A Zero Touch Emulation Framework for Network Slicing Management in a 5G Core Testbed

Shwetha Vittal, Sourav Sarkar, Prashanth P S, Antony Franklin A
Department of Computer Science and Engineering, Indian Institute of Technology Hyderabad
Email: {cs19resch01001, cs19mtech11031, cs20resch11005, antony.franklin}@iith.ac.in

***Abstract*—Network slicing is one of the core features of the 5G network to meet the requirements of various network services, namely, enhanced Mobile Broadband (eMBB), ultra Reliable Low Latency Communications (uRLLC), and massive Machine Type Communication (mMTC) by building an isolated virtual network of resources typically in a Network Function Virtualization (NFV) environment. We have built a 3GPP compliant 5G Core (5GC) testbed and enabled network slicing on it to provide eMBB, uRLLC, and mMTC services to end users. In this demonstration, we showcase the capabilities of our zero-touch framework of 5GC network slicing management and orchestration in an NFV environment with the network functions of 5GC and the applications on eMBB and uRLLC slice services. We believe that this work will guide Mobile Network Operator (MNO)s in building zero-touch autonomous network slices in 5GC along with their smart management and orchestration in closed loop automation.**

I. Introduction

Network slicing has emerged as a revolutionist in 5G network by enabling the heterogeneity of services, in the form of data plane throughput, very low latency, and numerous connecting users under three primary network slice categories enhanced Mobile Broadband (eMBB), ultra-Reliable Low-Latency Communications (uRLLC), and massive Machine-Type Communications (mMTC). In the same context, 3GPP has defined the 5G Core (5GC) as a Service Based Architecture (SBA) [1] with Control and User Plane Separation (CUPS) framework. SBA based 5GC can be sliced at the Network Functions (NFs) level, typically in a Network Function Virtualization (NFV) environment supporting slice services.

A Zero Touch Service Management (ZTSM) platform is typically built by an automatic and cognitive functioning of network components enabled with a Closed Loop Automation (CLA). Authors in [2] detail the challenges and risks in building a ZTSM framework to make it a reality, envisioning Artificial Intelligence(AI)-based techniques and its limitations. Slicenet [3] focuses on cognitive network management and orchestration of slices across multiple management domains. Works like Free5GC [4] and Kube5G [5] can be leveraged to explore the softwarization of the 5GC components in a cloud native environment. However, we showcase the ZTSM operation of the network slicing service and its management in the context of 5GC. Our focus here is to build a 3GPP compliant, zero-touch network slice management and orchestration (MANO) platform in 5GC to meet the varied needs of diverse applications arising from primary categories of slice services in eMBB, uRLLC, and mMTC. The following are the key features of our 5GC network slicing management framework that would be demonstrated.

- An emulation framework for zero-touch 5GC network slicing management and orchestration including monitoring, selection of slices, and their life cycle control in a CLA.
- Demonstration of an end-to-end eMBB and uRLLC slice services with HTTP video streaming from a remote cloud and Intelligent Transport Service (ITS) from the edge cloud.

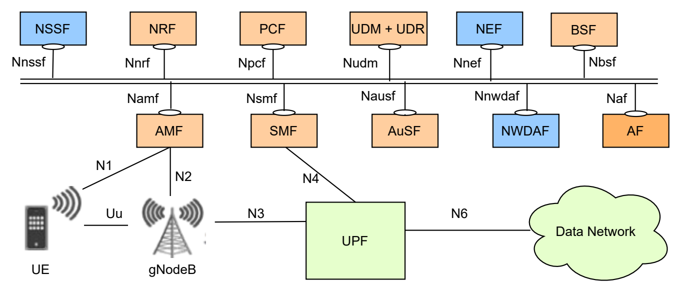

Fig. 1: 5G System Architecture.

II. 5G Core Network Slice Orchestration and Management Framework

The framework encompasses two important parts, one with slice MANO entities and the other consists of deployed slice instance(s) with respective NFs, to serve their required functionalities of 5GC in the control plane and data planes.

A. 5GC Prototype for Network Slice Support

The developed 5GC prototype is based on 3GPP Rel. 15 specification [1] (see Fig. 1) emulating the functions of various entities and call flow procedures between them. Our 5GC comprises of 5GC control plane Network Function (NF)s namely, Access and Mobility Management Function (AMF) with co-located Security Anchor Function (SEAF), Session Management Function (SMF), Network Repository Function (NRF), Authentication Server Function (AUSF), Unified Data Management (UDM) with co-located Unified Data Repository (UDR), Authentication Repository and Processing Function (APRF) along with Subscriber Identity De-concealing Function (SIDF) to support user id protection with Elliptic Curve Integrated Encryption Scheme (ECIES)-B profile. The framework leverages Service Based Interaction (SBI) between these

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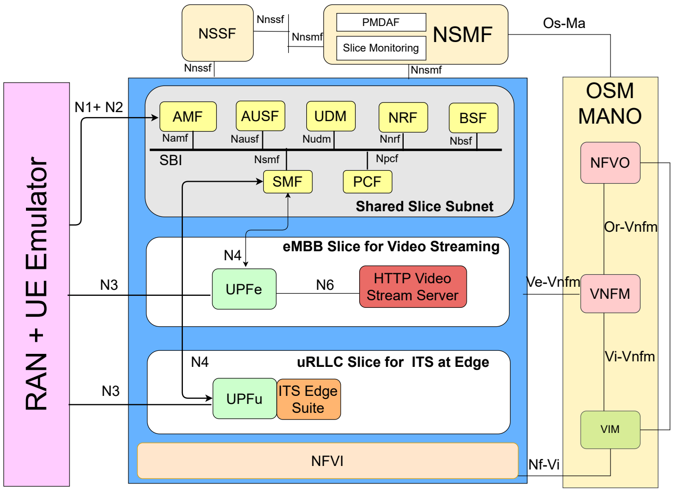

Fig. 2: A Zero-touch emulation framework for network slice management in 5GC.

NFs. SBI is realized with REST APIs using HTTP/2 library from nghttp2 [6]. Additionally, Policy and Charging Function (PCF) and Binding Support Function (BSF) are implemented to provision dynamic policy to the User Equipment (UE)s and external traffic influencing Application Function (AF) like Multi-access Edge Computing (MEC). UPF in the 5GC supports end-to-end data exchange with Application Server (AS) on $N6$ interface (AS represents Data Network (DN) connectivity point) and GPRS Tunneling Protocol User plane (GTP-U) on $N3$ with RAN.

For emulating the end-to-end UE control plane functions, we have developed a lightweight RAN + UE emulator on the control plane with Next Generation Application Protocol (NGAP) and embedded UE with Non Access Stratum (NAS) to support $N2$ and $N1$ interface functionalities with AMF. All these network functions including RAN + UE Emulator can run directly on bare metal host machines or orchestrated Virtual Network Function (VNF)s from OpenStack [7] or Cloud Native Function (CNF)s from Kubernetes (K8s) [8] providing their service running in a single or a multi-host networking environment. We limit to the below listed slice service applications for this demonstration. An end-to-end data flow on the slice occurs through UE App, RAN + UE Emulator, UPF, and AS on the data plane.

- HTTP video streaming application on the eMBB network slice.
- An Intelligent Transport Service (ITS) application called "Voice Phone Alert" on uRLLC network slice with the support of the edge cloud.

B. Slice Orchestration and Management Framework

The complete emulation framework for slice deployment, management, and orchestration is shown in Fig. 2. We rely on using Open Source MANO (OSM) Rel.10 [9] for NFV MANO functions with NFV Orchestration (NFVO) and VNF Management functionalities communicating with different Virtual Infrastructure Management (VIM)s. Additionally, we extended the Network Slice Management Function (NSMF) from one of our previous works [10] to support both OpenStack and K8s based slice deployment. NSMF utilizes OSM's NFV MANO functions over its North Bound Interface (NBI) to configure, deploy, and reconfigure different slice instances of various types (eMBB, uRLLC, and mMTC). NSMF and Network Slice Selection Function (NSSF) communicate with each other over SBI using nghttp2, just like SBI interaction between other 5GC NFs. The OSM is hosted on Intel® Xeon® CPU E5-1650 v4 @ 3.60GHz with 6 CPU cores and 32GB RAM. OpenStack and K8s along with network slices are hosted on Intel® Xeon® CPU E5-2690 v4 @ 2.60GHz with 14 CPU cores and 64GB RAM as per the demonstration setup (see Fig. 2).

C. Enabling Zero Touch Slice Management

ZTSM is enabled by the involvement of NSMF, NSSF, and other NFs of slice instances such as AMF. NSMF performs the deployment, configuration, and monitoring of the slices. It updates the active slice instance information to NSSF. Using this, NSSF selects the best candidate slices for the requests arrived from AMF and also keeps track of the current slice demand in terms of arrived UE slice requests from AMF. Further, NSSF also controls the life-cycle of slices (activation and deactivation) towards NSMF. Monitoring of individual slices includes recording the resource usage of slice's NFs in terms of CPU, memory, throughput in control- and data planes. Overall, the CLA at various NFs of the slice(s), enable smooth functioning of the slices along with on-demand triggering of auto scale-out/in of the slices by complimenting MANO functionalities.

In the demonstration framework, we create the following three slices.

- A common control plane slice with AMF, AUSF, NRF, NSSF, UDM, SMF, PCF, and BSF shared among eMBB and uRLLC slices to provide the 5GC control plane functions.
- An eMBB slice with UPF for serving Uplink (UL) and Downlink (DL) data to UE from the video stream server running at the remote site.
- An uRLLC slice with UPF and co-located ITS edge suite server for UL and DL data exchange with UE.

Every slice has a slice template as per the configuration requirement given by NFV MANO functions provided by OSM. At first, we define Virtual Network Function Descriptor (VNFD)s for each of the NFs which constitute different slices by specifying respective NF image and system resources such as memory and CPU cores. These VNFDs then become part of Network Service Descriptor (NSD)s packed into respective slice templates.

III. End-to-end Network Slice Management Demonstration

In the demonstration (see Fig. 2), first, NSMF on-boards the three slice templates with respective NFs (NRF, AMF, AUSF, NSSF, SMF, UDM, and UPF) to OSM. Upon successful

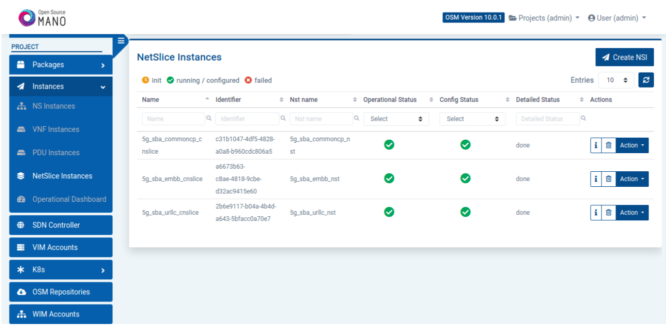

Fig. 3: Deployed network slices from the MANO GUI.

onboarding, it then instantiates the slices feeding their slice templates to OSM, to get them into the operation phase. As shown in Fig. 3, slices show the state as '*Running*' only after all their respective NFs are deployed successfully. Additionally, the application associated configuration is fed to the NFs like the NRF serving IP, subscriber information at UDM, and setting the NAS security protection algorithm like AES at AMF. Once the NRF is activated, other NFs in the 5GC from the shared control plane slice, as well other slices (eMBB and uRLLC) register their services at NRF. Upon completion of this procedure, they are ready to serve the traffic from the UE(s) at their respective control plane and data plane slices.

Once the RAN + UE emulator function gets active, it triggers the UE registration along with requesting specific slice services (eMBB and uRLLC) to 5GC on the control plane slice. During the registration, AMF queries the NSSF for the available and allowed slices for this UE. NSSF responds with eMBB and uRLLC slice instance(s) info using the available slice information from NSMF on the deployed slices. Once the UE completes its registration from 5GC, it establishes Packet Data Unit (PDU) sessions on the allowed slices (based on the allowed-NSSAI information received from AMF in the Registration Accept message) to avail the respective slice service in the data plane.

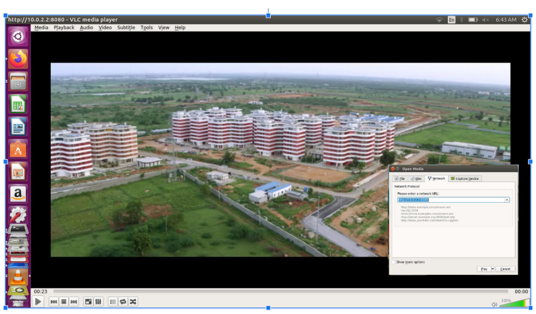

Fig. 4: Video streaming through an eMBB slice.

A. HTTP Video Steaming on an eMBB Network Slice

Here, we demonstrate the HTTP streaming on the end-to-end data plane using UPF from the eMBB slice. We enable the VLC media player at both the UE application and the AS at the remote cloud to showcase the HTTP streaming in the data path. Fig. 4 shows an instance of its execution.

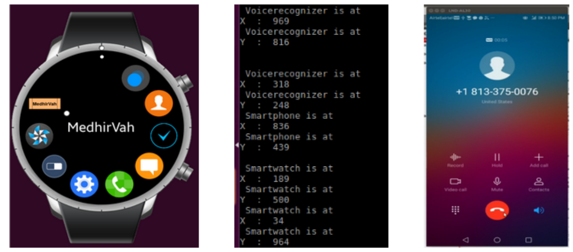

Fig. 5: VAD and voice phone alert through an uRLLC slice.

B. Voice Phone Alert on an uRLLC Slice

We have developed an end-to-end ITS application that works over the 5G network. In this slice application, the UEs are the 5G enabled smart IoT devices like smartwatches, phones, and vehicles with a Voice Activity Detection (VAD) plugged in. The goal of this ITS application is to help the users in emergencies (like in public safety and accidents). At the user end (IoT device), pressing a button or a VAD plugin notifies the ITS server (co-located with slice's UPF) in an emergency through the 5G uRLLC slice. An instance of this execution is shown in Fig. 5 where a smartwatch notifies the ITS server through the deployed slice at an edge site, and then, the ITS server triggers a phone call to the rescue service.

IV. Conclusion and Future Work

In this demo, we demonstrated the functioning of a zero-touch, fully virtualized, and sliced 5GC management framework, which can support a wide variety of applications and vertical industries with network slicing, in an agile way, to revolutionize the 5G MNOs for new business opportunities. In the future, we plan to extend this framework to make it a highly scalable and resilient self organizing network slicing platform enabled by Artificial Intelligence (AI) techniques.

Acknowledgment

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