Demonstrating Isolation Principles for 5G Network Slicing

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***Abstract*—5G Standalone (SA) networks introduce a range of new applications, including enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine-Type Communications (mMTC). Each of these applications has distinct network requirements, which current commercial network architectures, such as 4G and 5G Non-Standalone (NSA), struggle to meet simultaneously due to their one-size-fits-all design. The 5G SA architecture addresses this challenge through Network Slicing, creating multiple isolated virtual networks on top of a single physical infrastructure. Isolation between slices is crucial for performance, security, and reliability. Each slice owns virtual resources, based on the physical resources (e.g., CPU, memory, antennas, and network interfaces) shared by the overall infrastructure.**

In this demo, we define and showcase a real-life Proof of Concept (PoC), which enables Network Slicing guaranteeing isolation between slices in 5G SA networks, for each network domain i.e., Radio Access Network (RAN), Transport Network (TN), and 5G Core (5GC) network.

***Index Terms*—5G, Network Slicing, Isolation, O-RAN**

I. INTRODUCTION

5G Standalone (5G SA) networks are opening the doors to a multitude of new applications i.e., enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine-Type Communications (mMTC) [1]. For instance, eMBB applications, such as high-definition video streaming and Augmented Reality (AR), require a high throughput of more than 100 Mbps and moderate latency of less than 50 ms [1]. On the other hand, URLLC applications, such as remote surgery and vehicular applications, require extremely low latency of less than 5 ms and high reliability of 99.9999% [1]. Finally, mMTC applications, such as smart cities and IoT ecosystems, require high connection densities of up to 1,000,000 devices per cell [1]. As a result, the network must be able to address simultaneously multiple requirements for different types of applications in terms of throughput, latency, and reliability.

Network slicing, a pivotal technology introduced with 5G SA [2], enables the creation of multiple virtual networks on a single physical infrastructure, each tailored to satisfy precise network requirements i.e., URLLC, eMBB, and mMTC. Nonetheless, a critical challenge in implementing effective Network Slicing is ensuring isolation between different slices [3]. Isolation guarantees that each slice operates independently within the same physical network infrastructure, without interference from other slices. This means ensuring that the activities or failures of one slice do not compromise the performance, security, and reliability of another slice.

While Third Generation Partnership Project (3GPP) releases primarily address authentication methods and slice management/orchestration, ensuring isolation at the lower layers of the network i.e., infrastructure, remains a fundamental challenge. Effective isolation at the infrastructure layer provides a solid foundation for deploying a secure, reliable, and efficient Network Slicing mechanism.

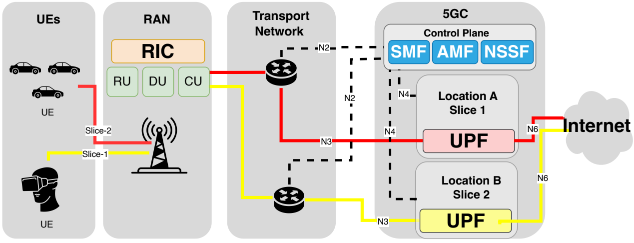

Fig. 1: Architecture of the Proof of Concept.

In this demonstration we provide a Proof of Concept (PoC) of 5G Network Slicing with isolation principles, ensuring that each slice operates independently and securely, in terms of i) performance, ii) security, and iii) dependability [3].

II. ISOLATION IN NETWORK SLICING: DEMONSTRATION AND ARCHITECTURE

The architecture of our PoC, illustrated in Figure 1, is designed to support flexible and modular implementations, adhering to Service-Based Architecture (SBA) principles of 5G SA networks by leveraging Software Defined Networking (SDN) and Network Function Virtualization (NFV). For the deployment of Network Slicing, we separate the control plane functions of the 5G Core (5GC) from the data plane functions, deploying a distributed 5G SA architecture. Furthermore, the key components of the different network domains involved on the 5G SA network i.e., Radio Access Network (RAN), Transport Network (TN), and 5GC, are strategically distributed to enable total isolation between slices in each network domain.

*1) **RAN Domain**:* Within our PoC, Network Slicing and isolation between slices are achieved through a dynamic allocation of Physical Resource Blocks (PRBs) among different slices. Our RAN setup leverages the Open Radio Access Network (O-RAN) paradigm [4], which incorporates a RAN Intelligent Controller (RIC) and xApps. The xApps guide the RIC on PRB allocation within the Distributed Unit (DU) based on Slice/Service Type (SST) and Session Description (SD) values, configured in the 5GC. In that way, we assign a specific pool of available radio resources i.e., PRBs, to each slice.

*2) **5GC Domain**:* In our setup, the control plane elements of the 5GC e.g., Access and Mobility Management Function

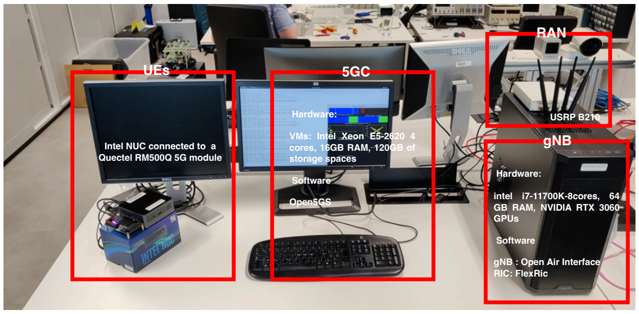

Fig. 2: Real-world Testbed.

(AMF), Session Management Function (SMF), and Network Slice Selection Function (NSSF), and the data plane element i.e., User Plane Function (UPF), are deployed on separate Virtual Machines (VMs). This decentralized approach simplifies the management and orchestration within the 5G SA network and enables Network Slicing by creating multiple UPFs, as shown in Figure 1. Each slice is identified by the SST and SD value pair, which defines i) the logical network and ii) the type of slice i.e., eMBB, URLLC, and mMTC. Each pair of SST and SD are identified by the User Equipments (UEs) using a specific Data Network Name (DNN). Furthermore, each UPF is deployed on its own VM, hosted in a different data center. This guarantees that slices do not use the pool of computing resources dedicated to other slices, and enables the application of different network policies per slice.

*3) **TN Domain**:* The isolation in the TN domain is realized by distributing separate links from the RAN to the UPFs. This physical separation ensures that data traffic between the RAN and the data plane remains isolated across different slices, mitigating potential bottlenecks and interference associated with sharing network resources.

III. DEMONSTRATION SCENARIO

To illustrate and validate our PoC, we have deployed a real-world testbed with Commercial-off-the-shelf (COTS) devices and open-source software solutions, shown in Figure 2. In our demo, we consider a smart city scenario where mission-critical applications i.e., Vehicle-to-Everything (V2X), are performing within the URLLC slice. Simultaneously, tourists in the city are using AR applications on their mobile devices, which require high-bandwidth downlink connections provided by the eMBB slice. Without Network Slicing and proper isolation between the slices, the high bandwidth demand of AR applications can disrupt the URLLC slice dedicated to V2X applications, potentially causing accidents and traffic congestion. To reproduce such a scenario, we use two UEs, one to represent AR applications and one to represent V2X applications. In our demonstration, first we generate data traffic from a remote server to each UE using MGEN[1] as a traffic generator. Then we apply dynamically our Network Slicing mechanism. Finally, we increase the volume of traffic for the AR application, to validate the isolation between the slices in terms of performance, security, and dependability. We show the behavior of the 5G SA network through a real-time dashboard, as shown in Figure 3. To validate the effective overall isolation between the slices,

Fig. 3: Real-Time dashboard for traffic monitoring within the 5G SA network.

we consider data traffic at the user space layer. Our dashboard shows the number of gNBs active within the same 5G SA network, the number of UEs connected, the location of the UPF per each slice, and multiple Key Performance Indicators (KPIs) such as i) throughput, ii) jitter, iii) Round Trip Time (RTT) latency, and iv) packet loss per slice.

IV. APPLICATIONS

In this demonstration, we showcase a PoC of Network Slicing with isolation across core network domains i.e., RAN, 5GC, and TN. The isolation in Network slicing guarantees that any issues or disturbances in one slice remain contained, preserving the overall reliability and performance of the network. For instance, eMBB applications like AR can operate without interfering with URLLC applications, such as vehicular applications, which require ultra-reliable and low-latency performance. The deployment of isolated slices is particularly beneficial for industries, and real-life scenarios, where multiple applications with different network requirements are using the same network infrastructure. In our demonstration, isolation in Network Slicing is achieved by i) on-demand allocation of radio resources, ii) robust configuration and design of network functions in the 5GC, and iii) dedicated communication paths in the TN.

ACKNOWLEDGEMENT

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