Test, Measurement, and KPIs Validation Working Group

White Paper

Validating 5G Technology Performance

Assessing 5G architecture and Application Scenarios

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Executive Summary

The involvement of vertical customers in the ongoing deployment of 5G networks increases the need for performing tests and measurements, considering the stringent requirements of the vertical applications and the introduction of new business models. The exploitation of network and computing resource virtualization and sharing, such as Network Functions Virtualization (NFV) and Software Defined Networking (SDN) and the different technology domains employed at the infrastructure substrate (i.e. radio, cloud, transport) are making the 5G network increasingly complex to manage, monitor and test. In case a vertical customer determines a Service Level Agreement (SLA) breach, the process of troubleshooting and conflict resolution includes cross-layer coordination of testing and monitoring. These are the main causes for a very broad and heterogeneous scenario that includes:

- Roles and expectation of the vertical customers
- Definition of testing and monitoring approaches and testing levels (from access network to service)
- The need for, and role of Test as a Service (TaaS) within the Zero-touch philosophy
- The need of clearly defined Key Performance Indicators (KPIs) to support the validation of the 5G technology
- The need of a clearly defined KPI Testing and Validation methodology, including KPI monitoring, analysis, verification, and performance diagnosis.
- The need for a common formalization process for standardizing tests representing different levels of the 5G network.

This White Paper tries to be a first step into providing a more clear and homogeneous view over these topics, that will be briefly introduced and clarified. The idea is to establish a unified vision on the Test and Measurement topics for 5G, allowing for common procedures and terminology on how to solve some of these challenging problems. This is considered to be beneficial not only the 5G PPP infrastructure owners, but the entire 5G ecosystem. The technical direction is mainly the most predominant one, providing best practices, methodologies and applied solutions, focusing primarily on the actual testing and evaluation of 5G technologies. Nevertheless, the vision is providing substantiated answers to more high-level relevant questions such as “does slicing help fulfilling vertical requirements?”.

Motivations

The envisaged landscape of pervasive 5G services calls for solid and extensive trials, validation tests and measurements that innovating vertical firms strongly need to carry out for extracting reliable conclusions related to 5G performance. The trial environments should mirror the conditions and configuration that the vertical applications will face on their launch in production networks, to verify whether the vertical application can be considered 5G-ready. And, even more importantly, by early testing their innovative use cases over a standards-based full-chain 5G facility, and following a systematic approach, a wide range of vertical industries may timely make well-informed business decisions on launching their services with guaranteed performance levels and therefore with higher chances of business success. To support such an effort, the 5G ecosystem needs to accommodate for frameworks that easily test, measure and demonstrate – for the wide range of new use cases and foreseeable conditions of deployments and scenarios – the Key Performance Indicators (KPIs) of the new softwarized 5G network carrier-grade environments. New approaches and types of testing shall allow the fastest upgrade and deployment paces enabled by the software. Bridging together telco and Cloud Computing changes how testing is performed, and even the type of tests, but there is a gap in End-to-End (E2E) and NFV characterizations, and performance evaluation in the new 5G heterogeneous infrastructure (embracing generalized Virtualization, Network Slicing and Edge/Fog Computing). Test and Measurements (T&M) procedures, tools, and methodologies (i.e. testing, monitoring, analytics, and diagnostics) need to be agreed upon, to ensure a proper functioning of the deployed networks. The goal is to provide a commonly agreed framework for T&M across the 5G PPP ecosystem that will allow vertical customers and Mobile Network Operators (MNOs) to verify and validate SLA for the different 5G Services. Considering this need, as the following section describes, the Test, Measurement, and KPIs Validation (TMV) Working Group (WG) in 5G PPP was founded in order to define and develop the processes of the T&M experimentation framework.

The 5G PPP Test, Measurement, and KPIs Validation Working Group

The Test, Measurement, and KPIs Validation (TMV) Working Group was founded as part of the 5G PPP effort to promote commonalities across projects that have strong interest in the T&M methodologies needed to provide support to the vertical use cases in the 5G Trial Networks. Such efforts include the development of Test and Measurement methods, test cases, procedures and KPI formalization and validation to the greatest possible extent, ensuring a unique European vision on how to support the entire lifecycle of the 5G network, from R&D to actual deployed environments.

The Group is comprised by several Phase II and Phase III 5G PPP projects, and it considers the following research areas and technology domains:

- Testing KPI definition, KPI sources, collection procedures and analysis
- Testing frameworks (requirements, environment, scenarios, expectations, limitation) and tools
- Testing methodologies and procedures
- KPI validation methodologies
- Testing lifecycle (i.e. testing execution, monitoring, evaluation and reporting)
- Common information models for 5G T&M

Another important topic is the use of and contribution towards open source projects such as OSM, OPNFV or ONAP and identification of relevant exploitation and dissemination targets to promote the European vision on T&M towards a more global adoption.

The Role of the Verticals in the 5G Ecosystem

The legitimate ambitions of verticals with regards to 5G Performance

This section surveys a few key aspects of the verticals' innovation lifecycle. Those verticals embracing digital transformation, and planning to leverage 5G as a key enabler in that journey, have the challenge of developing and validating new solutions:

a) addressing a basic business need of their operations and/or customers which is very dependent on and sensitive to the underlying communications' network performance. The expectations on those applications for meeting extreme network reliability, sustained high throughput levels, or close to real-time communication services– to mention a few of their potential requirements- have to be carefully assessed versus the 5G technology performance benchmarks (**viable performance assurance)**
b) must behave properly within their specific and expected performance levels, and according to prediction models, thus expecting that well-defined objectives of a SLA are attainable and guaranteed by the underlying 5G network, and satisfied for a variety of application scenarios and 5G network configurations and conditions (**predictable performance assurance**)
c) may scale and reach a global market, thus expecting smooth interoperability and guaranteed performance levels with a variety of commercial 5G networks worldwide they will be deployed upon (**plug-and-play performance assurance**).

The concurrence and convergence of fast-paced innovation at a variety of verticals with the development and roll-out of 5G by the global ICT ecosystem does bring new opportunities, but also poses additional risks and challenges, especially for pioneering initiatives. On the other hand, 5G vendors and MNOs can't just wait for verticals to transit along such challenges alone, and therefore offer their technical and logistics support from the early stages of development and through commercialization, for the benefit of all parties.

The clear conclusion is that verticals can only gain a competitive advantage and pursue business success provided they engage with the key actors of the 5G ecosystem and collaboratively address the testing and validation challenges enumerated above. That is H2020 5G PPP Programme's vision and interpretation of the technical and business context for 5G take-off, which has induced the launch of several test and experimentation infrastructure projects and reinforcing a constellation of fully-equipped 5G facilities for structured testing and validation across Europe.

The role of 5G KPIs, Testing and Measurement

Beyond the acknowledgement and activation of the necessary actors of this initiative, the question remains on the strategy and processes for jointly, safely and efficiently tackling the original testing and validation challenges. And here is where the 5G KPIs come into the picture, constituting a formal liaison, all along the testing and validation process, between the vertical and 5G counterparts. This section discusses the previously introduced viable-predictable and plug-n-play performance assurance aspects.

Viable performance assurance

A set of standard and well-defined 5G KPIs must be considered by the verticals for carefully assessing, prior to any development and testing activities, the potential feasibility of its use case over a standard 5G network. More than often, in 5G literature listed 5G KPIs are associated to their values for maximum theoretically achievable performance.

If we take the case of KPI User Experienced Data Rate (UL), the well-known value of 50 Mbps is that of the maximum performance that could be achieved with a standard deployment of 5G technology. In consequence, a theoretical vertical use case demanding a minimum sustained User Data Rate (UL) of 64 Mbps shall not be supported at standard 5G deployments, and further development and testing should be aborted under such assumptions. That type of preliminary assessment must be performed and logged in detail by the vertical, for each KPI: user date rate, peak data rate, capacity, E2E latency, mobility, reliability, and availability.

Moving from theory to practice, from the whiteboard to the planning of costly development and testing activities, the verticals should identify their best partner among the 5G actors and initiatives whose facilities can attest, beforehand, the delivery of performance KPI levels in line with the set expectations.

For all those reasons, the 5G PPP infrastructure projects do plan for increasing levels of 5G KPIs at their network facilities, deploy and upgrade their 5G infrastructures periodically, perform systematic measurements, testing, and validation for determining and demonstrating the best achievable performance, and make that information public for consultation by innovating vertical firms who might be interested in partnering with them.

Predictable performance assurance

The variety of standard 5G service slice types (eMBB, URLLC, mMTC), architectural options and alternative configurations have to be taken into account too, since they condition the actual feasibility for a standard 5G environment to support the specific set of 5G KPIs demanded by the application. And, by no means that should imply that verticals must become deep experts in 5G architecture and technology.

The common language between verticals' and 5G domain counterparts should simply remain that of the 5G KPIs, and the key success factor is the collaboration in the actual testing activities with a decisive focus on KPI monitoring and assessment, considering a variety of application scenarios (to be defined by the vertical) and a selection of 5G network configurations and conditions (to be proposed by the 5G facility owner).

Following that systematic approach, the verticals not only can benefit from assessing -and hopefully proving- the technical viability (performance-wise) of its service, but also deriving a model for predicting its service performance in operations for a wide range of foreseeable conditions. That will provide verticals with a solid basis for making a well-informed business decision on whether, when, and how they may attempt successfully launching their services.

A commercial 5G network is, unfortunately, not the type of environment that the verticals need, for completing this stage of development and testing. The real insight on behavior and performance needed by the vertical for completing their innovation cycle can only be provided by an experimentation facility providing them with the tools and processes to carry out their testing and measurement activities. 5G

PPP infrastructure projects aim at filling that gap in the 5G ecosystem and providing that kind of added value services to verticals. These infrastructures will help processing the KPI requirements of verticals for deriving and automatically synthesizing and launching several test cases over their 5G facilities. And the data generated by the execution of all those relevant test cases are gathered, analyzed, and summarized for the vertical users to help them characterize the behavior of their 5G-compatible applications and end-user devices, under a variety of internal and external conditions considered.

Plug-and-play performance assurance

The ultimate ambition of most verticals is to smoothly replicate the launch of their successful applications, for competing globally and increasing their Return on Investment (RoI). When confronted to this challenge, the variability of 5G commercial network deployments and service offerings on locations around the world can turn out to be overwhelming, creating a complexity perception that may slow down or even cause dropping the initial launch plans beyond the first pilot. But again, for this context, 5G KPIs, along with the insights obtained when addressing the predictable performance challenge, can be the lifeline for verticals involved in this journey.

At this critical stage where verticals have to transit from a successful development and testing cycle to putting their system into actual business operation over a variety of 5G networks, it would indeed not be a wise approach to start all over the full testing and characterization cycle at each of those 5G networks -and not realistic either, as commercial rolled-out networks don't really serve that type of purposes, they just deliver end-users with the performance agreed on an SLA.

Furthermore, the negotiation of the necessary SLA of 5G KPIs (well-derived and proved feasible at the previous stage) with the network provider is, of course, a necessary condition for moving forward, but unfortunately it is not a sufficient condition. It is just the trigger for the 5G network service provider to start an engineering effort for trying to secure that such specific SLA of 5G KPIs, for a set of conditions, can be achieved. Such an effort is not negligible, it takes time and involves costs. At this stage it is not the vertical who could use help, but the 5G network service provider.

What can 5G PPP infrastructure projects do to support this ambition? The answer lies on the valuable information logged at the extensive trials performed on the previous stage. It is the network architectures, configurations, test cases and monitored KPIs involved what should be the key source of information that the 5G network service provider can leverage for coming up, in a short time and at a reasonable cost, with a proposal for creating the service (slice, if we can overload that term) that can guarantee the vertical's required SLA, depending on specific 5G KPIs. All the time and effort saved by the MNOs at this stage, translates into faster time-to-market of the vertical services roll-out. And, even more importantly, the reuse of information and insights of earlier extensive validation tests by the 5G network operators supporting that vertical directly translates into a better guarantee of performance delivery and confidence for the vertical and their customers.

Testing and Monitoring: How We Look at the 5G Network

Previously we established the necessity for 5G systems to accommodate testing and validation frameworks to allow the increment of SLA assurance for the new verticals that are rolling out their services over 5G infrastructures. Therefore, we need to further define the testing methodology and the enablers in the infrastructure for acquiring metrics useful for our testing needs.

Testing (or Active Testing) provides a greater observability due to the active control over the type and intensity of traffic that is pushed through the network and through subsets of the network elements. This provides more degrees of freedoms in selecting what can be tested and measured (e.g. scalability or security resilience). Monitoring is instead a generally passive process that is providing metrics from various components/layers of the 5G network. For this reason, the KPIs that can be measured via testing are substantially different than through monitoring alone. An example of these differences can be seen in two similar documents coming from NGMN [1] and 3GPP [2]. The former is focused on testing aspects, while the latter provides an overview of KPIs to be measured during normal network operations.

Testing is normally applied during the network rollout, during the onboarding process of new Virtualized Network Functions (VNFs) or new software updates, and for the validation of newly deployed network services. Monitoring is instead constantly active during network operations and it is a key enabler of network management actions and processes. **The TMV has agreed on focusing on testing first to provide an actable set of methodologies and KPIs for validating the 5G technology and the 5G PPP contractual (high level) KPIs, and these are the aspects that this document is currently covering**.

Testing Approach

The 5G network is composed by several complex and heterogeneous components, blending IT, cloud, and telecommunication technologies. These technologies provide building blocks that can be stacked on top of each other to create the full 5G network, from the foundations up, like the pyramid in Figure 1.

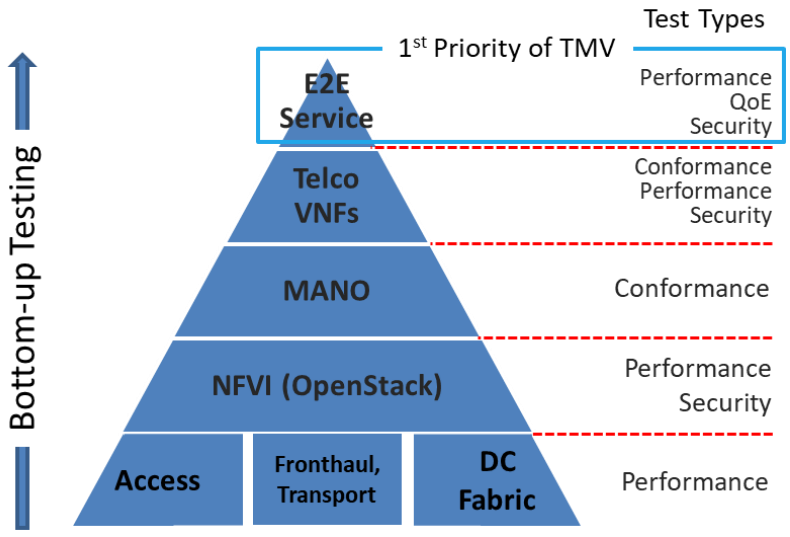

Figure 1 - The 5G system layers

At the bottom of the pyramid there are the basic transport technologies, such as front- and backhaul, and the Data Center network fabric. On those, the NFV infrastructure is built, with cloud technologies such as OpenStack. The Management and Orchestration (MANO) is instead a kernel component for enabling the NFV principles. The telecommunication and service components seen as Virtual Network Functions (VNFs) can be then included in the picture, and with those, at the tip of the pyramid (Figure 1), there are the E2E network services.

Each level carries along different types of tests that **must** be performed while deploying and integrating the network, onboarding the VNFs, and providing the services. A bottom-up approach is recommended by the TMV to deploy and provide a stable infrastructure to the vertical customers. Since most of the testing methodologies for the individual components are expected to come from the relevant standards, **the TMV's priority is to provide methodologies and Test Cases for the validation of the E2E services delivered to the verticals**.

Testing as a Service: Methods and Essential KPIs for Service Validation

Testing tools have always been an essential part of network deployment engineers and, to a very limited extent, to network management engineers. The advent in 5G of softwarization brings along an extreme number and variety of parameters that can affect the overall network performance. Constant software updates, optimization of NFVI parameters are only two examples of the huge number of possible use cases. Testing become then an even more important tool in the hand of network management and operations engineers for guaranteeing the Service Level Agreements (SLAs) contracted by the MNOs with their vertical customers.

Test as a Service

Test as a Service (TaaS) plays then an important role in reducing the effort that the MNOs' engineers need to put in testing the 5G infrastructure and components. By simplifying the testing operations and providing an interface to connect to the Continuous Integration / Continuous Deployment (CI/CD) pipelines of the MNOs NetOps, TaaS is promising a stable performance delivery while maintaining under control (or even reducing) the OPEX. TaaS is expected to become an essential component of the Zero-Touch philosophy that is currently pursued in standards like ETSI ZSM [3]or open source communities such as OPNFV [4] and ONAP [5].

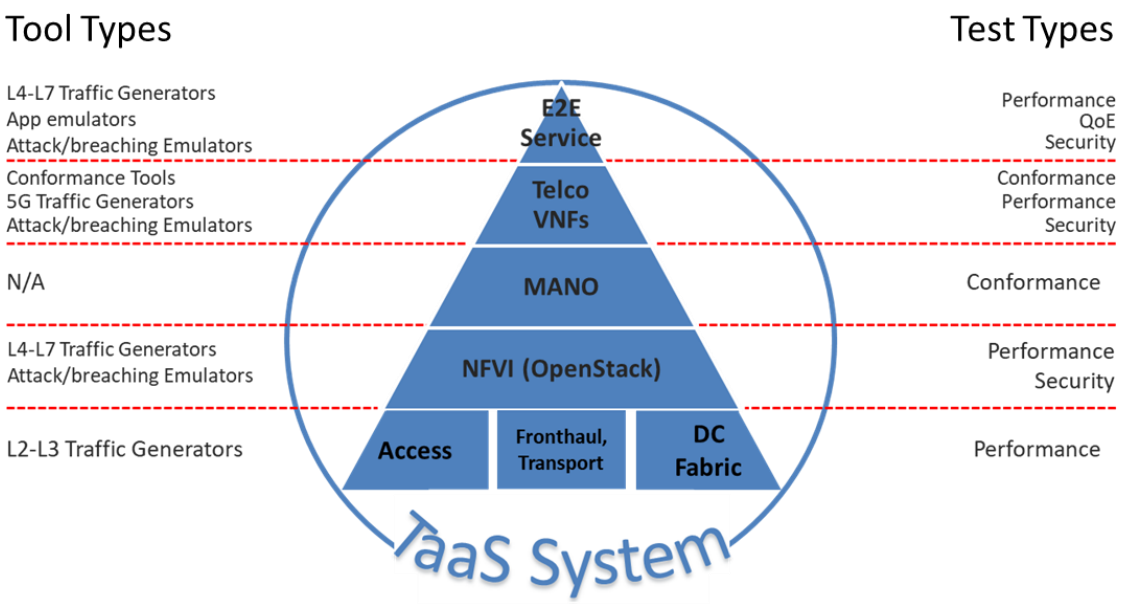

Figure 2 - TaaS system overview from a tooling perspective

TaaS is an automation and interfacing layer that allows to connect all the T&M tools needed for validating and verifying the 5G system, from the individual components up to the E2E service. The automation makes possible to abstract the complexity with a series of either standard or custom Test Cases. In Figure 2 it is clarified how a TaaS automation system can bind together different types of Test Tools, and which types of testing are covered. It possible to note that all the aspects ranging from Conformance to Security, from Performance to QoE can be test through a TaaS system, making it a powerful tool in the end of network equipment vendors, MNOs, and vertical customers.

The TMV recommends supporting and using a TaaS approach in the future 5G networks, and the group is currently working on identifying several commonly shared, standardized Test Cases useful at the validation of the E2E services.

Essential KPIs for Service Validation

The first essential step for creating the needed Test Cases is to identify which KPIs shall be stressed by the test. The priority was, for the TMV group, to identify those technical KPIs that were supporting the 5G PPP contractual KPIs validation [3]. The initial identified KPIs support mostly the following two contractual KPIs:

- **P1:** Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010.
- **P4:** Creating a secure, reliable and dependable Internet with a “zero perceived” downtime for services provision.

In practice, those two contractual KPIs can be translated in a series of **Technical KPIs**, as displayed in Table 1.

Table 1 - Identified Technical KPIs

Type	KPI name	KPI measurement points	5G PPP KPI Validated
SLA	Minimum Expected Upstream Throughput	UE transmitting IP packets to the N6 interface.	P1
SLA	Minimum Expected Downstream Throughput	UE receiving IP packets from the N6 interface	P1
SLA	Maximum Expected Latency	RTT of UE IP packets transmitted to the N6 interface.	P1, P4
SLA	Network Reliability	Transport layer packets are lost between the UE and the N6 interface	P4
SLA, Technology Validation	Quality of Experience	Measured at the UE side at application or application API level	P1, P4
Technology Validation	UL Peak Throughput	Single UE transmitting IP packets to the N6 interface.	P1
Technology Validation	DL Peak Throughput	Single UE receiving IP packets from the N6 interface	P1

The definition of these KPIs has mostly been derived or reworked starting from [7] and [8]. The "Type" column remarks for which purpose the KPI is useful. The SLA KPIs are the ones used to validate if the service design can support the SLA agreed with the vertical, and they can used as well during the network monitoring phases to trigger alarm and network management actions. The Technology Validation KPIs are instead focused on providing the proof that 5G is delivering the promised performances, mostly peak ones.

Formalization process, methods and format

As the experimentation on top of the 5G networks is ongoing, owners of 5G infrastructures need to selectively expose the network capabilities to experimenters, and allow for configurations, tailored to the needs of the related vertical industries. An initial response to this request is a modular form that includes a formalization of the information needed in order to configure a 5G infrastructure for an experiment. Meant to serve as a standardized template for bridging vertical-oriented requirements with network configurations, this form can be used for both technical and service level agreement (SLA) validations. At its initial state it includes at least the following interlinked fields:

- Experiment description
- Test case description
- Scenario identification

Experiment description. Information required to uniquely identify an experiment. Each experiment shall include combinations of at least the two mandatory fields for the experiment, namely, the test cases and the scenarios.

Test case description. The test case includes information which is related to the configurations of the experimentation infrastructure needed for receiving the measurement(s). The KPI definition, the measurements methodology and the information for the equipment preparation are added in this field. More precisely, a test case provides the following info:

- *Target KPI*. Each test case targets a single KPI. Secondary/complementary KPIs could also be defined as complementary measurements (see below). The definition of the main KPI declares at least the reference points from which the measurement(s) will be performed, the underlay system, and the reference protocol stack level. The physical formula, the unit, and the type of the KPI as defined in 3GPP TS 28.554 are included here.
- *Complementary measurements*. A secondary list of KPIs useful to interpret the values of the target KPI. Getting these measurements is not mandatory for the test case. However, allows for test cases that, besides the target measurement, provide an additional set of results useful for analysis and interpretation of the relation between different KPIs
- *Pre-conditions*. A list of test-specific information about equipment configuration and traffic description. Also, precise description of the initial state of the system under test, required to start executing a test case sequence.
- *Test case sequence*. It specializes the set of processes needed for executing the experiment in the selected underlay system.
- *Methodology, calculation process and expected output*. The experimenter shall provide the acceptable values for variables that affect the testing procedure, as the monitoring time, the iterations required, the monitoring frequency, etc. In addition, the units that shall be used in the measurements and, potentially, a request for first order statistics (Min, Max, etc.) of the target KPI measurement.
- *Applicability*. A list of features and capabilities which are required by the system in order to guarantee the feasibility of the test.

Scenario identification. The scenario includes information which is related to network, service and environment configurations and it is specific to the selected technologies and the target system. From the performance perspective the scenario quantifies the parameters that affect the values of the KPIs to be measured. More precisely, a test case that targets a specific measurement can be set for different scenarios that declare parameters such as the network slice characteristics, network configuration parameters (e.g. the level of the transmission power in a base station), mobility aspects (e.g. the mobility of the end devices), the network status (e.g. the traffic load in the system), etc.

It shall be noted that results processing, visualization, and reporting are not mentioned here. This doesn't mean that such aspects are not important. As a matter of fact, a unique way of reporting results for comparison across trials and facilities is wished. Nevertheless, that is a delicate process to formalize and agree upon, and it will surely be tackled by the TMV group in the near future.

Conclusions

This White Paper provided an initial overview on several of the challenges faced not only by the 5G PPP infrastructure project participants, but by the entire 5G ecosystem.

The journey of innovating verticals from service inception to market readiness has been analyzed, identifying issues and potential road-blockers while proposing strategies and approaches for overcoming them. The role and contribution of the 5G PPP infrastructure projects for supporting the business success of verticals has been outlined, featuring a single -yet compelling- set of structured processes for specifying, measuring and securing the delivery of 5G KPIs.

Testing as a Service (TaaS) is expected to play a major role in the 5G softwarized network. It is therefore recommended to implement such a system to facilitate the deployment, maintenance, and upgrade of the network components. A small group of essential KPIs for validating the E2E Service performances has been identified for starting to implement TaaS in the initial verification of the trial infrastructures. They cover the core needs of any network service: throughput, latency, reliability.

An initial formalization effort has also started as part of the 5G PPP TMV group activities, to facilitate the sharing and execution common Test Cases across different infrastructures and make sure that results can be commonly understood.

Contributing Projects

5G-VINNI	www.5g-vinni.eu	5GT	5g-transformer.eu
5G EVE	www.5g-eve.eu	5G-PICTURE	www.5g-picture-project.eu
5Genesis	5genesis.eu	ONE5G	one5g.eu
5Gtango	www.5gtango.eu	MATILDA	www.matilda-5g.eu

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