and activated, the experiment is started, and the metrics are continuously sent to the Kafka broker using the appropriate topics. The 5G EVE monitoring platform relies on a hierarchical Kafka deployment, where monitoring data are initially collected on local Kafka brokers available in each site and replicated on a centralized one at the IWL. The RAV consumes the metrics from the centralized Kafka broker based on the per-topic subscriptions performed at the configuration phase. The metrics are processed and translated into KPIs that are pushed back into the Kafka broker. Both metrics and KPIs are stored in the Data Collection Storage of the 5G EVE monitoring platform, and they can be visualized through graphs in the 5G EVE portal. At the end of the experiment, the RAV elaborates the entire set of KPIs, evaluating them according to the thresholds defined in the experiment blueprint. The results are summarized in a validation report, which can be visualized through the 5G EVE portal.

In the use cases developed in 5G-SOLUTIONS (LL2 side), the 5G-SOLUTIONS KPI VS has been integrated in the 5G EVE facility in the sense that the 5G EVE Platform allows the communication between the VNFs supporting the Vertical Services and the 5G-Solutions KPI VS. In this way, the Vertical KPIs of all use cases are communicated to the 5G-SOLUTIONS KPI VS through a set of suitable APIs made available by the Use Case Developer (Ares2t). For as concerns the Network KPIs, as far as I know, these are managed by the 5G EVE Platform and communicated to the 5G-Solutions KPI VS through another set of APIs, according to the work carried out by AppArt, Ares2t and TIM in WP3.

4.2.2 Leveraging and extending 5G EVE

It can be said that 5G-EVE represents the network operator, while 5G-SOLUTIONS is the customer. However, as in all simplifications, the "naive" picture we have just drawn is useful to give an idea but does not fully represent reality.

In fact, as per the mandate of the ICT-17 projects to which it is part, 5G-EVE has made the 5G connectivity necessary to perform its experiments available to 5G-SOLUTIONS, but there have been intense discussions between the two projects to be able to exploit the 5G-EVE infrastructure (Italian site) in order to better accommodate the tests on the 5G-SOLUTIONS living lab 2.

The Italian site facility offers different radio environments for testing with dedicated core networks; the current 3GPP release is 15 NSA architecture. Radio and Core network are based on Ericsson equipment. The facility is multi location, interconnected by high performance links (via TIM transport network or dark fiber). A service cloud (hosted in Politecnico di Torino) is available. It is based on Openstack and it can onboard the VNFs and PNFs from the IWL catalogue. It consists of three physical servers. The first one is acting as service server container, where all the services related to 5G EVE infrastructure, related to the POLITO site are instantiated. The other two servers are configured as OpenStack Compute nodes, where the VNFs are executed.

The resources of each server are defined in Table 3 and the EVE servers should be considered when scheduling concurrent vertical experiments, considering the dimension of their virtual machines and potential image snapshots that may be used for testing purposes and following instantiations. In particular, the dimension of the virtual machines should be validated considering the available resources in the compute nodes (eve2, eve4), while the dimension of the image snapshots impacts the controller node resource utilization (eve1).

Table 3: POLITO OpenStack nodes

Server	RAM	CPU	HDD	Notes
Eve1 (Controller Node)	8GB	4	300GB	The node hosts the images and snapshots. This impacts only disk space.
EVE2 (Compute node)	128GB	40	900GB	The node hosts the VNFs. All resources are impacted.
EVE4 (Compute node)	128GB	40	900GB	The node hosts the VNFs. All resources are impacted.

OneM2M platform is up and running in the field TIM network, its data can be taken by VMs in the Openstack cloud and dedicated devices can push data into the OneM2M platform (for example in the smart city use case).

The Italian architecture is depicted in Figure 12.

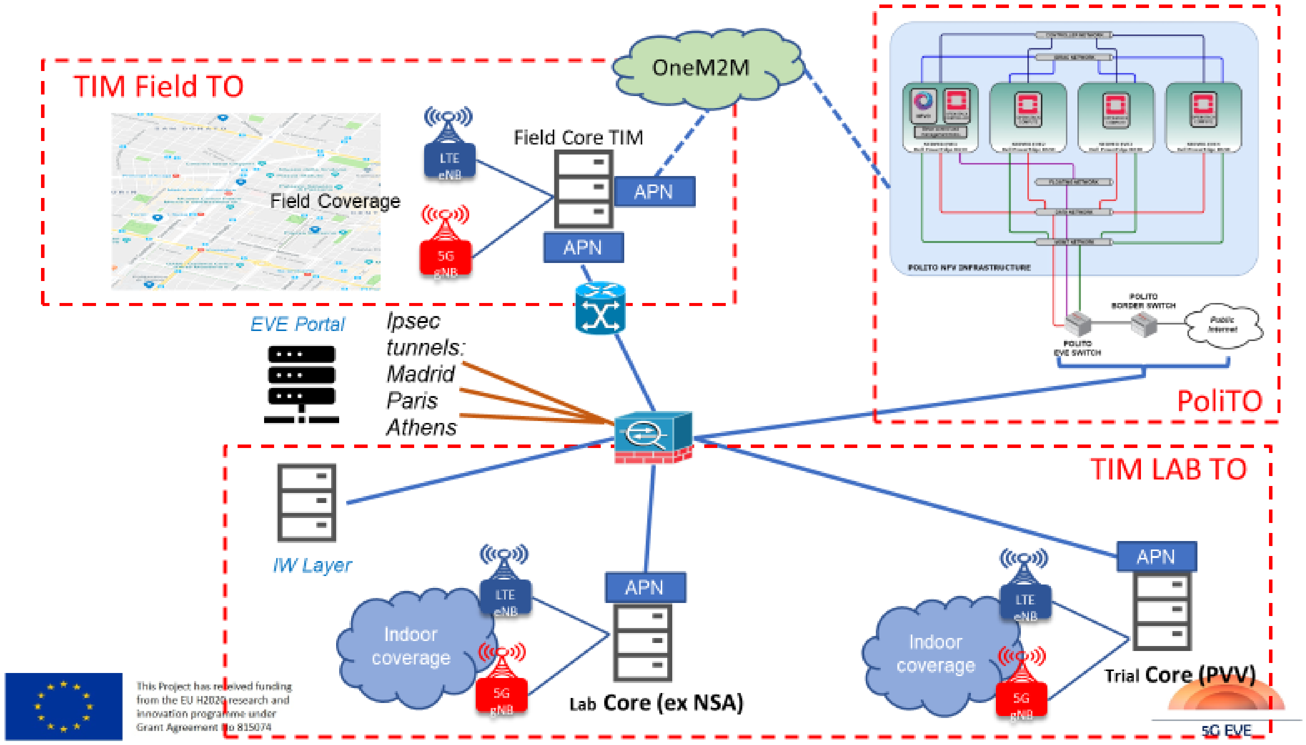

Figure 12: 5G EVE Italian site facility architecture

The radio access coverage is provided by 3 different environments.

- **Field Coverage**: a dedicated Private APN is active on the TIM commercial network. It is available in the "innovation mile" area, in Turin city, approximately between "Politecnico di Torino" University and PortaSusa railway station, the coverage is ensured by some macro sites (>4 sites, 3 cells/site). It allows the experimenters to access the 5G EVE private network (user plane) service platform.

  Field network is NSA, and works @3.6GHz licensed band, owned by TIM (80MHz).

- **Lab Core and coverage**: this in-lab network is a full mirror of the field network architecture. It is made by same devices and releases, to replicate conditions. By a dedicated Private APN, it provides to the 5G EVE experiments a controlled and ideal environment for controlled execution. The lab is also equipped with network/users emulator for impairment and load test (PRISMA multi user emulator). Same as Field network, Lab RAN is NSA and it works @3.6GHz licensed band, the coverage is indoor, and shielded rooms are available.
- **Trial core and coverage**: this core network is in-lab and is a virtual EPC in a box. The meaning is that all the core network components are virtualized (vMME, vEPG, vHSS-FE, vCUDB) and contained in VM as VNF. All the system runs on cloud environment that manages the cross function towards RAN part. This solution allows to have the EPC in a single server (1 RU only), allowing for electrical and spacing optimization and great flexibility in the deployment. As per the Lab Core, the same private APN has been setup to perform 5G EVE UC experimentation. The RAN part is connected directly to the vEPC. The Trial Core is currently connected to single BBU indoor B42 (TIM lab), but it is ready to manage dedicate coverage (indoor and outdoor) for specific project/Use Case (for example to support ICT-19 use cases, providing own small cells/ dotRRH), also using different radio bands (example: mmW @26 GHz). The Trial core network is an enabler for some Edge Cloud innovation activities leveraging on the

flexible EVE infrastructure supporting central and edge core 4G and 5G network services with possible future enhancements toward 5G SA solutions.

5G-SOLUTIONS side, the Living Lab 2, based on 5G-EVE infrastructure, is executed different test cases related to three use cases, namely:

- **Industrial Demand Side Management (UC2.1)** – This use case deals with Demand Side Management (DSM) in electric power distribution at the level of business/not residential users, with specific focus on optimal scheduling and dynamic aggregation of energy loads via mobile communication as well as peak power consumptions avoidance.
- **Electric Vehicle Smart Charging (UC2.2)** – The use case deals with mobile communication supporting remote control of charging sessions by the charging infrastructure operator's back end, with specific focus on distributed control strategy to improve the charging control and optimization in terms of the trade-off between number of served Electric Vehicle and sampling time.
- **Electricity network frequency stability (UC2.3)** – The use case deals with faster responsive adjustments between electricity production (including Renewable Energy Sources) and demand to limit irregularities in the grid frequency, with specific focus on distributed control strategy to control aggregation of many Electric Vehicles (UC2.2) to provide primary frequency regulation services.

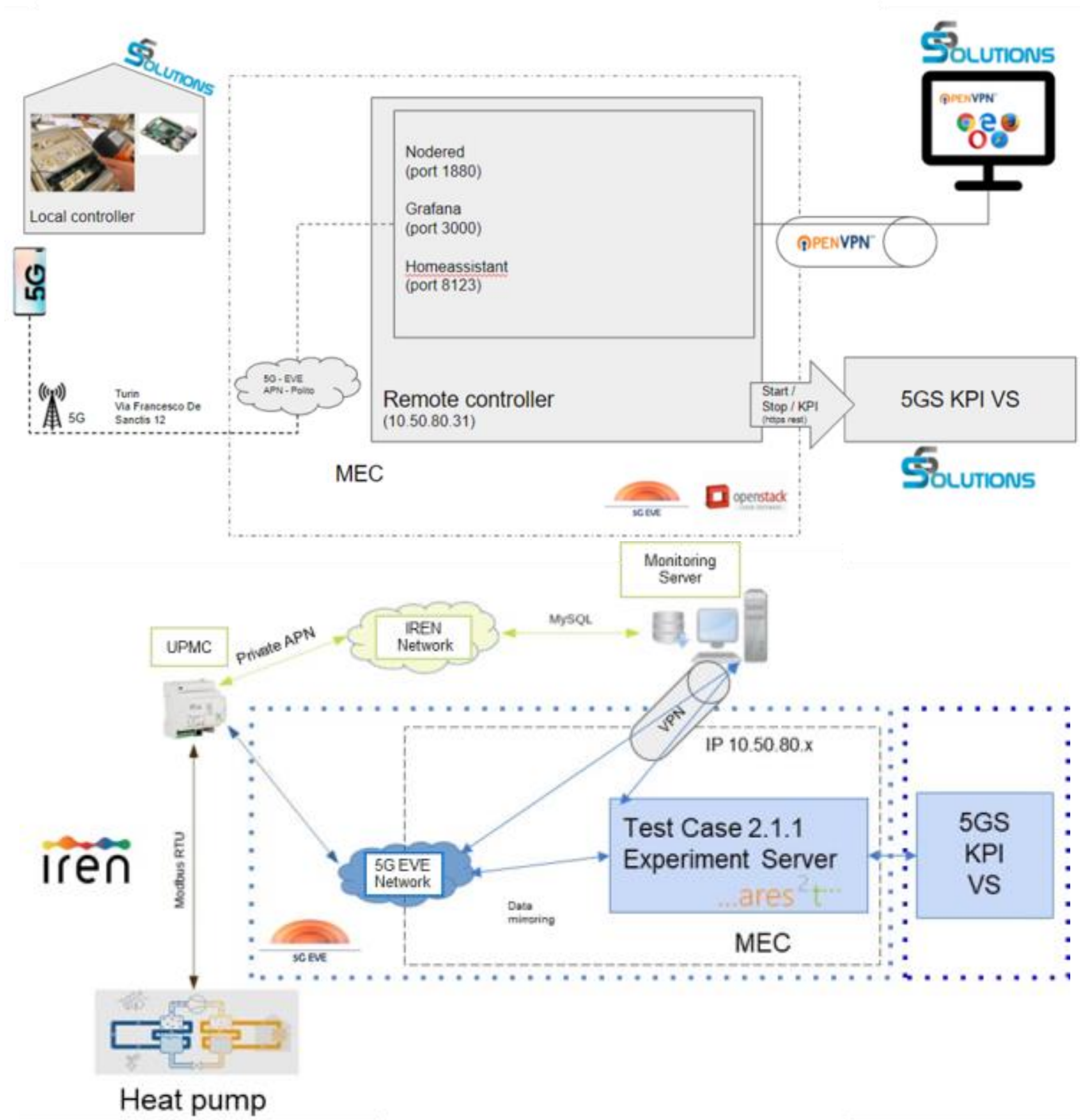

Figure 13: Architecture of test case Uc 2.1

Figure 13 shows two different sights of a simplified example of the interaction between 5G-SOLUTIONS and 5G-EVE platform. The idea is that:

- The client terminal (e.g. heat pump controller in the example) is connected through 5G network with the cloud hosted in the 5G-EVE servers
- 5G-SOLUTIONS interact with 5G-EVE through the CDSO and it receives performance data to be passed to the 5G-SOLUTIONS KPIs visualization system.

In multi living lab, also based on 5G EVE, the plan is to start the experiment design and execution of two test cases in Cycle 2 with dedicated technical and business-oriented activities, selecting a preliminary subset of test cases of interest for concurrent execution in two distinct testbed areas in the City of Turin.

An important enhancement with respect the 5G EVE infrastructure is the set-up of a VPN between the 5G EVE network (in Turin) and the IREN premises in Turbigo. This enhancement permits to close the experiments with a future commercial implementation of the use cases.

A key aspect for concurrent execution is the availability of suitable network resources in the test bed, hosted by the Italian Site of the 5G EVE project. Suitable requirements in terms of computation and data storage resources are under definition at this stage, so to guarantee the concurrent execution of two distinct experiments via the 5G EVE platform.

Of course, more details of the experiments and test beds are reported in specific 5G-SOLUTIONS deliverables (D5.2A [9] and D5.3A [13]). Directly going to the big question object of this deliverable, i.e. how 5G-SOLUTIONS leverages and extended 5G-EVE results, the answer is:

- “Leveraging” is quite simple: LL2 uses the connectivity infrastructure (RAN and core network) provided by 5G-EVE
- “Extended”. For a pure transmission point of view, the possibility of duplicate traffic inside 5G-Eve network (see Figure 1, right side). Furthermore, we are demonstrating the possibility of reach requirements (KPIs) about end-to-end latency (< 30 ms) and the integration with a complex commercial orchestrator (CDSO) and the sophisticated KPIs visualization system under URLLC profile. Specifically, to the multi living lab the extension is even bigger because 5G-SOLUTIONS is experimenting the possibility of running two different tests over the same space released by 5G-EVE, also together with other Projects (5GROWTH and 5G-TOURS). Currently 5G-EVE has not the possibility to have distinct network slices in the test bed, according to Release 15 and no further development in this sense are expected for the moment being. In any case 5G-SOLUTIONS facilities is studying how to run experiments in an architecture where slices will be possible (e.g. Rel. 16)

4.3 5GENESIS

4.3.1 Introduction

5GENESIS[5] is one of the ICT-17 open 5G platforms. Its architecture offers in the top layer, that is exposed to the experimenters, an Analytics-as-a-service component, alongside other components responsible for the experiment management (Figure 14). This component allows:

1. Support for correct platform setup, identifying possible issues in the setup that might reflect in inconsistencies in the KPIs,
2. Post-experiment processing, enabling identifying anomalies and relationships between different KPIs,
3. Detection of anomalies that could indicate security issues. This Analytics service is based on Docker micro-services. A full description of the Analytics component in 5GENESIS can be found in the 5GENESIS deliverable D6.3[6].

[5] https://5genesis.eu/

[6] 5GENESIS D6.3 https://5genesis.eu/wp-content/uploads/2021/05/5GENESIS_D3.6_v1.0_FINAL.pdf

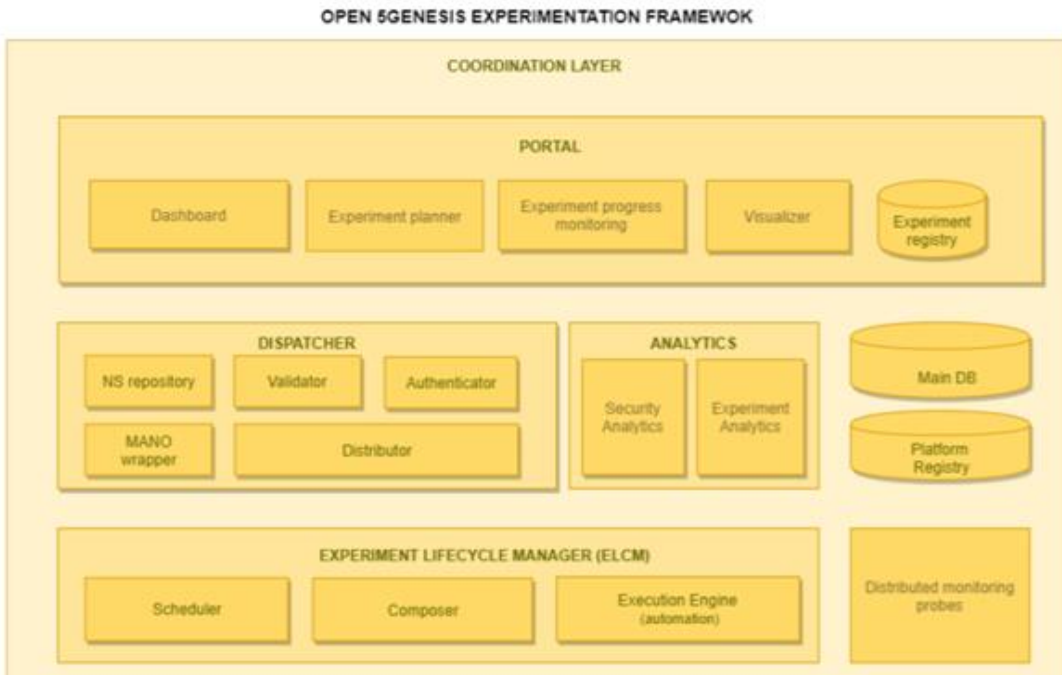

Figure 14: Coordination layer of Open 5GENESIS framework, including the Analytics component

4.3.2 Leveraging and extending 5GENESIS

5G-SOLUTIONS collects in a central KPI Visualisation System (KPI VS) data and KPIs from the verticals and underlying platforms. The KPI VS [ref to D3.2] comes with an Analytics service which will provide:

1. Insights to the verticals,
2. Input to the Zero-Touch Automation module, where needed. Its general architecture is shown in Figure 15.

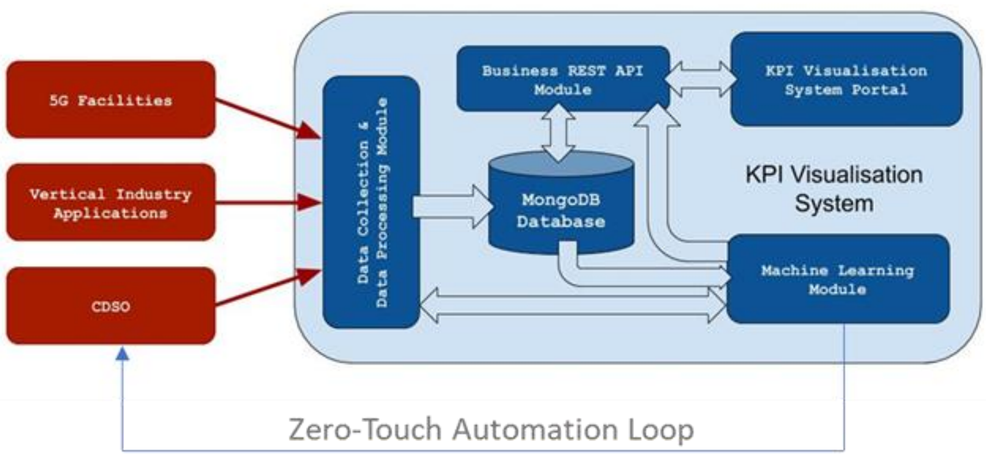

Figure 15: Architecture of KPI VS in 5G-SOLUTIONS, including the Machine Learning Module

LMI is a common partner between 5GENESIS and 5G-SOLUTIONS and has used its experience in developing the 5GENESIS Analytics service as underlying background to support the development of the ML services in 5G-SOLUTIONS.

However, while the focus of 5GENESIS is on analyzing platform data to ensure a good 5G setup and give post-experiment insights about performance, the 5G-SOLUTIONS ML services consider the particularities of KPI visualization system data collection and the needs of the 5G-SOLUTIONS use cases. These include, for example, multi-domain experiments, i.e., across vertical and platform domains, and live predictions to support zero-touch automation. As such, no containers were directly imported from 5GENESIS to 5G-SOLUTIONS, but rather the experience of how to create and structure the ML containers was used to speed up the development of the 5G-SOLUTIONS ML containers and supports their use towards providing insights to verticals.

The work in 5G-SOLUTIONS also goes beyond the type of work in 5GENESIS Analytics through:

- Providing a time-series forecasting service (implemented as ARIMA)
- The model store and model execution are functions in 5G-SOLUTIONS that do not exist at all in 5GENESIS. 5GENESIS only uses model training for predictive analysis where the last trained model can be downloaded, but no live predictions exist during the experiment runtime
- The Zero-Touch Automation (ZTA) function is a completely new feature, which takes input from ML containers. ZTA is specific to 5G-SOLUTIONS and its cross-domain orchestration feature, enabling runtime optimizations considering KPIs across the vertical and network domains.

5 Cooperation with ICT-19 projects

The 5G-SOLUTIONS project is really integrated with the other 5G projects, both by the participation in many 5G-PPP working groups, and, as consequence, collaborations between ICT-19 projects are very active.

It would therefore be impossible to report all the collaborative events as it is not a research fabric distributed over several projects where the exchange of ideas, information and results often takes place informally.

Below are the most significant collaborations.

5.1 5GROWTH

5GROWTH is an ICT-19 project with some similarities with 5G-SOLUTIONS, and some complementarities. The pilots considered by 5GROWTH are:

- Industry 4.0 These pilots deal with car manufacturing, aiming to demonstrate innovations and advantages by the adoption of 5G.
- Transport. In this Pilot 5GROWTH focuses on a particular use case: the automation of crossing level. In this use case, the adoption of 5G leads to the automation resulting not only in economic savings, but in reduction of accidents.
- Energy, close to the theme of smart grids.

From a technical point of view, despite being applied to completely different sectors, the ideas introduced by 5GROWTH industry pilots are like UC1.1 and UC1.2.

On the other hand, 5GROWTH pilots about Energy are like 5G-SOLUTIONS UC2.3.

These similarities necessitated close contacts between the two projects and exchanges of ideas, facilitated by the 5G-PPP working groups and by partners working in both projects.

Another point of contact between the two projects has been about economic evaluations. We realized that WP1, and T1.2 of 5GROWTH, is working on economic evaluations on the main Pilots and they released D1.2 (August 2020) containing some preliminary economic figures demonstrating the economic benefits of the implementations of the solutions envisaged by their project.

These preliminary evaluations had as result calculating the benefits introduced by CAPEX / OPEX savings and new revenues, considering the entire Pilot, without distributing these benefits among all the stakeholders. This action is the next step of the job. These results will be available in the new release of the deliverable, by the end of January 2022.

5G-SOLUTIONS has not yet produced numerical evaluations about the economic benefits of the case studies. It can take 5GROWTH's figures as an example, considering similarities, but also differences between the case studies envisaged in the two ICT-19 projects.

It is not a subject where 5G-SOLUTIONS leverages on 5GROWTH results rather than a collaboration in the participation of 5GROWTH members to the 5G-SOLUTIONS pre-standardization workshop, resulting in a contribution to 3GPP (see Section 6.2).

5.2 5GMediaHUB

The vision of 5G SOLUTIONS matches the 5GMediaHUB vision in the Digital Single Market focusing on the impact of 5G in the media sector. The vision acknowledges the need to accelerate the uptake of 5G-empowered services throughout Europe, including minimising deployment ambiguities for media application providers.

This common vision led to a fruitful collaboration because there's the need to provide a 5G-based secure and trusted experimentation playground through which media mobile app developers would have the opportunity to test and validate their applications in an integrated, open and cost-efficient manner, so as to remove operational uncertainties and reduce market entry barriers prior to being ported and deployed in industrial public 5G networks.

The common vision of 5G SOLUTIONS and 5GMediaHUB is to enable EU to achieve its goal of becoming a world leader in 5G, by accelerating the testing and validation of innovative 5G-empowered media applications and NetApps from 3rd party experimenters and 3rd party NetApps developers, respectively, through an integrated, open and fully featured Experimentation Facility. This will significantly reduce the time to market barrier, thus providing such actors that are primarily from SMEs, with a competitive advantage against their rivals outside EU.

To address the above needs and challenges and realise its vision, this initiative creates a high-level abstraction layer (through NetApps) between media applications and the underlying 5G infrastructure. This will allow experimenters to have a simplified but sufficient abstracted visibility (i.e. view of the network corresponding to a specific network slice) of the infrastructure state for network-wide control and resource management, in turn, enabling them to dynamically deploy, orchestrate and manage their services through elastic network slicing, to ensure service and workload isolation. This will subsequently provide tenants with a flexible and cost-efficient way to support their applications by providing access to 5G network resources.

In this way, 3rd party experimenters in the media sector will be able to:

- Have access to application testing and validation resources otherwise unavailable to them;
- Reduce entry barriers, reduce uncertainties and accelerate confidence prior to porting them to actual 5G MNO networks;
- Reduce the average service creation time cycle from hours to within minutes (as per 5G PPP KPIs);
- Significantly reduce the time to market, optimise the utilisation of resources, reduce the cost-of-service deployment through relevant NetApps and accelerate NetApp uptake via the DevOps environment;
- Offer performance and Service Level Agreement (SLA) guarantees for their offered services to their end-user customers through combined service oriented predictive Quality of Service (QoS) and Quality of Experience (QoE) indicators, resulting to a more promising and beneficial approach for service-level performance evaluation.

6 5G-PPP / 5G-IA and standardization

6.1 Active working groups, snapshot of the situation and contributions

5G SOLUTIONS partners are leading the activity of the 5GPPP KPIs/verticals task force analysing vertical use cases of various domains and their mapping to 5G network KPIs. The scope is to identify the potential impact on the service performance and user perceived quality.

The challenge is to understand the relative influence of 5G network performance indicators to the vertical services: the selected services KPIs are mapped on the respective network KPIs that impact the operation of the architectural elements that participate in the service provision process. The KPIs' targets are identified as well.

The first important step was the definition of the methodology, followed by the performance evaluation, the identification of the use cases, the architectures and the relative KPIs. During this activity 5G-SOLUTIONS contributed to define in a clear and solid way the KPIs mapping and their target values to prove and validate that the 5G technology can provide industry verticals with ubiquitous access to a wide range of forward-looking services with orders of magnitude of improvement over 4G.

Vertical industries address their connectivity and communication requirements with dedicated specific solutions. 5G technologies, slicing and virtualization provide a common base that delivers an open, cost-efficient, and interoperable eco-system enabling a solution platform for the different verticals. 5G caters in an economical way to the diverse requirements and business needs of a multitude of verticals. In addition, 5G infrastructure and architecture integrate heterogeneous technologies and enable network slicing, so that the multiple concurrent execution of vertical operational services is performed regardless of their diverse requirements.

3GPP and ITU have mapped in a similar way the vertical industries to large service categories called service classes by ITU-T, allowing for the design of a more 5G user-centric platform dictated by service types for specific uses cases with optimised networks with different characteristics and behaviours determined by key performance requirements.

In this context, service performance is referred to the evaluation of the overall behaviour of the high layer service with the targeted values of the relevant KPIs dictated by the actual service provided to the end user (could also be referred to as application level KPIs) and not only by the network performance results. It is also important to note that when it comes to the measurements of such service KPIs, they may not be directly measurable, hence the need for an analysis on possible aggregation/correlation between different KPI levels.

With this in mind, the mapping between vertical KPIs and network KPIs includes all the contributors including the ones that constitute the end-to-end network service: network infrastructures or functions. For instance, it may need to consider the physical properties of the system that the application interacts with as well as the computation or caching required.

Service/Vertical and network KPIs might have a relationship that can be different from a one-to-one mapping. Indeed, a service might imply the elaboration of information that is not only handled by network functions only but also by instruments (e.g., hypervisors) that are virtualising resources. If network functions are virtualised the end-to-end delay is impacted by the data packet propagation time but also by the load of the computing resource where the functions managing and elaborating the packet are virtualised. In addition, Service KPIs might not be directly measurable, and this is the reason why a mapping between Network/Core 5G KPIs and Service/Vertical KPIs is needed, combining different Core 5G KPIs (completely transparent for the verticals) and obtaining specific Service KPIs.

6.2 Standardization

To describe the plan and the contributions to the standardization bodies is out of the scope of this deliverable. In this section we report the 5G-SOLUTIONS initiative about the organization of a Pre-standardization workshop and a specific contribution to ITU-R, reported here because it has been generated in the cooperation inside the 5G-PPP working groups.

6.2.1 Pre-Standardization workshop

The project organized a pre-standardization workshop on the 10th of May 2021, to collect requirements from living labs, to be exported as a contribution to 3GPP.

The workshop was opened to ICT-19 projects and the participation has been extended by the participation as training of CTTC students and by members of the Pre-Standardization Working Group of 5G-PPP.

66 people attended to the workshop belonging to different affiliation, as shown in Figure 16.

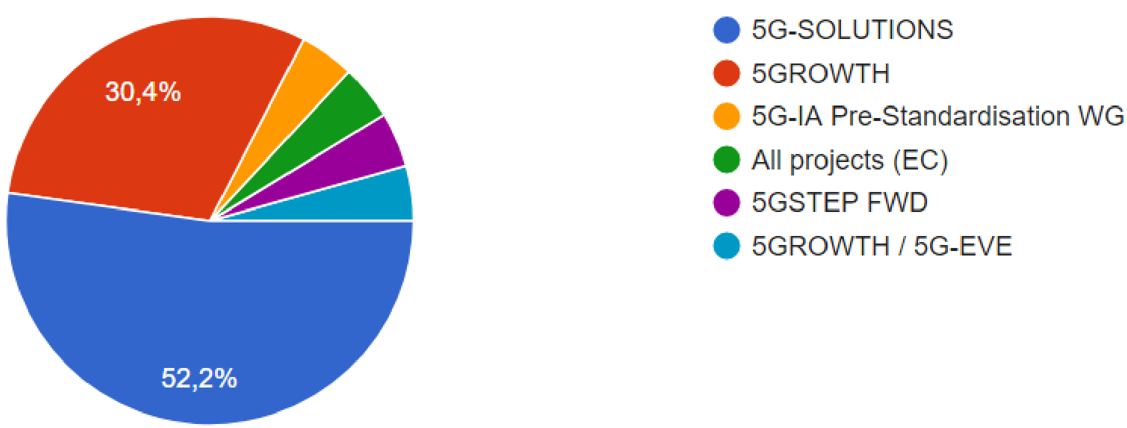

Figure 16: Pre-standardization workshop participants

The main results are the input from living labs about:

- Definition of “deterministic network” and if the network configuration is “deterministic” for living labs. In more details the idea is to understand is network based on 5G will follow the concept of Deterministic Networking (DetNet) defined by IETF DetNet Working Group, consisting in the implementation of deterministic data paths for real-time applications with extremely low data loss rates, packet delay variation (jitter), and bounded latency, such as audio and video streaming, industrial automation, and vehicle control.
- Devices. The main questions about the devices adopting 5G for their communications, not only cellular phones, but all kind of terminals are about the power consumption, as the lifetime of the battery is one of the KPI defined by ITU-R. In more details the analysis was focused understating if the majority of devise will be directly power supplied, or they will use batteries, and which will be the expected lifetime.
- The analysis of the characteristic of the network have been mainly focused on Bit-rate, that is to understand about the need of heavy uploads or heavy downloads and if the connections are delay sensitive.

- The network control is another theme that has been faced off. Methods to reconfigure and manage the network and how to share the responsibility in allocating resources in multiple domains facilities when slicing has been defined and adopted, has been discussed.

6.2.2 Simulation Assumptions and Performance Evaluation of the Scenarios Based on Release 15 5G-NR System-level Simulator

For defining 5G as an International Telecommunication Union (ITU) standard IMT-2020, the ITU-R has developed an approach of Standard Defining Organizations (SDO) submitting radio interface technology (RIT) proposals along with a self-evaluation against performance requirements set forth by ITU-R, following a methodology defined in [3]. Additionally, ITU-R has called out to academia and industry to —as an integral part of the process— form independent evaluation groups (IEG) that verify the self-evaluation results submitted by the SDOs.

This contribution is essential to support the validation of the 5G KPIS in 5G SOLUTIONS Living Labs activities, and it essential for 5G-SOLUTIONS high traffic demand scenarios like the 5G-SOLUTIONS UC4.x for “Media & Entertainment” or URLLC and massive connection density aspects in 5G-SOLUTIONS UC3.5 “Autonomous Assets & Logistics for Smart Port”.

Within the scope of this project, several configurations of 5G-NR wireless communication networks are analyzed. The analysis is performed using Nomor Research GmbH’s 5G-NR system-level simulator that has been calibrated against results shared by various 3GPP partners for simplified scenarios and configurations [2].

The scenarios that are considered in this project form a subset of those defined by the ITU-R in their report [3]. In particular, the following scenarios are evaluated:

- Dense Urban evaluation configuration C for the uplink (UL) assuming a TDD carrier at 30GHz and a supplementary UL carrier at 4GHz from the same site, where UEs in poor coverage are offloaded to the supplementary UL carrier. In line with the ITU-R evaluation methodology, user experienced data rate is evaluated for this scenario.
- Dense Urban evaluation configuration C for the downlink (DL) assuming a macro and a micro layer both operating at carrier frequency of 4GHz. In line with the ITU-R’s evaluation methodology, user experienced data rate is evaluated for this scenario.
- Dense Urban evaluation configuration B operating with a single carrier at 30GHz. In line with the ITU-R’s evaluation methodology, 5th percentile user spectral efficiency (SE), average cell SE, and user experienced data rate are evaluated for this scenario.

The results have shown that 100Mbit/s DL and 50Mbit/s UL user experienced data rate requirements, which are set in [1], are satisfied in Dense Urban Configuration C, both in UL and DL, whereas Configuration B is infeasible due to severe outdoor-to-indoor (O2I) penetration loss in frequency-range (FR) 2. In addition, 5th percentile spectral efficiency requirements for UL and DL, set in [1], are also not satisfied in the Dense Urban Configuration B, due to the reason mentioned above. On the contrary, average cell spectral efficiency requirements, set in [1], are satisfied by the Dense Urban Configuration B both in UL and DL.

Overall, this report shows that the performance requirements set by ITU-R in [1] are satisfied for Dense Urban Configuration C and are satisfied by Dense Urban Configuration B only with respect to average cell spectral efficiency KPI, but not with respect to 5th percentile user SE and the derived user experienced data rate. Overall, the 5G-IA's evaluation showed that 3GPP’s RIT proposal based on 5G-NR Release 15 does meet all performance requirements set forth by ITU-R for IMT-2020. The complete evaluation reports of the 5G-IA's IEG for the 3GPP’s and other SDOs’ RIT proposals are available for download from [4].

A more details explanation of the work is reported in Annex I.

7 Conclusions

The drafting of this document provided the opportunity for the project management to understand the degree of integration of 5G-SOLUTIONS in the scientific community and in the 5G-PPP context.

This integration takes place beyond the duration of the project, as we witness an integration before, during and after.

The "**before**" integration is given by the fact that the project has benefited from results obtained from previous initiatives, from projects funded by previous calls. In deliverable D1.3A it was even assumed to use a greater number of results, therefore numerous projects were analyzed (thanks also to the fact that many 5G-SOLUTIONS partners had participated in them), even if a smaller number of projects provided information useful and quality on which the research of 5G-SOLUTIONS has relied. More specifically, the topics of greatest interest were slicing, orchestration, based on NFV, Multimedia and broadcasting, the topic of cell fronthauling, disaggregation and mobile edge computing. To complete the picture, preliminary findings on security and machine learning related to 5G implementations not yet fully mature.

Integration “**during”** the life cycle of the project is of vital importance to the project itself. First, ICT-19 projects, such as 5G-SOLUTIONS, can be considered non-stand-alone, even less so than other research initiatives. In fact, the mandate of the projects approved in this call is to demonstrate the validity, innovation and exploitation/ commercialization of vertical solutions based on 5G, entirely or partially based on infrastructures developed by the projects of the ICT-17 call. Most of the use cases of 5G-SOLUTIONS are based on the infrastructures of 5G-VINNI, the living lab 2, centered on the theme of smart energy fa elva on 5G-VINNI and some use cases use "private" infrastructures developed by the project. Furthermore, 5G-SOLUTIONS actively participates in numerous working groups within 5G-PPP.

Regarding the "**after**" there are many initiatives. It obviously starts from the search for themes and ideas on which to contribute to the standardization bodies, and initiatives that can lead to the development of a business based on the ideas and solutions that the project develops. Particular attention is given to SMEs (Small and Medium enterprise) which represent an important share of the workforce and budget of 5G-SOLUTIONS. The project, however, he is not only interested in working SMEs, but is organizing initiatives aimed at involving other companies by creating a flywheel that can advance these small realities in technologically advanced fields and together with large industries or academic realities.

8 References

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9 Annex I –Simulation Assumptions and Performance Evaluation of the Scenarios Based on Release 15 5G-NR System-level Simulator

9.1 Introduction

9.1.1 Purpose and Scope

The purpose of this activity was to provide an independent evaluation of the radio interface technology specifications sent to the International Telecommunications Union Radiocommunication Group (ITU-R) by various standard defining organization as proposals for International Mobile Telecommunication (IMT)-2020.

This is very relevant for 5G SOLUTIONS because for the obtained simulations **results are essential for high traffic demand scenarios like the 5G-SOLUTIONS use cases 4.x for "Media & Entertainment" or URLLC and massive connection density aspects in 5G-SOLUTIONS use case 3.5 "autonomous Assets & Logistics for smart Port".**

The independent evaluation was done in Step 4 of the process to define IMT-2020. With strong encouragement and support from the European Commission, a number of 5G Public Private Partnership (5G-PPP) projects (including 5G-SOLUTIONS) joined forces to form such an Europe-centered independent evaluation group which has been working over the last two years and concluded its work by submitting its final evaluation reports to ITU-R in February 2020. Subsequently, the evaluation reports will be reviewed by ITU-R to build consensus and come to a decision and eventually globally valid recommendations regarding IMT-2020 implementation.

Based on the above, our independent evaluation activity plays a crucial role in the definition of next generation mobile communication systems. As such, its results also provide some guidance and reassurance to mobile network operators and manufacturers as to which candidate technologies fulfil the ITU-R's requirements and are hence likely to become part of IMT-2020 even before ITU-R will have come to a final decision later this year. This greatly facilitates further research and development both in terms of technology and deployments.

Furthermore, the details of the results obtained via system-level simulation and other means of analysis that are part of the performed evaluation give some indication as to what appropriate configurations and deployments are and what use cases can be supported. Clearly, due to differences between simulation channel models and real world, these studies cannot replace field tests as performed in 5G-SOLUTIONS, but they can serve as valuable input to streamline field tests and avoid expensive detours through investigations of scenarios that can be proven even by simulations to be either infeasible or obviously feasible.

In particular, the results obtained in the scope of 5G-SOLUTIONS on the one hand show the great potential of heterogeneous network deployments to boost area traffic capacity. On the other hand, they show that —even by 5G-standards very powerful antenna configurations— urban deployments of 5G networks consisting exclusively of base stations located outside and operating at 30GHz can provide very good performance for use cases outside, but not inside of buildings.

This deliverable report focuses on the evaluation of the scenarios that are a subset of those defined by the ITU-R in their report [3], against ITU-R's requirements for the IMT-2020 KPIs whose evaluation is based on system-level simulations.

In particular, the following scenarios are evaluated:

- Dense Urban evaluation configuration C for the uplink (UL) assuming a TDD carrier at 30GHz and a supplementary UL (SUL) carrier at 4GHz from the same site, where UEs in poor coverage are offloaded to the supplementary UL carrier. In line with the ITU-R evaluation methodology, user experienced data rate is evaluated for this scenario.

- Dense Urban evaluation configuration C for the downlink (DL) assuming a macro and a micro layer both operating at carrier frequency of 4GHz. In line with the ITU-R's evaluation methodology, user experienced data rate is evaluated for this scenario.
- Dense Urban evaluation configuration B operating with a single carrier at 30GHz. In line with the ITU-R's evaluation methodology, 5th percentile user spectral efficiency (SE), average cell SE, and user experienced data rate are evaluated for this scenario.

The purpose of the standardization document is to:

- Provide the configurations and assumptions used to perform system-level simulations of the above-mentioned test environments that ITU-R has defined for different eMBB scenarios,
- Provide the results of the system-level simulations in these test environments with respect to the defined KPIs,
- Assess the results obtained by system-level simulations in the different test environments and compare
- them with the ITU-R requirements.

The purpose of this activity was to provide an independent evaluation of the radio interface technology specifications sent to the ITU-R by various standard defining organization as proposals for IMT-2020. The independent evaluation was done in Step 4 of the process to define IMT-2020 and depicted in Figure 17. With strong encouragement and support from the European Commission, several 5G-PPP projects joined forces to form such a Europe-centered independent evaluation group which has been working over the last two years. The final evaluation reports were submitted to ITU-R in February 2020. Subsequently, the evaluation reports will be reviewed by ITU-R to build consensus and come to a decision and eventually globally valid recommendation regarding IMT-2020 implementation. Therefore, the independent evaluation activity that was partially executed under the umbrella of 5G-SOLUTIONS plays a crucial role in the definition of next generation mobile communication systems. As such, its results also provide some guidance and reassurance to the operators and manufacturers as to which candidate technologies fulfil the ITU-R's requirements and are hence likely to become part of IMT-2020 even before ITU-R will have come to a final decision later this year.

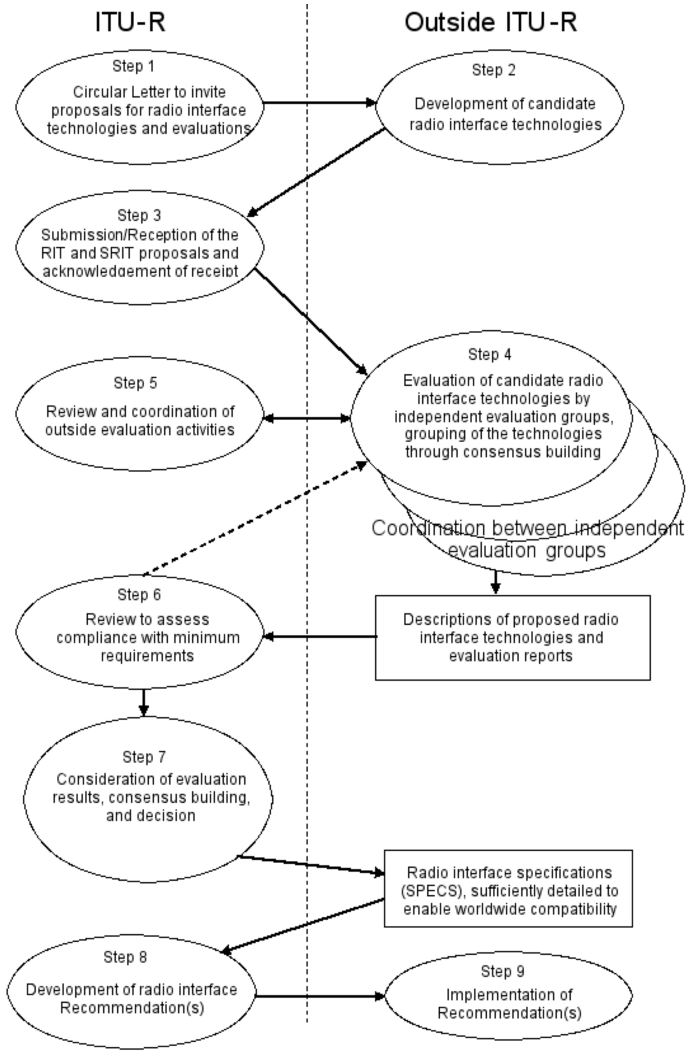

Figure 17: Scheme of the process define to define IMT-2020 and ITU-R

9.1.2 Structure of the Document

The rest of the annex is structured as follows:

- **Section 9.2**: Focuses on the evaluation methodology, including test environments, scenarios, simulation assumptions and the description of the relevant KPIs.
- **Section 9.3**: Presents the results obtained via system-level simulations and assesses the performance of the system with respect to the ITU-R requirements.
- **Section 9.4**: Briefly describes the conclusions obtained out of the system-level simulation results.

9.2 Evaluation Methodology

9.2.1 Scenarios and Simulation Assumptions

The assessment of above-mentioned simulation scenarios against the ITU-R requirements for the IMT-2020 KPIs has been made following the ITU-R reports [1] and [3]. The evaluations are held for Dense Urban test environment.

For evaluation configuration C (multi-band) in UL, the system-level simulation is employed to evaluate the user experienced data rate, where a TDD band on 30GHz and a SUL band on 4GHz are used. In the evaluation, approximately 50% users with lower reference signal received power (RSRP) on TDD band (below -106dBm) are offloaded to SUL band. Table 4 illustrates the corresponding simulation assumptions.

Table 4: Evaluation assumptions for system-level simulations in uplink of Dense Urban test environment configuration C (multi-band)

Parameters	Values	
	TDD Band	SUL Band
Test environment	Dense Urban - eMBB	Dense Urban - eMBB
Evaluation configuration	Configuration B	Configuration A
Channel model	UMa_B	UMa_B
ISD	200m	200m
Carrier frequency	30GHz	4GHz
TDD frame structure	DSUUD	UUUUU (FDD)
Simulation bandwidth	80MHz	20MHz
Subcarrier spacing	60kHz	15kHz
Symbols number per slot	14	14
Number of antenna elements per TRxP	128 x-pol Rx antennas (*M,N,P,Mg,Ng;Mp,Np*) = (8,16,2,1,1;1,16)	64 x-pol Rx antennas (*M,N,P,Mg,Ng;Mp,Np*) = (8,8,2,1,1;2,8)
Number of TXRU per TRxP	32 TXRU: Vertical 1-by-16	32 TXRU: Vertical 2-by-8
Number of antenna elements per UE	16 x-pol Tx with 0^o and 90^o polarization (*M,N,P,Mg,Ng;Mp,Np*) = (2,4,2,1,2;1,2)	2 x-pol Tx with 0^o and 90^o polarization
TRxP number per site	3	3
Mechanical tilt	90^o in GCS (pointing to the horizontal direction)	90^o in GCS (pointing to the horizontal direction)
Electrical tilt	105^o in LCS	105^o in LCS
Beam set at TRxP	N/A	N/A
Beam set at UE	Azimuth angle ϕi = [-pi/4, pi/4]; Zenith angle θj = [pi/4, 3*pi/4]	N/A
UT attachment	Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0	Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0
Scheduling	SU-PF	SU-PF
Guard band ratio	4.6%	6.4%
BS receiver type	MMSE-IRC	MMSE-IRC
CSI feedback	5 slots period based on non-precoded CSI-RS with delay	5 slots period based on non-precoded CSI-RS with delay
SRS transmission	Precoded SRS for 2Tx ports	Precoded SRS for 2Tx ports
	Period: 5 slots	Period: 5 slots
	2 symbols per slot	2 symbols per slot
Channel estimation	Non-ideal	Non-ideal
Waveform	OFDM	OFDM
UE power class	23 dBm	23 dBm

MIMO mode		SU-MIMO with rank 2 adaptation	SU-MIMO with rank 2 adaptation
UE precoder scheme		Codebook based	Codebook based
Power control		α=0.6, P_0 =-60dBm	α=0.6, P_0 =-60dBm
Power backoff model		Continuous RB allocation: follow TS 38.101 in Section 6.2.2; Non-continuous RB allocation: additional 2 dB reduction	Continuous RB allocation: follow TS 38.101 in Section 6.2.2; Non-continuous RB allocation: additional 2 dB reduction
Overhead	PUCCH	For each 10 slots, 2 slots with 3 PRB and 14 OS	For each 10 slots, 2 slots with 3 PRB and 14 OS, 8 slots with 1 PRB and 2 OS
	DMRS	Type II, 2 symbols (including one additional DMRS symbol), multiplexing with PUSCH	Type II, 2 symbols (including one additional DMRS symbol), multiplexing with PUSCH
	SRS	2 symbols per 5 slots	2 symbols per 5 slots
	PTRS	N/A	N/A

For another mode of evaluation configuration C (single-band multi-layer), system-level simulation is employed to evaluate the DL user experienced data rate, where in addition to a homogeneous dense urban macro-cell layout with fixed ISD of 200 m there is a micro-layer with three TRxPs randomly dropped per macro-cell. Both network layers operate on the same carrier frequency in the 4GHz band. With every micro TRxP, an additional set of 10 UEs are dropped aggregated within a radius of 20 m around the micro TRxP.

Table 5 illustrates the corresponding simulation assumptions for the macro-layer.

Table 5: Evaluation assumptions for system-level simulations in downlink of Dense Urban test environment configuration C (single-band multi-layer) for macro-layer

Parameters	Values
Test environment	Dense Urban - eMBB
Evaluation configuration	Configuration A
Channel model	UMa_B
ISD	200m
Carrier frequency	4GHz
TDD frame structure	DSUUD
Simulation bandwidth	20MHz
Subcarrier spacing	15kHz
Symbols number per slot	14
Number of antenna elements per TRxP	64 x-pol Tx antennas (*M,N,P,Mg,Ng;Mp,Np*) = (8,8,2,1,1;2,8)
Number of TXRU per TRxP	32 TXRU: Vertical 2-to-8
Number of antenna elements per UE	2 x-pol Rx with 0° and 90° polarization
Transmit power per TRxP	44 dBm
TRxP number per site	3
Mechanical tilt	90° in GCS (pointing to the horizontal direction)
Electrical tilt	105° in LCS
Beam set at TRxP	N/A
Beam set at UE	N/A

UT attachment		Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0
Scheduling		MU-PF
MIMO mode		MU-MIMO with rank 1-2 adaptation per user
		Maximum MU layer = 12
Guard band ratio		4.6%
CSI feedback		5 slots period based on non-precoded CSI-RS with delay
SRS transmission		Precoded SRS for 2Tx ports
		Period: 5 slots
		2 symbols per slot
Precoder derivation		SRS based
Overhead	PDCCH	2 complete symbols
	DMRS	Type II, based on MU-layer (dynamic in simulation)
	CSI-RS	32 ports per 5 slots
	CSI-RS for IM	ZP CSI-RS with 5 slots period; 4 RE/PRB/5 slots
	SSB	1 SSB per 10 ms
	TRS	2 consecutive slots per 20ms, 1 port, maximal 52 PRBs
	PTRS	N/A
Channel estimation		Non-ideal
Waveform		OFDM

The following parameters on Table 6 pertaining to micro-layer deployment and UE drop model apply on top of those specified above for the macro-layer. Where parameters are not specified, the same settings as for the macro-layer apply.

Table 6: Evaluation assumptions for system-level simulations in downlink of Dense Urban test environment configuration C (single-band multi-layer) for micro-layer

Parameters	Values
Micro TRxP drop model	u.i.i.d. with minimum distance of 40m between any pair of TRxPs
UE drop model	10 UEs per TRxP Macro: u.i.i.d. over macro-cell area Micro: u.i.i.d. within radius of 20m around micro cell
Transmit power per TRxP	33 dBm
TRxP number per site	1
Electronic tilt	102° in LCS

Third evaluation environment is the Dense Urban evaluation configuration B operating with a single carrier at 30GHz. Both for FDD and TDD, UL and DL performances are evaluated. In line with the ITU-R's evaluation methodology, 5th percentile user SE, average cell SE, and user experienced data rate are evaluated for this scenario. Table 7 illustrates the corresponding simulation assumptions.

Table 7: Evaluation assumptions for system-level simulations in downlink of Dense Urban test environment configuration B

Parameters		Values
Test environment		Dense Urban - eMBB
Evaluation configuration		Configuration B
Channel model		UMa_B
ISD		200m
Carrier frequency		30GHz
Duplexing		FDD/TDD
Simulation bandwidth		TDD: 80MHz FDD: 40MHz
Subcarrier spacing		60kHz
Symbols number per slot		14
Number of antenna elements per TRxP		128 x-pol antennas (*M,N,P,Mg,Ng;Mp,Np*) = (8,16,2,1,1;1,16)
Number of TXRU per TRxP		32 TXRU: Vertical 1-by-16
Number of antenna elements per UE		16 x-pol antennas with 0^o and 90^o polarization (*M,N,P,Mg,Ng;Mp,Np*) = (2,4,2,1,2;1,2)
Transmit power per TRxP		TDD: 44dBm FDD: 41dBm
TRxP number per site		3
Mechanical tilt		90^o in GCS (pointing to the horizontal direction)
Electrical tilt		105^o in LCS
Beam set at TRxP		N/A
Beam set at UE		Azimuth angle ϕi = [-pi/4, pi/4]; Zenith angle θj = [pi/4, 3*pi/4]
UT attachment		Based on RSRP (Eq. (8.1-1) in TR 36.873) from port 0
Downlink scheduling		MU-PF
Downlink MIMO mode		MU-MIMO with rank 1-2 adaptation per user
		Maximum MU layer = 12
Guard band ratio		TDD: 3.7% FDD: 8.2%
BS receiver type		MMSE-IRC
CSI feedback		5 slots period based on non-precoded CSI-RS with delay
SRS transmission		Precoded SRS for 2Tx ports
		Period: 5 slots
		2 symbols per slot
Channel estimation		Non-ideal
Downlink precoder derivation		TDD: SRS based FDD: NR Type II codebook (4 beams, WB+SB quantization, 8 PSK)
Waveform		OFDM
Downlink Overhead	PDCCH	2 complete symbols
	DMRS	Type II, based on MU-layer (dynamic in simulation)
	CSI-RS	32 ports per 5 slots
	CSI-RS for IM	ZP CSI-RS with 5 slots period; 4 RE/PRB/5 slots
	SSB	1 SSB per 10ms
	TRS	2 consecutive slots per 20ms, 1 port, maximal 52 PRBs
	PTRS	N/A
UE power class		23dBm

Uplink scheduling		SU-PF
Uplink MIMO mode		SU-MIMO with rank 2 adaptation
UE precoder scheme		Codebook based
Power control		α=0.6, P_0 =-60dBm
Power backoff model		Continuous RB allocation: follow TS 38.101 in Section 6.2.2; Non-continuous RB allocation: additional 2 dB reduction
Overhead	PUCCH	TDD: for each 10 slots, 2 slots with 3 PRB and 14 OS FDD: for each 10 slots, 2 slots with 3 PRB and 14 OS, 8 slots with 1 PRB and 2 OS
	DMRS	Type II, 2 symbols (including one additional DMRS symbol), multiplexing with PUSCH
	SRS	2 symbols per 5 slots
	PTRS	N/A

9.2.2 Key Performance Indicators

In the following, we present the different KPIs used when analysing the results obtained via system-level simulations.

9.2.2.1 5th Percentile User Spectral Efficiency

The ITU-R's minimum requirements on the 5th percentile user spectral efficiency are given in [1]. The following requirements and remarks are extracted from [1]:

> *The 5th percentile user spectral efficiency is the 5% point of the CDF of the normalized user throughput. The normalized user throughput is defined as the number of correctly received bits, i.e., the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bit/s/Hz.*
>
> *The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.*
>
> *With R_i (T_i) denoting the number of correctly received bits of user i, T_i the active session time for user i and W the channel bandwidth, the (normalized) user throughput of user i, r_i, is defined according to equation (4).*

$$r_i = \frac{\mathrm{R}_i(T_i)}{T_i \cdot \mathrm{W}} \qquad (4)$$

> *This requirement is defined for the purpose of evaluation in the eMBB usage scenario.*

The minimum requirements for the 5th percentile user spectral efficiency for Dense Urban test environment are shown in Table 8.

Table 8: Minimum requirements of the 5th percentile user spectral efficiency defined by ITU-R for the Dense Urban environment

Test Environment	Downlink [bit/s/Hz]	Uplink [bit/s/Hz]
Dense Urban	0.225	0.15

9.2.3 Average Spectral Efficiency

The ITU-R minimum requirements on the average spectral efficiency are given in [1]. The following requirements and remarks are extracted from [1]:

Average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs and is measured in bit/s/Hz/TRxP.

The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.

Let R_i (T) denote the number of correctly received bits by user i (downlink) or from user i (uplink) in a system comprising a user population of N users and M TRxPs. Furthermore, let W denote the channel bandwidth and T the time over which the data bits are received. The average spectral efficiency, SE_{avg} is then defined according to equation (5).

$$\mathrm{SE}_{\mathrm{avg}} = \frac{\sum_{i=1}^{N} \mathrm{R}_i(T)}{T \cdot \mathrm{W} \cdot M} \qquad (5)$$

This requirement is defined for the purpose of evaluation in the eMBB usage scenario.

The minimum requirements for the average spectral efficiency for Dense Urban test environment are shown in Table 9.

Table 9: Minimum requirements of average spectral efficiency defined by ITU-R for the Dense Urban test environment

Test Environment	**Downlink [bit/s/Hz/TRxP]**	**Uplink [bit/s/Hz/TRxP]**
Dense Urban	7.8	5.4

9.2.4 User Experienced Data Rate

The ITU-R minimum requirements on the user experienced data rate are given in [1]. The following requirements and remarks are extracted from [1]:

User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time.

In case of one frequency band and one layer of transmission reception points (TRxP), the user experienced data rate could be derived from the 5^{th} percentile user spectral efficiency through equation (3). Let W denote the channel bandwidth and SE_{user} denote the 5^{th} percentile user spectral efficiency. Then the user experienced data rate, R_{user} is given by:

$$R_{user} = W \times SE_{user} \qquad (3)$$

In case bandwidth is aggregated across multiple bands (one or more TRxP layers), the user experienced data rate will be summed over the bands.

This requirement is defined for the purpose of evaluation in the related eMBB test environment.

The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment:

– *Downlink user experienced data rate is 100 Mbit/s.*

– *Uplink user experienced data rate is 50 Mbit/s.*

These values are defined assuming supportable bandwidth as described in Report ITU-R M.2412-0 for each test environment. However, the bandwidth assumption does not form part of the requirement. The conditions for evaluation are described in Report ITU-R M.2412-0.

9.3 Results

9.3.1 5th Percentile User Spectral Efficiency

As stated in Sec. 9.1.1, the evaluation of the 5th percentile user SE is conducted for Dense Urban environment Configuration B for both UL and DL. Furthermore, as required in [3], the 5th percentile user SE is assessed jointly with average SE using the same simulations.

9.3.2 Dense Urban Configuration B

Table 10 shows the evaluation results for FDD and TDD of DL and UL 5th percentile SE for Dense Urban Configuration B.

Table 10: 5th percentile user SE evaluation results for Dense Urban Configuration B

	TDD		FDD	
	5th percentile user SE [bit/s/Hz]	**Requirement [bit/s/Hz]**	**5th percentile user SE [bit/s/Hz]**	**Requirement [bit/s/Hz]**
Downlink	0.0007	0.23	0.0004	0.23
Uplink	0.013	0.15	0.029	0.15

It is observed that the test environment fulfils neither downlink nor uplink 5th percentile user SE requirement. Configuration B is in general not feasible due to severe O2I penetration loss in FR2. Considering the CDF of geometry received during the calibration process. Herein, this does not seem to be all that surprising because there are geometry values down to -30dB. In addition, it is general knowledge that for large frequencies the penetration loss and pathloss is significantly higher and therefore it is difficult to achieve high SE in scenarios with O2I coverage.

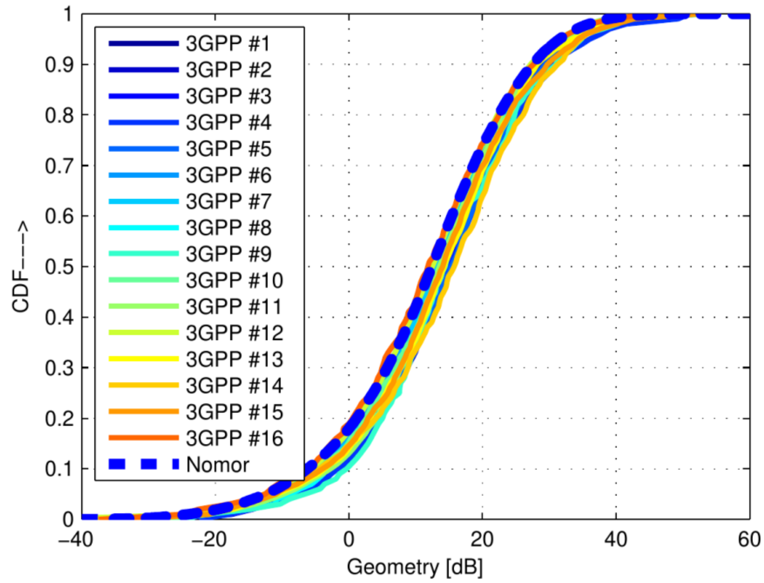

Figure 18: Distribution of WB-SINR for Dense Urban Configuration B (Figure 14 of [2])

9.3.3 Average Spectral Efficiency

As stated in Sec. 9.1.1, the evaluation of the average (cell) SE is conducted for Dense Urban environment Configuration B for both UL and DL. Furthermore, as required in [3], the average SE is assessed jointly with 5th percentile user SE using the same simulations.

9.3.4 Dense Urban Configuration B

Table 11 shows the evaluation results for FDD and TDD of DL and UL average SE for Dense Urban Configuration B.

Table 11: Average cell SE evaluation results for Dense Urban Configuration B

	TDD		FDD	
	Average SE [bit/s/Hz/TRxP]	**Requirement [bit/s/Hz/TRxP]**	**Average SE [bit/s/Hz/TRxP]**	**Requirement [bit/s/Hz/TRxP]**
Downlink	12.07	7.8	9.62	7.8
Uplink	7.41	5.4	7.42	5.4

It is observed that both TDD and FDD configurations fulfil DL and UL average SE requirement for Dense Urban test environment in Configuration B, due to very high spectral efficiency for UEs in advantageous channel conditions.

9.3.5 User Experienced Data Rate

As stated in Sec. 9.1.1, the evaluation of the user experienced data rate is conducted for Dense Urban environment configuration C (multi-band) in UL, configuration C (single-band multi-layer) in DL, and for Configuration B in both UL and DL.

9.3.5.1 Dense Urban Configuration C Multi-band Scenario

Table 12 shows the evaluation results of Configuration C (multi-band) scenario, where a TDD band on 30GHz and a SUL band on 4GHz are used. To meet the required user experienced data rate, multiple component carriers on both TDD and SUL band are aggregated. The required aggregated system bandwidth is given in Table 12.

Table 12: User experienced data rate evaluation results for Dense Urban Configuration C (TDD+SUL bands and macro-layer only)

	Frame structure	Assumed system bandwidth [MHz]	User experienced data rate [Mbit/s]	Requirement [Mbit/s]
Uplink	4GHz: full uplink 30GHz: DSUUD	4GHz: 80 (for UL) 30GHz: 560	64.6	50

It is observed that NR can meet the UL user experienced data rate requirement for Dense Urban test environment in Configuration C.

9.3.6 Dense Urban Configuration C Single-band Multi-layer Scenario

Table 13 shows the evaluation results of Configuration C (single-band multi-layer) scenario, where a TDD band on 4GHz is used. In addition to a homogeneous Dense Urban macro-cell layout with fixed ISD of 200 m there is a micro-layer with three TRxPs randomly dropped per macro-cell. With every micro TRxP, an additional set of 10 UEs are dropped aggregated within a radius of 20 m around the micro TRxP.

To meet the required user experienced data rate, multiple component carriers are aggregated. The required aggregated system bandwidth is given in Table 13.

Table 13: User experienced data rate evaluation results for Dense Urban Configuration C (macro + micro layer at 4GHz)

	Frame structure	Assumed system bandwidth [MHz]	User experienced data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	DSUUD	1200	104.71	100

It is observed that NR can meet the downlink user experienced data rate requirement for Dense Urban test environment in Configuration C with single-band multi-layer deployment.

9.3.7 Dense Urban Configuration B

For Configuration B, it is assumed that a component carrier of 200 MHz is used. Additionally, carrier aggregation is applied to achieve the ITU-R requirement. The assumed aggregated system bandwidths in case of DL and UL are listed beside the evaluation results in Table 14.

Table 14: User experienced data rate evaluation results for TDD mode of operation of Dense Urban Configuration B

	System bandwidth [MHz]	User experienced data rate [Mbit/s]	Requirement [Mbit/s]
Downlink	3200	7.25	100
Uplink	3200	1.25	50

It is observed that Dense Urban test environment Configuration B neither meets the DL nor the UL ITU-R requirements in terms of user experienced data rate. This is due to the fact that already the 5th percentile user SE requirement is by far not fulfilled, see Sec. 9.3.2. The reason for this lies in the insufficient O2I link budget for users in buildings with high penetration loss. Here, inter-cell interference is not the limiting factor, but noise based on a limited transmit power budget of communication devices in both UL and DL. Considering the CDF of geometry received during the calibration process, see Figure 14 in [2]. Herein, this does not seem to be all that surprising because there are geometry values down to -30dB. Besides, it is general knowledge that for large frequencies the penetration loss and pathloss is significantly higher and therefore it is difficult to achieve high spectral efficiency in scenarios with O2I coverage.

9.4 Conclusions

This annex focused on the evaluation of a subset of the scenarios defined by ITU-R in their report [3] against the requirements for IMT-2020 KPIs whose evaluation is based on system-level simulations. The analysis is performed using Nomor Research GmbH's 5G-NR system-level simulator that has been calibrated against results shared by various 3GPP partners for simplified scenarios and configurations [2].

In Sec. 9.3.2, the results have shown that the ITU-R 5th percentile SE requirements of 0.23bit/s/Hz in DL and 0.15bit/s/Hz in UL are not satisfied with Dense Urban test environment Configuration B. The results in Sec. 9.3.4 have shown that 7.8bit/s/Hz/TRxP DL and 5.4bit/s/Hz/TRxP UL average SE requirements are satisfied for both TDD and FDD with the same configuration. Moreover, Dense Urban test environment Configuration B does not satisfy the user experienced data rate requirements of 100Mbit/s in DL and 50Mbit/s in UL, as shown in Sec. 9.3.7.

The result in Sec. 9.3.5.1 has indicated that the user experienced data rate requirement of 50Mbit/s in UL is satisfied in Dense Urban Configuration C multi-band scenario. In addition, the result in Sec. 9.3.6 has shown that the user experienced data rate requirement of 100Mbit/s in DL is satisfied in Dense Urban Configuration C multi-layer single-band scenario.

In conclusion, we have evaluated Dense Urban test environment Configuration B and Configuration C, as defined by ITU-R, against ITU-R's requirements for IMT-2020 KPIs. The results have turned out such that the Configuration B cannot fulfil the 5th percentile user SE and user experienced data rate requirements, although it satisfies the average SE requirement, whereas Configuration C fulfils the user experienced data rate requirement in both UL and DL configurations. Overall, the outcome of the work of the 5G-IA's IEG over the last two years is that 3GPP's 5G-NR does fulfil the IMT-2020 performance requirements set forth by the ITU-R, thereby providing reassurance to mobile network operators and manufacturers as to the prospects of 5G-NR to become a globally valid mobile communication standard.