H2020 5Growth Project
Grant No. 856709

D5.5: Demonstrations at Mobile World Congress and EUCNC or equivalent

Abstract

One of the dissemination goals of 5Growth is to conduct technology demonstrations in high-impact venues, such as EuCNC. This document briefly explains the demonstration activities carried out the second year of the project, which have been virtual conferences and online events due to the COVID-19 global pandemic. Other information related to the demonstrations carried out by the project is also provided.

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Disclaimer

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List of Acronyms

5Gr – 5Growth

5Gr-AIMLP – 5Growth AI/ML Platflorm

5Gr-RL – 5Growth Resource Layer

5Gr-SO – 5Growth Service Orchestrator

5Gr-VoMs – 5Growth Vertical-Oriented Monitoring System

5Gr-VS – 5Growth Vertical Slicer

5GT – 5G-TRANSFORMER

5GT-MTP – 5G-TRANSFORMER Mobile and computing Transport Platform

5GT-MON – 5G-TRANSFORMER MONitoring Platform

5GT-SO – 5G-TRANSFORMER Service Orchestration

5GT-VS – 5G-TRANSFORMER Vertical Slicer

AD – Anomaly Detection

AdD – Administrative Domain

AI – Artificial Intelligence

BSS – Business Support System

CMD – Cyber Mimic Defense

CP – Control Plane

CSMF – Communication Service Management Function

CsA – Class of Service Algorithm

CSP – Communications Service

GUI – Graphical User Interface

HSS – Home Subscriber Server

IL – Instantiation Level

MANO – Management and Orchestration

ML – Machine Learning

MME – Mobility Management Entity

NFV – Network Function Virtualization

NFV-NS – NFV Network Service

NFVI – NFV Infrastructure

NPN – Non-Public Network

NS – Network Service

NSD – Network Service Descriptor

NSF – Network Service Federation

PGW – Packet Data Network Gateway

PoP – Point of Presence

SEC-GW – Security Gateway

SGW – Serving Gateway

SLA – Service Level Agreement

SOEc – Service Orchestrator Engine child

SOEp – Service Orchestrator Engine parent

SP – Service Provider

VNF – Virtual Network Function

VNFD – Virtual Network Function Descriptor

VPN – Virtual Private Network

1. Introduction

As part of the project Communication, Dissemination, and Exploitation Plan (CoDEP) [1], one of the dissemination goals of 5Growth is to present technical demonstrations of project results in relevant events. These demonstrations are used to showcase in a tangible way what is presented in the form of deliverables, papers, talks, etc. in other venues. This document briefly explains the demonstration activities carried out in the second year of the project during 7 online events and/or conferences, namely:

- IEEE INFOCOM’20.
- IEEE INFOCOM’21.
- Online webinar Layer123/5Growth.
- ACM MobiHoc 2020.
- ETSI ENI PoC#9.
- OSM Ecosystem day.
- IEEE NetSoft’21.

Additionally to these 7 events, 5Growth had a prominent participation during EUCNC21. Apart from the 7 demonstrations (4 pilots and 3 innovations), the project was actively represented in the following activites:

- Tuesday, 8 June 2021.
    - Workshop 6: 5G Private Networks.
        - Talk: 5Growth NPN Deployment Solutions & Industry 4.0 Pilot Examples.
        - Talk: Outlook for operator adoption of 5G Private Networks.
    - Workshop 8: From 5G to 6G Automated and Intelligent SecuriTy (FAST).
        - Paper: 5Growth: Hardening Interdomain Vertical Services with Moving Target Defense (MTD).
- Wednesday, June 9. NET1 – Network Softwarisation I.
    - Paper: 5Growth: Secure and Reliable Network Slicing for Verticals.
- Thursday, June 10, NET2 – Network Softwarisation II.
    - Paper: 5Growth Data-Driven AI-Based Scaling.
- Friday, 11 June. Special Session 8: Autonomous Network Management towards 6G.
    - Panel: Seeding the long-term vision for Autonomous Network Management on the road to 6G Projects.

During these events, several different demonstrations were shown (refer to Table 1 for the associated event):

- NFV Service Federation: enabling Multi-Provider eHealth Emergency Services.
- Arbitrating Network Services in 5GNetworks for Automotive Vertical Industry.
- vrAIn: AI-driven orchestration of vRAN resources.
- 5Growth Demo: Scaling Composite NFV-Network Services.

- ETSI ENI PoC #9: Autonomous Network Slice Management for 5G Vertical Services.
- Scaling Federated Network Services: Managing SLAs in Multi-Provider Industry 4.0 Scenarios.
- Demo: AIML-as-a-Service for SLA management of a Digital Twin Virtual Network Service.
- Demonstrating a Bayesian Online Learning forEnergy-Aware Resource Orchestration in vRANs.
- ETSI ENI PoC #9: Autonomous Network Slice Management for 5G Vertical Services.
- Demo: Vertical's intent evolution at service runtime driving vCDN automated scaling.
  Slice Isolation for 5G Transport Networks.

Information about other demonstrations carried out in the project as well as a summary of communication, dissemination, and exploitation activities can be found in D5.2 [1] and D5.3 [2].

This period was heavily impacted by COVID-19, with the cancelation of several major events (or of the 5Growth participation due to logistical issues). Moreover, the events that were not cancelled have been held in virtual fashion, with the limitations this format entails.

Event name	Demo(s) presented
INFOCOM'20	NFV Service Federation: enabling Multi-Provider eHealth Emergency Services
INFOCOM'20	Arbitrating Network Services in 5GNetworks for Automotive Vertical Industry
Online Webinar	vrAIn: AI-driven orchestration of vRAN resources
ACM MobiHoc 2020	Scaling Composite NFV-Network Services
ETSI ENI PoC#9	Autonomous Network Slice Management for 5G Vertical Services
INFOCOM'21	Scaling Federated Network Services: Managing SLAs in Multi-Provider Industry 4.0 Scenarios
INFOCOM'21	AIML-as-a-Service for SLA management of a Digital Twin Virtual Network Service
INFOCOM'21	Demonstrating a Bayesian Online Learning forEnergy-Aware Resource Orchestration in vRANs
OSM Ecosystem Day	Vertical's intent evolution at service runtime driving vCDN automated scaling
IEEE NetSoft'21	Slice Isolation for 5G Transport Networks
EUCNC´21	5Growth Pilot. EFACEC Energia´s energy pilot 5Growth Pilot. EFACEC Engenharia e Sistemas transportation pilot 5Growth Pilot. COMAU Industry 4.0 pilot 5Growth Pilot. Innovalia Industry 4.0 pilot 5Growth Innovation. ML-driven scaling of Digital Twin Service in 5Grwoth 5Growth Innovation. Performance Isolation for 5G Network Slicing 5Growth Innovation. Moving target defense

TABLE 1 – LIST OF 5GROWTH DEMONSTRATIONS AND EVENTS

2. INFOCOM'20: NFV Service Federation: enabling Multi-Provider eHealth Emergency Services

This work has been done in collaboration with the 5G-TRANSFORMER (5GT) project [3], whose developed NFV/SDN orchestration stack is the baseline architecture used to design, build and develop the 5Growth orchestration platform.

This demonstration [4] showcased the developed 5GT/5Growth network service federation (NSF) procedure [13] and how it is applied to satisfy the requirements of an eHealth vertical use case. This use case requires the deployment of a composite NFV-NS at different locations in two different administrative domains (AdDs). First, the monitoring back-end service (Monitoring NFV-NS) is deployed in the cloud of service provider 1 (AdD1) and, second, an Emergency Service, triggered by a detected anomaly (e.g., upon losing vital signs of the monitored patient), needs to be dynamically deployed at the edge in the premises of service provider 2 (AdD2), which is close to the patient.

In particular, the developed NSF procedure demonstrated (i) the deployment of a federated composite network service in different AdDs for the defined eHealth use case, and (ii) the dynamic initiation (and stitching with a previously running NFV NS) of the emergency service at NS run-time.

2.1. IEEE INFOCOM (2020)

IEEE INFOCOM is a top ranked conference on networking in the research community. It is a major conference venue for researchers to present and exchange significant and innovative contributions and ideas in the field of networking and closely related areas. IEEE INFOCOM covers both theoretical and systems research. For INFOCOM 2020, the conference included a main technical program, a number of workshops, a keynote speech, panels, a student poster session, and demo/poster sessions. The conference was held virtually from the 6th to the 9th of July 2020.

2.2. Media content

The presentation banner of the event is shown below:

FIGURE 1: WEBSITE FOR IEEE INFOCOM 2020

The programme is on the website at: https://infocom20.info/

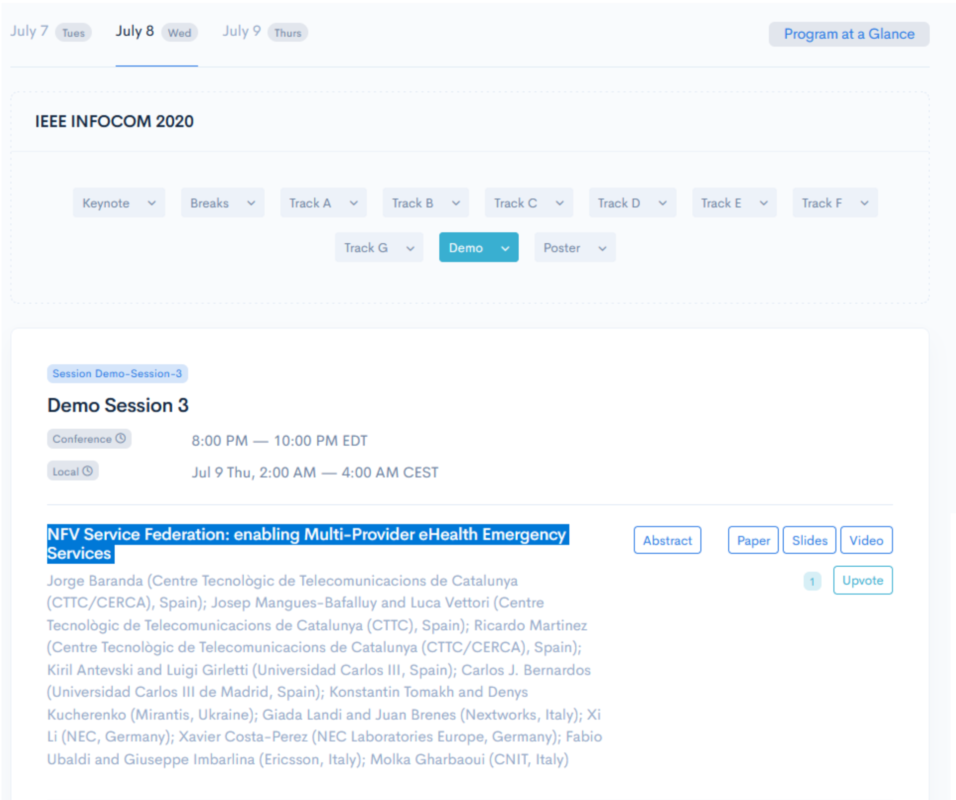


FIGURE 2: PROGRAMME AS SHOWN ON THE WEBSITE, WITH 5GROWTH'S CONTRIBUTION HIGHLIGHTED

The demonstration recording is available at: https://youtu.be/PNLYJyoMrak

FIGURE 3: YOUTUBE VIDEO OF THE NFV SERVICE FEDERATION DEMO

2.3. Demonstration details

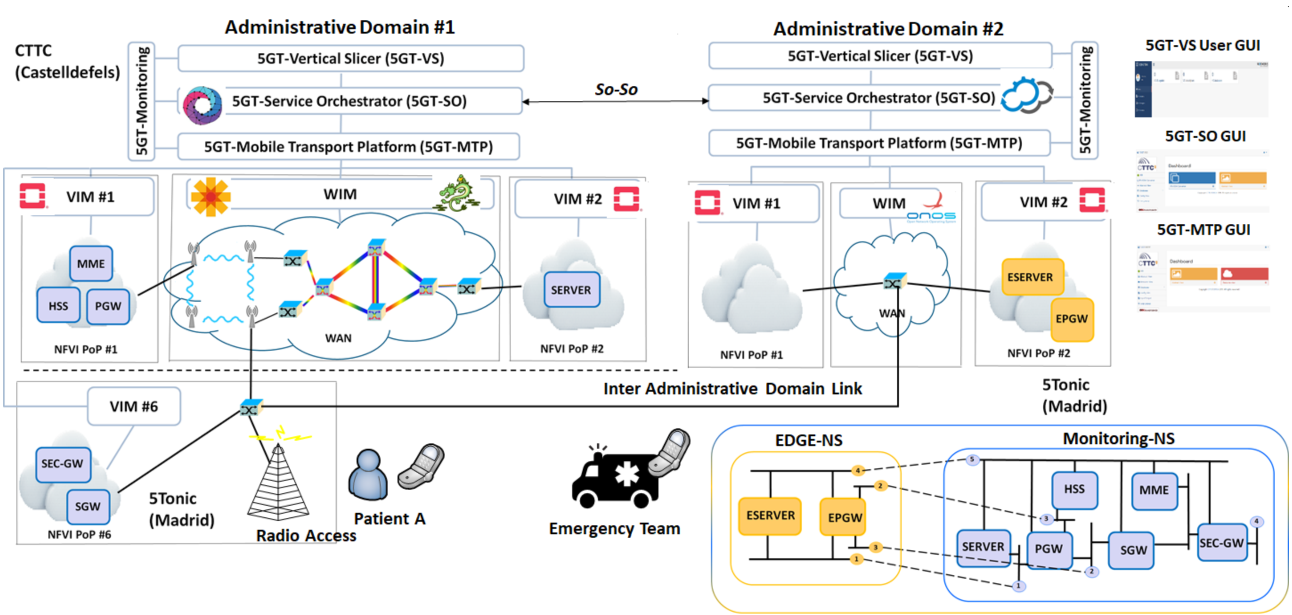


FIGURE 4: SETUP UNDER DEMONSTRATION FOR THE NFV SERVICE FEDERATION DEMO

Figure 4 presents the setup under demonstration, where each AdD (e.g., representing different service providers) runs its own 5GT platform (5GT-VS, 5GT-SO, 5GT-MTP and 5GT-MON). This setup is split between two sites: the CTTC 5G Lab (Castelldefels, Spain) and the 5TONIC Lab (Madrid, Spain).

We demonstrated the deployment of a composite NFV-NS in two different AdDs for the defined eHealth use case exploiting the NSF capabilities of the 5GT platform. This composite NFV-NS has two nested NFV-NSs. First, the Monitoring NS is the back-end service performing real-time monitoring of patients' location and vital signs (e.g., heart rate). It is represented by the blue VNFs in Figure 4. In case of emergency, the Edge NS is deployed close to the patients' location in order to assist emergency teams with for instance, AR/VR services, or to provide faster access to patient's health records, thus improving on-site medical care. In Figure 4, it is represented by the two yellow VNFs. The main steps of the demo are:

1) The Monitoring NFV-NS is deployed in AdD1 as explained in [5]. The VNFs are deployed over PoP#1 (MME, PGW & HSS), PoP#2 (SERVER) and PoP#6 (SGW & SEC-GW). Once the service is deployed, the vital signs data flow between SERVER and patient A UE can traverse PGW, SGW, SEC-GW and Radio access, which is a hardware element of PoP#6.
2) An emergency event is emulated (e.g., loss of vital sign from monitored patient). Then, the SERVER VNF triggers the deployment of the composite NFV-NS at the 5GT-VS of AdD1, which includes the Edge NFV-NS.
3) When processing the composite NFV-NS request, the 5GT-SO of AdD1 decides to deploy the remaining nested Edge NFV-NS at AdD2 due to NFV-NS availability and closeness to patient's location to satisfy the low-latency requirement imposed by the emergency situation. Then, it starts the NSF procedure to request the deployment of the Edge NFV-NS to the 5GT-SO of the AdD2 through the So-So interface. The Edge NS will be stitched with the Monitoring NFV-NS at the AdD1 to form a federated NFV-NS.
4) The Edge NFV-NS is deployed at AdD2 and the required links between the different nested NFV-NSs are established through the Inter Administrative Domain Link.
5) Upon successful Edge NFV-NS deployment, the data flows from the emergency team's UE to the ESERVER through Radio access, SGW and EPGW. This enables fastest and improved medical care by on-site emergency teams thanks to the dynamic deployment of NFV-NSs at the edge.

A more detailed explanation can be found at [4].

3. INFOCOM'20: Arbitrating Network Services in 5G Networks for Automotive Vertical Industry

This work has been done in collaboration with 5GT, whose developed NFV/SDN orchestration stack is the baseline architecture used to design, build and develop the 5Growth orchestration platform.

This demonstration [6] shows the capabilities of the 5GT/5Growth orchestration platform to arbitrate vertical services. In this context, arbitration refers to the handling of various services of a given vertical customer according to their SLA requirements, service priorities, and resource budget available to the vertical. In the 5GT stack the responsible of this task is the 5GT-VS, that allows the whole platform to handle the different service requests by the same vertical while satisfying the agreed SLAs between the service provider (SP) and the vertical.

3.1. IEEE INFOCOM (2020)

This innovation has been presented at the same flagship event INFOCOM 2020 as Innovation in Section 2 in this document. The conference was held virtually from the 6th to the 9th of July 2020 and the interested reader is referred to section 2.2 for Media Content references.

3.2. Demonstration details

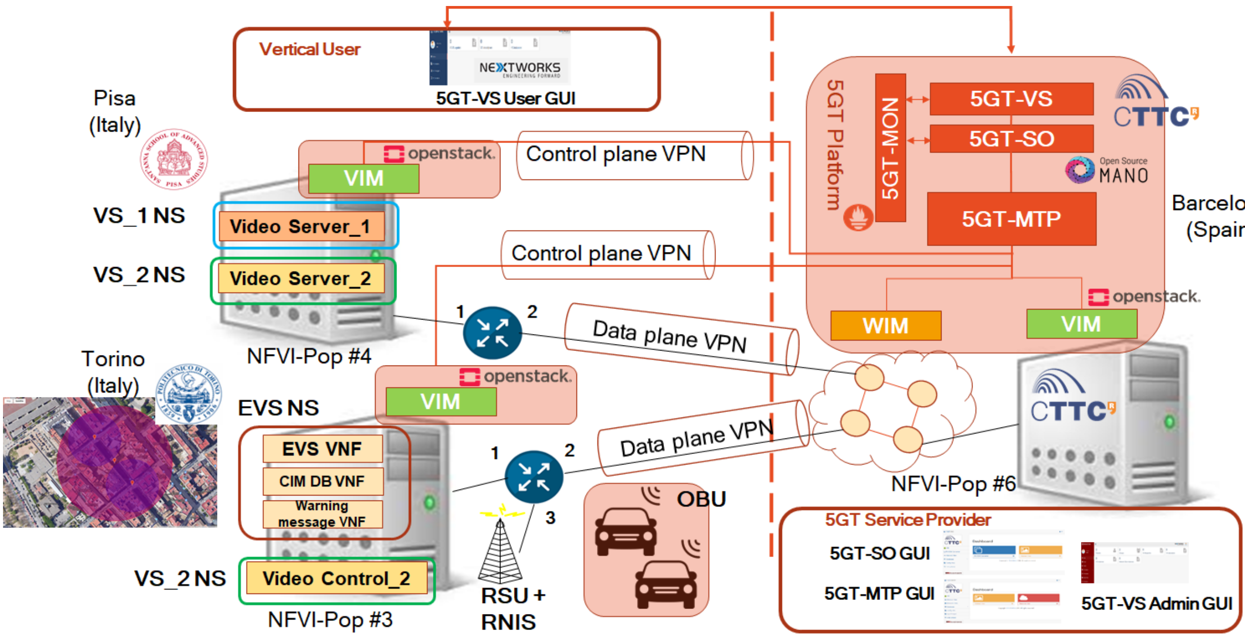


FIGURE 5: SETUP UNDER DEMONSTRATION FOR THE ARBITRATING NETWORK SERVICES DEMO

Figure 5 presents the setup used for the demonstration, which is split in three different geographical sites, namely Barcelona (Spain), Torino (Italy) and Pisa (Italy). These sites are interconnected by means of control and data plane virtual private networks (VPN). The whole 5GT platform (5GT-VS, 5GT-SO, 5GT-MTP and 5GT-MON) is placed in Barcelona.

In this case, we demonstrated the automated fulfilment of the established business SLAs between a vertical, namely an Automotive vertical, and the 5GT SP, by using the 5GT platform and the infrastructure in Figure 5. The 5GT platform satisfies the SLAs in two ways. First, the 5GT platform deploys automatically the requested automotive NFV-NSs while meeting the constraints (e.g, latency) expressed in the corresponding network service descriptors (NSDs). Second, and this is the main focus of this demonstration, the 5GT platform satisfies the resource budget available to the vertical through the arbitration capabilities. Two types of NFV-NSs are deployed during the demonstration, namely the Video Streaming (VS) NFV-NS and the EVS NS, as depicted in Figure 5. The VS NFV-NS provides multimedia content to vehicular users, while the EVS NFV-NS enhances road safety by detecting and alerting vehicles approaching an intersections that are on collision course. The VS NFV-NS presents two deployment flavours, with different priorities, as specified at the moment of onboarding through the 5GT-VS. The ”high priority” flavour consists of one video server VNF holding a web-server and a cache of videos, indicated as Video Server X in Figure 5. The ”low priority” flavour adds, to the above VNF, another VNF (Video Control X), which interacts with the Radion Network Information Service (RNIS) to adjust the video streaming quality based on channel quality experienced at the vehicle Onboard Unit (OBU). This flavour of the VS NFV-NS has lower priority because it consumes more resources and the primary goal of the Automotive Vertical is to offer the video streaming service, no matter which video quality can be provided. The EVS NFV-NS consists instead of three VNFs, namely the Cooperative Information Manager (CIM) DB, the Warning message VNF, and the EVS VNF. A full description on the logics of this NS can be found at [7]. Being a safety service, the EVS NFV-NS has high priority. The main steps of the demo are as follows:

1) The Vertical User requests the instantiation of the two VS NFV-NS flavours through the 5GT-VS User GUI. The 5GT-SO processes the request as explained in [5], deploying the VS NFV-NSs in the underlying infrastructure while satisfying the NFV-NS constraints embedded in the descriptors. The ”low priority” instance of VS NFV-NS is deployed between two PoPs and its ”Video Control 2” VNF is placed close to the RNIS as it needs to leverage low-latency channel quality measurements.
2) The Vertical User requests the instantiation of the EVS NFV-NS through the 5GT-VS User GUI. The arbitrator module of the 5GT-VS checks the resource budget available for this Vertical user and realises that the three NFV-NSs cannot run simultaneously. Based on the priority of the current deployed NFV-NSs and the new incoming request, the arbitrator decides to terminate the ”low priority” VS NS to release resources for the EVS NS.
3) Once the 5GT-SO confirms the termination of the ”low priority” VS NFV-NS, the 5GT-VS proceeds with the instantiation of the EVS NFV-NS, which is deployed in the PoP close to the roadside unit to honor the latency requirements embedded in the request.

A more detailed explanation can be found at [6].

4. Online webinar Layer123/5Growth: vrAIn: AI-driven orchestration of vRAN resources

In this demo we demonstrate vrAIn. VrAIn is an orchestration engine powered by deep learning to optimize jointly the allocation of computing and radio resources in Virtualized Radio Access Networks. VrAIn monitors the buffer states and the available channel quality information over time across all users in all radio access points or wraps in the system, which we refer to as contextual snapshots. These contextual snapshots are fed periodically along different decision periods into vrAIns main engine for processing.

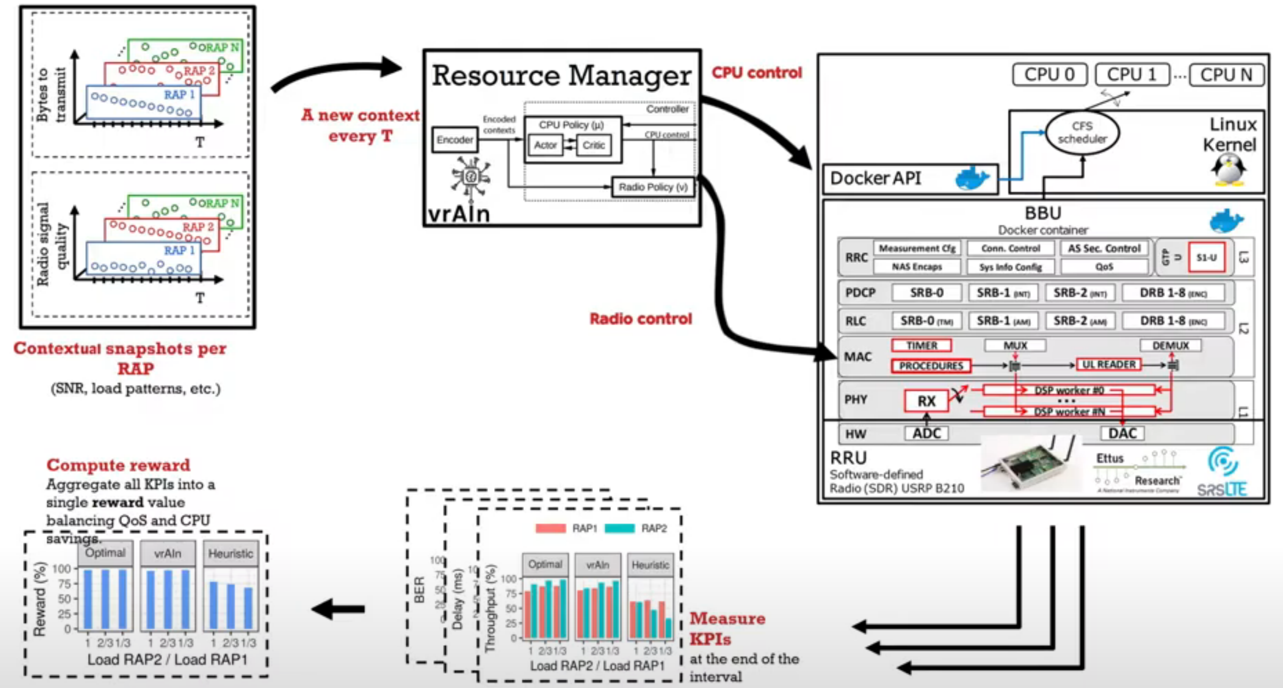


FIGURE 6: VRAIN SYSTEM OVERVIEW

As a result, we map a given contextual snapshot into a pair of policies: one a CPU control policy which imposes an upper bound on the relative time that the computing platform can process each virtualized access point, and two, a radio control policy which establishes an upper bound on the modulation and coding scheme eligible by each of the virtualized radio stacks. In addition to contextual data monitoring probes on the radio stack measure a number of Network Key Performance Indicators which we use to train the internal models of vrAIns engine.

4.1. Layer123

Layer123 connects everyone involved in the network transformation process – helping operators and network owners to virtualise their networks and find commercial benefits from the improved performance this transformation brings. Sessions cover technical details (like SDN, NFV, OpenRAN, edge computing, applied AI, disaggregation, automation and orchestration) and also reveal how operators and network owners are commercialising these technologies – making a real difference to operator profitability.

Layer123 events offer a neutral platform for those on the pulse of the network transformation, an arena for debate, analysis and contribution towards the ecosystems health and continued enhancement in the field, building towards best practice and benchmarking of operations against ones peers. Its flagship event is the Layer123 World Congress in the Hague.

4.2. Media content

Information on the webinar is available at 5Growth portal:

https://5growth.eu/2020/07/02/layer123-to-host-a-5growth-webinar-series-on-5g-use-in-industry/ and https://5growth.eu/2020/07/02/online-workshop-layer123-5growth-powering-5g-in-industry-9-july-2020-10am-cet/

The presentation banner is shown in the next figure:

FIGURE 7: PRESENTATION BANNER FOR "POWERING 5G IN INDUSTRY" WEBINAR WITH LAYER123 AND 5GROWTH.

The demonstration recording is available at: https://www.youtube.com/watch?v=AsrpwH6zudM

FIGURE 8: YOUTUBE VIDEO OF THE 5GROWTH/LAYER123 WEBINAR ON 5G IN INDUSTRY 4.0

Below, some of the tweets from 5Growth twitter account on this webinar are shown:

https://twitter.com/5growth_eu/status/1278627579994521600


5GROWTH
@5growth_eu

"Layer123 to host a 5Growth webinar series on #5G use in industry". Read the article about the work of 5Growth consortium, that's dedicated to empowering industries with an end-to-end 5G solution that's AI-driven, automated and shareable.
🔗Link: 5growth.eu/2020/07/02/lay... @5GPPP
Traducir Tweet

1:02 p. m. · 7 jul. 2020 · Hootsuite Inc.

2 Me gusta

https://twitter.com/5growth_eu/status/1280457151216041984


5GROWTH
@5growth_eu

Workshop-Layer123/5Growth: Powering #5G in Industry⚙️This webinar summarises the progress, deliverables completed and the exciting new applications & use cases that the work of our consortium is making possible.
Watch the session here: youtu.be/AsrpwH6zudM
Traducir Tweet

2:02 p. m. · 27 jul. 2020 · Hootsuite Inc.

1 Retweet 2 Me gusta

https://twitter.com/5growth_eu/status/1287720195903529000

4.3. Demonstration details

We first demonstrate a use case where the goal is to minimize the use of computing resources when the computing capacity of the system is unlimited or overdimensioned. To such a purpose we deploy one virtual radio stack and observe how vrAIn adapts the allocation of CPU resources to the dynamics of the contexts without any restriction on the availability of computing capacity.

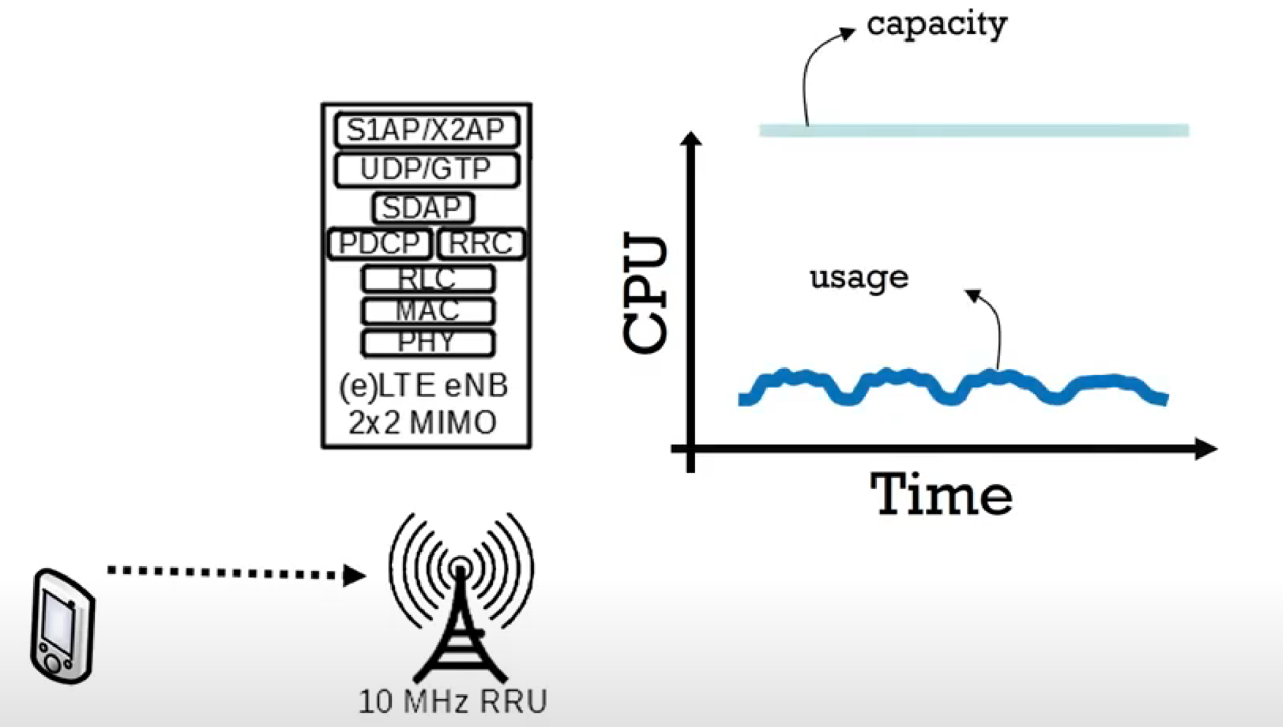


FIGURE 9: SETUP FOR THE FIRST USE CASE

For the first use case we bootstrapped the system with one virtualized radio access point. Let's explore the trade-off between performance and usage of computing resources.

1) When we let the wireless link enjoy good conditions and select a high Q value to favour performance over CPU savings. We can observe that vrAIn assigns substantial computing resources to guarantee a good throughput.
2) If instead we reduced the Q parameter, which is intended to favor CPU savings over performance, we can observe how vrAIn assigns considerably less computing resources to the virtualized stack. It is important to highlight that in order to accommodate such low CPU consumption vrAIn calculates a radial policy that imposes rather low modulation and coding schemes and hence lower throughput.
3) If the radio stack used high modulations in this context even with high channel quality, the CPU consumption during peak loads would exceed the allocation of computing resources yielding substantial decoding errors. This is precisely what happens with legacy compute-unaware radio schedulers. To show this we select state-of-the-art mechanisms in our dashboard. The radio stack selects modulations over the policy imposed by vrAIn, matching

the good channel conditions experienced but unaware of the unavailability of computing capacity. As a result the bit error rate grows leading to zero throughput.

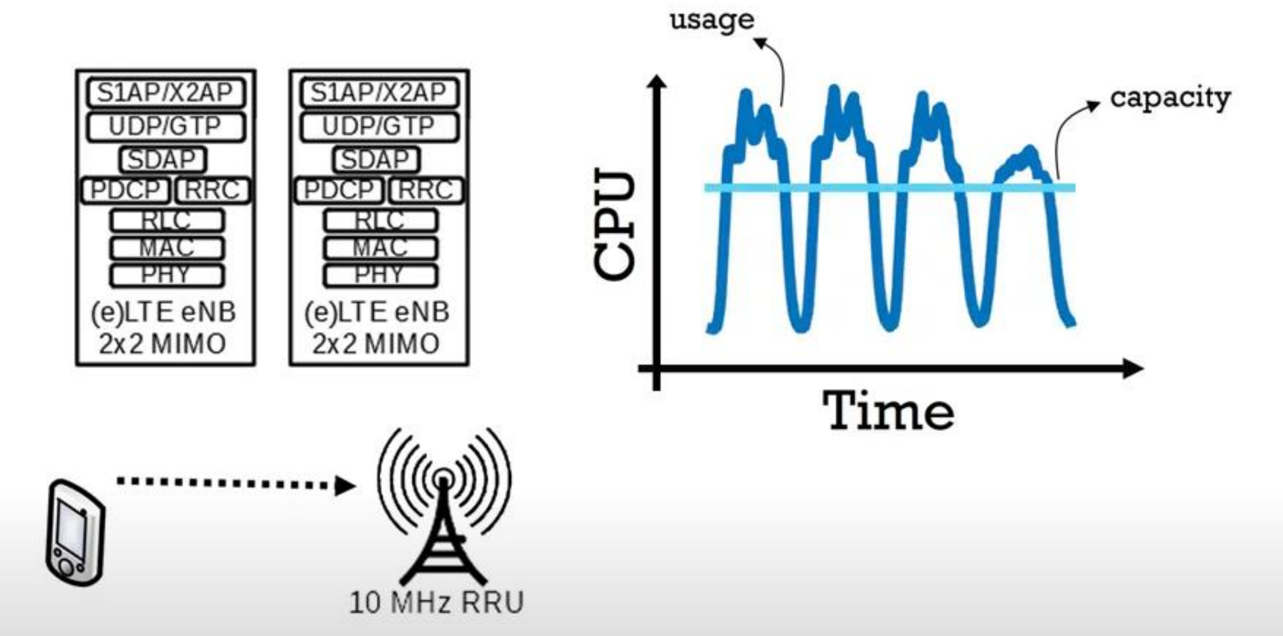


FIGURE 10: SETUP FOR THE SECOND USE CASE

For the second use case our goal is to assess the performance of the vRAN system when it's computing capacity is under dimension. For such a purpose, we deploy two virtual radio stacks over a single CPU core. In this context, the aggregated computational demand, when the load of both virtual radio stacks peak is reached at the same time, is well above the system's capacity.

Given that the context of both radio stacks evolved in an identical manner, vrAIn shares equally the computing capacity among the radio stacks. However, assigning 50% of computing resources is not enough to serve highly modulated traffic when the demand is high. To solve this issue, when the peak load is high for both radio stacks, vrAIn assigns low radio control policies to guarantee that the computational needs of both radio stacks respect the limited resource allocation. It must be noted that vrAIn optimizes the control policies to maximize throughput, while guaranteeing near zero bit error rate.

vrAIn can also assign priorities. If we select a high Q parameter on radio stack 1 and a low Q parameter on radio stack 2. With this selection, we are requesting vrAIn to promote performance on radio stack 1 over that of radio stack 2. This results in satisfying our requests vrAIn shifts computing resources from radio stack 2 to radio stack 1, around 10%. In addition, this allows vrAIn to assign high radio control policies to radio stack 1 at the expense of the radio policies imposed to radio stack 2. As a result radio stack 1 can attain higher throughput than earlier at the expense of lower radio policies and hence low throughput in Radio stack 1.

The previous process is explained with further details and with the corresponding figures in the following video: https://www.youtube.com/watch?v=1I8mcnHQcW8

5. ACM MobiHoc 2020: Scaling Composite NFV-Network Services

This demonstration [8] shows the capabilities of the 5Growth platform, and specially of its 5Gr-Service Orchestrator (5Gr-SO) to manage the end-to-end scaling of composite NFV-NSs deployed in a complex infrastructure featuring multiple transport technologies (wireless, optical) and several NFVI-Points of Presence (PoPs). To the best of our knowledge, this is the first operational demonstration of NFV-NS scaling implying network composition and sharing of a previously deployed single NFV-NS, i.e., non-composite NFV-NS. This work advances related work performed by ETSI NFV working groups [9], restricted to high-level specifications. In particular, this demonstration considers an emulated Industry 4.0 scenario where a Non-Public Network (NPN) [10] single NFV-NS is shared among composite NFV-NSs acting as industrial virtual services. Then, we show how the 5Gr-SO is able to satisfy successive scaling requests aiming to shape the deployed NFV-NSs to maintain the required SLAs during NFV-NS operation time.

5.1. ACM MobiHoc 2020

ACM Mobihoc: International Symposium on Theory, Algorithmic Foundations, and Protocol Design for Mobile Networks and Mobile Computing" is a premier international symposium dedicated to addressing challenges in dynamic networks and computing. It was held online druing October 11-14, 2020.

MobiHoc brings together researchers and practitioners from a broad spectrum of networking research to present the most up-to-date results and achievements in the field. Mobihoc 2020 featured a highly selective technical program, multiple distinguished keynote addresses, and an exciting panel. In addition, it included workshops focused on areas of emerging interest.

5.2. Media content

The presentation banner of the event is shown below:

FIGURE 11: WEBSITE FOR ACM MOBIHOC 2020.

The programme is on the website at: https://www.sigmobile.org/mobihoc/2020/program.html

1:15-2:15	Demo Session
	Demo: Fully-Digital Beamforming Demonstration with Pi-Radio mmWave SDR Platform
	Demo: DANGER - a Drones Aided Network for Guiding Emergency and Rescue operations
	Demo: Scaling Composite NFV-Network Services
	Demo: Visualizing the Bitcoin's OP_RETURN operator
2:15-3:45	Session 6: Smart Transportation, Advertising, and blockchain
	Learning to Price Vehicle Service with Unknown Demand Haoran Yu, Ermin Wei, and Randall Berry (Northwestern University)
	A Game-theoretic Approach to Storage Offloading in PoC-based Mobile Blockchain Mining Suhan Jiang and Jie Wu (Temple University)
	Optimizing Ad Allocation in Mobile Advertising Shaojie Tang, Jing Yuan, and Vijay Mookerjee (University of Texas at Dallas)
3:45-4:00	Break

FIGURE 12: PROGRAMME AS SHOWN ON THE WEBSITE, WITH 5GROWTH'S CONTRIBUTION HIGHLIGHTED.

The demonstration recording is available at: https://youtu.be/r9EFMIiVZno

FIGURE 13: YOUTUBE VIDEO OF THE SCALING COMPOSITE NFV-NS DEMO

5.3. Demonstration details

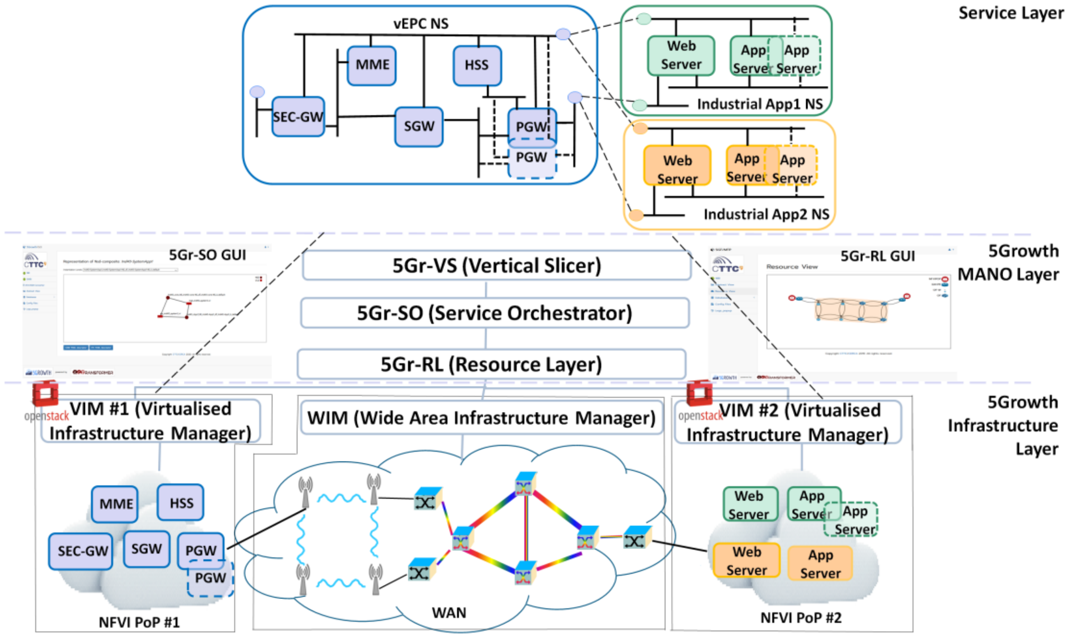


FIGURE 14: SETUP UNDER DEMONSTRATION FOR THE SCALING COMPOSITE NFV-NS DEMO

Figure 14 presents the setup under demonstration with an instance of the 5Growth stack and the different employed NFV-NSs. In this demonstration, we show the composite NFV-NS scaling capabilities of the 5Growth platform, which increase the NFV-NS deployment dynamicity to provide better adaption to the vertical industries' needs.

To illustrate this feature, we consider an Industry 4.0-like scenario, where a company uses the 5Growth platform to deploy a standalone NPN network [10]. Such NPN can be dynamically adapted to accommodate new necessities or address different conditions within the factory. Thanks to the use of the concept of NS composition, we define the "Industrial System" composite NFV-NS, where a new nested NFV-NS, which herein we refer to as "Industrial App", interacts with the previously instantiated NFV-NS implementing the mobile infrastructure (NPN). Thus, the envisaged "Industrial System" composite NFV-NS used in this demonstration consists of two nested NFV-NSs. First, we have the NFV-NS emulating a Virtualized Evolved Packet Core (vEPC). This vEPC NFV-NS is made up of five VNFs, namely SEC-GW, MME, HSS, SGW and PGW. The second nested NFV-NS represents the so-called "Industrial App". This NFV-NS is initially formed by two VNFs: the webserver (WS), which includes load balancing capabilities, and an application server. The main steps of the demonstration are:

1) The 5Gr-SO receives a request to deploy the emulated vEPC NFV-NS implementing the standalone NPN. The Service Orchestration Engine parent (SOEp) module processes the request and delegates it to the SOE child (SOEc) to instantiate the single vEPC NFV-NS (blue boxes in Figure 14), as explained in [5].
2) Then, we proceed with the deployment of two different "Industrial Systems". These systems are deployed as composite NFV-NSs, and both share the previously deployed vEPC NS. When

the 5Gr-SO receives the request, the SOEp considers the provided reference to orchestrate the required instantiation operations for the remaining nested NFV-NS of each composite NFV-NS [11]. These remaining nested NFV-NSs are represented by the "Industrial App" NSs in Figure 14 (green and orange boxes). At this point, there are three different deployed NFV-NSs: one single NFV-NS and two composite NFV-NSs sharing this single NFV-NS.

3) After the creation of the previous composite NFV-NSs, the expected increase of processed traffic may cause problems in the vEPC NFV-NS. To solve this issue, the 5Gr-SO receives a scaling request to change the instantiation level (IL) of the vEPC NFV-NS. Initially, the SOEp processes this request, which refers to a single NFV-NS, and relies on the SOEc to orchestrate this scaling operation. This IL implies the deployment of a new PGW VNF instance, to attain traffic load balancing among the upcoming new sessions. The new PGW VNF instance is represented in Figure 14 with the light blue box. After that, since there are two composite NFV-NSs sharing the vEPC NFV-NS, the SOEp proceeds with the update of the associated composite NFV-NS deployments. This consists of establishing the new inter-nested NFV-NS connections from the composite NFV-NSs to the new PGW VNF instance in the vEPC NFV-NS.

4) Next, upon an increase in the factory production, the Industrial App1 overloads due to a surge in the number of operations. Thus, this requires a change to scale the associated resources. Then, the 5Gr-SO receives a scaling request to change the IL of the Industrial System composite NFV-NS used by the Industrial App1. The SOEp analyses the request, concluding that this new IL for the composite NFV-NS implies the instantiation of a new application server VNF in the nested Industrial App1 NFV-NS. After instantiating the new VNF (light green VNF box in Figure 14), the SOEp proceeds with the update of the inter-nested NFV-NS connections towards the associated vEPC NFV-NS. During this demonstration, the graphical user interfaces (GUIs) of the 5Growth platform show the result of the successive demonstration steps. The 5Gr-SO GUI shows the structure of the different deployed NFV-NSs and the new VNFs resulting from the successive scaling operations. The 5Gr-RL GUI shows the underyling networking and compute infrastructure. Specifically, we will focus on the update of the inter-nested NS connections among the deployed NSs.

Further information on this can be found at [8].

6. ETSI ENI PoC#9: Autonomous Network Slice Management for 5G Vertical Services

The ETSI ENI PoC#9, on Autonomous Network Slice Management for 5G Vertical Services has been developed by Nextworks in the context of a collaboration with other European projects (5G EVE, 5G-TOURS and 5G-COMPLETE) and involves the participation of partners internal in 5Growth consortium (UC3M and TIM) as well as external ones (WINGS and Samsung). The PoC has been designed with the objective of demonstrating how the adoption of ENI principles can improve the network slice management strategies in support of 5G vertical services. In this context, the PoC proposes an integrated architecture where the ENI system assists a functional elements like the 5Growth Vertical Slicer in (i) identifying the characteristics of 5G network slices able to meet service-level requirements expressed in terms of intents and (ii) managing the sharing, composition and scaling of network slices.

The PoC started in January 2020, with its termination initially planned for December 2020. However, it has been extended until March 2021, with its final report approved in the 2nd quarter of 2021.

6.1. ETSI ENI

ETSI, founded in 1988, is one of only three bodies officially recognized by the EU as a European Standards Organization (ESO). ETSI is the recognized regional standards body dealing with telecommunications, broadcasting and other electronic communications networks and services.

ETSI provides its 900+ members from 65 countries with an open, inclusive and collaborative environment. This environment supports the timely development, ratification and testing of globally applicable standards for ICT-enabled systems, applications and services. In addition, ETSI patners in the international Third Generation Partnership Project (3GPP™), helping to develop 4G and 5G mobile communications.

The Experiential Networked Intelligence Industry Specification Group (ENI ISG) is defining a Cognitive Network Management architecture, using Artificial Intelligence (AI) techniques and context-aware policies to adjust offered services based on changes in user needs, environmental conditions and business goals. It therefore fully benefits the 5G networks with automated service provision, operation, and assurance, as well as optimized slice management and resource orchestration. ENI has also launched Proof of Concepts (PoCs, ours being PoC #9) aiming to demonstrate how AI techniques can be used to assist network operation including 5G. The use of Artificial Intelligence techniques in the network will solve problems of future network deployment and operation.

The ENI#16 meeting on 7-10 December 2020 was "online only" due to travel restrictions or delegates not allowed to travel. 29 delegates were registered and 29 were present. Operators were present from: China Telecom, China Mobile, Deutsche Telekom, NTT, Portugal Telecom, Telefonica and TIM. Government Ministry Institutes being members from Germany, China, Japan and South Korea. 163 documents were handled

6.2. Media content

All the documents regarding this demo can be consulted publicly at: https://eniwiki.etsi.org/index.php?title=Poc_09:_Autonomous_Network_Slice_Management_for_5G_Vertical_Services

6.3. Demonstration details

The system architecture of the PoC is represented in Figure 15 and it includes the "SEBASTIAN" software, i.e. the Vertical Slicer implemented as part of the 5Growth activities. In the PoC the Vertical Slicer acts as Service and Slice Manager and it is integrated with an ENI system to drive decisions about the lifecycle of vertical services and network slices. Such decisions are taken on the basis of service-level monitoring data collected from the virtual applications implementing the vertical service.

The demonstration of the PoC functionalities involves the deployment and the runtime management of a multimedia service, realized through an eMBB network slice. In particular, the ENI-driven service automation is translated at the Vertical Slicer level into decisions related to the lifecycle of the corresponding network slices and they are applied at the NFVO level. The PoC has integrated two different NFVOs, both opensource: TIMEO[1] and OSM[2].

The ENI-assisted functionalities implemented in the PoC are the translation of the verticals' intent and the automation of the service scaling. The first functionality helps the service providers to provision the services without a deep knowledge of its internal networking details. Moreover, in order to involve the vertical in the lifecycle management of the service, the system provides a "knob" that can be used to steer the autonomous operation in an human-understandable way. The service scaling automation exploit the forecasting of the future network load, used by the ENI system to provide scaling suggestion to the assisted system. In order to avoid issues with the network stability, due to excessive dynamicity of the data forecasting, the system implements a two-tier monitoring and forecasting system that 1) performs a long term forecasting, and 2) continuously re-evaluate the decision at short term, to correct the long term one only if needed.

[1] https://github.com/nextworks-it/timeo
[2] https://osm.etsi.org/

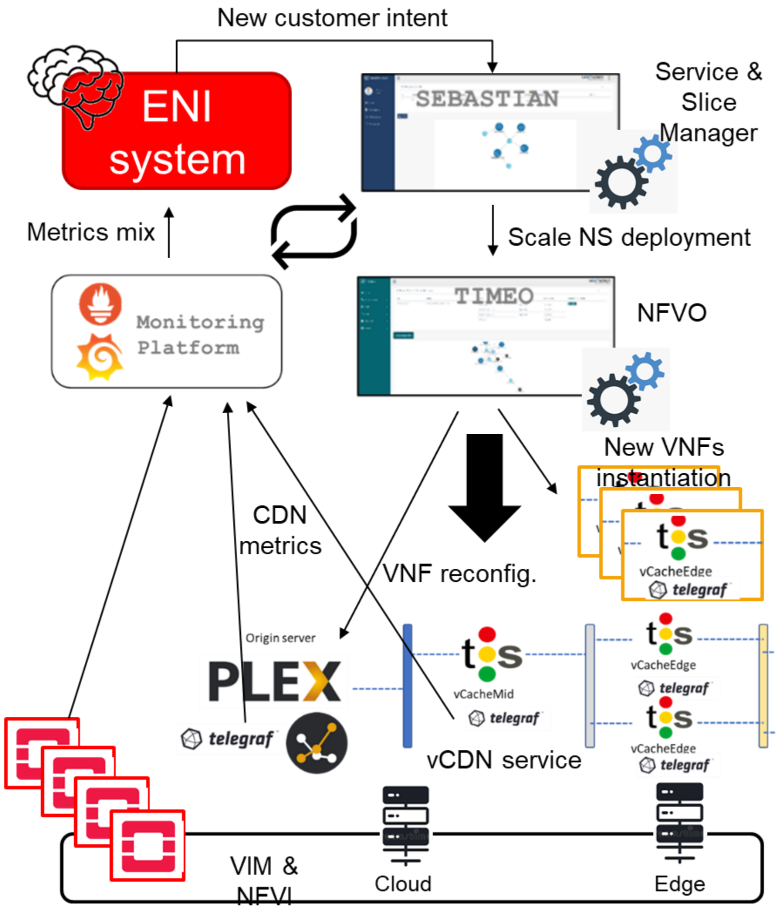


FIGURE 15: SYSTEM ARCHITECTURE OF ENI POC #9

7. INFOCOM'21: Scaling Federated Network Services - Managing SLAs in Multi-Provider Industry 4.0 Scenarios

This demonstration [12] showcases the capabilities of the 5Growth platform, and specially of its 5Gr-Service Orchestrator (5Gr-SO) module to support auto-scaling operations at the nested NFV-NS level of composite NFV-NS deployments implying network service federation (NSF). An essential aspect in this operation is the consideration of the resource orchestration perspective to handle the update of inter-nested connectivity between involved AdDs. . The scenario under demonstration considers an emulated Industry 4.0 scenario where a standalone Non-Public Network (NPN) [10] regular NFV-NS can be shared among composite NFV-NSs acting as industrial virtual services.

7.1. IEEE INFOCOM (2021)

IEEE INFOCOM is a top-ranked conference on networking in the research community. It is a major conference venue for researchers to present and exchange significant and innovative contributions and ideas in the field of networking and closely related areas. IEEE INFOCOM covers both theoretical and systems research. For INFOCOM 2021, the conference includes a main technical program, a number of workshops, a keynote speech, panels, a student poster session, and demo/poster sessions. The conference was held virtually from the 10th to the 13th of May 2021.

7.2. Media content

The programme of the event can be checked at: https://infocom.info/day/1/track/Demo

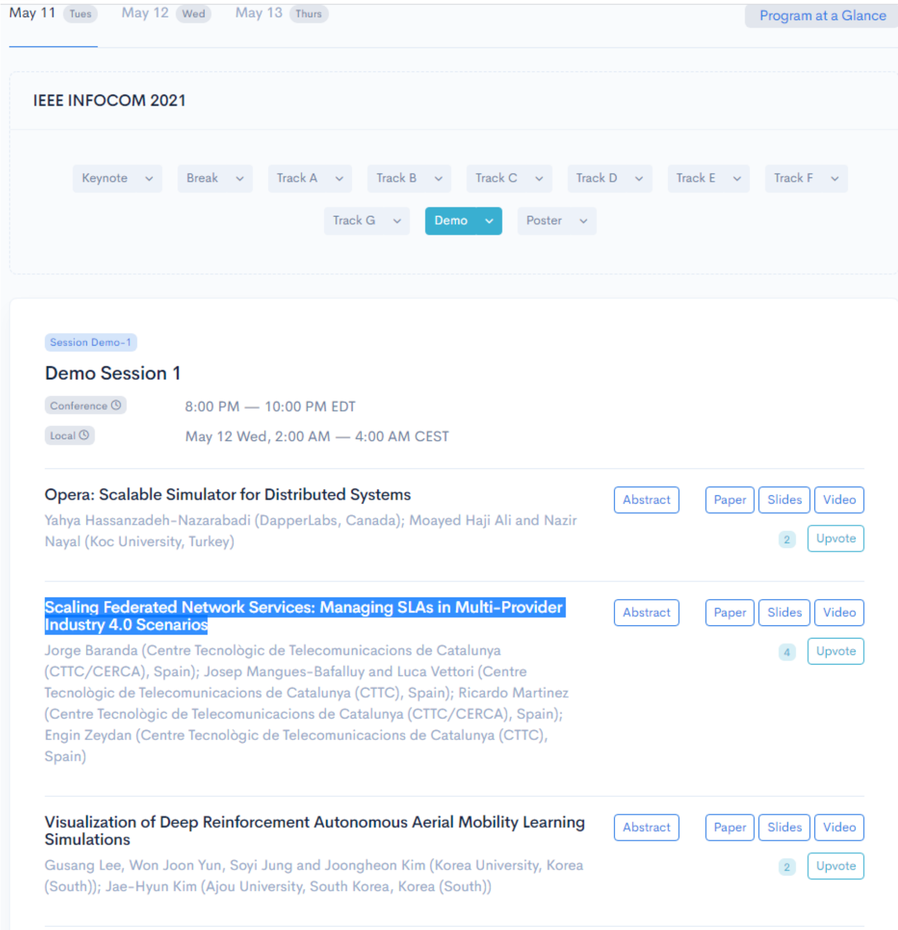


FIGURE 16: POGRAMME AS SHOWN ON THE WEBSITE, WITH 5GROWTH'S CONTRIBUTION HIGHLIGHTED.

The demonstration recording is available at: https://www.youtube.com/watch?v=RhO9ronLhTw

FIGURE 17: YOUTUBE VIDEO OF THE SCALING FEDERATED NETWORK SERVICES DEMO

Below are shown some of the tweets from 5Growth's twitter account on this demonstration:

https://twitter.com/5growth_eu/status/1367082764781166592

7.3. Demonstration details

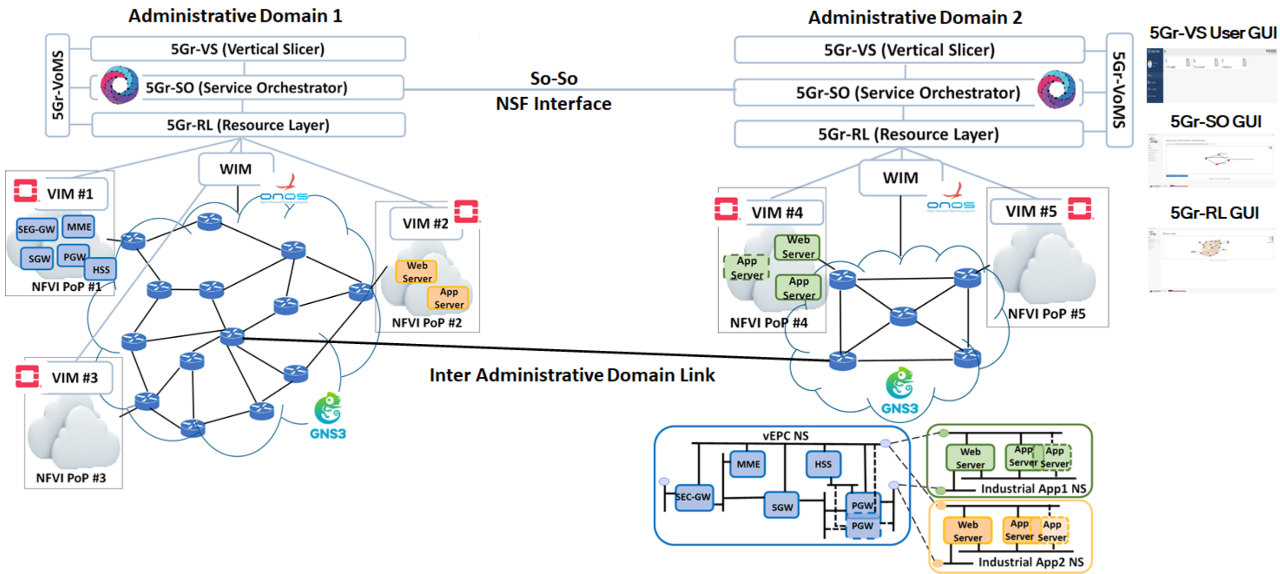


FIGURE 18: SETUP UNDER DEMONSTRATION FOR THE SCALING FEDERATED NETWORK SERVICES DEMO

Figure 18 presents the multi-AdD setup deployed at the CTTC 5G Lab, where each AdD runs its own instance of the 5Gr platform. The aim of this demonstration is to show the capabilities of the 5Gr-SO to handle the scaling of composite NFV-NSs, whose deployment implied the use of NSF [13].

We demonstrate the capabilities of the 5Gr platform to handle the scaling of federated NFV-NSs. Considering an Industry 4.0-like scenario, we focus on the auto-scaling of a federated nested NFV-NS part of a composite NFV-NS, which shares components with other composite NFV-NSs. The above-mentioned composite NFV-NSs have two nested NFV-NSs. The common nested NFV-NS is an emulated standalone NPN network [10] vEPC NFV-NS (represented by the blue VNFs in Figure 18) providing connectivity to different emulated industrial application NFV-NSs (represented by green and yellow VNFs in Figure 18). The composite NFV-NSs define multiple instantiation levels (ILs) covering the different ILs of its associated nested NFV-NSs to be able to adapt the structure of the whole service to cope with changes in network conditions and be able to satisfy SLA agreements. The main steps of the demonstration are:

1) The vEPC NFV-NS implementing the standalone NPN is instantiated in AdD1 as explained in [5]. The five VNFs of the NFV-NS (SEC-GW, SGW, MME, PGW and HSS) are deployed in NFVI-PoP#1, placed at the edge of the network (e.g., the factory premises).
2) Then, the two composite NFV-NSs are instantiated. Both composite NFV-NSs rely on and share the previously instantiated vEPC NFV-NS. However, the remaining nested NFV-NS is deployed in different AdDs. In the first case, the Industrial App1 NFV-NS is deployed in NFVI-PoP#4 of AdD2 as part of the agreement between AdDs to share its network service catalogue by means of NSF, as explained in [13]. In the second case, the Industrial App2 NS is deployed locally in NFVI-PoP#2 of AdD1 because this NFV-NS is available in the AdD1 catalogue and the characteristics of the composite NFV-NS require the nested industrial app to be deployed close to the vEPC NFV-NS.

3) Due to growing activity in the factory, the load on the App server VNF in Industrial App1 NFV-NS grows and starts jeopardizing the SLA requirements expressed in the NS descriptor (NSD) of the nested NFV-NS. The 5Gr-SO of AdD2 receives an (auto-)scaling operation request after processing the alert sent from the 5Gr-VoMs. It requests to change the IL of the Industrial App1 NFV-NS to increase the number of instances (scale out) of the App server VNF, hence coping with the increasing load.

4) When processing the scaling request, the 5Gr-SO at AdD2 realises that the Industrial App1 NFV-NS is part of a composite NFV-NS federated with AdD1. The 5Gr-SO of AdD2 notifies the change in the nested federated NFV-NS to AdD1 through the So-So interface. The 5Gr-SO at AdD1 checks the implications of the autoscaling being done at AdD2 in the NFV-NSs deployed in AdD1 and after confirming the execution of the scaling operation at AdD2, proceeds to update the inter-nested connections established though the available Inter-AdD Link. In this case, new internested connections need to be established between AdDs to communicate the new App server VNF with the vEPC NFV-NS.

5) When the traffic load decreases, the Industrial App1 NFV-NS can turn back to its initial IL with a single instance of the App server VNF. The 5Gr-SO at AdD2 is notified about this situation and receives an auto-scaling operation to change the IL (scale in) of Industrial App1 NFV-NS. Then, the 5Gr-SO performs again step 4) to adapt to the new situation. In this case, the previously established inter-nested connections are removed and the system turns back to the state after step 2).

A more detailed explanation can be found at [12]

8. INFOCOM'21: Demo - AIML-as-a-Service for SLA management of a Digital Twin Virtual Network Service

This work has been done in collaboration with the 5G-DIVE project [18]. This demonstration [14] presents an Artificial Intelligence/Machine Learning (AI/ML) platform offered as a service (AIMLaaS) and integrated in the management and orchestration (MANO) workflow defined in the project 5Growth following the recommendations of various standardization organizations. In such a system, SLA management decisions (scaling, in this demo) are taken at runtime by AI/ML models that are requested and downloaded by the MANO stack from the AI/ML platform at instantiation time, according to the service definition. Relevant metrics to be injected into the model are also automatically configured so that they are collected, ingested, and consumed along the deployed data engineering pipeline. The use case to which it is applied is a digital twin service, whose control and motion planning function has stringent latency constraints (directly linked to its CPU consumption), eventually determining the need for scaling out/in to fulfill the SLA.

8.1. IEEE INFOCOM (2021)

This innovation has been presented at the same flagship event INFOCOM 2021 as Innovation in Section 7 in this document. The conference was held virtually from the 10th to the 13th of May 2021 and the interested reader is referred to Section 7.1 for futher information as well as for Media Content references.

8.2. Media content

The programme of the event can be checked at: https://infocom.info/day/1/track/Demo

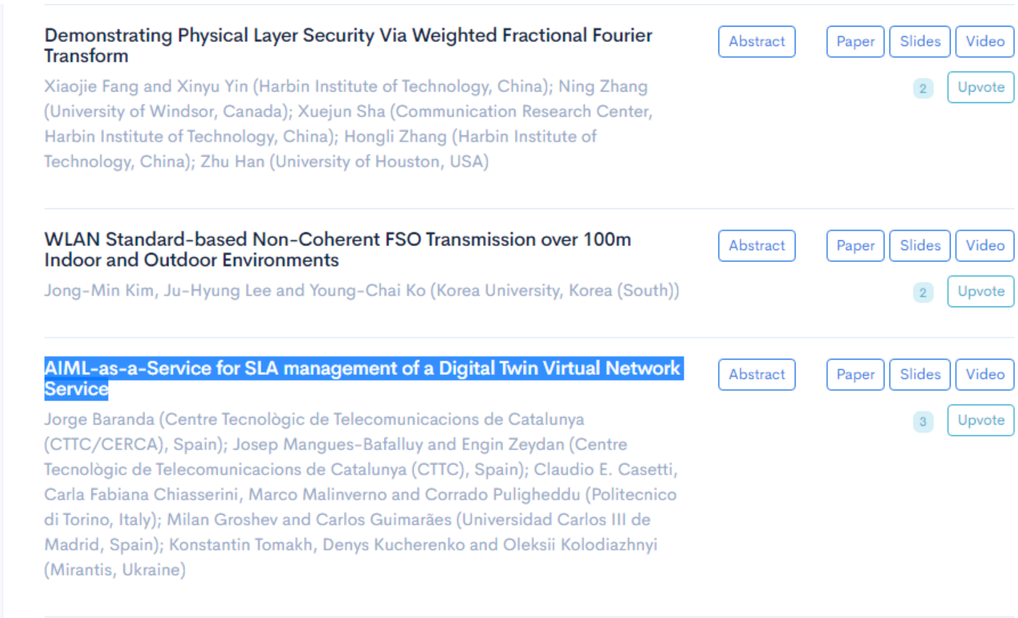


FIGURE 19: PROGRAMME AS SHOWN ON THE WEBSITE, WITH 5GROWTH'S CONTRIBUTION HIGHLIGHTED

A demonstration recording is available at: https://www.youtube.com/watch?v=7V3AKSrWzzY

FIGURE 20: YOUTUBE VIDEO OF THE ML-DRIVEN SCALING OF A DIGITAL TWIN SERVICE DEMO

Below are shown some of the tweets from 5Growth's twitter account on this demo:

https://twitter.com/5growth_eu/status/1364908412333621248

8.3. Demonstration details

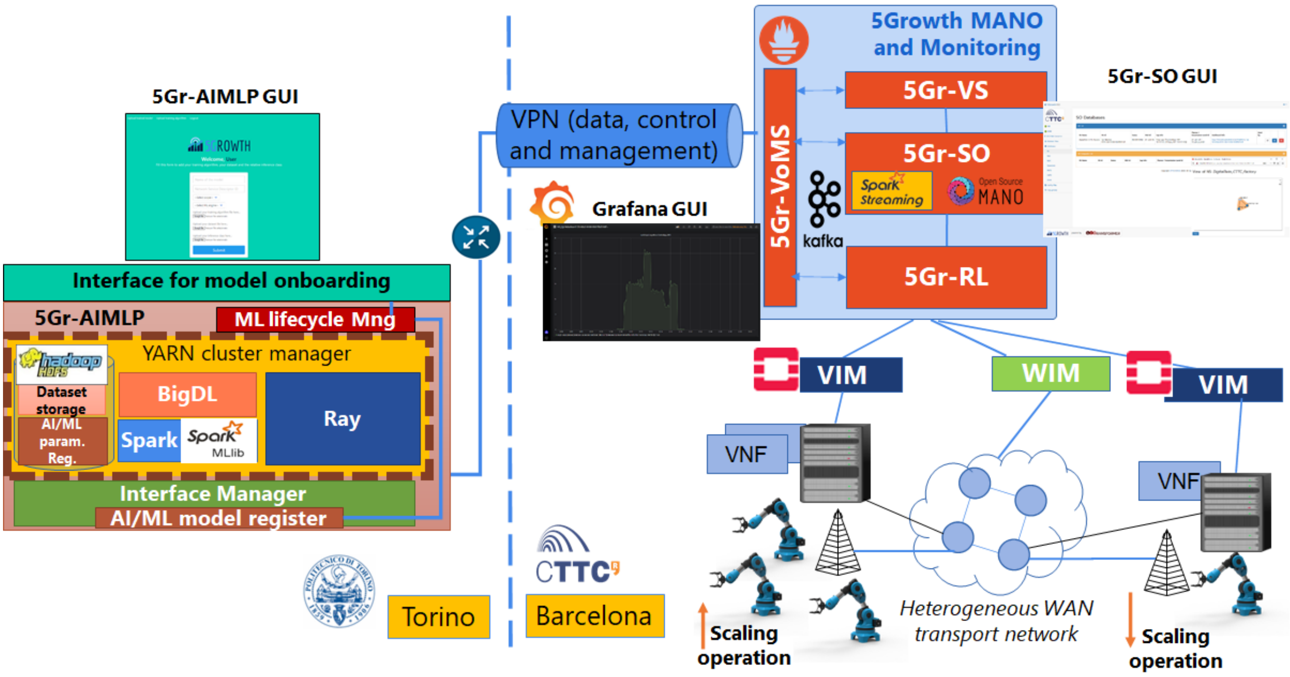


FIGURE 21: SETUP UNDER DEMONSTRATION FOR THE AIML-AS-A-SERVICE FOR SLA MANAGEMENT DEMO

Figure 21 presents the setup under demonstration. This setup has been deployed in two different geographical sites interconnected through a virtual private network. The 5Gr MANO stack, the monitoring platform (5Gr-VoMS) and the infrastructure of the 5Gr framework are deployed in Barcelona (Spain), while the 5Gr-AIMLP is deployed in Torino (Italy).

We show the capabilities of the 5Gr-AIMLP and the data engineering pipeline integrated in the 5Gr platform to perform AI/ML-based scaling operations based on dynamic service conditions, hence fulfilling NS SLAs during run time operation. The dataset and the emulated Digital Twin NS used during this demonstration are derived from [15]. The NFV-NS initially consists of two VNFs, namely the Digital Twin app (DT App) VNF and the Control and Motion Planning (C&MP) VNF. The DT App VNF receives the position information of attached robots, and processes this information to create the digital twin model of the robot so the human user can control its movement. Then, the C&MP VNF processes these movement commands to plan and generate the required instructions for the robot and enact the desired movement. The critical VNF is the C&MP VNF, whose CPU load, hence processing latency, is directly related to the number of attached robots. Such VNF thus needs to be properly scaled out/in to ensure that instructions are delivered to robots on time while avoiding wasting CPU resources. For this reason, this NFV-NS exhibits multiple instantiation levels (ILs), each corresponding to a different number of C&MP VNF instances, over which the load generated by multiple robots can be balanced. The main steps of the demonstration are:

1) The dataset, the training algorithm, and inference classes are uploaded in the 5Gr-AIMLP. The training algorithm is used to process the dataset and generate a trained ML model. In this demonstration, a Random Forest classifier is generated using Apache Spark MLlib.
2) The Digital Twin NFV-NS is instantiated according to the procedure explained in [16], with its NSD requiring the use of AI/ML-based techniques to manage the scaling operation. During the instantiation process, the ML model trained in step 1) and the inference file to run the on-line classification are downloaded from the 5Gr-AIMLP to the 5Gr MANO platform to perform scaling decisions based on the monitored CPU load of the C&MP VNF instance/s and the current IL.
3) We stress the CPU load of the initial C&MP VNF instance simulating the addition of multiple robots. Then, the online classification job, based on the measured CPU load and the current IL, determines the new IL of the NS, which corresponds to adding a new instance of the C&MP VNF. The 5Gr-SO receives a scaling (out) request to change the IL of the Digital Twin NFV-NS instance. Then, the 5Gr-SO proceeds with the requested scaling (out) operation, as explained in [17].
4) When the CPU load decreases, the online classification job determines that the system can return to the initial IL with a single instance of the C&MP VNF and the 5Gr-SO receives a notification requesting to scale (in) the Digital Twin NFV-NS instance to the former IL.

A more detailed expalanation can be found at [14]

9. INFOCOM'21: Demonstrating a Bayesian Online Learning for Energy-Aware Resource Orchestration in vRANs

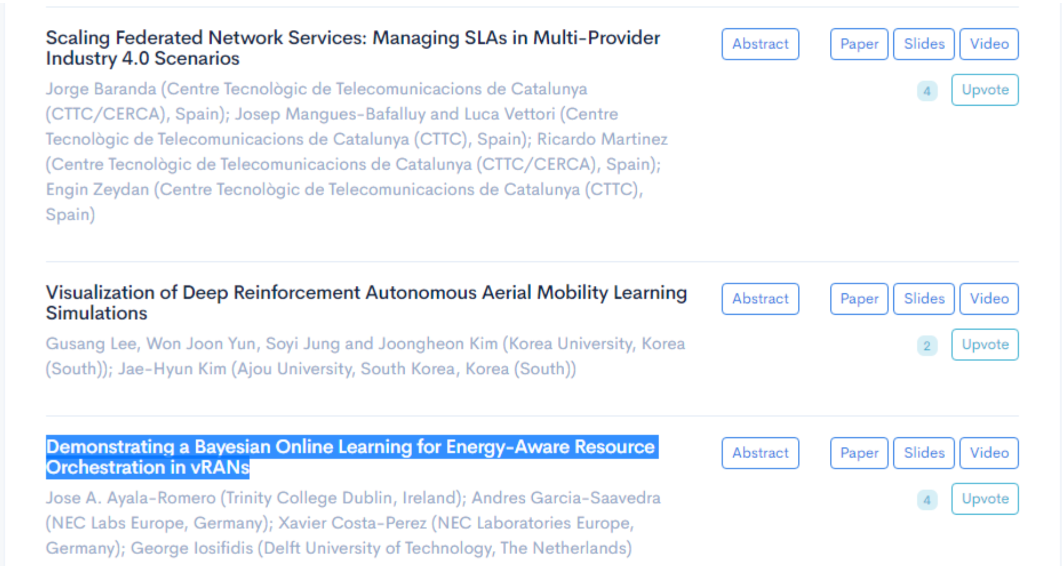
Radio Access Network Virtualization (vRAN) will spearhead the quest towards supple radio stacks that adapt to heterogeneous infrastructure: from energy-constrained platforms deploying cells-on-wheels (e.g., drones) or battery-powered cells to green edge clouds. We demonstrate a novel machine learning approach to solve resource orchestration problems in energy-constrained vRANs. Specifically, we demonstrate two algorithms: (i) BP-vRAN, which uses Bayesian online learning to balance performance and energy consumption, and (ii) SBP-vRAN, which augments our Bayesian optimization approach with safe controls that maximize performance while respecting hard power constraints. We show that our approaches are data-efficient— converge an order of magnitude faster than other machine learning methods—and have provably better performance, which is paramount for carrier-grade vRANs. We demonstrate the advantages of our approach in a testbed comprised of fully-fledged LTE stacks and a power meter, and implementing our approach into O-RAN's non-real-time RAN Intelligent Controller (RIC).

9.1. IEEE INFOCOM (2021)

This innovation has been presented at the same flagship event INFOCOM 2021 as the innovation in Section 7 in this document. The conference was held virtually from the 10th to the 13th of May 2021 and the interested reader is referred to Section 7.1 for further information as well as for Media Content references.

9.2. Media content

The programme of the event can be checked at: https://infocom.info/day/1/track/Demo


Scaling Federated Network Services: Managing SLAs in Multi-Provider Industry 4.0 Scenarios
Jorge Baranda (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Spain); Josep Mangues-Bafalluy and Luca Vettori (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain); Ricardo Martinez (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Spain); Engin Zeydan (Centre Tecnològic de Telecomunicacions de Catalunya (CTTC), Spain)
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Demonstrating a Bayesian Online Learning for Energy-Aware Resource Orchestration in vRANs
Jose A. Ayala-Romero (Trinity College Dublin, Ireland); Andres Garcia-Saavedra (NEC Labs Europe, Germany); Xavier Costa-Perez (NEC Laboratories Europe, Germany); George Iosifidis (Delft University of Technology, The Netherlands)
Abstract Paper Slides Video
4 Upvote

FIGURE 22: PROGRAMME AS SHOWN ON THE WEBSITE, WITH 5GROWTH'S CONTRIBUTION HIGHLIGHTED.

Below are shown some of the tweets from 5Growth's twitter account on this demonstration:

https://twitter.com/5growth_eu/status/1382287874800955393

In addition, here are some screenshots of the demo presentation:

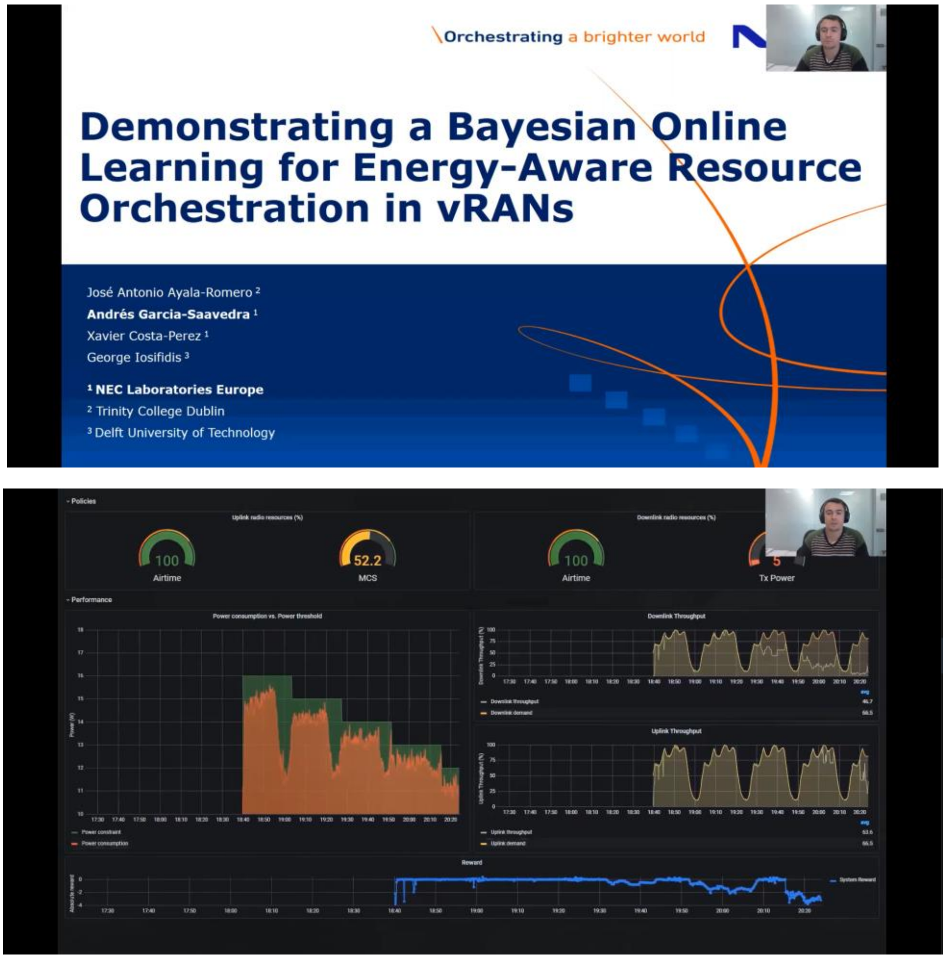


FIGURE 23: SCREENSHOTS OF THE DEMO PRESENTATION

9.3. Demonstration details

The algorithms used in this demo are founded on Bayesian theory, Gaussian Processes (GPs) and online learning. GPs model the behavior of the vBS in terms of performance and power consumption, using the collected measurements in real time. Accordingly, we use a contextual bandit approach to intelligently explore the space of vBS configurations, and exploit the best ones for each context, namely UL/DL traffic load and SNR patterns. The result is a non-parametric algorithmic framework that makes minimal assumptions about the system, adapts to user needs and network conditions, and provably maximizes performance.

Furthermore, drawing ideas from safe Bayesian optimization, our SBP-vRAN algorithm ensures that the vBS power constraints are not violated even during exploration, hence enabling the vBS deployment on energy-constrained platforms. By design, this framework outperforms other approaches requiring knowledge of the vBS functions or offline data to approximate them, and adaptive techniques that do not offer performance guarantees or have strict assumptions.

We consider a virtualized Base Station (vBS) comprising a Baseband Unit (BBU), which may correspond to a 4G eNB or 5G gNB hosted in a cloud platform and attached to a Radio Unit (RU), which are fed by a common and possibly constrained energy source. This type of BSs is relevant for low-cost small cells, Power-over-Ethernet (PoE) cells, and so on. Our goal is to use O-RAN's control architecture to select and adapt radio policies to system dynamics satisfying different energy-driven criteria. The figure shows the high-level system architecture, which is O-RAN compliant. The Learning Agent (LA) runs online algorithms within the Non-Real-Time (Non-RT) RAN Intelligent Controller (RIC) in the system's orchestrator, and sequentially selects efficient radio policies every orchestration period t (in the order of seconds) given the current context.

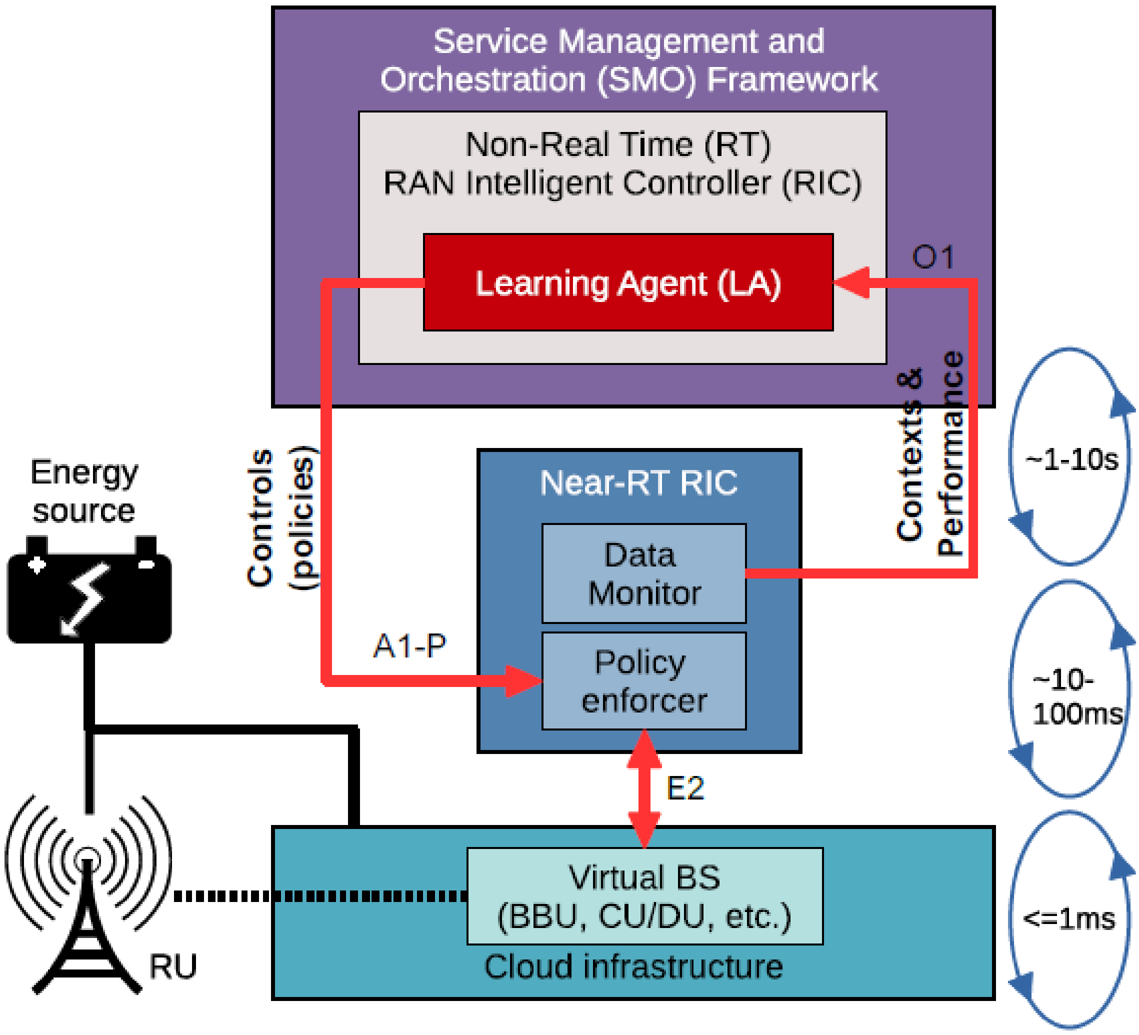


FIGURE 24: O-RAN COMPLIANT SYSTEM ARCHITECTURE AND WORKFLOW.

The testbed is shown in the next figure and comprises a vBS, the user equipment (UE)[3], and a digital power meter. Both the vBS and the UE consist of an Ettus Research USRP B210 as RU, srseNB/srsUE as BBU for both the eNB and UE, and two small factor general-purpose PCs (Intel NUCs with CPU i7-8559U@2.70GHz) deploying each respective BBU and the near-RT RIC of the previous figure. The vBS and the UE are connected using SMA cables with 20dB attenuators, and we adjust the gain of the RU's RF chains to attain different SNR values. Without loss in generality, we select a 10-MHz band that renders a maximum capacity of roughly 32 and 23 Mbps in DL and UL, respectively. We use the power meter GW-Instek GPM-8213 to measure the power consumption of the BBU and the RU by plugging their power supply cable to a GW-Instek Measuring adapter GPM-001.

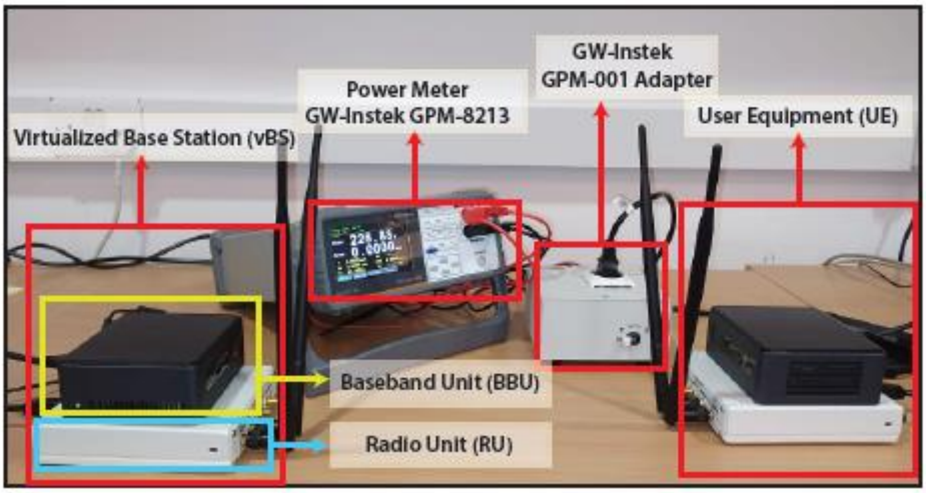


FIGURE 25: EXPERIMENTAL VBS AND UE TESTBED.

Finally, we have integrated E2's interface and the ability to enforce control policies on-the-fly in srseNB. We use three auxiliary PCs (not shown in the picture) hosting the non-RT RIC and the network traffic generators. We have finally implemented O1 interface using the USB-based power meter SCPI (Standard Commands for Programmable Instruments) interface concerning power consumption measurements and a REST interface for the remainder.

In our demonstration, we verify that both algorithms converge and find the optimal vBS configuration in a variety of scenarios. Using real traffic traces, we show, step-by-step, how our framework explores the configurations, and how it refrains from violating the power constraints when necessary. We also benchmark our solution with a state-of-the-art Reinforcement Learning (RL) solution. Namely, we implement a Deep Deterministic Policy Gradient (DDPG) algorithm using an actorcritic neural network (NN) architecture, which is presented in [20]. We find that our framework is more data-efficient tan such RL approaches which require orders of magnitude more measurements (hence, also more time) to train their NNs.

The details of the design of BP-vRAN and SBP-vRAN are presented in [19]. Our software implementation and the dataset used in our paper are publicly available (see [19]).

10. OSM Ecosystem Day: Vertical's intent evolution at service runtime driving vCDN automated scaling

On the 10th of March 2021, the Demo "Vertical's intent evolution at service runtime driving vCDN automated scaling" was presented at OSM Ecosystem Day. A brief summary of the demo is presented herein. 5G networks include several heterogenous devices and technologies with an increasing complexity of network infrastructures and services that is affecting Service Providers' management tasks. Orchestration, automation, analytics and AI/ML techniques are becoming important assets towards the implementation of automated network and service management procedures. At the same time, future networks will be intent-based, with the purpose of hiding such complexity and enabling network and service adaptation depending on a business logic. The proposed demo shows the automated scaling of a virtual Content Delivery Network performed upon the runtime evolution of the service's intent. In the demonstration the Vertical Slicer prototype, developed by Nextworks, has been integrated with ETSI Open Source MANO as NFV Orchestrator. Following the ETSI ENI approach, multi-layer data collected at virtual infrastructure and application feed a Cognitive Network Management system that recognizes changes in the service intents and takes optimization decisions for data-driven closed-loop automations.

10.1. OSM Ecosystem Day

ETSI's Centre for Testing and Interoperability and the OSM community organized a new OSM Hackfest on 8-12 March 2021. The event run remotely, allowing participants to join the hands-on sessions from home. Participation to OSM Hackfests is free and open to all upon Registration

Within the OSM Hackfest, the OSM Ecosystem Day was held virtually on Wednesday, March 10th from 14:30 to 18:00. The objective is to allow organizations in the OSM Ecosystem to share how OSM is helping them to achieve their goals. Presentations and demos cover a wide range of aspects from research activities in academia to production deployments and commercial initiatives, many of them focused on 5G use cases.

10.2. Media content

The programme to the event is shown at: https://osm.etsi.org/wikipub/index.php/OSM-MR10_Hackfest#OSM_Ecosystem_Day

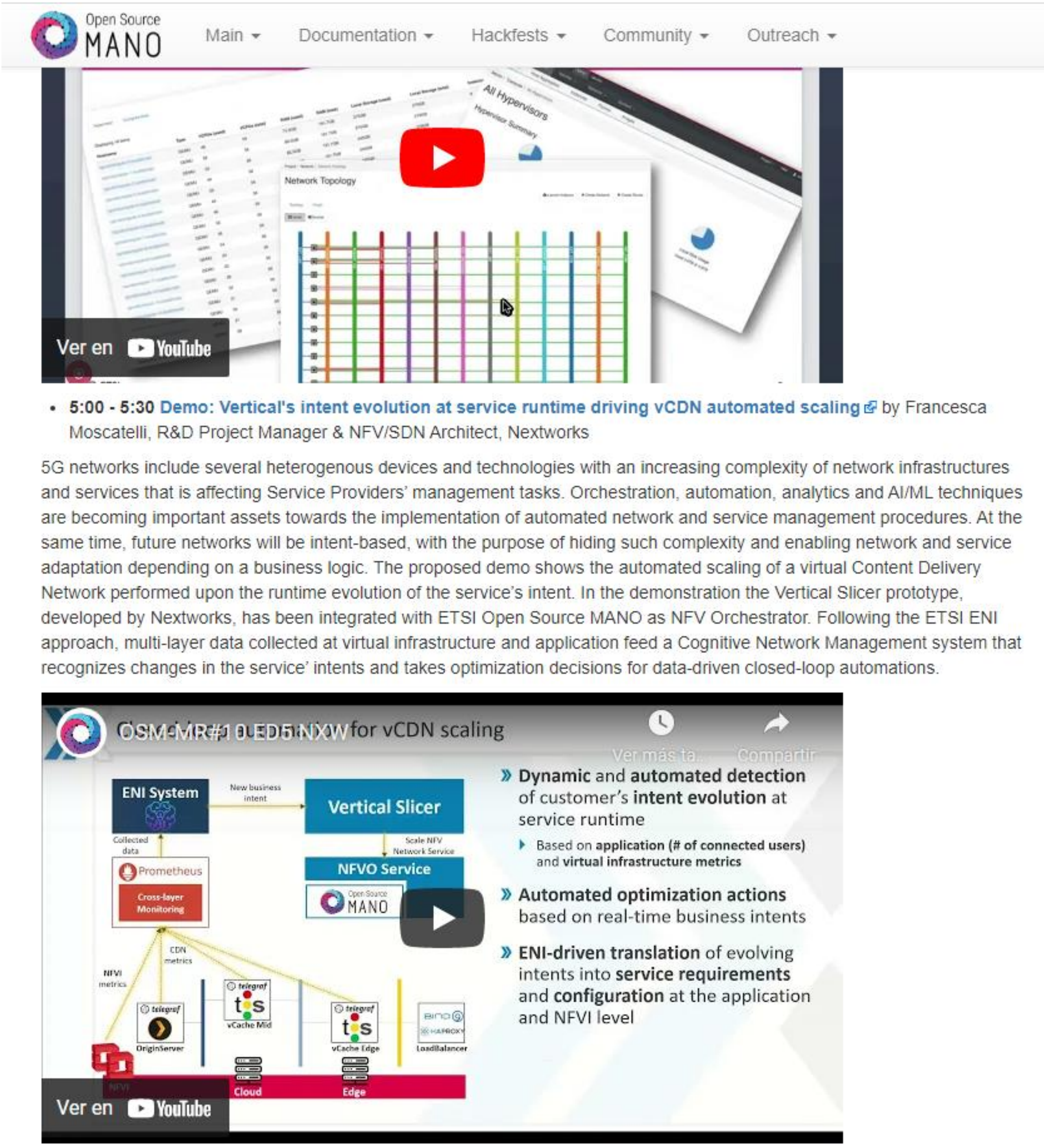


FIGURE 26: PROGRAMME AS SHOWN ON THE WEBSITE, WITH 5GROWTH'S CONTRIBUTION.

The demonstration recording is available at: https://www.youtube.com/watch?v=7Gzz-NGgOTM

FIGURE 27: YOUTUBE VIDEO OF THE VERTICAL'S INTENT EVOLUTION AT SERVICE RUNTIME DRIVING VCDN AUTOMATED SCALING

The slides can be found at: http://osm-download.etsi.org/ftp/osm-9.0-nine/OSM-MR10-hackfest/EcosystemDay/OSM-MR10%20ED5%20-%20Nextworks.pdf

Below are shown some of the tweets from 5Growth's twitter account on this demonstration:

https://twitter.com/OpenSourceMANO/status/1366750327949647880

10.3. Demonstration details

The demonstration shows an extended version of the 5Growth Vertical Slicer prototype, integrated with an OSM-based NFVO, which relies on third party ENI-like system embedding AI/ML algorithms to drive the scaling of a virtual Content Delivery Network service. The architecture of the system is represented in Figure 28, which indentifies (i) the Vertical Service Manager and Network Slice Manager composing the Vertical Slicer, (ii) the NFVO and the VIM where the service is deployed, based on OSM and OpenStack, respectively, (iii) the Prometheus-based monitoring platform, used to collect metrics and monitoring data from the different layers of the sytem, and (iv) the ENI System, which retrieves the monitoring data from Prometheus and, applying the AI/ML algorithms, takes scaling decisions on the basis of the service intents evolution. Such decisions are then translated into service scaling commands that are triggered through the North-Bound Interface of the Vertical Slicer, at the Vertical Service Manager level. The scaling decisions are processed internally by the Vertical Slicer and translated into the corresponding NFV Network Service scaling requests which are forwarded to the OSM-based NFVO and here executed.

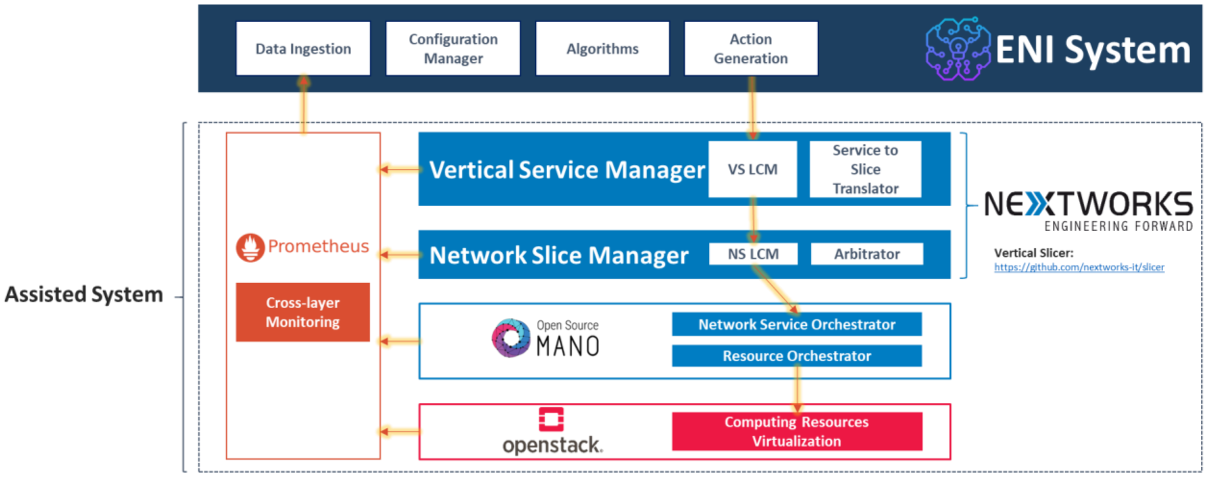


FIGURE 28: SYSTEM ARCHITECTURE DEMONSTRATED AT THE OSM ECOSYSTEM DAY

This demonstration is also showing some of the major functionalities of the 5Growth Vertical Slicer, like the modelling and instantiation of vertical-driven services across 5G network slices, the automated translation of business/service requirements into network slices and the automated arbitration of resources based on tenants' SLAs at instantiation/scaling time. Moreover, for this demonstration, the Vertical Slicer has been extended and integrated with external components to implement a closed-loop service-level scaling. This has been achieved introducing functionalities for (i) the dynamic configuration of the Vertical Service's components at runtime for the VNFs and PNFs composing the service (Day 1/ Day 2 configuration), (ii) the configuration of service-specific alerts (i.e., based on service-related parameters in the Vertical Service Blueprint) in Prometheus and (iii) the scaling the Vertical Service upon the selection of a different Vertical Service Descriptor that is triggered by the ENI System.

The virtual service components and their interconnection with the system components of the platform are represented in Figure 29. Their definition is modelled in the system following the format of the Vertical Service Blueprints, Vertical Service Descriptors and Network Slice Templates defined in the 5Growth project, while the NFV Network Service Descriptors and VNF Packages follows the OSM Information Model. A specialized OSM-driver has thus been developed to enable the interaction and data models adaptation between the Vertical Slicer and the OSM-based NFVO.

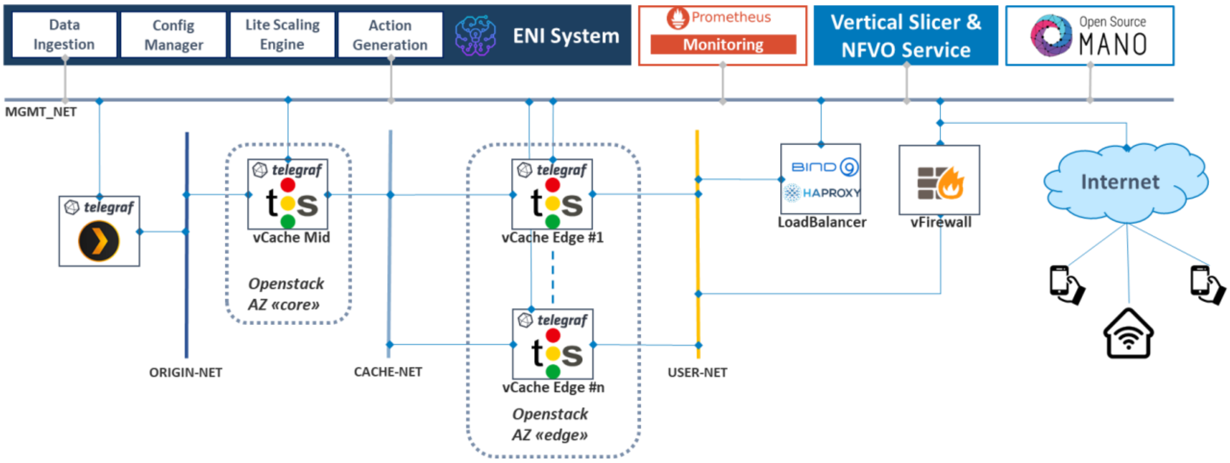


FIGURE 29: SERVICE COMPONENTS FOR THE DEMONSTRATION AT THE OSM ECOSYSTEM DAY

11. IEEE NetSoft'21: Slice Isolation for 5G Transport Networks

Network slicing plays a key role in the 5G ecosystem for vertical industries to introduce new services. However, one widely-recognized challenge of network slicing is to provide traffic isolation and concurrently satisfy diverse performance requirements, e.g., bandwidth and latency. In this workshop, we showcase the capability to retain these two goals at the same time, via extending the 5Growth baseline architecture and designing a new data-plane pipeline, i.e., virtual queue, over the P4 switch.

To demonstrate the effectiveness of our approach, a proof-of-concept is presented serving different service requests over a mixed data path, including P4 switches and Open vSwitches (OvSs).

11.1. IEEE NetSoft'21

The 7th IEEE International Conference on Network Softwarization (IEEE NetSoft 2021) will be held in Tokyo, Japan from June 28 to July 2, 2021. The theme of the IEEE NetSoft 2021 "Accelerating Network Softwarization in the Cognitive Age" reflects the current trend of research in the area of network softwarization. The IEEE NetSoft 2021 will showcase the latest research and development results including artificial intelligence / machine learning, self-driving and autonomic networking, policy-based network management, dynamic network slice provisioning, among other promising research areas for the sake of robust, reliable and cognitive softwarized networks.

11.2. Media content

The presentation banner is shown in next figure:

FIGURE 30: PRESENTATION BANNER ON NETSOFT'21 CONFERENCE

A summary of the demo can be found at: https://www.youtube.com/watch?v=DSGHUBFuvYs

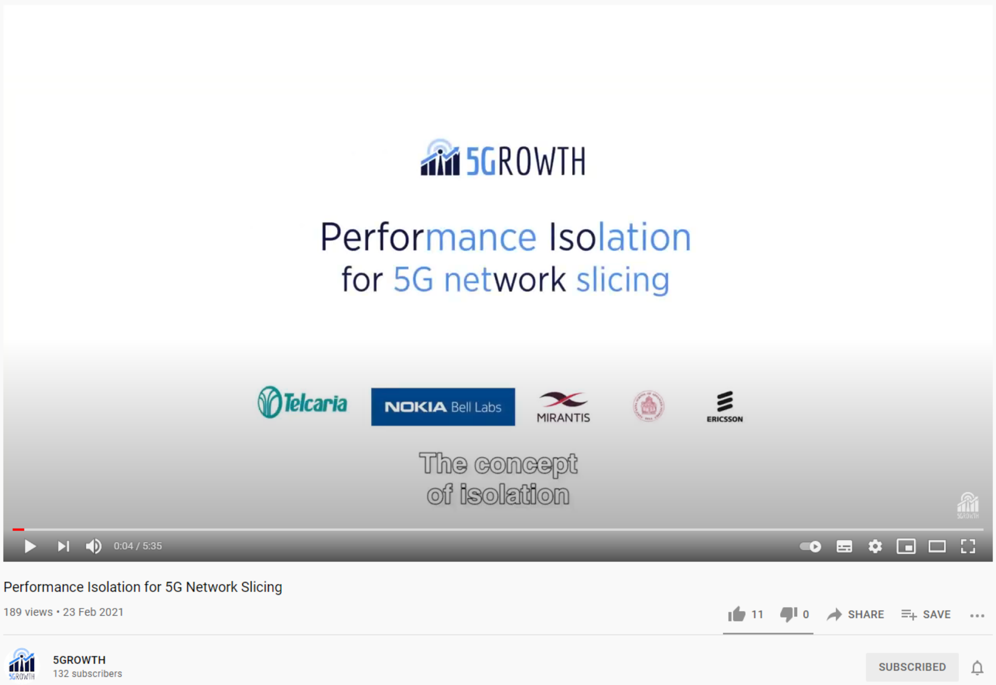


FIGURE 31: YOUTUBE VIDEO OF THE PERFORMANCE ISOLATION FOR 5G NETWORK SLICING DEMO

Slice Isolation for 5G Transport Networks

Thursday, July 1

9:36 pm - 9:48 pm

Virtual Room #1

Speaker

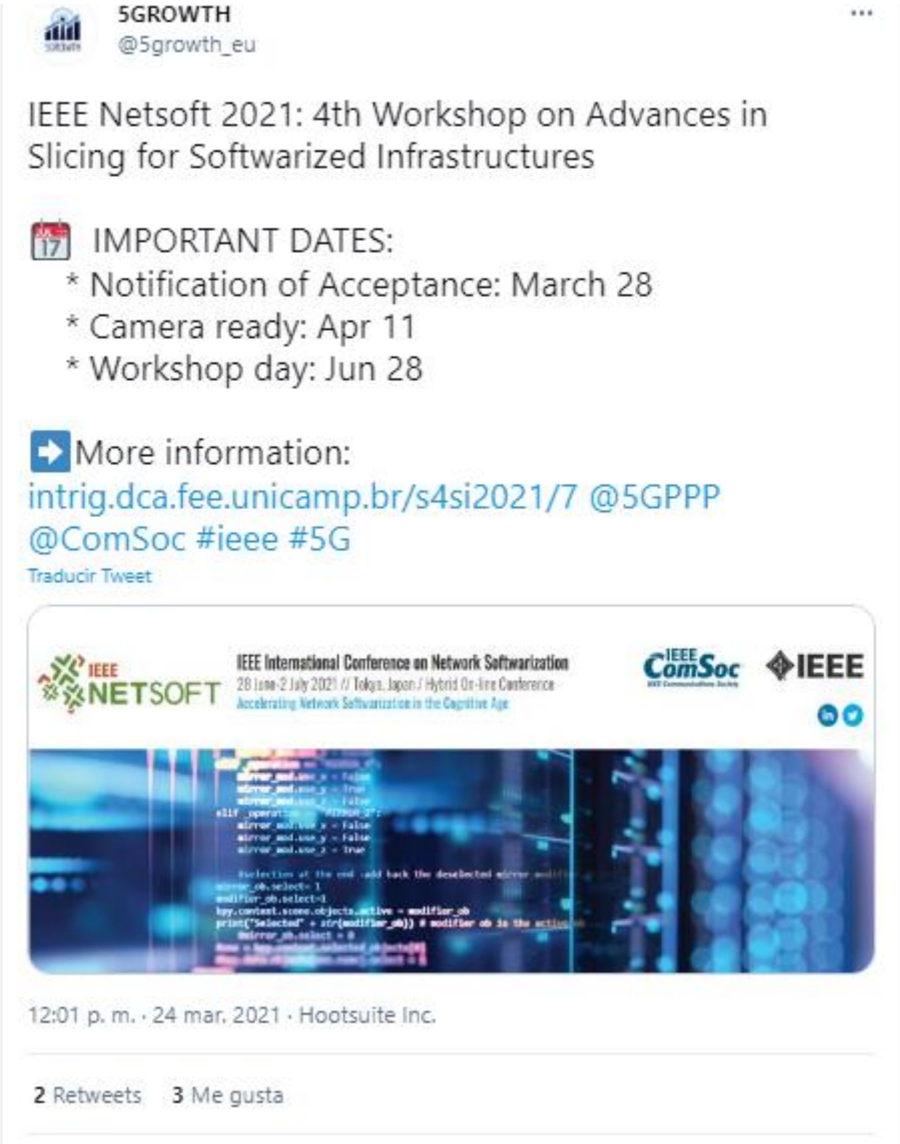
- **Chia-Yu Chang** (Presenter) Nokia Bell Labs

Description

Chia-Yu Chang, *Nokia Bell Labs*, Belgium
Manuel Angel Jimenez, *Telcaria Ideas*, Spain
Molka Gharbaoui, *CNIT*, Italy
Javier Sacido, *Telcaria Ideas*, Spain
Fabio Ubaldi, *Ericsson*, Italy
Chrysa Papagianni, *University of Amsterdam*, The Netherlands
Aitor Zabala, *Telcaria Ideas S. L.*, Spain
Luca Valcarenghi, *Scuola Superiore Sant'Anna*, Italy
Davide Scano, *Scuola Superiore Sant'Anna*, Italy
Konstantin Tomakh, *Mirantis*, Ukraine
Alessio Giorgetti, *National Research Council of Italy*, Italy
Andrea Boddi, *Ericsson*, Italy
Koen De Schepper, *Alcatel-Lucent*, Belgium

FIGURE 32: DEMO SESSION PROGRAMME

Below are shown some of the tweets from 5Growth's twitter account on this demonstration:



https://twitter.com/5growth_eu/status/1374677792915398665

11.3. Demonstration details

The concept of isolation between network slices is a central point for 5G, in terms of traffic security and performance. In this demo we demonstrate performance isolation, a network slicing capability providing personalized traffic, bandwidth and delay isolation guarantees in an SDN based network. It is worth noting that such isolation is independent of congestion and performance levels of other slice instances, sharing the same infrastructure. Starting from traffic isolation among slices by utilizing the VPLS, we can monitor and control closely the traffic using standard metering. To go beyond the limited information provided by metering, and to also meet advanced delay guarantees, we introduced the use of virtual cues in the P4 pipeline. Such virtual cue mechanism aims to model the sojourn time of the queue, as if the packets arrive at the real queue with per slice defined capacity. Via using virtual cues to perform policing, we can meet the delay requirements of each slice.

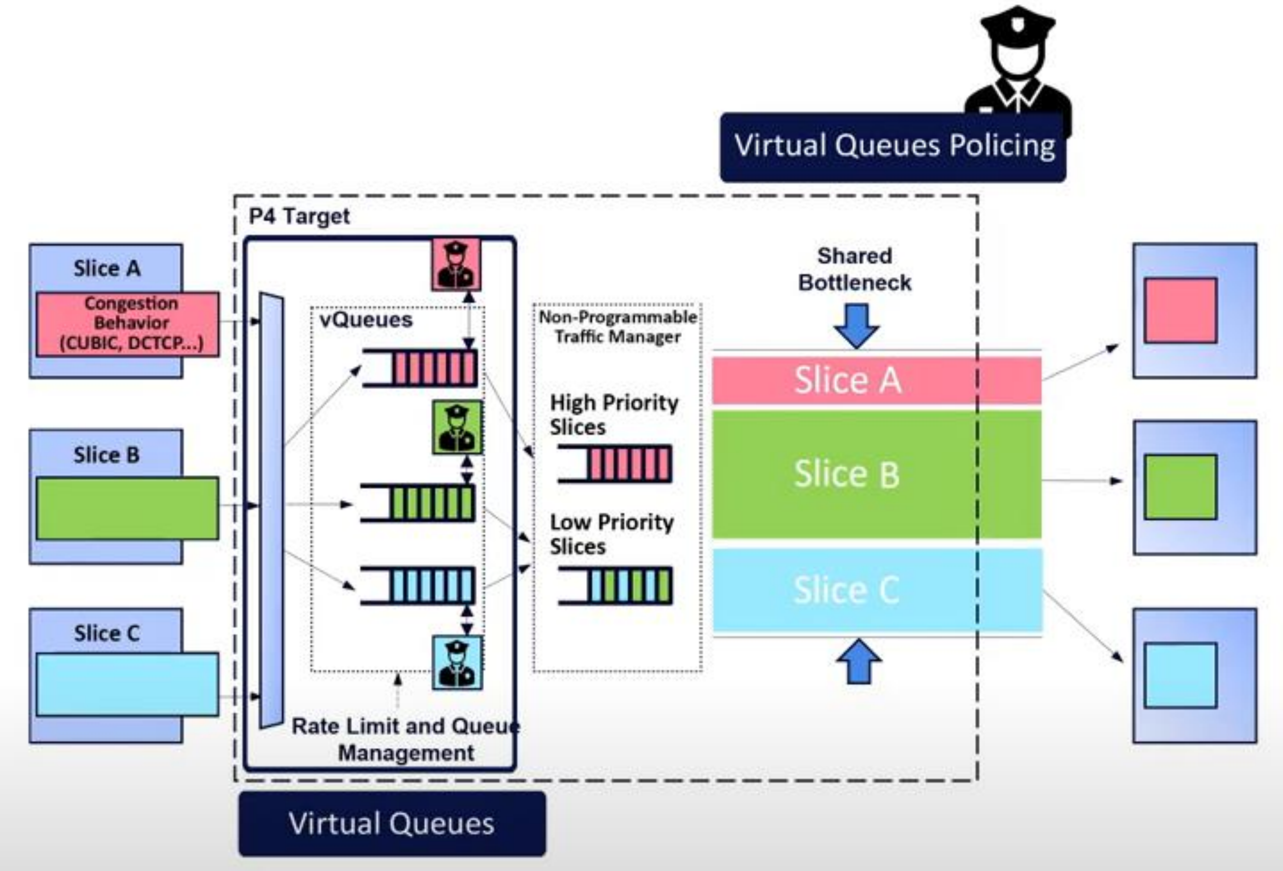


FIGURE 33: VIRTUAL QUEUE IMPLEMENTATION OVER P4 PIPELINE

To demonstrate that our slicing capability is portable to multiple SDN technologies, we showcase the performance isolation under a mixed data path composed of two SDN protocols: openflow and P4. Openflow protocol is capable of performing basic traffic metering, and P4 protocol can perform both traffic metering and the aforementioned virtual cueing, providing bandwidth and advanced delay guarantees. Furthermore we deploy ONOS to control and coordinate the SDN protocols ONOS is a carrier grade SDN controller being capable of managing openflow and p4 protocols.

Nevertheless ONOS nowadays only provides traffic isolation across slices by using VPLS native application, without the capability of bandwidth and delay guarantees. Therefore 5Growth has introduced QOS slicing as an application managing both meters and virtual cues across slices and exposing a unified interface towards the upper control layers.

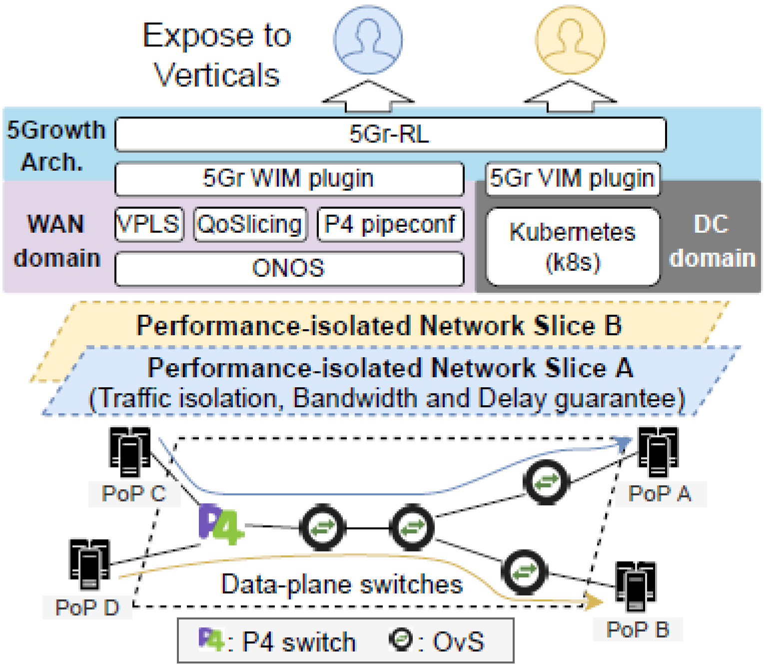


FIGURE 34: SYSTEM OVERVIEW

To expose performance isolated slicing to the verticals we developed two plug-ins for 5Growth resource layer virtual infrastructure manager plugin and wide area infrastructure manager plugin. These two plugins will enable an end to end deployment for performance isolated slices across different points of presence in the transport network. Regarding the evaluation of network slice performances, four key performance indicators are introduced:

1) E2E latency by measuring the round-trip time between two endpoints in a slice
2) Throughput of each slice
3) Virtual delay measured from virtual cues
4) Real delay measured as the experience delay of the physical queue

In the first step of demo, we show the system behavior with no performance isolation in the slices, and a traffic flow saturating the maximum capacity. As we do not enable any bandwidth or delay guarantees the end-to-end latency will increase up to more than two seconds. This large latency is caused by the full utilization of link capacities and the buffers fill up.

When activating the performance isolation in one slice, it is configured to guarantee 12 megabits per second and 10 milliseconds delay. As the throughput guarantee is below the maximum capacity, zero real delay is shown and the buffers do not fill up. The virtual delay experienced at the virtual queue limits the bandwidth to 12 megabits per second.

If we increase the rate limit to 120 megabits per second, as the guaranteed throughput is above the 70 megabits per second maximum capacity, the results show that the real delay can be bounded to 10 milliseconds latency, together with no virtual delay because there is congestion at the real link and the virtual cue rate limit is not reached.

Last we add a second slice, with both slices rate limited to 48 megabits per second, and slice B configured with only 5 millisecond delay guarantee. As slice A has a higher delay guarantee than slice B it will be limited by the virtual queue, while slice B will be limited by the maximum capacity and the real queue. This means that the slice with the most stringent delay bound determines who will suffer from lower throughput. Such phenomenon can be further revised or even reversed via using multiple real cues with weighted schedulers or aqm mechanisms.

FIGURE 35: PROOF-OF-CONCEPT PHASE IV RESULTS

12. EUCNC'21 FAST Workshop: Hardening Interdomain Vertical Services with Moving Target Defense (MTD)

The 5Growth stack enables deploying vertical services in different provider domains, optionally performing end-to-end interdomain services across providers. The interdomain communications may go through untrustworthy public networks. Therefore, we need to protect both the 5Growth stack and the vertical services against adversarial action from these public networks. In this demo, we described the type of attacks we have to defend from and how the Moving Target Defense (MTD) approach addresses these challenges, thus hardening the interdomain vertical services made possible by the 5Growth stack. Using the same Proof-of-Concept setup from the evaluation of the working MTD system, we have shown how the system thwarts the attacks, its caveats, and practical effectiveness.

12.1. EUCNC'21

The 2021 Joint EuCNC & 6G Summit, initiated this year, builds on putting together two successful conferences in the area of telecommunications: EuCNC (European Conference on Networks and Communications), in its 30th edition of a series, supported by the European Commission; the 6G Summit, in its 3rd edition, originated from the 6G Flagship programme in Finland, one of the very first in its area. The conference is sponsored by the IEEE Communications Society and by the European Association for Signal Processing, and focuses on all aspects of telecommunications ranging from 5G deployment and mobile IoT to 6G exploration and future communications systems and networks, including experimentation and testbeds, and applications and services.

It brings together cutting-edge research and world-renown industries and businesses, globally attracting in the last years more than 1300 delegates from more than 40 countries all over the world, to present and discuss the latest results, and an exhibition with more than 70 exhibitors, for demonstrating the technology developed in the area, namely within research projects from EU R&I programmes.

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12.2. Media content

The presentation banner is shown in next figure:

FIGURE 36: EUCNC'21 CONFERENCE BANNER

FIGURE 37: DEMO SESSION IN THE PROGRAMME

12.3. Demonstration details

We have started by showing the 5Growth stack in its regular operation, using a sample vertical service and the interactions required to instantiate it. Figure 38 shows the particulars of the stack used in this demo. We have the vertical domain on the left, with the 5Growth Vertical Portal and the Vertical Slicer's underlying function (CSMF). The vertical can instantiate the service through the 5Growth-Vertical Portal (as shown earlier) or optionally using the Vertical Slicer API (e.g., for custom solutions). On the right, we have the 5G-VINNI domain. Starting with the interdomain communication entry point (green arrow), we can find the VS adapter for Sonata (NSMF) and their NFV Orchestrator (Sonata powered by 5Gtango). The critical Sonata-adapter API is exposed on TCP port 8088. Thus, the instantiation request (or any other LCM interaction, for that matter) goes through an untrusted network to that Sonata adapter. If an attacker manages to intercept those LCM requests, manipulate them, or forge them at his will, there may be severe consequences to the vertical service (e.g., DoS style of attack via a forget termination)

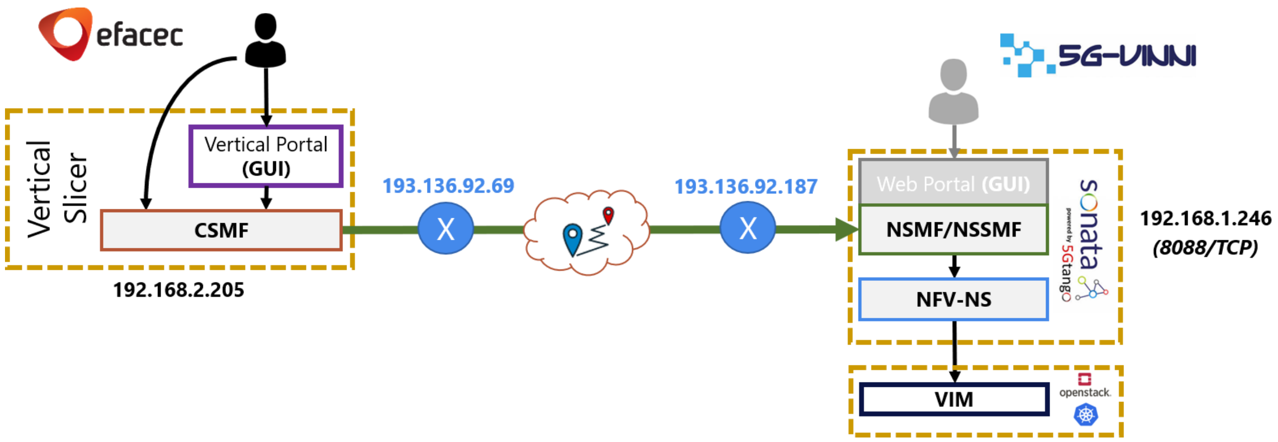


FIGURE 38: SYSTEM MODEL

We then characterized the attack process using the Cyber Kill Chain (CKC), which consists of seven stages (as shown in Figure 39). In (1) Reconnaissance, the attacker finds the targets and discovers their characteristics (aka "enumeration"). Then, in (2) Weaponization, the attacker identifies a vulnerability and devises a tailored exploit (usually offline). The (3) Delivery follows next when the attacker sends the exploit's payload to the vulnerable network service. Crucially, in stage (4) Exploitation, the payload is executed, and the vulnerability is exploited. The later stages of the CKC are not that relevant for our demo because we will be disrupting the actions in the earlier stages (thus breaking the attack before reaching the later stages).

FIGURE 39: THE CYBER KILL CHAIN (CKC)

In particular, we are addressing two cases:

- Case 1: Incomplete Intelligence / Unknown target

  The attacker first needs to probe the services available, discovering their characteristics and potential vulnerabilities.

- Case 2: Advanced Threat / Known target

  The attacker already has sufficient intelligence about the target and its characteristics. At least one vulnerability is already weaponized, but the exploitation process has yet to begin.

We then placed an attacker in the public network and demonstrated how the attacker would exploit our stack within each of the considered cases (the changes to the setup are shown in Figure 40).

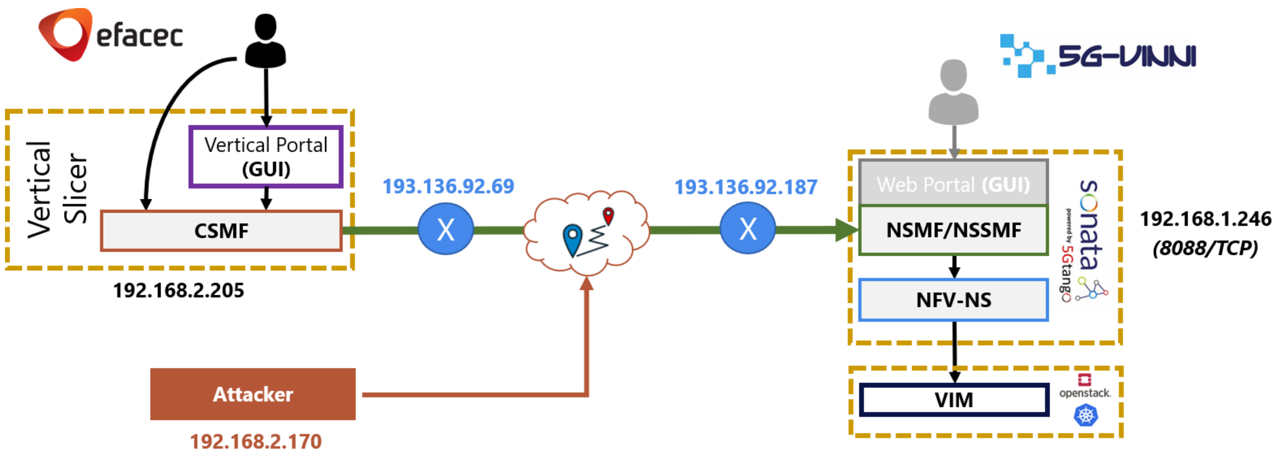


FIGURE 40: DEMONSTRATING THE PROBLEM STATEMENT

After successfully showing the exploitation of two types of security vulnerabilities (information disclosure and a Denial-of-Service (DoS) type of attack), we have showcased how the MTD innovation defended against the same adversarial actions. The updated demo setup is shown in Figure 41.

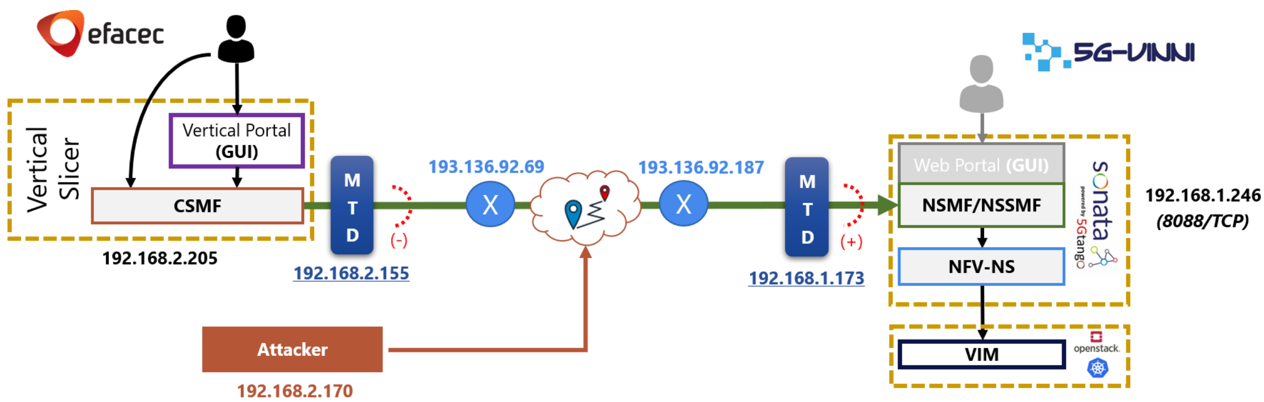


FIGURE 41: SETUP WITH THE MTD FUNCTIONS DEPLOYED

Further details into the MTD mechanism and a more thorough evaluation are available can be found in [21].

13. EUCNC'21: Demonstration Booth

During the EUCNC´21 congress, the 5Growth project has organised a booth to support 4 vertical and 3 5Growth innovation demonstrations. EUCNC´21 demonstrations have benefited from the demonstration activities performed in previous events. Particularly, the EUCNC´21 booth hosted the innovation demonstrations performed at INFOCOM´21 and IEEE NetSoft´21 in addition to others.

FIGURE 42: EUCNC'21 EXHIBITOR'S HALL

13.1. EUCNC'21

The 2021 Joint EuCNC & 6G Summit, initiated this year, builds on putting together two successful conferences in the area of telecommunications: EuCNC (European Conference on Networks and Communications), in its 30th edition of a series, supported by the European Commission; the 6G Summit, in its 3rd edition, originated from the 6G Flagship programme in Finland, one of the very first in its area. The conference is sponsored by the IEEE Communications Society and by the European Association for Signal Processing, and focuses on all aspects of telecommunications ranging from 5G deployment and mobile IoT to 6G exploration and future communications systems and networks, including experimentation and testbeds, and applications and services.

It brings together cutting-edge research and world-renown industries and businesses, globally attracting in the last years more than 1300 delegates from more than 40 countries all over the world, to present and discuss the latest results, and an exhibition with more than 70 exhibitors, for demonstrating the technology developed in the area, namely within research projects from EU R&I programmes.

13.2. Media Content

Virtual Platform link

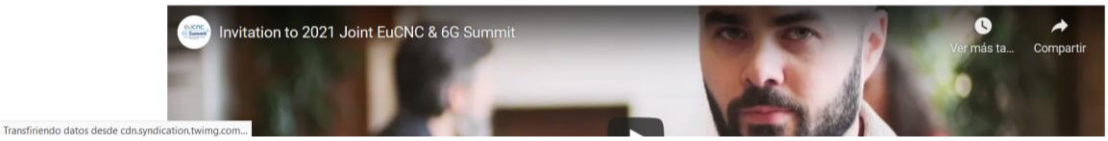


FIGURE 43: PRESENTATION BANNER ON EUCNC'21 CONFERENCE

Below are shown some of the tweets from EUCNC and 5Growth's twitter accounts on EUCNC demonstrations:

https://twitter.com/EuCNC/status/1402580549789683713

https://twitter.com/5growth_eu/status/1403321197287325698

13.3. Demonstration details

The demonstrations were accessible through the 5Growth virtual booth, which provided the links to videoconferencing sessions presenting the pilots and demonstrations. Vertical demonstrations where organised around Industry 4.0 (COMAU, INNOVALIA) and Transportation and Energy (EFACEC) pilots. Additionally, 3 5Growth innovation demos were also performed.

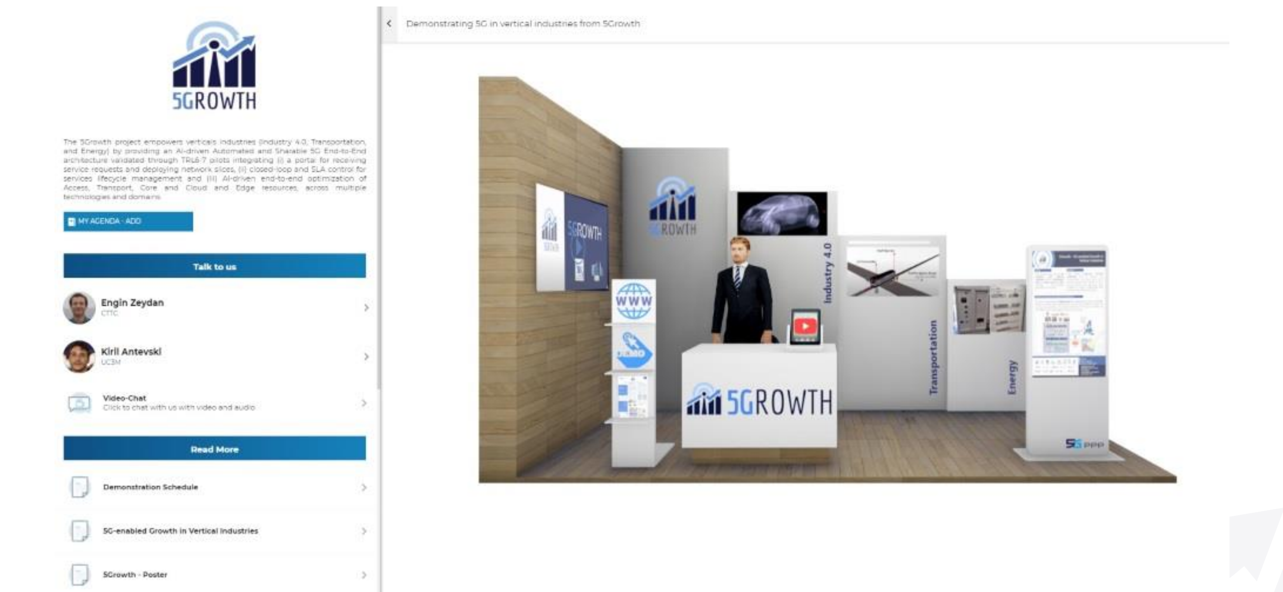
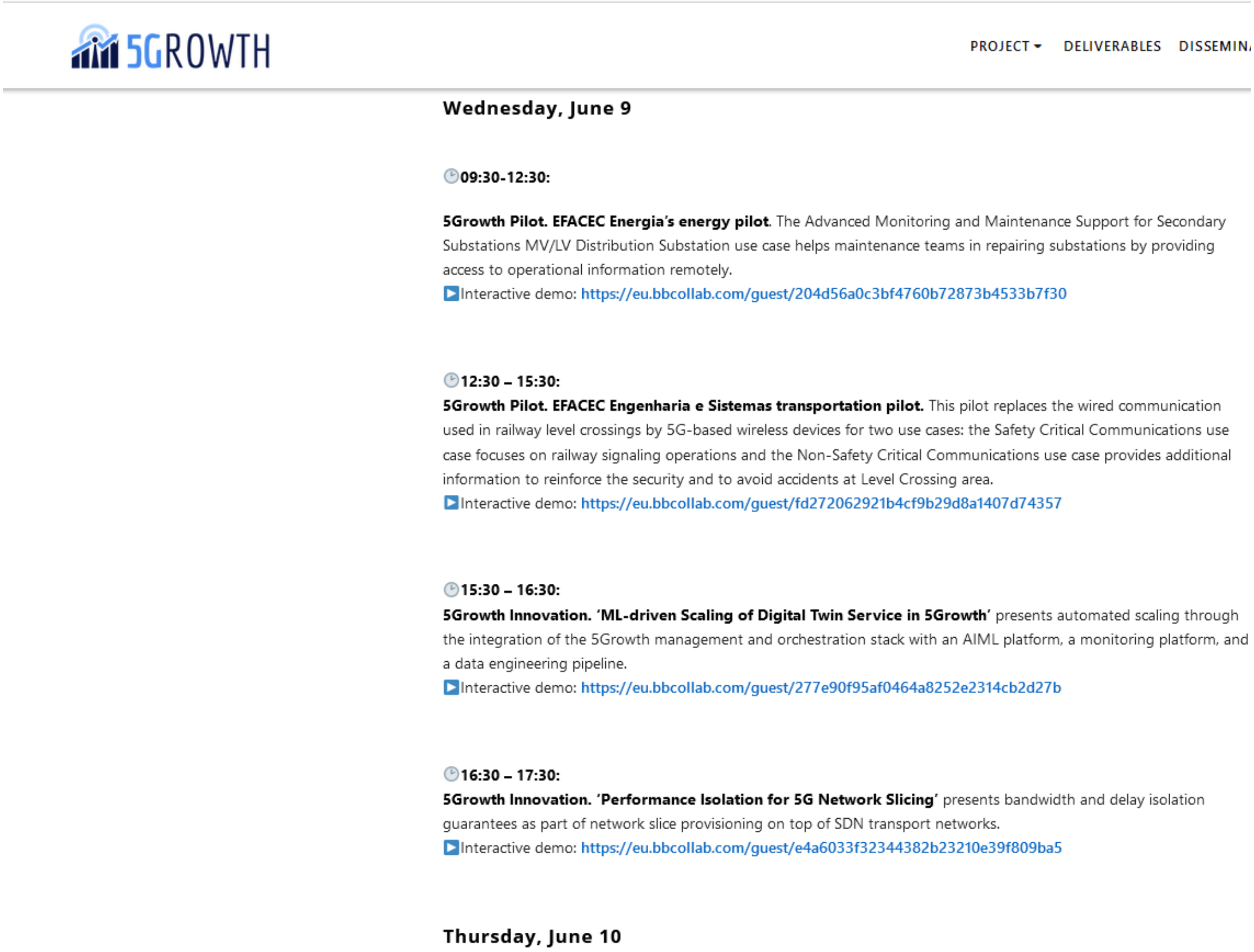


FIGURE 44: 5GROWTH BOOTH AT EUCNC 2021

Demonstration interactive sessions were organised throughout the conference (https://5growth.eu/2021/06/09/5growth-demonstration-schedule-at-eucnc-2021/)



PROJECT ▾ DELIVERABLES DISSEMIN

Wednesday, June 9

09:30-12:30:

5Growth Pilot. EFACEC Energia's energy pilot. The Advanced Monitoring and Maintenance Support for Secondary Substations MV/LV Distribution Substation use case helps maintenance teams in repairing substations by providing access to operational information remotely.
Interactive demo: https://eu.bbcollab.com/guest/204d56a0c3bf4760b72873b4533b7f30

12:30 – 15:30:
5Growth Pilot. EFACEC Engenharia e Sistemas transportation pilot. This pilot replaces the wired communication used in railway level crossings by 5G-based wireless devices for two use cases: the Safety Critical Communications use case focuses on railway signaling operations and the Non-Safety Critical Communications use case provides additional information to reinforce the security and to avoid accidents at Level Crossing area.
Interactive demo: https://eu.bbcollab.com/guest/fd272062921b4cf9b29d8a1407d74357

15:30 – 16:30:
5Growth Innovation. 'ML-driven Scaling of Digital Twin Service in 5Growth' presents automated scaling through the integration of the 5Growth management and orchestration stack with an AIML platform, a monitoring platform, and a data engineering pipeline.
Interactive demo: https://eu.bbcollab.com/guest/277e90f95af0464a8252e2314cb2d27b

16:30 – 17:30:
5Growth Innovation. 'Performance Isolation for 5G Network Slicing' presents bandwidth and delay isolation guarantees as part of network slice provisioning on top of SDN transport networks.
Interactive demo: https://eu.bbcollab.com/guest/e4a6033f32344382b23210e39f809ba5

Thursday, June 10

FIGURE 45: INTERACTIVE SESSION PROGRAMME FOR EUCNC 2021 5GROWTH BOOTH

As well as access to the various media material supporting the various demonstrations were also made available via the various tools facilitated by EUCNC´21 booth platform.

5Growth Pilots:

- **5Growth Pilot. EFACEC Energia´s energy pilot**
  https://www.youtube.com/watch?v=JcLEF3T5nLg
- **5Growth Pilot. EFACEC Engenharia e Sistemas transportation pilot**
  https://www.youtube.com/watch?v=XP7E_txgmzY
- **5Growth Pilot. COMAU Industry 4.0 pilot**
  https://www.youtube.com/watch?v=rY6ZH75agOk
- **5Growth Pilot. Innovalia Industry 4.0 pilot**
  https://www.youtube.com/watch?v=EBLm0l32iTQ&t=671s

5Growth Innovations:

- **5Growth Innovation. ML-driven scaling of Digital Twin Service in 5Grwoth**
  Details described in section 8 of this document
  https://www.youtube.com/watch?v=K5GyrAD7h_Q
- **5Growth Innovation. Performance Isolation for 5G Network Slicing**
  Details described in section 11 of this document
  https://www.youtube.com/watch?v=K5GyrAD7h_Q
- **5Growth Security Innovation. Moving Target Defense**
  Details described in section 12 of this document
  https://youtu.be/MTneJD2Kh1k

It can be remarked that **the booth has received the EUCNC Best Booth Award** (Figure 46 - https://www.eucnc.eu/awards/) as indication of the interest raised by the attendants to the conference on the showed deminstrations.

FIGURE 46: EUCNC'21 BEST BOOTH AWARD RECEIVED

14. References

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[19]. J. A. Ayala, A. Garcia-Saavedra, X. Costa-Perez, and G. Iosifidis, "Bayesian Online Learning for Energy-Aware Resource Orchestration in Virtualized RANs," in IEEE INFOCOM '21

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