# A KPI-enabled NFV MANO Architecture for Network Slicing with QoS

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***Abstract*—Communication systems are not only used by voice or file exchange applications but also by other types of applications due to the co-existence of multiple and different verticals. Each vertical has its own requirements in terms of Key Performance Indicators (KPIs) for their applications. Mapping the verticals KPIs into network Quality of Service (QoS) parameters and enforce it at the network level is a complex procedure. Network slicing allows the deployment of multiple virtual networks (one per vertical) to work in parallel with their specific QoS based on the KPIs. This article presents and experimentally validates a KPI-enabled Network Function Virtualisation (NFV) Management and Orchestration (MANO) architecture able to manage network slices, to monitor the vertical KPI requirements and react in case they are not met. We address this objective from a holistic perspective, defining the network QoS parameters that enable to meet vertical KPIs along all levels of the NFV MANO architecture: the network slices using 5G QoS Identifier (5QI) parameter, the NFV Network Services using Service Level Agreements (SLAs) and the networking and computing services with QoS parameters. Finally, the described architecture is validated through an experimental use case based on a vertical real-time communications application.**

***Index Terms*—KPI, Network function virtualization, Network slicing, QoS, SLA, Software defined networking**

## I. Introduction

One of the major problems from a vertical point of view is the use of a common 5G infrastructure together with other verticals with much different Key Performance Indicators (KPIs) at the application level. Each vertical has its own and specific set of KPI requirements which can be mapped to different Quality of Service (QoS) parameters in terms of 5G networks. As such, an e-health application service differs from an automotive service in terms of specific network performance aspects. The use of network slices is a novel approach to ensure that all requirements from different verticals are fulfilled over the same physical network and, at the same time, keeping their specific requirements. Network Slicing [1] allows to create and manage parallel virtual networks, each specifically dedicated to a single vertical service with specific QoS requirements at the network level.

Due to the existence of multiple verticals and their specific requirements, the network slices management is a complex task as there are different stakeholders involved [2]. For example, M.Vincenzi et al. [3] presented a network slice auctioneer as the central element for the different stakeholders in 5G networks to interact with each other. In another example, A.Papageorgiou et al. [4] describes an SLA manager on top of an architecture defining how the Network Slices must be. Y.Cui et al. [5] shows a Network Slicing architecture for automotive communications and, finally, F. Ansah et al. [6] studies communications with services focused on industrial networks. While these work focuses either on a specific vertical scenario [2], [5], [6] or the architecture presented might constrain the Network Slices definition to the SLAs [4], this article aims to present a solution to deploy network slices for all vertical scenarios and in which Network Slices are not defined by SLA but combined with SLAs.

This article presents and demonstrates beyond the state of the art techniques, across the following main axes: (i) the extension of the architecture of Network Function Virtualisation (NFV) Management and Orchestration (MANO) with the capability to deploy network slices with the required QoS to fulfil the vertical / application domain KPIs, (ii) the runtime monitoring of the aforementioned KPIs in the deployed network slices and the triggering of adaptation decisions in order to ensure their fulfilment, and (iii) the capability to provide QoS guarantees at the 5G network level across all the involved layers: from the network slice and its NSs to the final deployed connectivity and computing services.

To do so, the whole process is described; first by mapping vertical KPIs within the network slice descriptor using a QoS classification. Then, based on this QoS classification, the appropriate Service Level Agreement (SLA) is selected for each NS composing the network slice and, finally, based on the selected SLAs and NSs, the corresponding virtual instances are deployed with the correct resource configuration to enforce the expected QoS. To validate the previously introduced concepts, an experimental validation using a real market Real-Time Communications (RTC) application was selected to deploy multiple network slices with different associated QoS and then, a set of metrics were used to check the correct QoS implementation and monitoring of the vertical KPI parameters.

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The rest of this paper is organized as follows. The second section presents the KPI-enabled NFV MANO architecture with the QoS and KPI monitoring functionalities to apply the different actions to create and manage network slices. The third section describes the implementation of the proposed architecture over a real testbed infrastructure, the network slices and QoS parameters design and it finishes with a set of results validating the correctness of the whole process. Finally, in the last section, the conclusions are presented.

## II. Architecture and Workflows

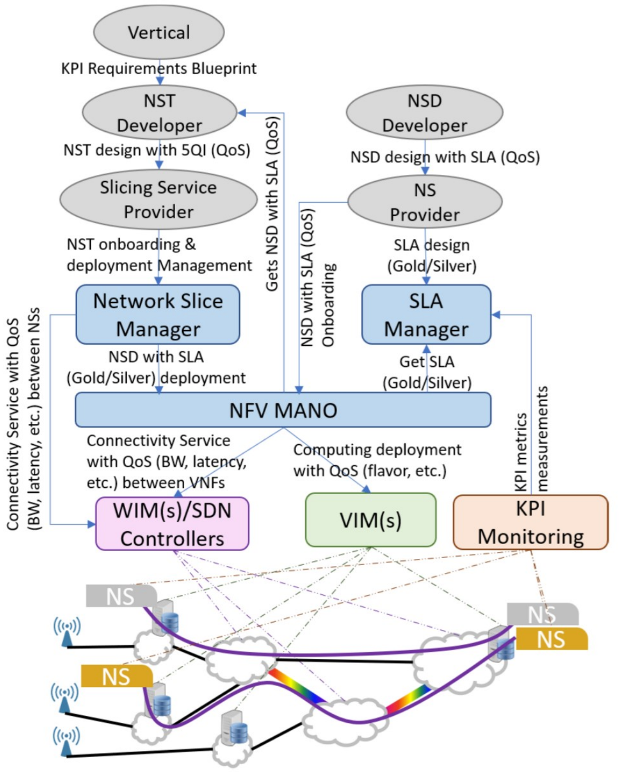


Fig. 1. Generic Architecture with Network Slicing and SLA life cycle management.

This section describes the vertical KPI-enabled NFV MANO architecture for network slices with QoS and how the different actors (i.e., Verticals, Developers and Service Providers (SPs)) participate to have the Vertical KPI requirements correctly mapped at each architecture layer and deployed over the physical 5G infrastructure.

The designed system allows to define customized SLA with different QoS parameters and to monitor them in parallel allowing the coexistence of different requirements defined by the 5G services (i.e., Enhanced Mobile Broadband (eMBB), Ultra-reliable and Low-latency Communications (uRLLC), and Massive Machine Type Communications (mMTC)). For this reason, the system can manage different Network Slices and each with its own QoS requirements being monitored in parallel.

Figure 1 shows the different modules composing the architecture (rectangular-shape modules), the different actors using it (circle-shape modules) and the different actions between modules and actors. Fig.2 presents the workflow with the interactions between the actors and the architecture modules.

### A. *KPI-enabled NFV-MANO Architecture*

The designed architecture has the following components (rectangular modules):

*1) Network Slice Manager:* It controls the network slice life cycle by managing the Network Slice Templates (NSTs) and Network Slice Instances (NSIs) data objects. NSTs describe the set of NSs and the links to interconnect them that compose a network slice. NSIs keep the information of a deployed NST; the set of computing and networking instantiated resources to have a network slice. Based on the ETSI NFV standard [7], the Network Slice Manager communicates with the NFV MANO by passing the different requests to apply any action over the virtual elements composing the network slice.

*2) NFV MANO:* It manages the life cycle of NSs and their internal elements, the Virtual Network Functions (VNFs). Like the Network Slice Manager, the NFV MANO makes use of NS descriptors (NSD) to define how a NS is composed by a set of VNFs and links. When a request from the Network Slice Manager to deploy a NS with an associated SLA arrives, the NFVO MANO takes care to instantiate the corresponding VNFs.

*3) SLA Manager:* It manages SLA Descriptors (SLADs) with the QoS requirements, applying them over the corresponding NS and, finally, it monitors and controls if any SLA has been violated while the network slice is deployed.

*4) Virtualized Infrastructure Manager (VIM):* It creates virtual computing elements with the required characteristics (i.e., CPU, memory and storage) for the VNFs.

*5) Software-Defined networking (SDN) Controller/WAN Infrastructure Manager (WIM):* It creates the connectivity services between the VNFs composing each NS and between the NSs composing a network slice.

*6) KPI Monitoring:* It receives metrics from the different VNFs, gathers them and generates SLA violation alerts for the SLA Manager. The KPI Monitoring provides several mechanisms like monitoring probes deployed next to the VNFs, Application Programming Interface (APIs) in which VNFs can directly push metrics or well-known protocols like Simple Network Management Protocol (SNMP) to make the collection of the performance metrics easier.

*7) 5G Physical Infrastructure:* It is distributed in different domains (edge, transport, core), each of them with its own set of computing and/or networking resources.

### B. *From the KPI requirements to the network QoS ensurance: A QoS chain*

The most important aspects to know before discussing how the different elements involved in the architecture interact between them are: first, how the vertical KPIs are mapped to network QoS parameters and, second, how they are considered at each architecture layer in Fig.1.

When a NST is designed, the NST Developer must map the vertical KPI requirements into a set of metrics that can be monitored at a NS/VNF level. To do so, a standardized

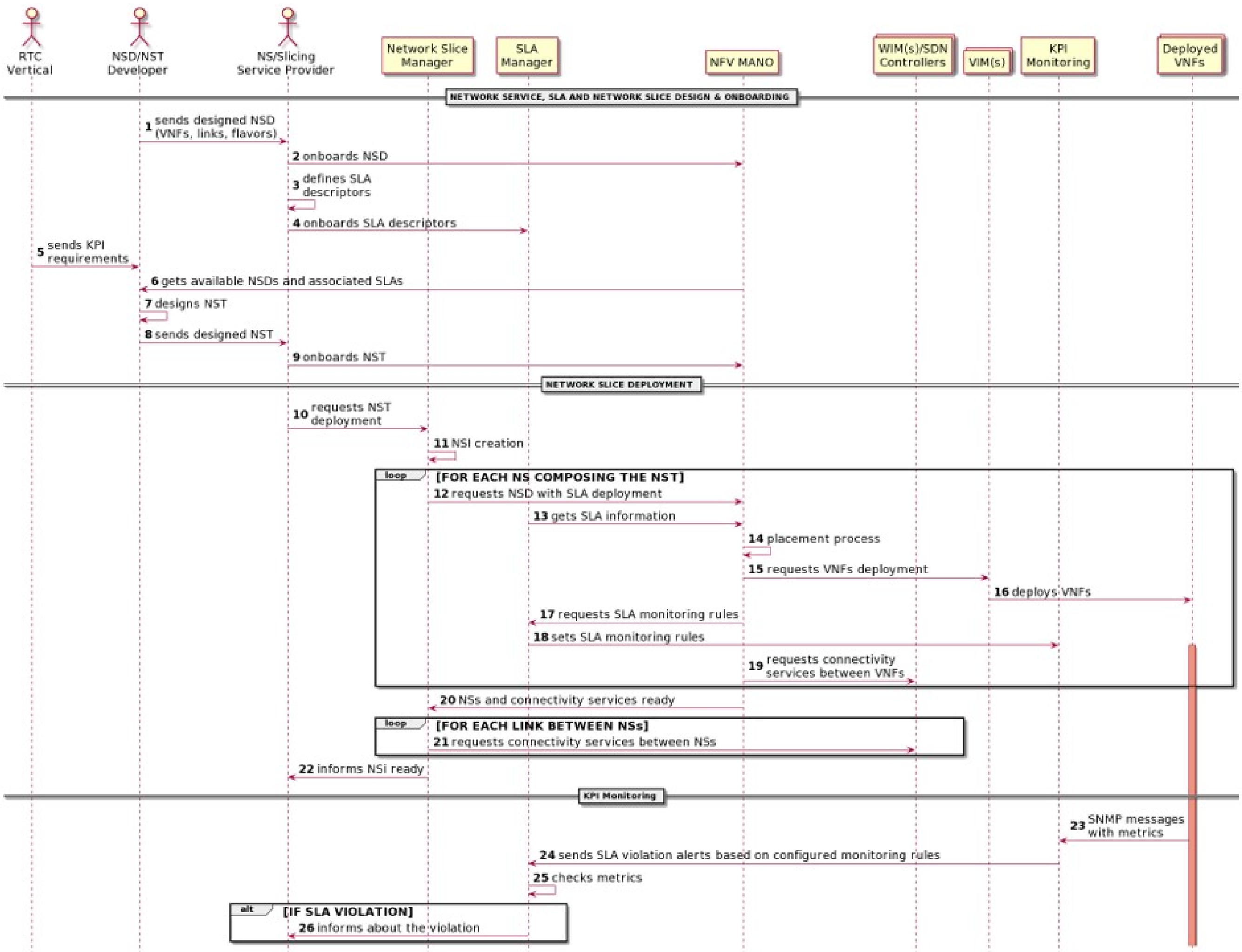


Fig. 2. Design, onboarding, deployment and monitoring workflow steps.

QoS classification should be used. The option selected in this article and used during the experimental section is the 5G QoS Identifier (5QI) parameter, defined by the 3rd Generation Partnership project (3GPP) [8]. The 5QI is a scalar value that defines a set of 5G QoS characteristics. This parameter is usually associated to be used in Radio Access Network (RAN) and Core domain scenarios and in our current work we selected because it for two reasons. It allows to define a set of QoS parameters for a Network Slice by using a single reference and, in future works involving RAN, the implemented architecture will already be based on it. Based on the vertical KPI requirements, the NST Developer selects the most appropriate 5QI value (i.e., 5G QoS characteristics) and chooses the NS and SLA descriptors with more possibilities to guarantee them.

The QoS mapping from a network slice layer to a NS layer uses SLAs and NS flavors. The concept of flavor should be understood as a NS with specific instantiation parameters associated to several properties, such as Bandwidth (Bw), latency, etc. Thus, defining multiple flavors in a single NSD allows to deploy the same NS with different QoS requirements and to avoid the management of many similar NSDs in the Data Base (DB). Flavors are necessary when designing SLAs for an existing NS. Based on the SLA requirements, the most appropriate flavor will be associated and when deployed, the required amount of networking resources will be selected.

Keeping in mind the previous chain (vertical KPI - 5QI - SLAs) and once a network slice is requested to be deployed, the Network Slice Manager passes the NSs and their associated SLAs information to the NFV MANO. The NFV MANO will check which flavor is associated to each SLA and request to deploy a NS with the specific parameters that will allow to fulfill the expected QoS defined by the vertical KPI requirements.

### *C. Designing and Onboarding Network Services, SLAs and Network Slices*

To offer a service for a certain vertical, the following actions need to be done.

From the NS point of view (top right side in Fig.1) and as Fig.2 presents, these actions begin when a NSD Developer creates the NSDs with the following information: the VNFs composing the NS, how the VNFs are linked to each other and, finally, a set of flavors. With the NSD ready, the NSD Developer sends it to the NS SP (step 1 in Fig.2) and the NS SP onboards it to the NFV MANO (step 2). Together with the NSD onboarding action, the NS SP defines the SLA descriptors (step 3) to have them available to be selected when a NS deployment is requested. When an SLA is defined, aside of the Service Level Objectives (SLOs) and metrics to monitor, it is necessary to associate the SLA to a NS flavor. By doing so, when a NSD is requested to be deployed with a specific SLA, the right flavor within the NSD will be selected to create the virtual computing and networking elements with the most suitable characteristics to fulfil the SLOs. Finally, the SLAD is onboarded (step 4).

From the network slice point of view (top left side in Fig.1) and as Fig.2 presents, the process to design a NST begins when a vertical defines the KPI requirements blueprint to the NST Developer (step 5). With these requirements, the NST Developer requests to the NFV MANO to get the available NSDs and their associated SLAs (step 6). This information, together with the Vertical KPI requirements, allows the NST Developer to design the NST (step 7) by: selecting the appropriate 5QI value that maps better with the vertical KPI requirements and, choosing the NSDs with the most appropriate SLA, so each NS will have the desired QoS to reach the threshold values defined by the 5QI and fulfil the vertical KPI requirements blueprint. With the 5QI, the NSDs and their SLAs selected, the NST Developer defines how the NSDs will be linked to each other. Once the NST is defined, the NST Developer will give it to the Slicing SP (step 8), who will onboard it in the Network Slice Manager (step 9) and leave it ready to be deployed when requested.

### *D. Network Slice Deployment*

As presented in Fig.2, the deployment of a NST starts when the Slicing SP requests the Network Slice Manager (step 10) the desired NST based on the agreed QoS to meet the vertical KPI requirements. Once the Network Slice Manager receives the request, it starts creating a new NSI record (i.e., JSON data object) with the context deployment information such as an internal ID, the name, the description of the overall network slice element given in the instantiation parameters and other parameters (step 11). Once the context is ready, the Network Slice Manager will start to request the instantiation of each NS composing the network slice to the NFV MANO by passing the NSD and the associated SLA identifiers (step 12).

Using this information, the NFV MANO can check through the SLA Manager which flavor of the NSD is associated to the selected SLA (step 13). Then, based on the selected flavors defining the required QoS, the Network Slice Manager applies a placement procedure (step 14) to identify which of the available VIMs is the most suitable to deploy each NS composing the network slice and to fulfil the QoS. Once the NFV MANO has all the necessary information, it makes the following requests: a) the instantiation of the multiple VNFs composing the NSs to the selected VIMs (steps 15 - 16), b) to configure the SLA monitoring rules to the SLA Manager which sets them in the KPI Monitoring (Steps 17 - 18) and, c) the creation of connectivity services (i.e., virtual links) based on QoS parameters to interconnect the VNFs composing each NS to the different domain WIMs/SDN Controllers (step 18) where a NS is placed. Then, when the NSs are ready and allocated across the multi-domain infrastructure (step 19), the Network Slice Manager requests the interconnection between NSs with the required QoS to the WIMs/SDN Controllers in charge of the transport domains (step 20). Finally, once all the network slice components are ready, the Slicing SP is informed (step 21).

### *E. KPI Monitoring*

Once the network slice is deployed, the Slicing SP may inform the final users of how to access and use the deployed service. However, the tasks for the Slicing SP are not finished. From this moment on, it must control and ensure that the service performance is within the expected QoS for as long as the service is alive. The Slicing SP will take all the necessary measures by reacting to the SLA monitoring alerts to ensure the requested QoS in the network.

Within the infrastructure presented in Fig.1, the KPI Monitoring module configures the reception of metrics so that they can be sent directly from the VNFs using SNMP. As Fig.2 shows, each VNFs exposes a set of performance metrics (e.g., via SNMP) to the KPI Monitoring module (step 22). Then, the KPI Monitoring evaluates the status of the SLA monitoring rules and in case of an alert event, it sends a notification to the SLA Manager (step 23). Once the information has reached the SLA Manager, this checks if the QoS is accomplished (step 24) or, on the contrary, an SLA has been violated (step 25) and informs the Slicing SP about it.

Making the VNFs responsible of sending the metrics implies that, when the VNFs are being designed for a NS, the NS Developer must add the required information (e.g., metrics, SNMP OID, etc.) inside the VNF descriptor to configure properly the SMNP mechanism of the KPI Monitoring module.

## III. Experimental Validation

This section presents how the previously described architecture has been implemented in a testbed. Then, the selected NS and SLA to be deployed through network slicing are described. Finally, a set of results are presented to demonstrate the correct functionality of the testbed implementation and the vertical KPIs fulfillment.

### *A. The CTTC ADRENALINE Testbed*

Figure 3 shows the implementation of the architecture presented in Fig. 1. This testbed has been designed and implemented following the idea of a disaggregated network model, which makes its maintenance more flexible and agile due to the use of hardware that does not depend on a specific software. Thanks to the latest standards on optical/packet transport networks, edge/cloud computing architectures and, overall, the implementation of the SDN/NFV control and service layer.

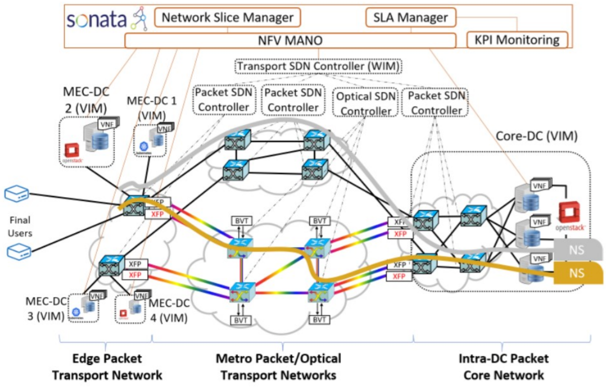


Fig. 3. CTTC ADRENALINE Testbed.

For the CTTC ADRENALINE testbed [9] we evaluated multiple open-source MANO implementations [10] and decided to use SONATA Service Platform because it allows to have the Network Slice Manager, the NFV MANO, the SLA Manager and the KPI Monitoring modules in a single piece of software. Below, there are Cloud and MEC Data Centers (DCs) allocated in different network domains with a VIM in each DC. Each VIM uses either an OpenStack or a Kubernetes implementation to manage kernel-Virtual Machines (kVM) or container-based resources, respectively.

The Transport SDN Controller (WIM) [11] used has been developed by the CTTC and it is based on the IETF Application-Based Network Operations (ABNO) architecture [12]. It communicates with a set of SDN controllers placed below. In the packet-based domains, the SDN controllers are based on OpenDaylight (ODL) and, in the optical domain, it is an Open Line System (OLS) controller. The Transport SDN Controller communicates with the NFVO above and the Transport SDN Controller below using Transport API (TAPI) [13].

Finally, the physical network infrastructure has different computing domains (edge and core) interconnected by multiple transport networks based on packet and optical technologies. Ten Open-Flow switches are distributed in the multiple packet-based networks and are controlled using Open vSwitch (OVS). Regarding the optical-based network, it is designed as a Photonic Mesh Network (PMN) managed by an Open Line System (OLS) controller. One last and important aspect is the fact that the Transport SDN Controller may use the packet-based or the optical transport networks based on the QoS parameters requested.

### *B. RTC Vertical KPIs definition and RTC Network Service and SLA design*

The vertical selected is a RTC application for media applications. Three KPIs were selected for the experimental validation: Packet loss (Pl), Symmetric User Datagram Protocol (UDP) throughput and Round-Trip time (RTT).

The selected RTC NS was composed by the following set of VNFs:

- Media-Server (VNF-MS): It manages the Real-Time Protocol (RTP) traffic exchange among all the participants.
- Reverse proxy VNF (VNF-RP): It receives all the HTTP/WebSocket incoming traffic and forwards it to the different VNFs composing the NS.
- WebRTC Application Controller (VNF-WAC): It manages the application logic for Authentication, Authorization and Accounting (AAA) tasks related to the users and the signaling logic to setup the videoconferences. Compared to the VNF-MS, this VNF has lower requirements in terms of Bw or delay as its internal traffic is not of a media type.
- Dispatcher (VNF-DS): It manages the different Selective Forwarding Units (SFUs) that may be generated and sends their information to the VNF-WAC, so this last VNF can create new multimedia sessions for each SFU.
- Back-end Services (VNF-BS): It contains the DB and the queue system used to store status information and to interact between the different services.

Together with the NS, two different SLADs were created based on the vertical KPI requirements: a) GOLD SLA (i.e., Pl < 1 %, Symmetric UDP throughput > 100 Mbps and RTT < 40 ms), and b) SILVER SLA (i.e., Pl < 2 %, Symmetric UDP throughput > 80 Mbps and RTT < 40 ms).

For simplification, only the GOLD and SILVER SLAs were proposed, but it is possible to define other SLAs to have better granularity with the QoS. To be more accurate, a service profiling should be used to solve. Although this aspect is out of the scope of the current work, a possible solution could be the use of the Validation and Verification tool [14] included in the SONATA framework, which can be used for NS profiling.

Finally, within the NSD, two different flavors were designed. For simplicity on the relationship between each SLA and its associated NSD flavor, we kept similar names. One called "gold" (related to the GOLD SLA) with a required minimum bandwidth of 1000 Mpbs, and the second called "silver" (related to the SILVER SLA) with a required minimum bandwidth of 500 Mpbs.

Further information about the use case preparation such as the servers technical specifications or other details regarding the NS and the SLAs used, can be found in [15].

### *C. Network Slice and QoS design*

Having described the NS and the SLAs, the last necessary element to complete the creation of a specifically dedicated virtual network for this service is the NST design. Any NST follows the same pre-defined structure with three main sections: the NST metadata (i.e., NST name, author, 5QI, etc.), the list of NSDs composing the Network Slice and the list of virtual links that interconnects them. Due to the design of the RTC NS, there is no need to add more NSs within the NST to get the complete RTC functionality. Keeping this in mind, two different NSTs were created, onboarded and deployed: one using the GOLD SLA and another one using the SILVER SLA. As previously described, within each NST there is the 5QI parameter that defines a set of QoS requirements that each NS must fulfil. In the case of the two created NSTs, the values were 5QI = 2 that limits the packet delay < 150 ms for the SILVER (60 ms) case and a 5QI = 3 that limits the packet delay < 50 ms on the GOLD case (40ms).

### D. Results

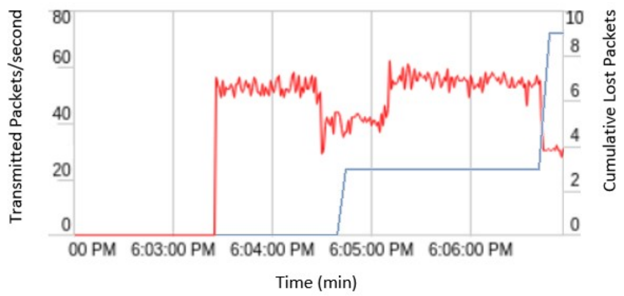


Fig. 4. Transmitted packets per second (red line) versus cumulative value of lost sent packets (blue line).

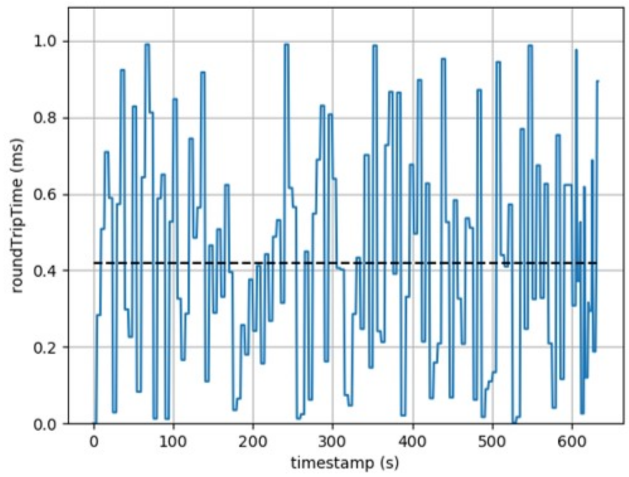


Fig. 5. RTT values for the video data flow.

To demonstrate the described architecture feasibility, different videoconferences tests were launched to validate the NS deployment and to check if the QoS requirements were accomplished. The tests were done using different cases; with the GOLD and SILVER SLAs and then, without SLA (i.e., best effort). To have stable results, each test had a time duration of 180 s minimum and the RTC NS was deployed in the cloud DC to use the transport domains.

An initial outcome to identify the difference between the GOLD SLA (the best) and the other cases was obtained by checking the bandwidth (Bw) at the application layer. The NS deployed with the GOLD SLA had a stable Bw of 300 Kbps and with the SILVER SLA, the Bw was of 128 Kbps. The main reason for this difference is the use of different transport domains: optical for the GOLD SLA and packet-based for the SILVER SLA. Finally, when no SLA was utilized and despite the videoconference was quite irregular but still possible, the Bw was at 80 kbps. Furthermore, we did an additional evaluation to define the lowest BW value in which the Quality of Experience (QoE) becomes bad and the image is blocked, which was achieved around 50 Kbps Bw.

In addition to the Bw results, statistics regarding the packets lost were taken. For a call with a duration of 180 s, the mean value of transmitted packets per second was of 50 (Fig.4 red line), giving a total of 9000 transmitted packets. Based on the cumulative value of lost sent packets presented in Fig.4 (blue line), the packet-loss probability was of a 0.022 %, which is a much lower than the 1 % requested in the GOLD SLA. This means that the network slice deployment using the GOLD SLA was well implemented and the final users received the appropriate QoS and had the expected QoE.

Another parameter to validate the proper deployment of the GOLD SLA is the RTT value for the audio and video data flows. For both data flows, the RTT requirement while using the GOLD SLA was limited to a value lower than 60 ms. Figure5 shows the histogram of the RTT for the video data flow during one of the videoconferences with GOLD SLA. As Fig.5 shows, the mean value of the RTT is much lower than the maximum threshold, being around 0.41 ms. In addition, when we looked at the histogram of the RTT for the audio data flow in that same call, the mean value was of 0.5 ms.

To ensure the stability on the previous results and accomplish the different SLA requirements, the implemented architecture uses the NS flavors to configure the appropriate connectivity services (CSs) across the transport network domains. As the NS gold flavor required a minimum Bw of 1000 Mbps and the NS silver flavor a minimum Bw of 500 Mbps, once the NS was deployed, the NFV MANO requested the Transport SDN Controller selected the most suitable transport domain to deploy the CSs with the required Bw values. So, for the GOLD SLA, the optical domain was used and for the SILVER SLA, the packet-based domain was selected.

An interesting aspect regarding the results is the difference of Bw resources; while the SLAs requested a Bw of 500 (SILVER) and 1000 Mbps (GOLD) at the physical layer. The values at the application layer the Bw (i.e., transmission rate) were of 128 Kbps (SILVER) and 300 kbps (GOLD). There is a low use of resources and so, to solve this issue, a possible solution is the implementation of policies.

## IV. Conclusions

With this article we presented an NFV architecture able to ensure and monitor the expected QoS required by a set of KPIs requirements using of network slices. The architecture components and their interactions with the different actors were described together with all the chain that links the QoS across all the architecture layers. The architecture allows to create parallel virtual networks working in parallel and each one of them achieving its QoS.

The presented infrastructure has been implemented and tested using the CTTC ADRENALINE testbed. By setting up a set of tests that used an RTC Service deployed with different SLAs (based on a set of KPIs), visual and statistical results were presented to validate the correct network slicing deployment, the SLA monitoring and allowed to demonstrate how users may have different QoS and QoE.

The results show that the described and implemented architecture works correctly regarding the management of the service deployment and monitoring actions. Moreover, the different QoS levels for the same service are respected and the system can ensure them. So, the implemented testbed could be exploited to test and validate services in an environment close to future real-world control scenarios. One more conclusion regards the underused networking resources, this is due to an error on the design of Ns and SLA deployment. Possible solutions could be to test and to correct the descriptors or the use of policies to apply re-configuration action.

There are additional challenges to be investigated and addressed regarding this type of architectures. Such challenges include the resolution of SLA violations, the low use of resources, and the use of policies as potentially the most suitable means to address issues related to SLA violations or low resources utilization. Another topic of interest is the security aspects at any NFV/SDN level by using Security SLA or other technologies such Machine Learning to manage slices in a multi-domain/multi-operator scenario and in a more autonomous way.

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## References

[1] NGMN P1 WS1 E2E Architecture Team, *Description of Network Slicing Concept*, 15th ed., NGM Alliance, 2018.

[2] J. Ordóñez et al., "Cross-domain slice orchestration for advanced vertical trials in a multi-vendor 5g facility," in *2020 European Conference on Networks and Communications (EuCNC)*, 06 2020.

[3] M. Vincenzi et al., "Multi-tenant slicing for spectrum management on the road to 5g," *IEEE Wireless Communications*, vol. 24, no. 5, pp. 118–125, 2017.

[4] A. Papageorgiou et al., "Sla management procedures in 5g slicing-based systems," in *2020 European Conference on Networks and Communications (EuCNC)*, 2020, pp. 7–11.

[5] Y. Cui et al., "An intelligent coordinator design for network slicing in service-oriented vehicular networks," in *GLOBECOM 2020 - 2020 IEEE Global Communications Conference*, 2020, pp. 1–6.

[6] F. Ansah et al., "Worst-case delay slicing for time-sensitive applications in softwarized industrial networks," in *2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*, vol. 1, 2020, pp. 1652–1659.

[7] NFV-ETSI-ISG, *Report on Network Slicing Support with ETSI NFV Architecture Framework*, 3rd ed., ETSI, 2017.

[8] 3rd Generation Partnership project (3GPP), *System Architecture for the 5G System (5GS); Stage 2,*, 16th ed., 3rd Generation Partnership project (3GPP), 2020.

[9] R. Muñoz et al., "The adrenaline testbed: An sdn/nfv packet/optical transport network and edge/core cloud platform for end-to-end 5g and iot services," in *2017 European Conference on Networks and Communications (EuCNC)*, 2017, pp. 1–5.

[10] P. Trakadas et al., "Comparison of management and orchestration solutions for the 5g era," *Journal of Sensor and Actuator Networks*, vol. 9, no. 1, p. 4, 1 2020.

[11] A. Mayoral et al., "Sdn orchestration architectures and their integration with cloud computing applications," *Optical Switching and Networking*, vol. 26, pp. 2 – 13, 2017, advances on Path Computation Element. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1573427716000047

[12] D. King et al., "Rfc7491: A pce-based architecture for application-based network operations," *Internet Engineering Task Force (IETF)*, 03 2015.

[13] V. Lopez et al., "Transport api: A solution for sdn in carriers networks," in *ECOC 2016; 42nd European Conference on Optical Communication*, 2016, pp. 1–3.

[14] M. Peuster et al., "Introducing automated verification and validation for virtualized network functions and services," *IEEE Communications Magazine*, vol. 57, no. 5, pp. 96–102, 2019.

[15] 5GTango Project, "D7.3 final demonstrators and evaluation report," PDF, 2 2020, accessed on 26/11/2020.

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