Test, Measurement, and KPIs Validation Working Group

White Paper

KPIs Measurement Tools

From KPI definition to KPI validation enablement

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Executive Summary

This white paper summarizes the 5G Key Performance Indicators (KPIs) and the tools that have been identified and utilized in several ICT-17, ICT-19, and ICT-52 projects. In particular, the document lists the identified 5G KPIs, with a brief and unified description, mapping them also to the measurement operations. Then, the tools recognized in the different projects are presented, including open-source, ad-hoc developed and proprietary tools. Each tool is presented, highlighting the main functionalities and the list of KPIs that can be measured. Finally, the platforms for data collection and the tools for visualization are reported, highlighting their features and the availability of plugins/APIs to connect other tools/frameworks.

1 Motivation

The aim of this document is to summarize the utilized tools and methodologies considered in the different EU ICT projects, including the details related to the measurement points/interfaces at which the measurements are performed. The 5G KPIs have been defined by several Standard Developing Organisations (SDOs) and researchers, and several tools are available in the different communities to perform KPI measurements. This white paper would like to present a selection of tools that have been utilized in the 5G-PPP projects and the respective measurement methodologies that have been adopted. In this way it is possible to understand the limitations of currently available tools for 5G KPI measurements and collect insights that are necessary for future enhancements or even complete redesign of new tools to support measurements in 6G.

2 5G KPIs

The joint work of the 5G-PPP Test, Measurement and KPI Validation Working Group (TMV-WG) [3] and of many ICT-17, ICT-19, ICT-41, ICT-42 and ICT-52 projects, such as 5G EVE [32], 5G-VINNI [33], 5GENESIS [34], 5G-TOURS [35], 5G-HEART [36], Int5Gent [37], 5GASP [37], 5G-LOGINNOV [39] and 5Growth [40], have contributed to the definition of Key Performance Indicators (KPIs) of 5G networks.

Their goal is to measure 5G network performance from different perspectives, such as the one of the vertical/customer or of the network/service provider as depicted in Figure 1. Although their contexts might be similar, they can differ in the effective end-points/interfaces where the measurements are performed. Consequently, the tools that are used to complete the measurement are also different, because they are based on specific layer (e.g., physical, network or application layer) or segment of the 5G network architecture (e.g., radio, transport or core network).

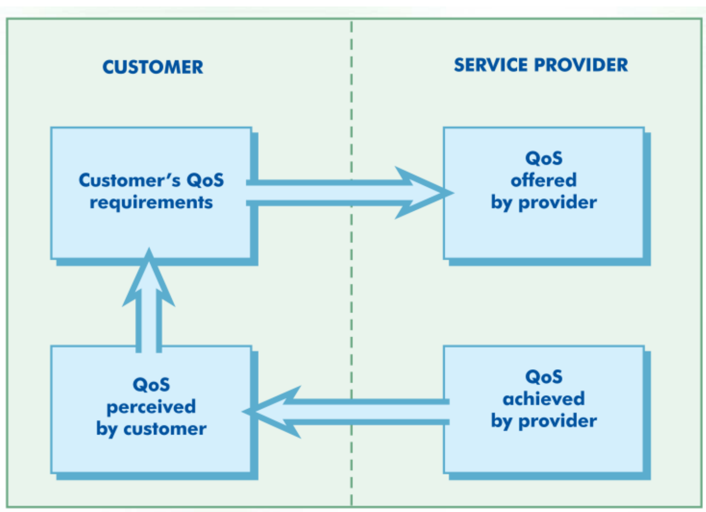

Figure 1 Relationship between customer QoS and service provider QoS [1]

To deliver a general and appropriately flexible definition, Table 1 attempts to consolidate the different KPIs utilized in different projects and on different layers.

Table 1: Example of 5G KPI definition

KPI Name	KPI Id	KPI Description	Units
One-way-latency	KPI-1	One-way latency is the total amount of time required for a packet to be sent at the communication unit at the transmitter's side until it is received at the communication unit at the receiver's side.	ms
Jitter	KPI-2	Variation of the one-way latency, experienced by the packets sent by the communication unit at the transmitter's side to the communication unit at the receiver's side	ms
Availability	KPI-3	Expressed in percentage, it represents the ratio between the amount of time during which a specific component of the use	%

		case (application, server, network function, etc.) is responding to the received requests and thus fulfilling the expected QoS requirements, and the total amount of time that the component has been deployed.	
Reliability	KPI-4	Expressed in percentage, it represents the ratio between the number of sent network layer packets that were successfully delivered to a given system node (including the User Equipment) within the time constraint required by the targeted service, and the total number of sent network layer packets.	%
Packet Loss	KPI-5	Expressed in percentage, it represents the ratio between the number of packets that fail to reach their destination, measured on specific interfaces of the use case's logical architecture, and the total number of sent packets.	%
Connection Density	KPI-6	The total number of connected and/or accessible devices per unit area	Device/km^2
Area Traffic Capacity	KPI-7	The total traffic throughput served per geographic area	bps/m2
User Experienced Data Rate	KPI-8	Data rate that is experienced by the 5G UE for delivering or receiving the traffic. Thanks to 5G technology, higher user data rates can be achieved to accommodate high traffic volumes (e.g., high resolution video streams in 4K, UHD).	Mbps
Guaranteed Data Rate	KPI-9	The ratio between the number of bits, sent on a specific interface of the use case's logical architecture, and the unit of time. The guaranteed data rate is the minimum expected data rate for the overall use case to function correctly.	Mbits/s
Data Volume	KPI-10	The total quantity of information transferred over a given interface during specific use case operation, measured in bits.	Gbits
Components Onboarding and Configuration	KPI-11	Time required to complete the onboarding of a component.	min
Components Deployment Time	KPI-12	Time required to deploy a component.	min
Slice Creation/adaption Time	KPI-13	Time elapsed since the triggering of a slice creation/reconfiguration until the slice is fully operational.	ms
Time to Scale	KPI-14	Time required to scale an already deployed component.	min

SS-RSRP	KPI-15	Synchronization Signal (SS) reference signal received power is defined as the linear average over the power contributions (in [W]) of the resource elements that carry secondary synchronization signals.	dBm
CSI-RSRP	KPI-16	Channel State Information Reference Signal Received Power (CSI-RSRP), is defined as the linear average over the power contributions (in [W]) of the resource elements of the antenna port(s) that carry CSI reference signals.	
SS-RSRQ	KPI-17	Secondary Synchronization Signal Reference Signal Received Quality (SS-RSRQ) is defined as the ratio of N×SS-RSRP / NR carrier RSSI, where N is the number of resource blocks in the NR carrier RSSI measurement bandwidth.	dB
CSI-RSRQ	KPI-18	CSI Reference Signal Received Quality is defined as the ratio of N×CSI-RSRP to CSI-RSSI, where N is the number of resource blocks in the CSI-RSSI measurement bandwidth.	dB
SS-SINR	KPI-19	SS Signal-to-Noise and Interference Ratio is defined as the linear average over the power contribution (in [W]) of the resource elements carrying secondary synchronisation signals divided by the linear average of the noise and interference power contribution (in [W]).	dB
CSI-SINR	KPI-20	CSI Signal-to-Noise and Interference Ratio (CSI-SINR), is defined as the linear average over the power contribution (in [W]) of the resource elements carrying CSI reference signals divided by the linear average of the noise and interference power contribution (in [W]).	dB

The defined KPIs can be measured at different network points, based on the positioning of the measurement probes. In case of latency for example, the white paper of the 5G PPP Architecture Working Group - View on 5G Architecture, Version 3.0, specifies partitioning of the functional network segments of a 5G system (see Figure 2). It includes UE, RAN, Backhaul, edge cloud, transport/core network and central cloud. Based on this partitioning the authors in [15] specified a reference framework of delay contributions for the end-to-end-latency. The framework separates the transmission time, the processing time and the client/server response time for the different network segments. In particular, it identifies T_Radio, T_Backhaul and T_Core representing the transmission contributions of the radio, backhaul and core segments, respectively. In addition, the reference framework identifies P_UE, P_RAN, P_UPF_Edge and P_UPF_Core for the processing time, which contribute to the increase in latency in the identified segments. Finally, it identifies R_Client, R_Server_Edge and R_Server_Core as the response times of the application components that also contribute to the increase of the end-to-end latency.

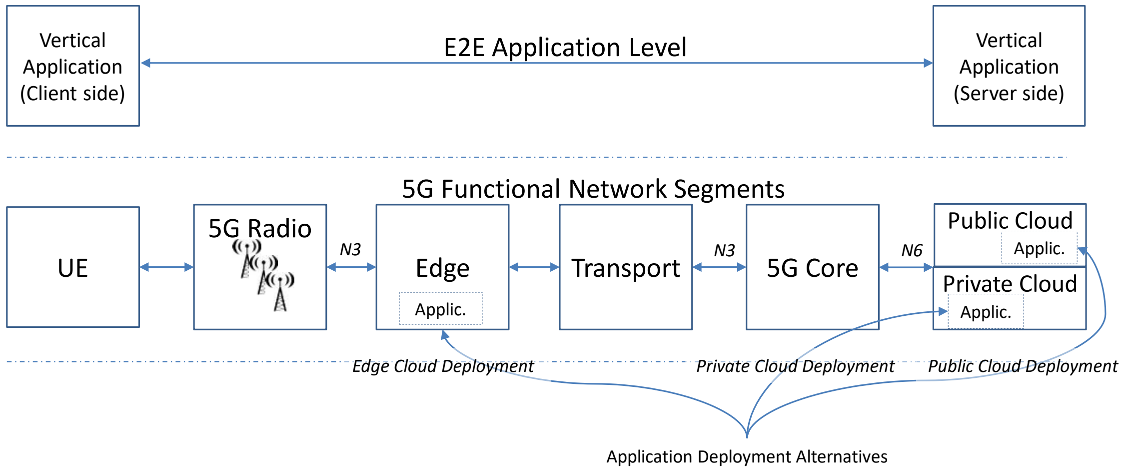

Figure 2 Functional Network Segments of a 5G System (Figure 6-1 in [16])

Each of the identified latency contributors can be measured through the introduction of measurement probes at the right reference points. In this way, the latency of each segment can be measured, enabling the estimation of an aggregate latency of concern, up to the user perceived latency at the application level.

3 Experiment Description and Data Collection

Experiment description

Besides providing standard ways of measuring KPIs, it is also important to provide standardized ways of creating the experimental context around the measurement. This factor is increasingly important when the focus moves towards the implementation of large scale 5G use cases, which go beyond laboratory and small-scale ones, and which can be affected by external (e.g., the crowdedness of an area) or internal (e.g., the service configuration and the user behaviour) factors. For this reason, in some ICT-19 projects, a set of templates are used that can capture these factors ([8][9]).

The GSMA Generic Network Slice Template (GST) [29] is a set of attributes that can characterize the type of network slice/service. GST is generic and is not tied to any specific network deployment. The GSMA NEtwork Slice Type (NEST) is a GST completed with values, expressing a given set of requirements to support a network slice customer use case (see Figure 3).

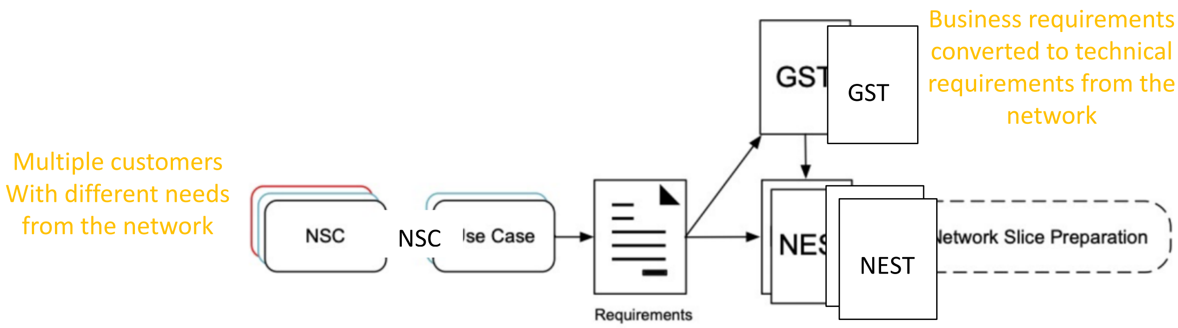

Figure 3. GSMA NEST Template

In addition, the GSMA Network Slice Type (NEST) Templates [29] define the slicing requirements of different use cases in a standardized manner with regards to the underlying infrastructure. A slice is a logical network that provides specific network capabilities and network characteristics to its owner. The slice can have specific requirements, agreed between the vertical (owner of the slice) and the network operator (provider of the slice). This relationship of infrastructure provider and vertical/experimenter is very well represented in many use cases.

In general, a network slice can span across multiple network domains, with the resources of the slice dedicated to the experimenter. This should be taken into consideration in the collection, analysis and evaluations phases of the measurements because it may provide insights for the performance of different network segments of the end-to-end path.

In order to create a GSMA Template, the verticals follow a simple methodology that consists of analysing its network requirements and translating them into a GST file by answering a set of standard questions present in the standard GSMA Template, as illustrated in Figure 4.

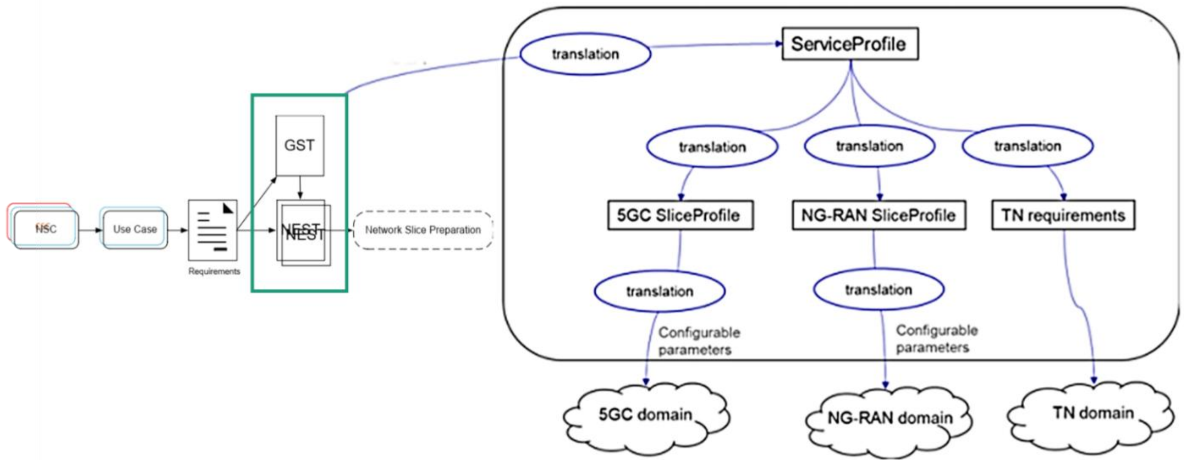

Figure 4. From requirements to slice description

In addition, to facilitate the translation between the NEST templates and the actual site deployment/configuration, the Testing Scenario Templates (TSTs) are used in some projects (e.g. 5G-TOURS [9]). The TSTs (realized per network slice) enhance and extend the NEST templates with additional information related to:

- network configuration (both in RAN and Core),
- UE capabilities,
- service characteristics,
- environmental details in which the tests are executed,
- metrics and KPIs to be collected and validated.

This way, the TSTs provide guidance for the technical teams responsible for the actual deployment of the UCs to realize the translation steps described in Figure 4. The TSTs together with some indicative values are presented in Table 2.

Table 2. Testing Scenario Templates (TSTs).

Parameter group	Test scenarios parameter	Example value
3GPP standard	3GPP Release	Rel.15
	3GPP Architecture option	NSA
RAN	Band	3.5 Ghz
	Bandwidth	50 MHz
	Carrier aggregation	16
	UL/DL pattern	FDD
	Modulation	64QAM

	MIMO	2 layers
Core	Deployment	Edge/Central
UE	Category	CAT 7
	MIMO	2 layers
Service	Deployment	Edge/Central
	Service type	eMBB/URLLC/mMTC
Environment	Indoor/Outdoor	Indoor
	Number of UEs	10
	Number of cells	3
	Device density	#devices/km^2
	Mobility	60Km/h
	Background traffic	UE emulation
Metrics (list)	Metric name	RTT latency
	Unit	ms
	Probe position (network)	UE
	Probe position (layer)	APP layer
	Sampling rate	1min
KPIs (list)	KPI name	E2E latency
	Unit	ms
	Criteria	<10ms
	Analysis equation	AVG (RTT latency (metric)/2)

Data collection

Another aspect represents the collection of the measurement data. FOT-Net—a European Commission-funded Support Action regarding Field Operational Tests (FOTs) [1], describes an approach called the "space mission" in which as much data as possible are collected, because the FOT provides a unique opportunity (and funding) to collect data which may be hard to collect later on. This approach gives a rich dataset that enhances the probability that the data will be re-used in future projects. However, before starting data collection, it is recommended to develop a plan on how to store the data and how to make them available for later analysis or analysis by others. This plan should specify detailed data dictionaries, open software formats, rules for data access and other relevant information as meta-data". Figure 5 describes the high-level architecture devised for 5G-LOGINNOV [39] in order to collect a rich dataset tailored to the project evaluation needs.

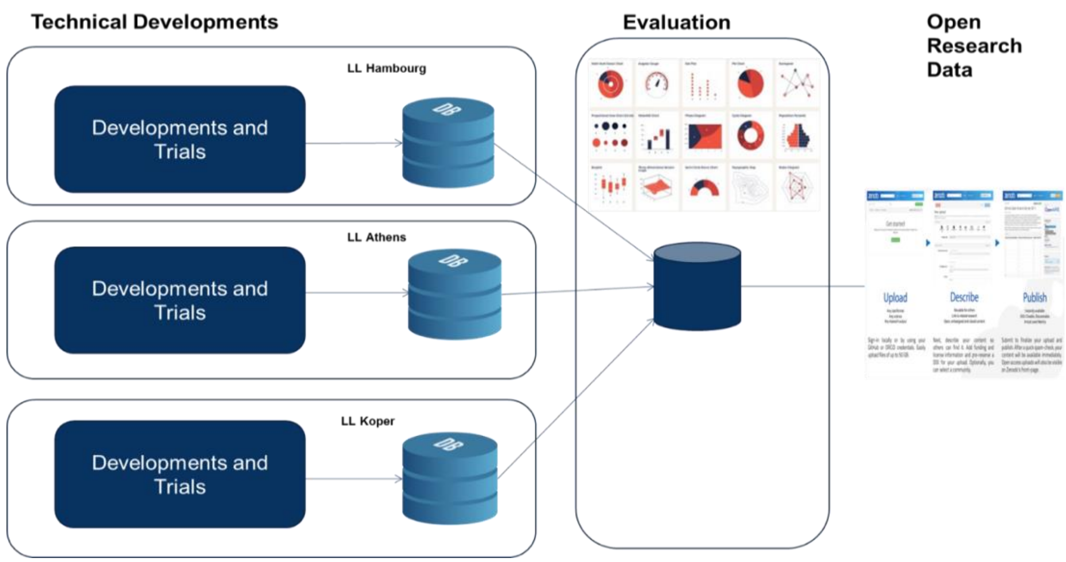

Figure 5. FOT-Net approach

Also, in order to simplify the exchange of information of data related to the measurement phase, many methods/models have been adopted and metadata is one of them. More specifically, metadata represent a key aspect of data collection as it allows the user of the data to understand for example the experimental setup or the context of the project. Therefore, prior to any data collection endeavour, care must be taken to define a consistent metadata schema, agreed and used by all participants in the data collection.

Several organizations have defined metadata schema, such as:

- Datacite: DataCite is a non-profit organisation acting as a persistent identifiers (DOIs) provider. DataCite proposes an extensive metadata schema that has been adopted by other persistent identifiers providers helping to make research data FAIR.
- FAIR: FAIR metadata consists of all metadata required to make data FAIR. FAIR metadata and DataCite metadata serve the same objective, hence there is some overlapping between the two as can be seen below.

4 Available Tools

This section includes a collection of tools that have been used in the different EU ICT projects to perform KPI measurements during the experimental validation of the considered use cases. Before entering in the tool's description, a generalized classification of the types of probes is needed.

In general, KPI measurements is based on the use of 5G network probes for the data collection and a cloud-based controller platform for data analysis.

Probes are devices or software plug-ins inserted at key junctures on the network, in order to monitor certain parameters, either passively (i.e., non-intrusively) or actively (i.e., intrusively), by generating small amounts of traffic that simulate user traffic.

These probes generally fall in two categories:

1. Hardware probes that are devices/equipment placed close to RAN (e.g., 5G UE, gNb) or core network elements (e.g., UPF, routers, switches, and servers), or even on them (e.g., small form-factor pluggable (SFP) modules) to monitor certain performance parameters.
2. Software probes that are in the form of software plug-ins that are built-in or installed separately on the mobile network elements, or even on the end user devices, e.g., user equipment (UE).

As mentioned, two possible measurement operational modes can be considered:

1. Passive measurements monitor network parameters, such as throughput and network utilization, without generating ad-hoc data traffic. For high quality measurements, time synchronization is essential.
2. Active measurements send control data in order to measure time-dependent parameters, such as latency, jitter and packet loss. Typically, active probes can monitor the KPIs after Service Activation and while the Service is being delivered.

Five types of deployment patterns can be considered for the measurement tools:

I. *Client and server-based* tools aim to measure the end-to-end KPIs, such as the RTT and, throughput, in a stateful fashion (e.g., via TCP sessions).

II. *Single node* tools send (arbitrary) traffic towards any node and measure the response times of either the host node itself or the service the specific node is hosting by crafting the requests. They also measure availability (of the service or node) and can measure jitter.

III. *In-network* tools passively observe the traffic flows and report the statistics about them. These are especially powerful when combined with clear-text transport protocol such as RTP, where a single passive probe can report the exact packet loss rates, RTTs, etc. experienced by the streaming applications by parsing the content of RTCP messages.

IV. *In-hypervisor* tools are deployed on the host OS of the servers and provide fine-grained visibility over all the services hosted at the same machine.

V. *Hardware* tools are less flexible, as they cannot be deployed through software containers/package. However, in turn they are more powerful for testing the lower layer of a 5G network such as emulating large number of UEs, RSSI degradation, etc.

Typically, the target KPI metrics assess the performance of different entities (e.g., 5G cells, network links, nodes, services, physical/service ports and signal levels). The measurements are being performed with (sub)millisecond accuracy and exported/exposed to a cloud server for further processing and analysis.

4.1 Open-source tools

Ping [17] is a TCP/IP command used to troubleshoot connectivity, reachability, and name resolution. The command is based on ICMP protocol and provides connectivity statistics (round-trip-time and packet loss) in a bidirectional view.

iPerf [18] is a widely used tool for network performance measurement and tuning, providing active measurements of the maximum achievable bandwidth on IP-based networks. It supports the tuning of various parameters related to timing, buffers and protocols (TCP, UDP, SCTP with IPv4 and IPv6). For each test it reports the bandwidth, packet loss, and other parameters. iPerf has client and server functionality and can create data streams to measure the throughput between the two end points in one or both directions.

Bmon [19] is a network monitoring and debugging tool for Unix-like systems, which captures networking related statistics. It is a reliable and effective real-time bandwidth monitor and rate estimator.

NetEm [20] is an enhancement of the Linux traffic control facilities that allows to add delay, packet loss, duplication and other characteristics to packets outgoing from a selected network interface. NetEm is built using the existing Quality of Service (QoS) and Differentiated Services (diffserv) facilities in the Linux kernel.

Ostinato [21] is a packet crafter, network traffic generator and analyzer with a friendly GUI. It also offers a powerful Python API for network test automation. Ostinato is able to craft and send packets of several streams at different configurable traffic rates and it supports several protocols.

Tcpreplay [22] is a suite of free open-source utilities for editing and replaying previously captured network traffic traces.

Fping [23] is a tool for network diagnostics and statistics. The program sends ICMP echo probes to network hosts, similar to ping, but much better performing in case of multiple hosts.

Moongen [24] is a high-speed packet generator built on DPDK and LuaJIT. It supports 10 Gbit/s traffic stream with 64 byte of packet size using a single CPU core. It is fully scriptable software that allows accurate timestamping and rate control.

Curl [25] is a command used to transfer data. It is available in many devices and applications and supports many transfer protocols and data type.

ntopng [26] is the next generation version of the original ntop and it is a network traffic probe to monitor network usage. ntopng is based on libpcap/PF_RING and it supports the execution in Unix, MacOS and Windows platforms.

Cilium [27] is open-source software for providing, securing and observing network connectivity between application services deployed using Linux container management platforms like Docker and Kubernetes.

TWAMP [28] (two-way active measurement protocol) is a protocol described in RFC 5357, that extends the One-Way Active Management Protocol (OWAMP), considering bidirectional measurements. TWAMP defines an open protocol for measuring two-way or round-trip metrics with greater accuracy than other methods by using timestamps. There are different network probes implementation for TWAMP: a)

Software based on opensource tools; b) Hardware SFP based for network elements and; c) Commercial software-based ones.

4.2 Tools developed within EU projects

5Growth Tools [9-12]:

End-to-end Unidirectional Link Latency Evaluator: This tool has been designed and developed within the 5Growth project and it has been integrated with the 5Growth monitoring platform. It is an example of active probe that allows the estimation of a unidirectional link spanning across the network. The tool requires the execution of two probes (i.e., at the source and at the destination of the end-to-end link to be evaluated). The probe behaviour is based on two main processes: (i) the periodic unidirectional link latency evaluation (the real link latency estimation), (ii) the clock offset estimation (i.e., the clock difference) to be compensated for the link latency evaluation. The probes have been equipped with a Prometheus exporter to export the data to the collector (e.g., monitoring platform).

5GPorbe: These probes are example of passive probes (i.e., elements that can sniff the network traffic during the experiments) and produce log information with the measurements of some parameters of the sniffed traffic sent and received within the 5G network. These probes are not generating traffic and are not disturbing the 5G network load in any way. 5Probe is a passive probe that extracts information from end-user traffic by analysing the packets with programmable Shallow Packet Inspection using a packet-capture (pcap) library to generate the 5G network metrics.

The following table lists a selection of tools that could be integrated with the 5Growth monitoring platform providing alternatives to monitor all the CKPIs. In this table, “X” represents the CKPIs that are directly measured by the tool, while “+” represents that the CKPIs are only partially measured.

Passive Network Interface probe: This tool is a passive network interface probe, designed to report the average throughput (considering both packet per second and bits per second) in each direction of a Virtual Machine (VM) hosted within a hypervisor or a CPE. It uses a Prometheus Pushgateway to export the data towards the monitoring platform. The probe uses the network interface statistics gathered by the Operating System's (OS) kernel via the *psutil*[1] Python module, allowing for more extensive compatibility with the different OS types available within the CPEs. When running within a *qemu+KVM* hypervisor environment, such as an OpenStack deployment, the probe gathers the statistics straight from the TAP interfaces exposed in the compute node that hosts that VM. Because of this, the upload of the hypervisor is the download of the VM (and vice-versa). Therefore, the probe has different code paths for hypervisors and CPEs that automatically inverts the send and receive direction, when needed. Furthermore, the metrics are always reported to evaluate a vertical service. Thus, when monitoring VMs from the hypervisor, the reported metrics will be consistent with those measured within a CPE.

Telemetry for P4 programmable switches: with the emergence of data-plane programmability, new approaches to network telemetry are available. One of these approaches, enabled by P4, is the In-band Network Telemetry (INT). To advance in the telemetry issues, in-band network telemetry is an emerging representative of the network telemetry, which has received extensive attention in both academia and

[1] https://github.com/giampaolo/psutil

industry in recent years. Different from the traditional network measurement and software-defined measurement, in-band network telemetry combines both data packet forwarding with network measurement. In-band network telemetry collects the network status by inserting meta-data into the data plane packets. With in-band network telemetry, problems like performance bottlenecks, network failures or misconfigurations are easier to detect since the network administrators have direct visibility of what is happening on the data plane.

Table 3: Open-source tools and corresponding 5G KPIS

Tools	5G KPIs								
	KPI-1 oneway	KPI-2 jitt	KPI-3 avail	KPI-4 rela	KPI-5 p loss	KPI-7 area capa	KPI-8 exp datarate	KPI-9 Guara rate	KPI-10 Data vol
Ping		X			X				
Iperf		X	X		X		X	X	X
Bmon		X							X
NetEm	X	X	X	X	X		X	X	X
Ostinato	X	X	X		X		X	X	X
Tcpreplay							X	X	
Fping		X			X				
Moongen		X	X				X	X	
Curl						X			
Ntopng		X	X		X		X	X	
Cilium		X	X		X		X	X	X
TWAMP	X	X			X		X	X	

4.3 Commercial tools

4.3.1 Keysight tools

CyPerf: This is a tool to perform testing of cloud performance, scalability and security. The tool allows the tester to quickly validate cloud and SD-WAN migration by replicating distributed deployment environments with realistic workloads. It also allows to validate elastic scalability of cloud infrastructures and security architectures with auto-scaling test agents. The tool can discover undisclosed infrastructure issues such as traffic shaping and throttling that might impact the application.

BreakingPoint Security: This is a tool for performing security penetration testing with 1000s of attack vectors. The tool generates scalable real-world traffic for complete performance and security testing and validates both virtual and physical devices using a complete test software solution.

IxNetwork: This is a tool for layer 2/3 testing of network performance of NFVI. The tool validates virtual networks functions (VNF) with functional testing and performance benchmarking. It provides comprehensive control plane protocol coverage across a large set of Layer 2/3 (L2/3) networking technologies.

IxLoad: This is a tool for performing L4-7 application performance testing of virtualized compute and network elements. This can be used for testing 4G and 5G NSA core deployments, emulating UEs and UE traffic. The tool delivers end-to-end testing of converged application delivery infrastructure and services.

LoadCore: This is a tool for testing 5G SA core deployments, performance and conformance, both control and user plane. LoadCore enables users to simulate behaviour of millions of UEs in 5G deployments by performing service quality validation with subscriber modelling and multiplay traffic generation, and by validating complex scenarios for service-based architectures.

Hawkeye: This is a tool for testing user plane end-to-end network performance. This is done by generating traffic between traffic probes (endpoints), which a capable of emulating application traffic types (web, video, voice, etc) and generating simple dummy traffic (TCP, UDP). The deployment of endpoints is simple and only need to register with the server, which then acts as a command-and-control server, configuring and scheduling tests involving the endpoints.

UeSIM: UeSIM UE emulation solutions enable infrastructure vendors, chipset providers and mobile operators to validate end-to-end Radio Access Network performance by emulating real network traffic over both radio and O-RAN fronthaul interfaces. Fully scalable, the system has been designed to accelerate multi-standard end-to-end network verification by generating IP traffic load, simulating applications running on thousands of concurrent devices operating real voice and data sessions. Both conducted and live testing across the full range of frequencies is supported, with the possibility to cover real-world scenarios spanning protocol and load testing in the lab to field testing, trials and deployments.

4.3.2 VIAVI Tools

Probes

Selected 5G-TOURS and 5G-HEART use case measurement campaigns are based on the use of Viavi hardware network probes, as well modified open source-based software probes. In order to have more flexibility and cover a wider range of measurements, with use open-source solutions, an in-house developed KPI Management & Validation Platform (KMVaP), as well as Viavi's commercial controller software (i.e., Network Integrated Test, Real-time analytics and Optimization (NITRO) (nitro) platform Nitro Fusion ™[2]). The data collection is an automated process running 24x7, with 1min monitoring granularity and 10 ms sampling granularity. Relevant description is from 5G-HEART D6.3 KPI Assessment Tools [12].

[2] https://www.viavisolutions.com/en-us/products/fusion

All the components of the KMVaP platform are Virtual Machines using a VM Hypervisor (hvfs). A KAFKA interface is enabled in the the KMVaP management Platform to achieve interoperability with the 5G-EVE KAFKA s/w modules used by many projects. This way, the transfer of network data to be correlated with application data is facilitated and this led to specific AI/ML innovation in 5G TOURS project.

Hardware tools:

The Viavi **MTS-5800** handheld network tester can test throughout the service life cycle, including, service activation, troubleshooting, and maintenance. Advanced Ethernet test features such as throughput testing with TrueSpeed per RFC 6349 have also been employed.

The **VIAVI JMEP** micro Ethernet probe for Ethernet and IP performance assurance, are gigabit Ethernet **smart SFP** transceivers, available in two varieties, a 1 Gbps JMEP3 and a 10 Gbps JMEP10, that both can seamlessly be deployed inline into existing network devices.

Software tools:

Fusion TrueSpeed VNF: Throughput testing as a virtual network function based on RFC 6349, operating as a virtual network function (VNF) in conjunction with VMware hypervisors, Red Hat Linux, and x86 compute resources.

VCPE1 Software based probe: Being a virtual software probe a VCPE can host a number of different probe functionalities tailored to the measurements required by the network operator and/or Vertical user.

Software Based Probes (TWAMP Software): For time related KPI measurements like latency (one-way or round-trip), jitter, etc. it is very common to use ICMP based packet (most commonly referred to as PING). This is mostly a connectivity tool when the network infrastructure is being established or a new node is installed and configured. For more accurate time measurements, the Two-Way-Active-Measurement Protocol (TWAMP) is more appropriate.

As many probes as possible are deployed along the full E2E network, to evaluate separately the performance of all distinguished network segments (e.g., access, backhaul, aggregation, core, etc.), in terms of layer 2 & 3 KPIs. A HW probe is also connected at an interface (GE/10GE) in the core of the 5G network where all the network traffic is passing through. It will provide recording of the layer 3 & 4 (and above) signals using hardware and software filters. Accurate timestamping of the recorded signals is performed.

4.3.3 INTERNET INSTITUTE Tools

qMON [30] is a quality monitoring system optimized for test automation of heterogeneous (mobile, cloud and fixed) networks and services. It supports quality assurance testing, benchmarking and KPIs (5G NR phy, network and application level) validation with capabilities for end-to-end quality monitoring and QoE/SLA assurance. The solution is adaptable for specific architectures and extendable for KPI, SLA and performance metrics (e.g., throughput, delay, jitter, RSRP, RSRQ, SINR), which allows for flexible applied real-time performance and quality validation. Supported use cases are:

- 5G drive and benchmark testing,
- 5G end-to-end QoS and QoE monitoring of network and services in live environments,
- Continuous service and SLA/SLS monitoring in real-time,
- 5G NR coverage and performance assessment,
- Live 5G network and service troubleshooting,
- 5G Network and services trending,
- Device and system performance predictions under realistic load conditions.

qMON agents are available in various form factors (e.g., industrial 5G UE, Commercial 5G UE, VNF or containerised) to be used in different environments (outdoor or indoor) and mobile network segments (e.g., RAN, core network or cloud).

5 Data Collection Platforms

Prometheus node exporter: it is a piece of software, installed on Linux machines, that exposes to the Prometheus server hardware and OS metrics. Running on the machine the Prometheus node exporter is able to collect from the OS different metrics: CPU, disk I/O (filesystem statistics, disk space usage), network I/O (interface statistics such as bytes transferred), etc. Prometheus node exporter does not require an additional configuration once installed.

Prometheus Blackbox exporter: it is a piece of software, installed on Linux machines, that enables the possibility to probe endpoints over HTTP, HTTPS, DNS, TCP, and ICMP, measuring core KPI - "Availability". The Prometheus Blackbox exporter allows the possibility to monitor service status and notifies the Prometheus server this information.

ELK stack: ELK stack can be used for measuring application related KPIs (e.g., the core KPI "creation/adaptation time"). It is composed by three main open-source products developed, managed and maintained by Elastic13, which perform the three main functions defined for the toolchain:

- Logstash for data collection, aggregation and pre-processing. It is a server-side data processing pipeline that collects data from multiple input sources simultaneously, executes different transformations and enhancements and then ships the data to various supported output destinations; in our case, Elasticsearch.
- Elasticsearch for data indexing and storage. It is an open source, distributed, RESTful, full-text and JSON-based search and analysis engine, based on the Apache Lucene search engine, which is easy to use, scalable and flexible.
- Kibana for data visualization. It is a visualization layer that works on top of Elasticsearch, providing users with the ability to analyse and visualize the data with charts and graphs.
- Filebeat: By installing the Filebeat component of the ELK stack on each component of the orchestration, it is possible to collect the related logs.

The Elastic Stack can be installed using a variety of methods and on a wide array of different operating systems and environments. In fact, it can be installed locally, on the cloud, using Docker and configuration management systems like Ansible, Puppet, and Chef. The environment chosen for the installation of the Elastic Stack in the 5G-EVE project will be described in future deliverables related to implementation issues.

Log Management tool: This system is based on a data pipeline that manages the monitoring of instantiation, scaling, and termination time-related metrics from network services initiated by the 5Growth Service Orchestrator (5Gr-SO) in both batch and real-time mode, collecting log changes inside the 5Gr-SO. To build the data engineering pipeline, the whole architecture is composed of five main modules: (a) *Data Connection*; (b) *Data Ingestion*; (c) *Data Pre-processing*; (d) *Data Visualization*; and (e) *Data Analysis*. First, the 5Gr-SO starts logging the whole service instantiation (termination or scaling) process. The Flume application (running in the connection module) periodically monitors the changes in the logs of the 5Gr-SO as given in and sends data to the data ingestion layer. The Kafka application (running in the ingestion module) ingests log messages transmitted from Apache Flume and the log messages fetched by Kafka are temporarily stored in the Kafka broker under a specific topic. In Data Pre-processing module, Apache Spark is used for cleansing real-time data, parsing and cleansing the incoming log messages from the Kafka topic and extracting the relevant metric values. The obtained data is sent back to the Kafka broker. Finally, Elasticsearch (ELK) stack is used in the Data Visualization module, collecting the data from Kafka and pushing it ed to Elasticsearch. The output of log time differences of the system is then visualized by Kibana.

Telegraf is a plugin-driven server agent for collecting and reporting metrics. Telegraf has integrations to source a variety of metrics, events, and logs directly from the con-tainers and systems it's running on, pull metrics from third-party APIs, or even listen for metrics via a StatsD and Kafka consumer services. It also has output plugins to send metrics to other datastores, services, and message queues, including InfluxDB, Graphite, OpenTSDB, Datadog, Librato, Kafka, MQTT, NSQ, and many others

OML is an instrumentation tool to support monitoring systems in testbeds. It allows ap-plication writers to define customizable Measurement Points (MPs) inside new or pre-existing applications. The MPs define the metrics that will be monitored. Data are col-lected for each measurement point in OML stream format. Experimenters running the applications can then direct the measurement streams from these MPs to remote collec-tion points, for storage in measurement databases.

Librato is a cloud-based monitoring platform for development and operations teams who want the flexibility to monitor the metrics and events important to their application de-ployment, while leaving storage, analysis and alerting to a service that can scale with their operation.

Fluentd [31] is an open-source project which is widely used as data collector achieving a better use and understanding of data. It aims to: a) Unify the logging with a common JSON data structure; b) Offer a pluggable architecture based on data sources, data filters and data outputs; c) Use as minimum resources as possible; d) Offer a built-in reliability.

6 Visualization Tools

Grafana is a data visualization and monitoring tool with support for many different storage backends for your time series data (Data Source). Each Data Source has a specific Query Editor that is customized for the features and capabilities that the particular Data Source exposes. The following data sources are officially supported: Graphite, InfluxDB, OpenTSDB, Prometheus, Elasticsearch, CloudWatch.

Graphite is a free open-source software tool that monitors and graphs numeric time-se-ries data such as the performance of computer systems. It focuses on being a passive time series database with a query language and graphing features. Graphite collects, stores, and displays time-series data in real time.

Tableau Public is a free service that lets anyone publish interactive data visualizations to the web. Visualizations that have been published to Tableau Public can be embedded into web pages and blogs, they can be shared via social media or email, and they can be made available for download to other users. Visualizations are created in the accompanying app Tableau Desktop Public Edition. No programming skills are required.

An example of KPI results visualization collected as part of a 5G drive test and continuous 5G network monitoring in the 5G-LOGINNOV project is depicted in the Figure 6 and Figure 7.

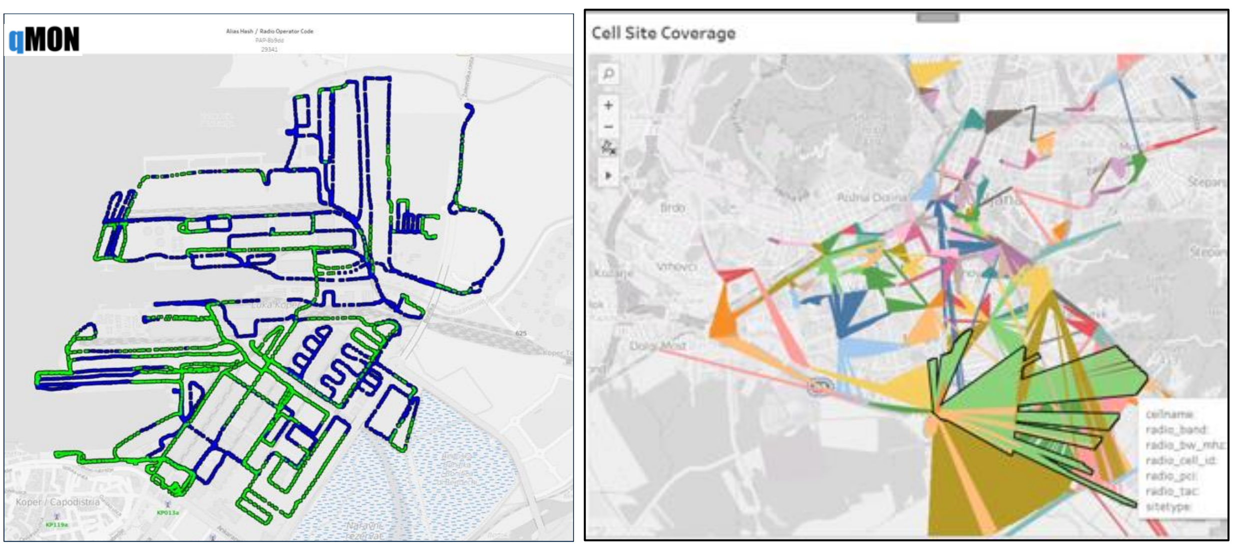

Figure 6: KPI results visualization collected as part of a 5G drive test.

Figure 7: KPI results visualization collected as part of a 5G network continuous monitoring.

7 Conclusions

This document performs a recognition on the 5G Key Performance Indicators (KPIs) and the tools that have been considered during the execution of 5G trials in different European projects. In particular, the involved members of the different projects, including ICT-17, ICT-19, ICT-41 and ICT-52 projects, have reported the 5G KPIs and the tools considered.

The document reports the list of 5G KPIs, considering the different technologies and the different segments of the mobile network involved. Each KPI is described in an effecting manner, also including the measurement unit and a label. In addition, a generalized methodology for the mapping of the KPI and the measurement operation is presented.

The document also provides the tools utilised by the members of the different projects. The list of tools has been classified into three main categories of tools: the open-source tools, the ad-hoc defined tools and the commercial tools. The open-source tools have been described and mapped to the KPI they can measure. The lists include heterogeneous tools spanning from networking metrics (i.e., latency, throughput), to API testing and service streams emulation. For specific metrics, where no open-source tools were available, some of the projects has developed use-case tailored tools. Those tools/probes have been described, highlighting the interfacing features developed in the context of the specific project. Finally, the commercial tools list reports the recognized products, provided by different vendors, that have been included in the evaluation of KPIs during the execution of the experimental validations.

Finally, the document presents the platforms that have been considered for the data collection, interfacing the tools and the probes described, and the tools for visualization of the metrics. In this case, the analysis of the tools has been carried out considering the main functionalities provided by each tool, highlighting the features/availability of plugins/APIs to connect external tools/frameworks, including probes, data sources and databases.

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Contributing Projects

Project	
5G EVE	
5G-VINNI	
5GENESIS	
5G-TOURS	
5G-HEART	
Int5Gent	
5GASP	
5G-LOGINNOV	
5Growth	

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