Multi-domain Network Slicing: Open, Programmable, and Shareable 5G Standalone

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***Abstract*—5G Standalone (SA) networks introduce a concept of Network Slicing that enables a range of new applications, such as enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), and massive Machine-Type Communications (mMTC). However, despite the promising potential of 5G SA networks, real-world deployments have revealed significant limitations, particularly in terms of signal coverage, resulting in performance degradation for eMBB, URLLC, and mMTC services. To mitigate these challenges and reduce the costs associated with deploying new infrastructure, Network Sharing among multiple operators has emerged as a cost-effective solution. While the 3rd Generation Partnership Project (3GPP) introduced Network Sharing in 5G Release 15 and added an Indirect Network Sharing configuration in Release 19, real-life implementation remains limited due to immature mechanisms and the lack of automated systems for neutral hosts providers to easily onboard new operators and dynamically allocate network resources to meet specific network requirements. In this paper, we explore the application of Network Slicing as a mechanism to deploy Network Sharing among multiple operators, presenting a 5G SA Indirect Network Sharing architecture as proof of concept (PoC). Through our experiment, performed in a real-world and open-source testbed based on O-RAN principles, we demonstrate how applying Network Slicing technology, Neutral Host providers can effectively deploy resource isolation and enable collaboration in a multi-operator environment while guaranteeing service quality to their users.**

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

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]. However, recent deployments of 5G SA networks also highlight the limitations of 5G SA in real-world scenarios. For instance, the signal strength becomes significantly after 2 km distance from the base stations, resulting in network degradation in terms of throughput, latency, and reliability [2]. This is due to the fact that high-frequency signals attenuate rapidly, resulting in a much smaller coverage area than previous generations of cellular networks. Therefore, more base stations need to be installed to cover a large area, requiring investment and permits to build new infrastructure along the territory, resulting in a slowdown in 5G deployment worldwide [2]. One effective solution to reduce costs is Network Sharing.

Network Sharing is a concept that allows multiple operators to share network resources, improving coverage and reducing investment [3]. There are two main modes of network sharing: passive mode (Passive Sharing) and active mode (Active Sharing). In the passive mode, operators share only physical infrastructure, such as towers, sites and supporting equipment, keeping their active equipment separate. On the other hand, active mode allows operators to share not only the physical infrastructure, but also equipment such as Radio Access Network (RAN), radio network controllers, and spectrum. In addition, using Open Radio Access Network (O-RAN) architecture, interoperability and disaggregation of different network components enable greater flexibility and reduce operational costs.

In this paper, we propose Network Slicing as an enabling technology to deploy Network Sharing by creating multiple layers of isolated virtual networks (slices) on a single physical infrastructure, ensuring resource isolation in a multi-operator environment. To evaluate the benefits of such solution, we created a Proof of Concept (PoC) of Network Sharing in 5G SA networks leveraging Network Slicing and the O-RAN paradigm. Each slice is configured to support specific performance and security requirements, ensuring isolation of resources between (i) operators sharing the same infrastructure, and (ii) between users across the same operator. In this context, Network Slicing allows us to optimize the use of network resources by distributing the capacity of the infrastructure among (i) various operators and (ii) the slices of various operators.

II. Network Sharing Background

Network Sharing enables mobile operators to share network components and infrastructure resources, listed in Table I, when delivering services to their customers [3]. This concept began with passive sharing of site components and evolved into active sharing of network elements.

One of the earliest examples of passive Network Sharing was in 2001 when Tele2 and Telia in Sweden agreed to share their 3G infrastructure[1]. The Third Generation Partnership Project (3GPP) advanced this concept by introducing active Network Sharing configurations such as Multi-Operator Radio Access Network (MORAN) and Multi-Operator Core Network (MOCN) in Releases 6 and 8 [4]. MORAN allows operators to share RAN infrastructure while maintaining separate Core Network (CN) and spectrum, whereas MOCN enables sharing of both RAN infrastructure and spectrum resources. Another Network Sharing configuration is CN Sharing, where servers and CN functionalities are shared. For instance, one practical example of Network Sharing is roaming, which allows customers to use the infrastructure of other operators when they are outside their home network coverage. Table II compares different Network Sharing configurations, highlighting the shared components in each model. With the evolution of 5G networks and the O-RAN paradigm, 3GPP Release 19 introduced enhancements in Network Sharing introducing an Indirect Network Sharing configuration, facilitating

[1]https://www.tele2.com/media/news/2001/tele2-ab-and-telia-ab-sign-final-agreement-to-form-a-jointly-owned-umts-network-company/

TABLE I: Components needed to build the network infrastructure.

Layer	Radio Access Network	Transport Network	Core Network
Physical Layer	gNB: Main radio base station in 5G.	Fiber Optic Cables: High-speed data transmission medium.	Servers: Hardware for processing and storage.
	Small Cells: Low-power nodes to enhance coverage and capacity.	Microwave Links: Wireless communication links for data transmisison.	Data Centers: Facilities housing core network hardware.
	Antennas: Transmit and receive radio signals.	Ethernet: Wired network for data transmission.	Air Conditioning: Ensure optimal operating temperature.
	Power Supply Units: Ensure continuous power.	Power Supply Units: Provide power to network components.	Sites: Locations of core network equipment.
	Sites: Physical locations for RAN equipment.	Sites: Physical locations housing network equipment.	-
	Air Conditioning: Maintain optimal temperatures.	-	-
	BTS (Base Transceiver Station): Transmits and receives radio signals to/from user devices.	-	-
	Amplifiers: Boost the power of transmitted signals.	-	-
	BSC (Base Station Controller): Manages multiple BTS sites.	-	-
Resource Layer	PRBs : Units of time-frequency resources.	Bandwidth: Data transmission capacity.	Processing Power: Computational resources for data handling.
	Frequency Bands: Spectrum allocated for 5G.	Routers: Direct data traffic within the network.	Storage Capacity: Data storage resources.
	Radio Channels: Communication channels for data.	Switches: network devices that manage data flow.	Memory: RAM for processing tasks.
	Beamforming: Focused signal transmission.	Firewalls: Network security devices.	Virtualization Resources: Hypervisors and VMs.
	-	-	CPUs: Central Processing Units for computing tasks.
	-	-	Cache: Memory for fast data access.
	-	-	RAM: Random Access Memory for data processing.
	-	-	GPUs: Accelerate parallel processing tasks.
	-	-	Accelerators: Specialized hardware for AI and machine learning tasks.
	-	-	Storage Capacity: High-capacity storage devices for data.
Service/App	RRC (Radio Resource Control): Manages radio resources and signaling.	IP/MPLS: Protocols for efficient data transport.	AMF (Access and Mobility Management Function): Manages user access and mobility.
	MAC (Medium Access Control): Manages access to the physical layer.	QoSManagement: Ensures service quality.	SMF (Session Management Function): Manages user sessions.
	PDCP (Packet Data Convergence Protocol): Header compression and encryption.	VPN: Secure tunnels for data privacy and protection.	UPF (User Plane Function): Handles user data traffic.
	PRB Allocation: Assigns PRBs to different users/services.	Traffic Management Systems: Manages data flow and congestion.	NRF (Network Repository Function): Manages network function registration.
	Beamforming Control: Directs radio signals to improve coverage.	SDN : Centralized network control.	PCF (Policy Control Function): Controls network policies.
	mMIMO (Massive MIMO) Control: Manages advanced antenna systems.	-	UDM (Unified Data Management): Manages user data.
	Carrier Aggregation: Combines multiple carriers to increase bandwidth.	-	NSSF (Network Slice Selection Function): Manages network slices.
	Network Synchronization: Ensures network components work in harmony.	-	APIs
	RIC: Controls the RAN and is responsible for radio resource management.	-	-
	QoS Management: Ensures performance levels for different services.	-	-

the development of new business models, such as Neutral Hosting. The Network Sharing configurations in Table II have led to multiple business models during the time, such as Unilateral Service Provisioning, Joint Ventures, and Neutral Hosting [5]. Table III summarizes the pros and cons of each business model. However, current solutions are still unable to fully support Network Sharing in large-scale real-world scenarios [6], lacking in providing dynamic, isolated, and fine-grained network resources (Table I) among the different network domains, i.e., RAN, Transport Network (TN), and CN. Such limitation makes it challenging to effectively apply the Neutral Hosting model in real-life deployment, limiting Neutral Host owners from allocating network resources and adapting them to different network requirements demanded in real-time by different operators. In the literature, current approaches remain limited to enable full sharing of the entire 5G network architecture that involves different network domains i.e., RAN, TN and CN.

Zhao et al. [7] primarily focus on RAN sharing in a 5G SA environment. Their solution emphasizes spectrum sharing to ensure scheduling fairness among multiple operators. However, the proposed approach does not address the TN and CN domains, nor does it consider isolation aspects or provide Key Performance Indicators (KPIs), such as the impact on throughput, latency, packet loss, and jitter when the User Equipment (UE) is generating traffic. Mahboob et al. [8] present a multi-operator spectrum and a resource-sharing scheme in which each operator retains its own network infrastructure while sharing specific resources, such as spectrum and Multi-access Edge Computing (MEC) capabilities. However, this scheme does not involve shared infrastructure; instead, it assumes that UEs can subscribe to multiple operators and it relies on handover mechanisms to ensure service continuity in a shared resource environment. Navidan et al. [9] proposed an intelligent Radio Resource Management approach to optimize resource allocation across different operators' slices within a shared RAN. In that work, the experiments are conducted under simulated network conditions with various assumptions, rather than in an actual network deployment. Bonati et al. [10] proposed a Neutral Host framework, NeutRAN, which leverages the O-RAN architecture to enable zero-touch RAN and spectrum sharing among multiple operators. This solution is primarily focused on the RAN domain, without addressing isolation aspects or the other network domains. Furthermore, the experimental results do not provide insights into the performance impact on traffic when the UE is generating traffic, specifically in terms of throughput, latency, packet loss, and jitter. While these studies offer valuable insights into radio resource allocation, they have major shortcomings. In these works, the entire 5G SA network chain (RAN, TN, and CN) is not treated, focusing only on the RAN domain to enable Network Sharing. Moreover, the critical aspect of ensuring isolation across the entire 5G SA infrastructure chain, so the isolation of the pool of resources allocated to each operator or participant, is not discussed, or is only partly mentioned.

TABLE II: Network Sharing Configuration Models.

		Passive		Active			
		Site sharing	**shared TN**	**Roaming**	**MORAN**	**MOCN**	**CN Sharing**
	Core Network	Individual	Individual	Individual	Individual	Individual	Shared
Infrastructure	TN	Individual	Shared	Visited	Shared	Shared	Shared
	Spectrum	Individual	Individual	Visited	Individual	Shared	Shared
	Base Station	Individual	Individual	Visited	Shared	Shared	Shared
	Site	Shared	Shared	Visited	Shared	Shared	Shared

Our solution presented in the following sections, addresses the shortcomings in existing approaches by applying the Network Slicing mechanism to the actual 5G SA network architecture, offering a comprehensive method to enable Neutral Hosting in 5G SA environments.

III. Network Sharing in 5G Networks

The 5G SA architecture consists of the main components: i) the UE, ii) the RAN, which connects UEs to the 5G network, iii) the TN that links the RAN and the 5G Core (5GC), and iv) the 5GC that manages authentication, session, mobility, and network policy control between the UEs and the internet.

The 5G SA configuration employs a cloud-native infrastructure to enable the modularity and flexibility. The implementation of such infrastructure is based on micro-services virtualization [11], where the implementation of Network Functions (NFs) is based on containers and Virtual Machines (VMs). This virtualized and modular network setup enables: i) dynamic resource allocation e.g., CPU, memory, and radio resources, crucial for building a scalable and flexible network infrastructure, and ii) portability of NFs to different physical locations and different hardware. The 5G SA network architecture involves three different network domains i.e., RAN, TN and 5GC. The components and network resources belonging to each of these network domains are summarized in Table I. So, in a nutshell, through virtualization i.e., Software Defined Networking (SDN) and Network Function Virtualization (NFV), it is possible to build a flexible, scalable, and architecture-agnostic network infrastructure capable of supporting the 5G SA network design.

Furthermore, flexibility and modularity are crucial for deploying Network Sharing. In that regard, Release 19 introduces an indirect configuration of Network Sharing, to extend the support for the business models in Table III. In the Indirect Network Sharing configuration, shown in Figure 1, the communication between the base station of the 3rd party

TABLE III: Business Models for the Network Sharing concept.

Model	Pros	Cons
Unilateral	Full control over network operations and management. High flexibility, tailored to the single operator's needs. Simplified regulatory considerations. -. -.	Higher Capex and Opex. High Risk. Limited coverage and capacity compared to shared models. Not fast response to the change of the market. Difficult to keep the business agile. No sharing of infrastructure, leading to potential inefficiencies.
Joint	Shared investment cost. Enhanced coverage and capacity through pooled resources. Potential for innovation and synergy through collaboration. Shared risk and responsibilities.	Requires coordination and alignment among partners, slower decisions. Potential regulatory hurdles and need for approvals. Possible reduction in competition among MNOs. Complex management/conflicts among partners.
Neutral Host	Lower Capex and Opex for MNOs. Enhanced coverage and capacity through shared infrastructure. Facilitates competition and market entry for new operators. High flexibility, adaptable to needs of multiple MNOs. fast response to market changes. Low complexity for coordination and agreements between MNOs. Low Risk for MNOs.	Requires strong regulatory support and agreements. Complexity in managing MNOs requirements. MNOs depend on the NH for control in the Infrastructure Layer. Challenge in resource allocation/Isolation. -. -. -.

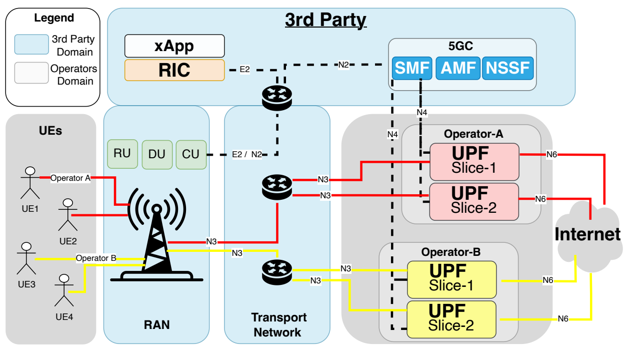

Fig. 1: Indirect Network Sharing Architecture enabled by Network Slicing.

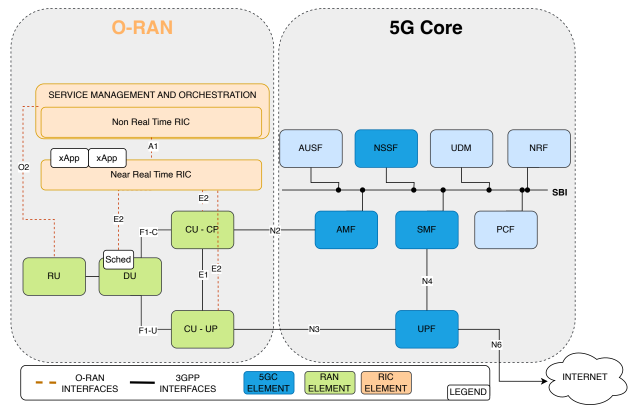

Fig. 2: 5G Standalone Architecture with O-RAN paradigm.

and the 5GC of the participants e.g., operators, is routed through the 5GC of the 3rd party.

The 3rd party can manage and allocate resources of its infrastructure to participants, in an isolated and dynamic approach applying Network Slicing. However, to fully exploit Network Slicing in 5G SA networks to enable Network Sharing, the links between the 3rd party infrastructure and participants (e.g., operators) must be facilitated by open and standardized communication channels. In this regard, the O-RAN paradigm standardizes and facilitates the integration of the different components of the 5G SA architecture by providing open interfaces between RAN and 5GC, as shown in Figure 2. O-RAN ensures compatibility between components from different vendors, which is particularly beneficial in scenarios of Network Sharing, where different parties are involved.

A. Network Slicing as Indirect Network Sharing Enabler

Although the initial conception of Network Slicing was based on partitioning traffic based on types of service i.e., eMBB, URLLC, and mMTC, the concept has broadened [12]. According to 3GPP, a slice is a set of network functions and corresponding resources necessary to provide the required telecommunication services and network capabilities [4]. Hence, a slice can be established to support a logical and isolated network dedicated to a customer e.g., in a Neutral Host model, where 3rd party can deploy a slice for each participant in the Network Sharing agreement (e.g., operator), applying Network Slicing in the 5GC and in the RAN.

*1) **5G Core Architecture**:* In an Indirect Network Sharing configuration, shown in Figure 1, the 3rd party provides access to its network infrastructure to the participants through its 5GC. The indirect configuration of Network sharing can be enabled through Network Slicing. The 5GC architecture employs a Service-Based Architecture (SBA) with NFs as key components. The main NFs of the 5GC are listed in Table IV. These NFs are software entities responsible for networking tasks e.g., authentication, routing, and forwarding.

The Access and Mobility Management Function (AMF), an NF part of the control plane, manages user registration, handovers, and authentication over the N2 interface using the Next-Generation Application Protocol (NGAP)[2]. The Session Management Function (SMF), another control plane NF, manages session contexts, coordinates session setup with the AMF, and manages the data plane session via the N4 interface. The SMF is responsible for the allocation of Internet Protocol (IP) addresses to the UEs and the coordination of session setup with other NFs. By isolating the SMF, the integrity of these sessions is maintained, ensuring that the operations and performance of one slice do not affect the rest of the network. The User Plane Function (UPF) is in charge of the data plane. The UPF handles data routing and policy enforcement, deep packet inspection, charging data collection, and interfacing directly with the base station via the N3 interface. The Network Slice Selection Function (NSSF) handles (i) network slice selection and (ii) access to slices based on the configurations of the UE, by coordinating with the AMF and the SMF through the N2 interface. The 5GC uses Slice/Service Type (SST), Session Description (SD),

[2]NGAP protocol: https://docs.magmaindia.org/Free5gc_5gCore/amf/amf.html

TABLE IV: Network Functions and Configuration settings.

Architecture Segment	Name Element	Interface	Name Parameter	Value	Scope Parameter
5GC	AMF	N2,N11	PLM_ID	Num	Identifies mobile networks globally.
	SMF	N4,N11	DNN	String	Specifies the name of the network to which the device connects
			5QI	1-90	Defines the specific QoS characteristics of data traffic
	UPF	N4,N3,N6	DEV	String	Interface where the data traffic pass
	NSSF	SBI	SST	URLLC=1 eMBB=2 mMTC=3 V2X=4	Identifies the type of service the slice is intended to support
			SD	24 bit (optional)	Distinguishes between multiple network slices that share the same SST
RAN	DU	E2	RBs	12 sub-carriers per RB	Small units that divide the radio frequency (spectrum) and are used to transmit data.
	CU	E2,E1, F1C,F2C	RRM Policy Ratio	Dedicated Ratio	The amount of resources that are dedicated to a slice and cannot be used by other slices
				Min Ratio	The minimum guaranteed resources that a slice will always have available.
				Max Ratio	The maximum limit of resources that a slice can use,if resources are available

Data Network Name (DNN), and 5G QoS Identifier (5QI) (explained in Table IV) to manage slice descriptions and slice configuration. Furthermore, the Public Land Mobile Identifier (PLMID) parameter is used to identify the operators.

Hence, by configuring NFs with the correct values of PLMID SST, SD, and DNN, is possible to deploy logical networks belonging to different participants (operator) within the same infrastructure (owned by the 3rd party). However, each NF belonging to a participant must be isolated to ensure that participants do not interfere with each other.

*2) **RAN**:* Within the ORAN paradigm the RAN is disaggregated into RU, CU, and DU [13], as shown in Figure 2. The RU implements operations related to the lower physical layer. The DU implements the part of the Medium Access Control (MAC) and the Radio Link Control (RLC). The CU is responsible for the control plane and the data plane to communicate with the 5GC. DU and CU are controlled by The Near-real-time RIC trough the E2 interface [13]. Furthermore, the ORAN architecture introduces xApps [14], software applications designed to run on the Near-Real-Time RIC. In the context of Network Slicing, xApps play a crucial role in enabling dynamic resource allocation and optimizing the RAN resources for each slice. Through the parameters listed in Table IV, it is possible to create network slices by deploying xApps to allocate radio resources to slices. Hence, to enable Network Sharing, the 3rd party can manage the radio resources e.g., Resource Blocks (RBs), for each participant as slices, configuring xApps with the parameters listed in Table IV.

B. The importance of Isolation in Network Sharing

In a Network Sharing scenario, a 3rd party offers the resources of its infrastructure as a service to the participants (e.g., operators) as a slice. Hence, participants utilizing these services agree to share a common pool of resources (listed in Table I) with other participants. However, despite this shared infrastructure, each participant must be independent, as if operating on its own network infrastructure. This means that operators need to meet Service Level Agreements (SLAs) to their users, in terms of throughput, latency, and reliability. Hence, the 3rd party must allocate a dedicated and isolated pool of resources (slice) to each participant, guaranteeing isolation in terms of (i) performance, (ii) security, and (iii) dependability in each network domain i.e., RAN, TN, and 5GC. Guaranteeing isolation in terms of performance means that the 3rd party must satisfy the network requirements demanded by one participant (e.g., operator), without affecting the performance of other participants. Furthermore, security is critical for safeguarding the confidentiality, integrity, and availability of data and services among participants. Isolation in terms of security means that UEs belonging to different participants should not be able to communicate directly, even if they are connected to the same network infrastructure. In terms of dependability, isolation involves ensuring that failures or issues faced by one participant do not affect the reliability and operational continuity of other participants. For example, in a Neutral Host scenario dependability between operators ensures that each operator maintains its network configurations and network policies independently.

IV. Network Sharing Solution Enforced by Network Slicing

The 5G SA architecture, as discussed in Section III, is designed to be flexible and modular, allowing for decentralized configurations. This flexibility is crucial for deploying Network Slicing to enable Network Sharing. In this section, we describe the deployment of our PoC for an Indirect Network Sharing infrastructure, shown in Figure 1, implemented by Network Slicing techniques.

A. PoC architecture with Isolation among operators

The 5GC separates the control plane and data plane elements using SDN and NFV. The SBA architecture of 5G SA enables a distributed network architecture where NFs can seamlessly discover and communicate with each other. As mentioned in Section III-A1, the main NFs of the 5GC that create a slice are the SMF for the control plane and the UPF for the data plane. In our PoC, each NF is deployed as a container. The NFs belonging to a particular slice associated with a party in the sharing agreement (e.g., operators), are deployed across different VMs.

In an Indirect Network Sharing configuration, the 3rd party i) manages and allocates network resources among participants, and ii) forwards the data plane to each participant. Hence, the 3rd party handles the control plane, while the participants manage the data plane generated or consumed by the UEs. In practice, this means properly configuring the SMF of 3rd party to forward the data plane from the shared base station to the UPF of the operator (or vice-versa).

Our PoC, shown in Figure 1, has a centralized control plane consisting of AMF, SMF, and NSSF, and multiple decentralized UPFs, located in different data centers, for each participant. We design each participant as a slice of the 3rd party, by configuring the SST, SD, and DNN parameters appropriately in each NF. Furthermore, we deploy multiple UPFs for each participant, enabling Network Slicing within the participant domain.

This decentralized structure inherently supports dynamic network scaling, as additional UPFs for new participants can seamlessly be integrated into the 3rd party infrastructure through appropriate network configurations, ensuring that the system can grow efficiently in response to increasing

TABLE V: Testbed Components Overview.

Component	Software	Role	Slices	Characteristics
5GC	Open5GS	Control Plane (VM3)	-	16GB of RAM, Intel Xeon E5-2620 v4-4 cores at 2.10GHz, 120GB of storage space.
		UPF (VM1)	URLLC	16GB of RAM, Intel Xeon E5-2620 v4-4 cores at 2.10GHz, 120GB of storage space.
		UPF (VM2)	eMBB	140GB storage, Intel Xeon Silver - 4 cores 2.40GHz, 8GB RAM.
RAN	OAI	gNB	eMBB-URLLC	Intel i7-11700K - 8 cores, 64GB RAM, NVIDIA RTX 3060 GPUs, USRP B210, dual 10 GB SFP
RIC	FlexRIC	RAN controller (VM3)	-	Same specifications as the CP VM for 5GC.
UEs	Real equipment	users	eMBB	Intel NUC connected to a Quectel RM500Q 5G module.
			URLLC	Same as eMBB UEs.
MGEN Server	-	Traffic generator/receiver	-	Remote VM used to generate/receive data traffic, synchronized with nodes with an error of 0.003 ms.

Fig. 3: 5G SA Testbed.

demands. Moreover, we use xApps to mix and match the configurations between the participants and their slices configured in the 5GC with the radio resources in the RAN. With the xApp, we define parameters such as Min Ratio, Max Ratio, and Dedicated Ratio of RBs, enabling a precise distribution of RB along the slices, using SST, SD, DNN, and PLMID,

Such an architecture shown in Figure 1 ensures that the 3rd party has full control over the infrastructure, while each participant maintains full control over their respective data plane. In that way, each participant can independently manage network resources e.g., radio and computing, and set network policies and traffic rules for their respective users. For instance, the allocation of a dedicated portion of RBs to each participant, creates a pool of radio resources from which a participant can fetch limited resources. In this way, participants do not interfere with each other. Furthermore, the deployment of separate VMs for control plane functions (e.g., AMF, SMF) and user plane functions (UPF) ensures i) isolation on the data plane, and ii) confines network policies within a certain slice. Moreover, we deploy separate links for the data plane of each slice. This physical separation ensures the traffic between the 5GC of the 3rd party and the participants remains isolated, preventing potential bottlenecks and interference.

B. Testbed

The main components of our testbed are illustrated in Table V. Our 5G SA testbed is designed to be O-RAN oriented. The testbed runs open-source solutions software to deploy a 5G SA network. This setup integrates Open Air Interface (OAI)[3] for the RAN functionalities and Open5GS[4] for the 5GC, with FlexRIC[5] serving as the RAN Intelligent Controller (RIC) to facilitate advanced radio network management. To conduct over-the-air transmission experiments within our real-world testbed, we obtained the appropriate spectrum licenses, which include 50 MHz within the 5G NR band 77.

V. Validation and Results

In our experiments, we considered a 3rd party hosting two participants, i.e., Operator-A and Operator-B. Both of them offer two different slices to their users. Operator-A offers slice-1 as the default slice for best-effort applications and slice-2 as eMBB for high-throughput applications. Instead, Operator-B offers slice-1 as eMBB and slice-2 as the default slice. The eMBB slice allows us to stress the network due to its high resource demands.

To validate the configuration and the design of our PoC, discussed in Section IV, we conducted real-life experiments using our testbed (Table V and Figure 3), and four UEs.

On the 5GC side, we utilized five VMs(VM1-VM5). VM3 is dedicated to the control plane operations for the 5GC and the RIC of the 3rd party. This means that AMF,SMF, NSSF, RIC, and xApps are located in VM3. VM1 and VM2 are dedicated to the UPFs of Operar-A. VM4 and VM5 are dedicated to the UPFs of Operator-B. This approach allows us to manage the Indirect Network Sharing infrastructure offered by the 3rd party, connecting his 5GC to the 5GC of the operators. Finally, we used a remote VM as a server to generate/receive data traffic. To generate the data traffic, we used Iperf[6] . We will call the remote VM as Iperf server.

To validate our PoC, we evaluate the Network Sharing infrastructure in terms of performance and isolation between i) the operators, and ii) the slices belonging to Operator-A and Operator-B. During the experiment, we generated approximately 40 Mbps of traffic in the downlink from the Iperf server to the UEs belonging to the slices of each operator. As mentioned previously, we use four UEs, and one UE for each slice of the operators.

In the PoC setup, we split the RBs equally between the operators.

Figure 4 shows the performance results, at the user space level. That means that the data flows traverse all the network domains, before arriving at the UE. In this way, we are able to observe the performance in the overall network.

In the first segment in the graph related to the throughput, from 0s to about 30s, each UE belonging to an operator consumes the same amount of data, showing a uniform behavior. During that interval, the operators receive an equal distribution of resources from the 3rd party i.e., 50% computing resources and 50% of radio resources. However, a slight decrease in throughput is observed for some slices at certain times, caused by disturbances present on the radio channel. These disturbances caused a slight decrease in jitter, which is negligible and still under study.

The graph of packet loss indicates that the network provided by the 3rd party does not offer sufficient resources to operators to satisfy the resources needed by the UEs to consume the traffic coming from the Iperf Server. In the first 30 seconds, there is an average packet loss of 10% on each slice due to the bottleneck created by the limited radio resources of the RAN. For this reason, starting from the second 30, we considered the scenario where operators decide to sacrifice the default slice to prioritize the eMBB slice. As a result, each operator must be willing to modify the resource pool assigned to it by configuring the slices differently. However, the operator is not allowed to violate the initial 50% pool of resources given by the 3rd party. Failing to separate shared resources among the slices would compromise the stability and security of the entire network, violating agreements between operators and the 3rd party. In the second part of the graph, from the second 30 on, we observe the application of this scenario.

The throughput of the default slices, i.e., slice 1 for Operator-A and slice 2 for Operator-B, decreases from about

[3]OAI: https://gitlab.eurecom.fr/oai/openairinterface5g

[4]OPEN5GS: https://open5gs.org/

[5]FLEXRIC; https://gitlab.eurecom.fr/mosaic5g/flexric

[6]Iperf: https://iperf.fr/iperf-doc.php

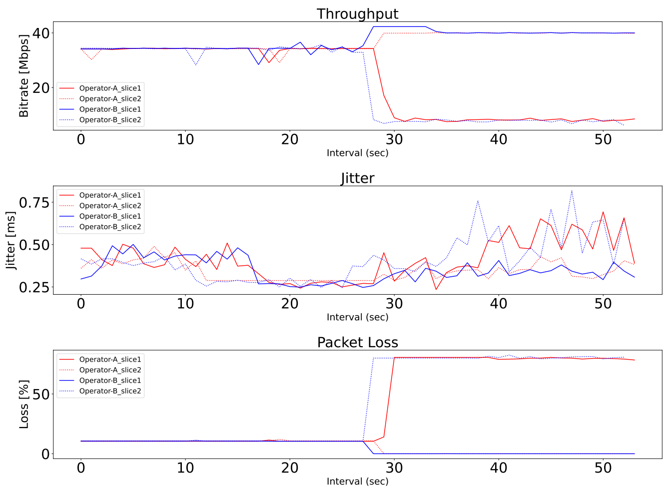

Fig. 4: Experiment results.

35Mbps to 8Mbps. In contrast, the slices dedicated to eMBB services manage to consume 40Mbps traffic sent by the Iperf Server. The jitter graph shows a clear separation between the default and eMBB slices, with the default slices having a higher average jitter after the second 30. Finally, the graph of packet loss shows a significant change: the eMBB slices receive 100% of the packets sent by the Iperf Server, while the default slices experience a loss of about 80%, as operators allocate more radio resources to the eMBB slices

Considering all three performance indicators, we can see that the Network Slicing mechanism ensures isolation between operators in a Network Sharing scenario, allowing them to independently configure their own slices using the allocated pool of resources.

As discussed in Section III-B, isolation is a crucial aspect of Network Sharing. Figure 4 demonstrates that our deployment provides isolation between i) operators, and ii) slices belonging to operators. From second 30, the Iperf Server keeps sending 40Mbps of traffic to the default slices, but the UEs belonging to the default slice receives only 20% of the packets. At the same time, the eMBB slices guarantee 100% of the packets to their UEs. Hence, the network does not allocate additional resources to the default slices and the 3rd party prevents operators from using resources outside the allocated pool.

VI. Conclusion

In this paper, we investigated the role of Network Slicing in facilitating Indirect Network Sharing within 5G SA networks. We designed and deployed a PoC using a real-world 5G SA ORAN-based testbed. Within our setup, Network Sharing was enabled by connecting the control plane of the 5GC of the 3rd party, to the 5GC data plane of the participants. Our PoC demonstrated how a 3rd party can manage the resources of its network infrastructure by using the control plane of the 5GC and the xApps standardized by ORAN. This approach allows: (i) multiple operators to share the same network infrastructure, and (ii) a single operator to use Network Slicing. Furthermore, our results showed that the proposed deployment ensures isolation between different operators and between the slices of the operators. However, the base station in our PoC does not support multiple PLMIDs for the RAN. For that reason, our configuration is based on the slice parameters. Future work will focus on incorporating support for multiple PLMIDs in the RAN to enhance the applicability and scalability of the proposed solution.

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