Automatic deployment, execution and analysis of 5G experiments using the 5G EVE platform

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Abstract—The 5G EVE is a 5G PPP phase 3 Infrastructure project aimed at building a European 5G validation platform for extensive trials. One of the main objectives of 5G EVE is to offer an accessible and fully operational 5G end-to-end infrastructure, flexible enough to support a plethora of tests for different vertical industries, distributed among several sites. When executing the declared tests, vertical industries with expertise deploying such services may state the operational key performance indicators, and the platform will provide an analysis of the results. This paper presents the design and results of the first 5G end to end experiment deployed on the 5G EVE infrastructure. In particular, we present the 5G EVE architecture, all the steps required to design and execute a simple experiment. Finally, this paper also provides an analysis and discussion of the results provided by our platform.

Index Terms—5G, 5G EVE, KPI, Metrics

I. INTRODUCTION

5G networks have attracted immense attention from diverse vertical markets ranging from manufacturing (Industry 4.0), tourism, smart cities, automotive, public utilities, and smart transport, etc. These vertical markets encompass an ecosystem made up of operators, vendors, verticals, and Small and Medium-sized Enterprises (SMEs), each with unique capabilities, and the potential to drive the adoption of 5G technologies. However, for these vertical industries to fully embrace 5G, and enjoy the numerous advantages that the technology promises, they will need an end-to-end fully-realized 5G platform with means to test the various 5G technologies (i.e., from the Access Network to the Transport Network, up to the Core Network). Besides, a platform that supports vertical industries in testing their services and validates the related Key Performance Indicators (KPIs) before going to market. In order to address these challenges, the 5G European Validation platform for Extensive Trials (5G EVE) [1] project was funded by the European Commission as one of the three 5G PPP Phase3, Part 1: Infrastructure projects [2].

5G EVE aims to provide an end-to-end 5G capable facility that will enable vertical industries to test and validate their service performance with the envisioned 5G technologies under realistic conditions using easy to use intuitive interfaces. To this end, 5G EVE has partnered with different players in the 5G ecosystem, including but not limited to: operators, vendors, academic institutions, research centers, and vertical industries. The participating vertical industries that have influenced the

design and evolution of the 5G EVE platform are detailed in [3]. Furthermore, the 5G EVE end-to-end facility spans across four interconnected sites in four European countries (Spain, France, Greece, and Italy) to provide options for multi-domain and/or multi-site network slice orchestrations, and management. Moreover, 5G EVE delivers a centralized view and access to all the infrastructure resources available in the different 5G EVE sites. Additionally, 5G EVE builds on the research outputs of previous 5G PPP phase 1 [4], and 5G PPP phase 2 [5] projects by extending their research output to accommodate a wide range of vertical service requirements. Besides, 5G EVE aims to have a platform that lives beyond the project scope and offers services to other EU-funded projects. To this end, 5G EVE has interacted with the 5G PPP phase3 ICT-19 [2] projects, and other external vertical industries to gather, assess, and document their network requirements [6]. The other two 5G PPP Phase3, Part 1: Infrastructure projects are 5G-VINNI[1], and 5GENESIS[2].

In this paper, we present the complete workflow to validate any end-to-end use case on a 5G network, leveraging on the 5G EVE platform. All required steps for this validation will be described in this paper by using a basic vertical service composed of a web server and a client. With this use case, we test all the major functionalities of the platform, from designing, defining, and preparing, to automatically deploying and executing an experiment on the platform. In addition, we also examine the implemented experiment testing and KPI validation mechanisms.

The rest of this paper is organized as follows. Section II provides an overview of the 5G EVE platform focusing on the information models, user roles, and architecture. Section III anatomizes the different activities involved in the experiment design, definition, and preparation for the considered vertical service. Finally, Section IV presents the experiment execution, and KPI validation results for the vertical service, as well as a discussion of the results. We conclude this section with the future work regarding the vertical service evolution.

II. 5G EVE PLATFORM OVERVIEW

In this section, we present an overview of the 5G EVE platform, starting from the adopted information models, user

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[1]5G-VINNI https://www.5g-vinni.eu/
[2]5GENESIS https://5genesis.eu/

roles, and lastly, the platform architecture.

A. 5G EVE INFORMATION MODELS

As already mentioned in Section I, one of the main goals of the 5G EVE project is to provide an end-to-end 5G facility that allows vertical users to define their services easily. Subsequently, run a set of specific experiments to validate the required key performance indicators (KPIs) associated with the service. In this respect, it is important to distinguish between metrics and KPIs [7]:

- Metrics. These refer to data that must be collected by the 5G EVE platform during experiment execution. 5G EVE models two types of metrics, i.e., application and infrastructure metrics. Application metrics are generated by the vertical service, whereas infrastructure metrics are availed by the different 5G EVE sites infrastructure.
- Key Performance Indicators (KPIs). KPIs are used to validate the experiment results following specified criteria. In 5G EVE, KPIs could be a formula applied to one or more metrics. A KPI threshold is set, and this determines whether the experiment passed the tests or failed.

For the design, execution, and analysis phases of an experiment, 5G EVE makes use of various types of blueprints, which are high-level network service deployment templates that abstract the lower layers complexity, and can be customized by the vertical. The concept of using blueprints to define a network service is based on the work done by the 5G TRANSFORMER [8] project, and the 5G EVE project has extended this concept to cater for the various project needs. Accordingly, the 5G EVE project defines the following information models [7] [9] [10]:

- Vertical Service Blueprint (VSB). This template contains the high-level definition of a vertical service in a natural language. The VSB can be customized at the experiment preparation phase by the vertical. These blueprints may include application metrics if the vertical service has been designed to generate these measurements.
- Context Blueprint (CtxB). The CtxB is also a high-level template that defines the operational conditions (context) of a vertical service. The 5G EVE platform provides generic CtxBs that apply to most network services such as delay, and artificial background traffic; that can be customized by verticals to suit their test scenarios. Otherwise, if none of the available CtxBs suit the vertical service test scenarios, then new CtxBs can be defined. These blueprints may also include application metrics if the context components have been configured to produce such values.
- Test Case Blueprints (TCBs). These are templates used to define the sequence of actions required to run tests on an experiment. Besides, TCBs can be customized by providing the requisite user and infrastructure parameters.
- Experiment Blueprints (ExpB). In 5G EVE, an ExpB is a high-level definition of an experiment. The ExpB includes a customized VSB, CtxBs, and TCBs. These

blueprints may include application metrics defined in the respective VSB and CtxBs that have to be customized. Apart from that, infrastructure metrics and KPIs are defined in experiment blueprints.

To accurately define VSBs and CtxBs, it is essential also to include network service descriptors (NSDs), virtual network function descriptors (VNFDs), and physical network function descriptors (PNFDs). VNFDs and PNFDs refer to lower-level deployment templates used to define the resource requirements needed to achieve particular virtual or physical network functions. On the other hand, NSDs are also lower-level deployment templates used to define the lifecycle operations of network services and are composed of VNFs and/or PNFs, and their interconnections. In 5G EVE, the descriptors are defined utilizing technology-agnostic information models: ETSI GS NFV-IFA014 [11] for the NSDs, and ETSI GS NFV-IFA011 [12] for the VNFDs.

Finally, to accurately define an actual experiment, the user has to select a blueprint and then complete the missing information, creating an experiment descriptor (ExpD). An ExpD in 5G EVE refers to an exact experiment in the platform where all the blueprints (i.e., VSB, CtxBs, ExpB, TCBs) have been selected and customized. In addition, the applicable KPI thresholds have also been set. Furthermore, the 5G EVE project offers an intent-based tool [7] to translate free text input introduced by a user to the most suitable blueprints and parameters. If any parameter is missing or not well extracted from the input provided by the user, the tool requests such missing information through a graphical web interface.

B. 5G EVE USER ROLES

5G EVE has defined different roles for the platform users [7], where each role serves a specific purpose in the experiment design, definition, preparation, and execution ecosystem. Subsequently, each 5G EVE user accesses specific platform functionalities depending on their role. A summary of the different roles available in the platform is presented in Table I.

C. 5G EVE PLATFORM ARCHITECTURE

The 5G EVE platform architecture is composed of three main blocks: Portal [7] [13] [14], Interworking layer (IWL)

TABLE I
5G EVE USER ROLES

5G EVE Role	Permitted Operations
Anonymous User	No permissions
VNF Provider	VNF package on-boarding
Vertical	Service definition (VSB, TCBs, and associated metrics & KPIs)
Experiment Developer	Blueprints & descriptors definition, and on-boarding
Experimenter	Prepare, schedule, deploy, execute, and validate an Experiment
Site manager	5G EVE site infrastructure management VNF packages approval & on-boarding
System administrator	All access except for 5G EVE site-specific infrastructure

[15], and the Site-Specific layer [16] as illustrated in Fig. 1. The former two blocks are common across all 5G EVE sites, whereas the latter block differs across all 5G EVE sites depending on the deployed site technologies [17]. In this subsection, we explain the major functionalities of the different components indicated in Fig. 1, and their interactions with the other components in the 5G EVE platform.

By logging on to the 5G EVE platform using the Sign-up/login component, this tool interacts with the Role-Based Access Control (RBAC) component, which is in charge of user authentication and management, consequently regulating access to the platform functionalities. The RBAC component plays such a pivotal role on the 5G EVE platform; henceforth, all portal components first contact it before rendering any services. Once inside the portal, the Browse, Look Up, and On-boarding (BLUO) tool can be used to browse, create, retrieve, and delete blueprints and descriptors related to the vertical services, operational contexts, experiments, and test cases. The BLUO tool leverages on the portal catalogue service to store and provision these elements. The catalogue service stores, and provisions information elements related to the blueprints, and the blueprint descriptors, while relying on the Multi-site Catalogue in the IWL for the storage, and query information associated with NSDs, and VNFDs. In addition, the Multi-site Catalogue provides a centralized view, unified access point to all the descriptors, and deployment information available in the local catalogues of the four 5G EVE sites. Consequently, the Multi-site Network Service Orchestrator (MSNO) makes use of this information for the lifecycle management of network services across the distinct orchestration domains available in the 5G EVE sites. The MSNO utilizes the Multi-site Inventory for the storage and retrieval of information related to the running network services. The Experiment Blueprint Builder (EBB) tool is a step-by-step wizard that guides platform users in creating their own ExpBs.

In order to request an experiment on the 5G EVE platform, the portal offers two main tools: Intent-Based Networking (IBN) and Run experiment. The IBN tool provides intuitive interfaces (i.e., using natural language) for verticals with little networking knowledge to prepare and schedule an experiment on the platform. The Run Experiment tool also offers the same service, but in this case, for users who have an outstanding knowledge of their vertical service implementation details. The use of either of these tools invokes the Experiment Life-cycle Manager (ELM) component, which manages the entire lifecycle (i.e., creation, modification, instantiation, execution, monitoring, and termination) of experiments on the platform. For creation and modification of experiments, the ELM coordinates with the Catalogue service, whereas to instantiate an experiment, ELM contacts the MSNO, which is in charge of multi-site, and multi-domain network service orchestrations.

Once an experiment is instantiated on the 5G EVE platform, then the ELM generates topics for the Data Collection Manager (DCM). Topics are used by the DCM to manage specific groups of experiment data (i.e., metrics and KPIs) following the publish-subscribe model [18] based on Apache Kafka[3]. Henceforth, the DCM notifies the Reports Analysis and validation (RAV) and Data-Collection and Storage (DCS) tools about the new topics, and in turn, they subscribe to these topics. Accordingly, the RAV and DCS tools use these topics to consume experiment data.

An experiment execution request on the portal translates to the ELM contacting the Experiment Execution Manager (EEM) component, which is responsible for experiment tests execution, and collection of status updates. The EEM and ELM components keep exchanging messages about the execution status. Consequently, the EEM contacts the Run-time Configurator (RC) to perform Day-2 configurations (i.e., triggered on demand), and run test scripts on the already provisioned network functions (i.e., VNFs & PNFs), and network services. The RC component utilizes Ansible [4] to perform these configurations. Accordingly, these network functions will produce test case related metrics data, which will be published to the DCM and consumed by the DCS & RAV components. The RAV component analyses the received metrics and computes the KPIs according to the pre-defined formula; henceforth, it sends the computed KPI results to the DCM. These KPI results are consumed by the DCS component, which in turn collects the KPI and metrics results and forwards them to the Data Visualization tool of the portal where the data can be visualized, and browsed. More information about the internal workflows of the 5G EVE monitoring framework can be found in [18]. The DCS and Data Visualization tools design is based on the ELK stack[5]. Once the experiment execution is completed, the RAV component generates a report with summary test statistics and the KPI validation results. This report is sent to the EEM, which in turn sends it to the ELM, and from this point on, the report is available for viewing in the 5G EVE portal.

The 5G EVE platform has a ticketing system composed of both the Ticketing Graphical User Interface (GUI) and Ticketing System Backend (TSB) components. This system is used to create, modify, and delete tickets in case of: (i) errors on the portal to notify the responsible parties, (ii) an experiment schedule request to inform the site manager(s), and (iii) VNF onboarding request which is triggered by the VNF storage component, and forwarded to the File storage module which in turn generates tickets to notify the site manager(s) of this change. The 5G EVE ticketing system is based on Bugzilla [6].

Finally, the site-specific layer of the 5G EVE platform contains the different layers composing each site. Given that each site implementation is independent of the other, the main objective of the IWL is to provide a centralized global scope of the 5G EVE infrastructure and resources. The 5G EVE sites planning and technology implementation details have been documented in [16].

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[3]Apache Kafka https://kafka.apache.org/
[4]Ansible https://www.ansible.com/
[5]ELK stack https://www.elastic.co/elastic-stack
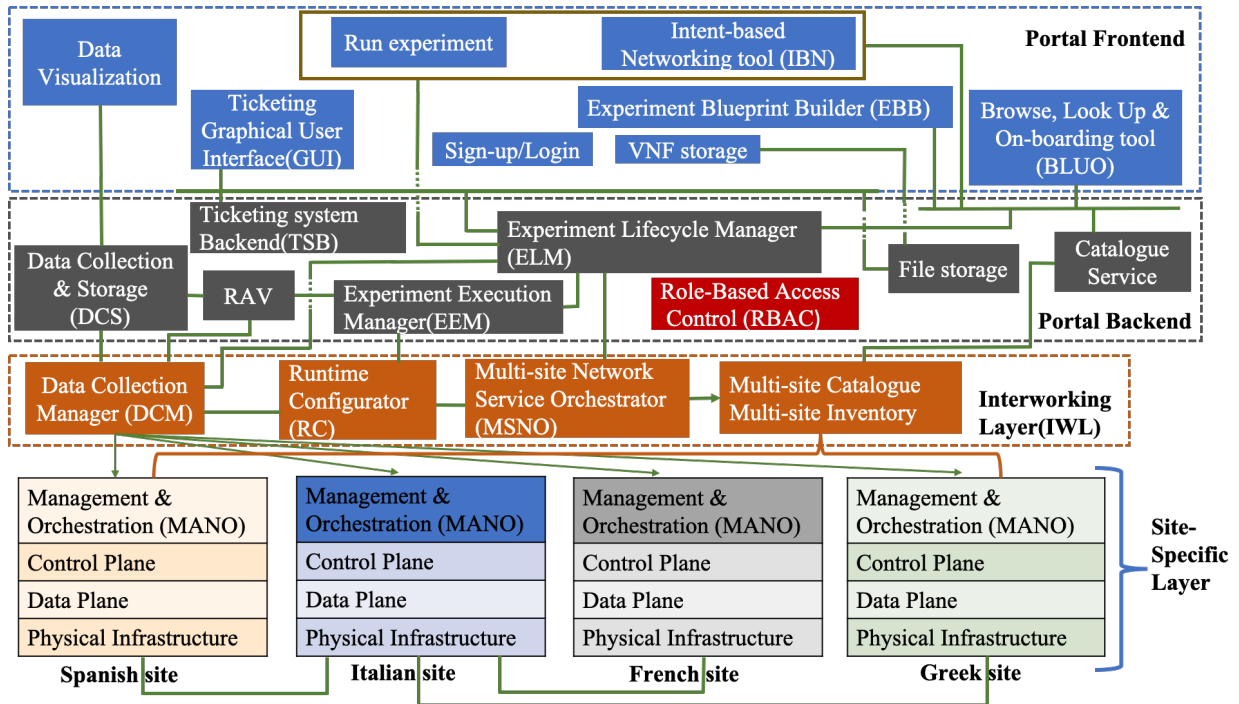[6]Bugzilla https://www.bugzilla.org/

Fig. 1. 5G EVE platform architecture

III. EXPERIMENT DESIGN, DEFINITION AND PREPARATION

In this section, to test the end-to-end workflow of the 5G EVE platform discussed in Section II, we modeled a simple vertical service composed of a client and a web server. This vertical service was orchestrated and monitored using the MANO platform of the 5G EVE Spanish site. Subsequently, the different activities involved in designing, defining, and preparing our vertical service for deployment on the 5G EVE platform are discussed next.

A. EXPERIMENT DESIGN AND DEFINITION

Initially, we prepared the VNF images for the client and web server machines. The operating system installed on both entities was Ubuntu 16.04 Server edition. After that, on the client VNF image, we installed the Apache benchmark (*ab*) [7] tool to emulate web clients connecting to a web server. This tool allows the emulation of several concurrent requests, and to configure a given number of requests, annotating different statistics for each request, which we will use to provide the application metrics. Subsequently, we installed Filebeat [8] on the client VNF to act as a data shipper to publish these metrics to the DCM component of the IWL. On the other hand, on the web server VNF image, we installed Apache web server software [9]. Furthermore, these prepared VNF images were uploaded to the MANO platform of the 5G EVE Spanish site.

Secondly, we defined the blueprints (i.e., VSB, TCB, ExpB), associated descriptors (i.e., ExpD, and NSDs) for the vertical service [10]. For this simple use case, and for the sake of simplicity, we did not consider any operational contexts, therefore, no CtxBs were defined.

The VSB consists of two VNF components (i.e., client and web server), their virtual links, and connection points. Besides, we defined one application metric with identifier (ID) "*requests_time_taken*" inside the VSB, which represents the time taken per request sent to the web server. This metric ID will be used by the ELM to generate a unique topic for this experiment in the monitoring framework, as already discussed in Section II-C. In addition, the VSB contains one customizable user parameter, i.e., the number of client VNFs. A corresponding NSD was also prepared following the ETSI NFV-IFA014 [11] model.

The TCBs for this vertical service consists of two scripts: configuration, and execution scripts. These two scripts are executed by the RC module of the 5G EVE IWL. The configuration script is designed to modify the Filebeat configuration with the generated topic ID that is automatically created by the ELM component, as discussed in Subsection II-C. It then restarts the Filebeat service in the client VNF. The Filebeat service is instructed to check the output file generated by the *ab* application continually, extract new lines, and create JSON [11] format, which includes the value of the metric and other fields like the units of the metric, the timestamp, and identifier

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[7] Apache Benchmark https://httpd.apache.org/docs/2.4/programs/ab.html
[8] Filebeat https://www.elastic.co/beats/Filebeat
[9] Apache web server http://httpd.apache.org/

[10] The blueprints and descriptors used for this vertical service can be assessed at https://github.com/5GEVE/blueprint-yaml
[11] JavaScript Object Notation https://www.json.org/json-en.html

TABLE II
TCB USER AND INFRASTRUCTURE PARAMETERS

User parameters	
user name	Used by *RC* to access client VNF
password	
concurrent(c)	Number of client connections to open
noOfRequests(n)	Number of requests to send
Infrastructure parameters	
Client VNF IP address	Used by *RC* to access VNF
Web server VNF IP address	Used by Client VNF to send requests
Metric topic ID	Used by *ELM*, to generate a unique topic

Fig. 2. Vertical service test case execution end-to-end workflow

of the device generating the metrics.

On the other hand, the execution script executes the *ab* application with the configured parameters (concurrency and number of requests) defined in the ExpD. After *ab* finishes all requests, it generates the output file, which is then processed by the Filebeat service, publishing the requested metrics. These metric data are consumed by the DCS and RAV components of the 5G EVE portal. To test the vertical service, the TCBs were configured with the user, and infrastructure parameters indicated in Table II.

By selecting different values of *n* (number of requests) and *c* (concurrency) for each TCB, and different KPI thresholds, its possible to test the web server under varying conditions.

The ExpB for this use case was a composition of the VSB, associated TCBs and NSD, as well as the KPI. The KPI formula was set to be equal to the application metric that was defined in the VSB, i.e., *requests_time_taken*.

Finally, all these blueprints were on-boarded to the 5G EVE platform by utilizing the BLUO tool of the portal.

B. EXPERIMENT PREPARATION

This phase involves requesting an experiment on the 5G EVE platform by: (i) creating an experiment descriptor (ExpD), which represents a specific instance of the experiment, and (ii) scheduling an experiment. As discussed in Subsection II-C, these two tasks can be achieved by using either the Run experiment or IBN tools of the portal.

To create an ExpD for this vertical service, we first provide a name and an identifier to uniquely identify the ExpD in the portal, followed by the selection of the applicable ExpB, and compatible 5G EVE site(s) where the experiment should be carried out. In our case, the compatible site was the *5G EVE Spanish site*. Thereafter, the applicable VSB is selected to provide the actual values for the defined user parameters, i.e., the number of client VNFs. In our case, this value was set to 1. In addition, we selected and parameterized the applicable TCB to create the Test Case Descriptor (TCD) with the following values: a concurrency value of four emulated clients ($c = 4$) and the number of total requests sent to five thousand ($n = 5000$). Furthermore, we set the KPI threshold value to $25ms$; this implied that if any of the client requests experienced a delay greater than or equal to $25ms$, then the KPI validation test fails; otherwise, the test is a success. At this stage, the ExpD is successfully created at the portal.
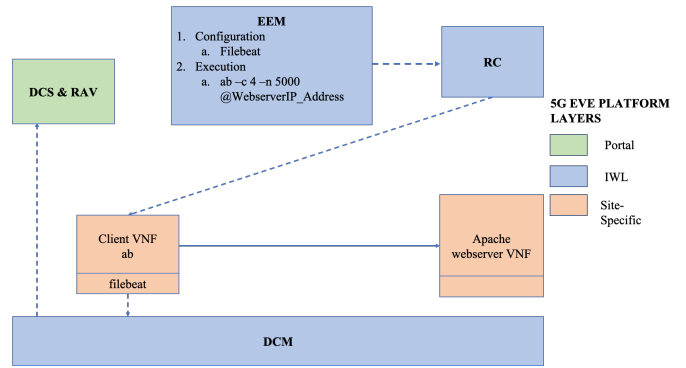
To schedule an experiment with the 5G EVE platform, we first provide the experiment name, followed by selecting the applicable ExpD together with the compatible 5G EVE site (i.e., Spanish site), and finally the date(s) when we want to carry out the experiment. Upon submission of this request, we receive a message on the portal that our experiment is ready to deploy; this implies that our experiment request and schedule has been accepted by the site manager(s) of the chosen 5G EVE site. Henceforth, we proceed to implement and execute our experiment on the 5G EVE platform.

IV. RESULTS AND DISCUSSION

In this section, we present the results of deploying and thereafter, executing our experiment on the 5G EVE platform. Furthermore, we discuss the results of the KPI validation process.

A. RESULTS

On deploying our experiment on the 5G EVE platform, we received a message on the portal that our deployment was successful in a few minutes. This means, using Fig. 2 as a reference, that the virtual machines (light orange boxes) are deployed, as well as the data plane networks connecting the client with the web server, and the management network, connecting each virtual machine with the IWL, and particularly with the RC. Subsequently, we proceeded to execute our experiment by invoking the TCB created in Section III-B.

On running the test case scenario shown in Fig. 2 inside the EEM component, the first action is to configure the Filebeat at the client-side. After that, the EEM pushes the execution command to the RC, which in turn runs the *ab* command at the client-side. After the execution of the command, and as commented before, the Filebeat publishes the metrics to the DCM, so the DCS and RAV components can consume such metrics. This way, the RAV component of the portal availed us with the test case report. On the one hand, the report contains the test case summary statistics, as presented in Fig. 3. On the other hand, the report contains a graph with the KPI validation results, as depicted in Fig. 4.
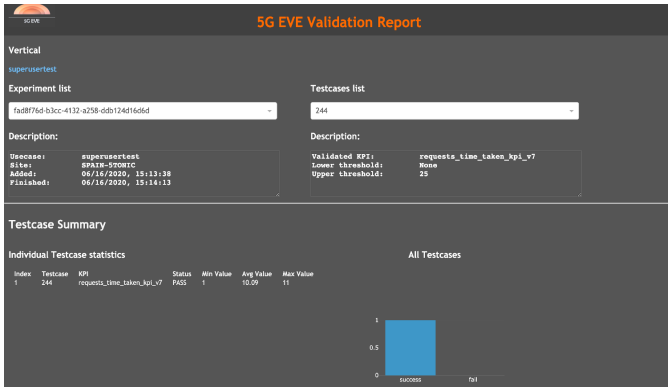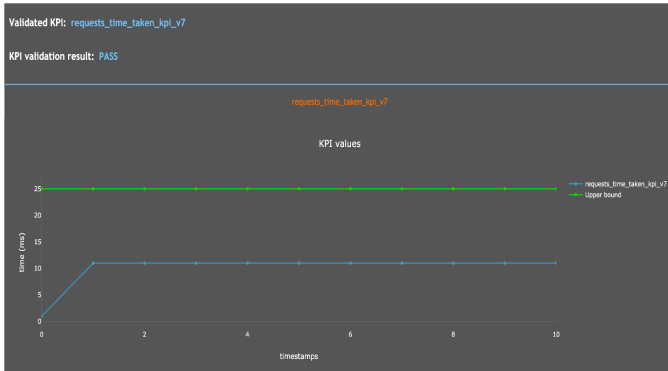
Fig. 3. Vertical service test case summary report

Fig. 4. Vertical service test case KPI validation results

B. DISCUSSION

From the test case results report presented in Fig. 3 and Fig. 4, we can extract the following information: (i) the validated KPI was "*requests_time_taken_kpi_v7*", (ii) the tests were carried out in the 5G EVE Spanish site, (iii) the maximum KPI threshold was set to $25ms$, (iv) the minimum delay that was experienced by the client requests was $1ms$, whereas the maximum delay was $11ms$, and the average delay was $10.09ms$, and (v) finally, we notice that this test passed the KPI validation. The success of the KPI validation for this test was expected given the KPI threshold (i.e., $25ms$) that was set, compared to the actual delays that were experienced by the client requests.

With these tools, an experimenter may analyze the results provided, first checking the overall outcome of the experiment, which can be an experiment success or a failed one. In the latter case, experimenters may analyze all defined metrics to detect the point or points where he or she needs to act to improve the performance of the service.

V. CONCLUSION

In this paper, we have presented the results of the first end-to-end experiment deployed on the fully operational 5G EVE platform. These results show that, as declared in the description of the 5G EVE project aims, our platform is fully functional and ready to deploy more complex use cases, both

from the own project and other projects, like 5G PPP ICT-19 projects. We plan to extend this use case by including context blueprints, connecting it to physical network functions, collecting metrics from infrastructure components, and deploying multi-site experiments.

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