End-to-end Slicing of RAN based on Next Generation Optical Access Network

Carlo Centofanti
University of L'Aquila
Andrea Marotta
University of L'Aquila
Venkateswarlu Gudepu
Indian Institute of Information Technology Dharwad
Dajana Cassioli
University of L'Aquila
Fabio Graziosi
University of L'Aquila
Hal Roberts
Calix (United States)
Chris Bernard
Calix (United States)
Koteswararao Kondepu (k.kondepu@iitdh.ac.in)
Indian Institute of Information Technology Dharwad

Research Article

Keywords: Slicing, Next Generation Access Network, RAN, SDN, PON

Posted Date: September 13th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3322325/v1

Additional Declarations: No competing interests reported.

End-to-end Slicing of RAN based on Next Generation Optical Access Network

Carlo Centofanti · Andrea Marotta · Venkateswarlu Gudepu · Dajana Cassioli · Fabio Graziosi · Hal Roberts · Chris Bernard · Koteswararao Kondepu* ·

Received: date / Accepted: date

Abstract Given their widespread use, optical access networks suitable as a practical infrastructure for mobile networks and services. The diverse range of

This work has been partially supported by the H2020-MSCA-RISE OPTIMIST project (GA: 872866) and by the Italian Government under CIPE resolution no. 135 (December 21, 2012), project INnovating City Planning through Information and Communication Technologies (INCIPICT). This work is also partly supported by DST SERB Startup Research Grant (SRG-2021-001522).

Carlo Centofanti
University of L'Aquila, L'Aquila, Italy
E-mail: carlo.centofanti1@univaq.it

Andrea Marotta
University of L'Aquila, L'Aquila, Italy
E-mail: andrea.marotta@univaq.it

Venkateswarlu Gudepu
Indian Institute of Technology Dharwad, Dharwad, India
E-mail: 212011003@iitdh.ac.in

Dajana Cassioli
University of L'Aquila, L'Aquila, Italy
E-mail: dajana.cassioli@univaq.it

Fabio Graziosi
University of L'Aquila, L'Aquila, Italy
E-mail: fabio.graziosi@univaq.it

Hal Roberts
Calix, Inc, 2777 Orchard Parkway, San Jose, CA
E-mail: hal.roberts@calix.com

Chris Bernard
Calix, Inc, 2777 Orchard Parkway, San Jose, CA
E-mail: chris.bernard@calix.com

*Corresponding author
Koteswararao Kondepu
Indian Institute of Technology Dharwad, Dharwad, India
E-mail: k.kondepu@iitdh.ac.in

services supported by mobile networks requires the implementation of slicing mechanisms that can manage resources across all associated network segments, from the mobile user to the core network.

In this study, we present a fully operational and integrated 5G network deployment that caters to end-to-end slicing in next-generation access networks. We assess the impact of resource allocation mechanisms within the optical access network on the performance of a slice, particularly in terms of latency and jitter experienced by mobile users.

Keywords Slicing · Next Generation Access Network · RAN · SDN · PON

1 Introduction

Telecommunication structures inherently possess a decentralized, mutual architecture that is engineered to transmit data from one point to another. The journey from the first generation to the fifth generation (1G to 5G) of mobile networks has witnessed an accelerated progression in technology for over four decades. The current generation, 5G, is being deployed globally, introducing a whole new spectrum of mobile network applications. However, the adaptability that 5G technology offers also brings about new challenges that need to be addressed, one of which is the increased density of next-generation Node B (gNB) required to cater to uRLLC and eMMTC applications.

In order to meet the dynamic Quality of Service (QoS) demands of 5G networks, service providers are tasked with amplifying network capacity by adding more RAN components (gNBs). This increases both Capital Expenditure (CAPEX) and Operational Expenditure (OPEX). An alternative approach to this would be sharing the RAN, enabling service providers to divide the costs of CAPEX and OPEX and enhance mobile coverage [17]. RAN sharing can be defined as a strategy where multiple network operators share equipment like the antenna, tower, power, mast, and backhaul for the access network to offer diverse vertical services [12].

Among the critical features of 5G is network slicing, which delivers a broad spectrum of applications with varied service demands through network virtualization [22]. It involves creating dedicated virtual network functions (VNFs) with capabilities tailored to the service or client across a common network infrastructure [1]. Network slicing is made possible with the help of Network Function Virtualization (NFV), which provides these VNFs with a flexible, customizable, and module-based network environment [20, 11, 13].

The 5G Core (5GC) employs its Service Based Architecture in a way that could be termed as "cloud-native." Network slices are created by NFV under the control of the Network Slice Selection Function (NSSF). Every 5GC slice may consist of a set of 5G core VNFs that are interconnected to support a specific use case. A pivotal feature of 5G is the Control and User Plane Separation (CUPS), enabling the 5G core system to be divided into two parts: the Control Plane (CP) and the User Plane (UP). The CP operates as a common slice, while the UP can be divided into multiple customized slices with varied bandwidth and latency requirements. The UPF (User Plane Function), the only UP 5G network function, is responsible for creating and maintaining Packet Data Unit (PDU) sessions to route and forward data packets to various external Data Networks (DNs). 5G UPFs can be sliced to serve different services in order to satisfy diverse QoS needs.

Passive Optical Networks (PONs) are particularly attractive as a supporting infrastructure for a range of services with different requirements such as multimedia [7], IoT, critical services, and mobile networking due to their extensive reach. Therefore, the implementation of network slicing in PONs could be advantageous from both commercial and network efficiency perspectives. The integration of PONs and RANs may be beneficial in terms of costs [16] and network efficiency [15, 14] however, it poses some research challenges.

The challenges of a shared access network serving a 5G Radio Access Network (RAN) are outlined in [2]. An optimal virtual PON (vPON) slice configuration supporting uRLLC scenarios is proposed in [8] while slice management strategies in PONs via NETCONF are discussed in [5]. The virtualization and isolation problems in RAN are analyzed by the authors in [10]. They established a testbed to deploy dynamic and isolated RAN slices to deliver end-to-end slices to end users, but they only managed to run a LTE testbed and didn't consider slicing with PON. Recent efforts addressed resource allocation strategies for sliced PONs [9] in mesh optical network scenarios with particular focus on virtual PON slice formation to support 5G front-haul.

The joint management of radio and optical access networks offers a practical solution to improve network efficiency, especially in slicing scenarios [4]. This paper extends out previous work [6] and aims to demonstrate the feasibility of a fully-functional and integrated 5G network deployment to meet the needs of real end-to-end slicing in next-generation access networks.

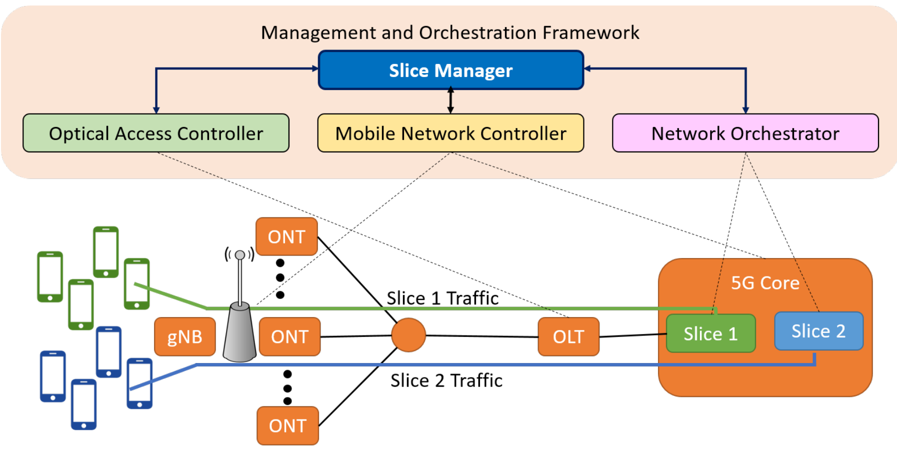

Fig. 1 Network Architecture

2 System Model

Our reference architecture, as depicted in Fig. 1, encompasses three network segments: the Radio Access Network (RAN), the Optical Access Network (OAN), and the 5G Core. The OAN, structured as a Passive Optical Network (PON), acts as the backhaul infrastructure for gNBs. Each gNB is equipped with an Optical Network Termination (ONT), and the PON also serves as Fiber-To-The-X (FTTx) infrastructure for various other services such as residential and business connectivity, and the Internet of Things (IoT).

To deploy end-to-end network slices, resources across the three network segments need to be allocated in a cohesive manner. To attain this holistic resource allocation, we propose a Management and Orchestration Framework, inclusive of software-defined controllers for the optical access and mobile networks, and a network orchestrator. The role of managing the mapping of different slice requirements into tailored configurations of the network segments and coordinating the network controllers and the network orchestrator throughout the slice life-cycle falls on a Slice Manager element.

The network controllers undertake the implementation of resource allocation strategies, ensuring that the targeted slice performance is met. In the mobile core segment, the network orchestrator is tasked with deploying 5G core functions like Access Management Function (AMF), User Plane Function (UPF), Network Repository Function (NRF), and Session Management Function (SMF) that form the slices at the mobile core level.

This framework also facilitates the placement of UPF in diverse physical locations based on the Service Level Agreement or the user's needs. An edge-deployed UPF can offer ultra-low latency, making it suitable for ultra-reliable and low latency communication (uRLLC), while a UPF situated at a central office or a cloud provider may contribute to reductions in CAPEX and OPEX, albeit at the expense of increased latency.

Given that the OAN may be shared with other users (e.g., residential customers), isolation on the optical link is critical to maintain the desired Service Level Agreement (SLA) for the services running on the 5G network. The 5G traffic on this segment includes user data and control traffic for managing the radio network, both of which demand isolation and prioritization. This differentiation in traffic is realized on the PON by employing varied bandwidth allocation strategies such as: (i) Request-Grant based access that leverages Dynamic Bandwidth Assignment procedures to maximize statistical multiplexing and enhance network efficiency, although this may result in increased latency; and (ii) Expedited Forwarding, which allows a specific slice to use a pre-allocated amount of bandwidth in a Grant-free manner, thereby reducing experienced latency.

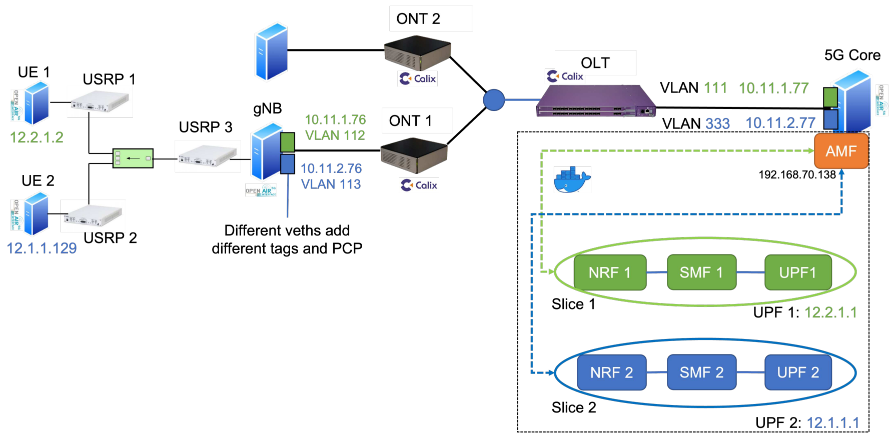

Fig. 2 Experimental Setup

3 SDN-Based RAN scheduling

SDN-Based RAN scheduling is a network management approach that leverages the principles of SDN to enhance the efficiency and flexibility of RAN resource allocation and management. In traditional cellular networks, RAN elements (e.g., base stations) are often managed individually, making it challenging to adapt to dynamic traffic patterns and optimize resource utilization. However, in 5G networks scheduling algorithms such as Round Robin (RR) [21], Maximum Throughput (MT) [21], and Proportional Fairness (PF) [21] ensures that available resources are allocated to active users to meet their QoS demands. gNB has included a packet scheduler that used these algorithms for both the uplink and the downlink.

The RR scheduler, a time-insensitive approach, allocates radio resources without considering channel conditions. While it enhances user fairness, it degrades overall network performance. It's simplicity ensures fairness but ignores user Channel Quality Indicator (CQI), causing low and inconsistent throughput. In contrast, the MT scheduler allocates radio resources based on channel conditions, considering user's CQI value. It prioritizes users with the highest CQI (i.e., best channel conditions), maximizing throughput. However, this approach can disadvantage cell-edge users, as it often favors the user with the highest CQI, potentially neglecting others. Meanwhile, the PF scheduler allocates more resources to users with better channel conditions while maintaining fairness. It aims for a balance between high cell throughput and fairness, resulting in optimal performance. The OAI gNB that we employed in the experimental setup uses the PF scheduler and offers both the advantages of RR and MT.

```
1  <config>
2      <config xmlns="http://www.calix.com/ns/exa/base">
3          <profile>
4              <pon-cos-profile xmlns="http://www.calix.com/ns/exa/gpon-interface-base">
5                  <name>ont1_ef</name>
6                  <prio>4</prio>
7                  <bw>
8                      <type>explicit</type>
9                      <maximum>MAXVALUE</maximum>
10                     <minimum>MINVALUE</minimum>
11                 </bw>
12                 <cos-type>expedited</cos-type>
13             </pon-cos-profile>
14         </profile>
15     </config>
16 </config>
```

Fig. 3 NETCONF excerpt for Expedited Forwarding configuration

4 NETCONF-based PON Control

In order to control the PON infrastructure via SDN we developed a Python-based controller. The developed controller offers the possibility to use north-bound Application Programming Interfaces (APIs) to setup ONTs and configure service-specific resource allocation policies.

In particular, we focus on the application of bandwidth allocation policies to enforce low latency for the backhaul traffic belonging to Slice 1. The controller encompasses a driver layer which is responsible to translate north bound APIs into NETCONF configuration messages composed according to CALIX YANG data model [3].

Fig. 3 exhibits a NETCONF excerpt for the definition of an *Expedited Forwarding* profile. Here, we see that in line 12 the *cos-type*, i.e. class of service type, attribute is set to *expedited*. This will inform the OLT to allocate dedicated transmission opportunities for the service which can be accessible without performing request-grant handshake. The amount of bandwidth to be reserved can be configured via the *bw* attribute in line 7. Note that both a minimum and a maximum value can be specified to offer some flexibility to the OLT DBA. However, in this work we configure an exact value of bandwidth for Slice 1 setting maximum and minimum to the same value.

5 Experimental Setup

Figure 2 shows the considered experimental setup primarily consisting of three different parts that are the RAN, OAN and CN.

Radio Access Network (RAN)

The RAN is deployed by using OpenAirInterface (OAI) open-source RAN software stack [18]. Then we deployed two OAI-based UEs (*UE 1* and *UE 2*) using two different physical machines. The UEs are connected to the RAN by using National Instrument X310 Universal Software Radio Peripherals (USRPs). The UE side USRPs are connected with the gNB side USRP through a two-way signal splitter/combiner with SubMiniature version A (SMA) connectors as shown in Fig. 2. This allows to evaluate multi-user connection with the single gNB.

On the other end, the OAI gNB is configured with Single − Network Slice Selection Assistance Information (S-NSSAI) list to support two different Slice/Service Type (SST) and Slice Differentiator (SD) values to evaluate the RAN slicing scenario.

We have set up the Radio Access Network (RAN) using the open-source RAN software stack from OpenAirInterface (OAI)[18]. Subsequently, we established two OAI-based User Equipments (UEs), namely UE 1 and UE 2, employing two separate physical machines. These UEs are linked to the RAN via National Instrument X310 Universal Software Radio Peripherals (USRPs). The USRPs at the UE side are interfaced with the USRP at the gNB side through a two-way signal splitter/combiner equipped with SubMiniature version A (SMA) connectors, as illustrated in Fig.2. This setup allows us to handle flow isolation at every segment of the network.

Additionally, the OAI gNB is set up with a Single − Network Slice Selection Assistance Information (S-NSSAI) list to accommodate two different Slice/Service Types (SST) and Slice Differentiator (SD) values, facilitating the evaluation of the RAN slicing scenario.

Optical Access Network (OAN)

Our setup features an Optical Access Network (OAN) segment situated between the RAN and CN. This is implemented using the commercial Calix Axos E7-2 NG-PON2, which offers NETCONF support useful to dynamic slice configuration and to set isolation and network traffic rules during runtime. For traffic differentiation and isolation on the forwarding plane, we've implemented a slicing mechanism grounded on the IEEE 802.1Q Virtual Local Area Networking (VLAN) standard.

The 802.1Q standard also designates a 3-bit Priority Code Point (PCP) to categorize traffic type. It is woth noting that 802.1Q doesn't provide a specification for the traffic type differentiation process based on PCP.

With the help of the Calix Axos E7-2, we can configure the ONT to distinguish traffic based on VLAN tags and PCP. As a result, services requiring high priority and low latency can utilize VLANs to meet their Service-Level Agreements (SLAs). Our OAN has been configured such that traffic belonging to Slice 1 (linked to VLAN 112 and PCP 7) is treated as Expedited Forwarding - being transmitted from the ONT to the Optical Line Terminal (OLT) without invoking the request-grant mechanism to reduce latency. Traffic associated with Slice 2, linked with VLAN 113 and PCP 3, is transferred as Best Effort traffic, employing the traditional request-grant process based on dynamic bandwidth allocation.

To guarantee low latency for a specific slice throughout the entire network, the following mechanism is put into place:

1. The gNB assigns a VLAN tag and PCP to each packet destined for the 5G CN, for each UE, by utilizing virtual ethernet interfaces.
2. The ONT utilizes the PCP to apply forwarding policies such as Expedited Forwarding or Best Effort.
3. The traffic is then directed through the OAN to the 5G CN, where the CN slicing consists of two separate User Plane Functions (UPF) linked with two different VLAN tags, as shown in Fig. 2.

The forwarding policies at the OLT can be dynamically configured with the assistance of the Slice Manager (and NETCONF) as depicted in Fig. 1.

Core Network (CN)

Our 5G Core, based on OAI, is designed in a scalable way that allows it to easily adapt to the needs of a variety of 5G use-cases [19]. Within this setup, distinct Network Functions (NFs) are implemented to provide services. In this context, the Control Plane (CP) and User Plane (UP) functions are separated to facilitate independent scaling. In this process, the Network Slice Selection Function (NSSF) determines the appropriate NSSAI and designates the Access and Mobility Management Function (AMF) to serve the UE. As depicted in Fig. 2, each Slice is linked to three distinct NFs, i.e., Network Repository Function (NRF), Session Management Function (SMF), and User Plane Function (UPF). The selection of these NFs primarily relies on the S-NSSAI and is facilitated by the NSSF.

We have deployed a Docker container-based 5G Core with all the necessary NFs. Specifically, during our experiments, two UPFs (corresponding to Slice 1 and Slice 2) are connected to the two UEs to ensure isolation and improve slice performance.

6 Experimental Results

To assess the influence of various resource allocation strategies used in the OAN on slice performance, we conduct delay evaluations: (i) from gNB to Core (i.e., the delay in optical access) and (ii) from the UEs to Core (i.e., end-to-end delay). For the measurement of round trip time, we dispatch ICMP packets at a ping interval of 10ms. Also, we conduct throughput evluations: (i) from gNB and Core (i.e., pon throughput) and (ii) from the UEs and Core (i.e., end-to-end throughput) using iperf3 tool.

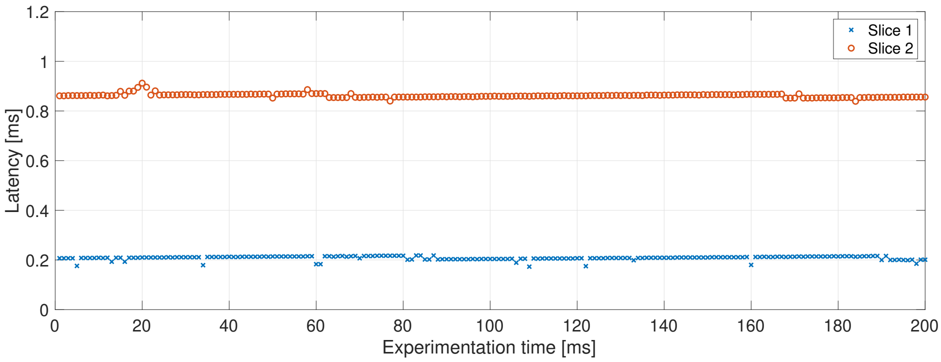

Fig. 4 PON latency for different slices

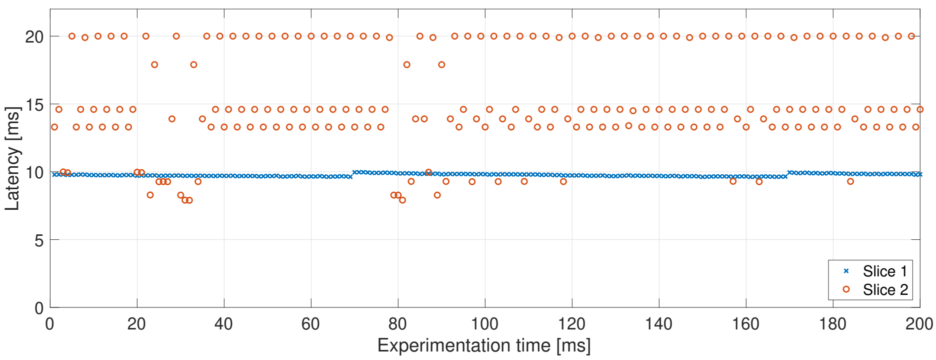

Fig. 5 UEs to Core (UPFs) latency for different slices

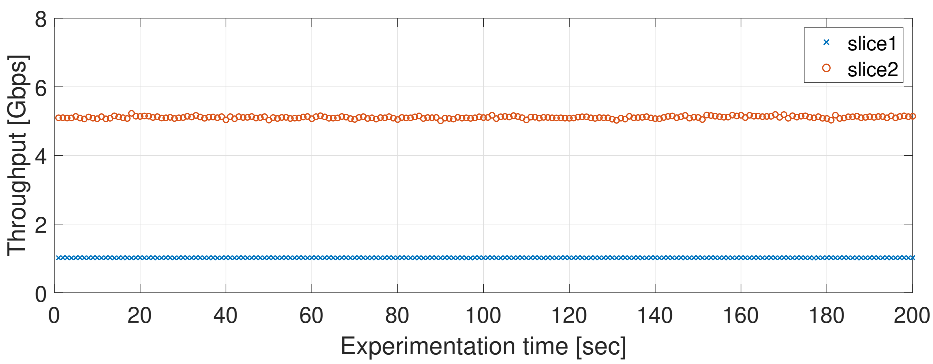

Fig. 6 PON throughput for different slices

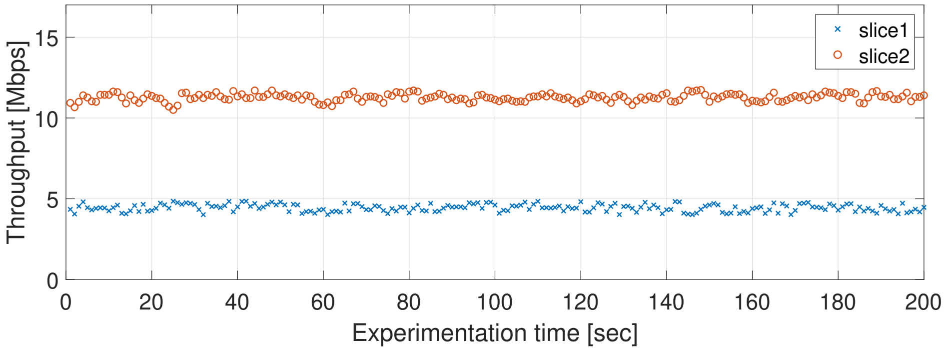

Fig. 7 UEs to Core (UPFs) throughput for different slices

6.1 PON impact analysis

Fig. 4 illustrates the optical access delay measured between the gNB and the Core for the two slices under consideration. *Expedited Forwarding* allocation strategy used for Slice 1 reduces the delay in the PON by 80% compared to Slice 2, which relies on a *Best Effort* strategy. Specifically, the average optical access latency for Slice 1 is only 0.25ms, while for Slice 2 it's approximately 0.85ms. This significant reduction is due to the absence of the request-grant procedure for Slice 1. Transmission opportunities in the upstream for Slice 1 are reserved in advance, allowing the ONT to transmit in a grant-free manner, thereby reducing packet queuing at the ONT.

6.2 End-to-end delay analysis

Fig.5 presents the end-to-end latency measurements for both slices. It's evident that the end-to-end delay for Slice 1 is considerably less than that of Slice 2. These delays take into account both the contributions from the RAN and the OAN. Notably, Fig.5 demonstrates that resource reservation in the optical access network not only improves performance by reducing latency, but also by lowering end-to-end jitter. This is because packets belonging to Slice 1 aren't queued at the ONT, significantly diminishing delay variations, which can reach up to 10ms as observed for Slice 2.

6.3 PON throughput analysis

Fig. 6 illustrates the throughput measured between the gNB and the Core for the two slices under consideration. *Best Effort* allocation strategy used for Slice 2 offers a higher throughput in the PON by 4 times compared to Slice 1, which relies on a *Expedited Forwarding* strategy. Specifically, the average obtained throughput for Slice 2 is 5.4 Giga bits [Gbits], while for Slice 1 it's approximately 1.02 Gbits. This significant difference is due to the prioritization and resource allocation strategies employed by each slice.

6.4 End-to-end throughput analysis

Fig.7 presents the end-to-end throughput measurements for both slices. It's evident that the end-to-end throughput for Slice 1 is considerably less than that of Slice 2. These throughput values take into account both the contributions from the RAN and the OAN. The Slice 2 offers an average throughput of 11.2 Mbps, whereas Slice 1 offers approximately 4.42 Mbps. Notably, Fig.7 demonstrates that resource reservation in the optical access network not only improves performance by higher throughput, but also by lowering end-to-end packet loss.

7 Conclusion

In this study, we showcased a practical realization of end-to-end slicing in a Radio Access Network (RAN) built on an optical access network. Our approach leverages a commercial Next-Generation Passive Optical Network 2 (NG-PON2) for backhauling mobile traffic and employs containerized elements of a sliced core network. We analyzed the effects of our proposed slicing strategy for the optical access segment, which is based on VLAN and PCP. Our findings demonstrate that the suggested slicing method can reduce latency and lower jitter for mobile users within a particular slice.

Declarations

Conflict of interest The authors declares no conflict of interest.
Data availability There is no associated data with this publication.

References

1. Afolabi, I., Taleb, T., Samdanis, K., Ksentini, A., Flinck, H.: Network slicing and softwarization: A survey on principles, enabling technologies, and solutions. IEEE Communications Surveys & Tutorials **20**(3), 2429–2453 (2018). DOI 10.1109/COMST.2018.2815638
2. Afraz, N., Slyne, F., Gill, H., Ruffini, M.: Evolution of access network sharing and its role in 5g networks. Applied Sciences **9**(21), 4566 (2019)
3. CALIX: Using the AXOS NETCONF Management Interface R23.x. `https://www.calix.com/content/dam/calix/mycalix-misc/lib/iae/axos/m/nbi/netconf-22/index.htm?toc.htm?98705.htm` (2023). [Online; accessed 19-July-2023]
4. Centofanti, C., Marotta, A., Cassioli, D., Graziosi, F., Gudepu, V., Kondepu, K.: End-to-end slicing via o-ran and software defined optical access. In: 2023 Optical Fiber Communications Conference and Exhibition (OFC), pp. 1–3. IEEE (2023)

5. Centofanti, C., Marotta, A., Cassioli, D., Graziosi, F., Sambo, N., Valcarenghi, L., Bernard, C., Roberts, H.: Slice Management in SDN PON Supporting Low-Latency Services. In: 2022 European Conference on Optical Communications (ECOC). IEEE (2022)
6. Centofanti, C., Marotta, A., Gudepu, V., Cassioli, D., Graziosi, F., Kondepu, K., Roberts, H., Bernard, C.: End-to-end slicing of ran based on next generation optical access network. In: IEEE International Conference on Advanced Networks and Telecommunications Systems. IEEE (2022)
7. Centofanti, C., Marotta, A., Rinaldi, C., Franchi, F., Cassioli, D., Graziosi, F.: Improved DASH Video Streaming Performance by MEC-Enabled Optical Access. In: Asia Communications and Photonics Conference 2021, p. T4A.144. Optica Publishing Group (2021). DOI 10.1364/ACPC.2021.T4A.144. URL `http://opg.optica.org/abstract.cfm?URI=ACPC-2021-T4A.144`
8. Das, S., Ruffini, M.: Optimal virtual pon slicing to support ultra-low latency mesh traffic pattern in mec-based cloud-ran. In: 2021 International Conference on Optical Network Design and Modeling (ONDM), pp. 1–5. IEEE (2021)
9. Das, S., Ruffini, M.: Optimal virtual PON slicing to support ultra-low latency mesh traffic pattern in MEC-based Cloud-RAN. In: 2021 International Conference on Optical Network Design and Modeling (ONDM). IEEE (2021)
10. Foukas, X., Marina, M.K., Kontovasilis, K.: Orion: Ran slicing for a flexible and cost-effective multi-service mobile network architecture. In: Proceedings of the 23rd annual international conference on mobile computing and networking, pp. 127–140 (2017)
11. Foukas, X., Patounas, G., Elmokashfi, A., Marina, M.K.: Network Slicing in 5G: Survey and Challenges. IEEE Communications Magazine **55**(5), 94–100 (2017). DOI 10.1109/MCOM.2017.1600951
12. Kassis, M., Costanzo, S., Yassin, M.: Flexible Multi-Operator RAN Sharing: Experimentation and Validation Using Open Source 4G/5G Prototype. In: 2021 Joint European Conference on Networks and Communications & 6G Summit (EuCNC/6G Summit), pp. 205–210. IEEE (2021)
13. Kim, D., Kim, S.: Network Slicing as Enablers for 5G Services: State of the Art and Challenges for Mobile Industry. Telecommun. Syst. **71**(3), 517–527 (2019). DOI 10.1007/s11235-018-0525-2. URL `https://doi.org/10.1007/s11235-018-0525-2`
14. Marotta, A., Cassioli, D., Antonelli, C., Kondepu, K., Valcarenghi, L.: Network solutions for comp coordinated scheduling. IEEE Access **7**, 176624–176633 (2019)
15. Marotta, A., Cassioli, D., Kondepu, K., Antonelli, C., Valcarenghi, L.: Exploiting flexible functional split in converged software defined access networks. Journal of Optical Communications and Networking **11**(11), 536–546 (2019)
16. Marotta, A., Kondepu, K., Cassioli, D., Antonelli, C., Correia, L.M., Valcarenghi, L.: Software defined 5G converged access as a viable techno-economic solution. In: 2018 Optical Fiber Communications Conference and Exposition (OFC), pp. 1–3. IEEE (2018)
17. Nokia Network Sharing White Paper: available online at https://www.nokia.com/networks/solutions/network-sharing/, accessed on Aug. 2022.
18. OAI: OpenAirInterface: A Flexible Platform for 5G Research (2022). URL `www.openairinterface.org/.`
19. OpenAirInterface 5G Core: (2022). URL `https://openairinterface.org/oai-5g-core-network-project/`
20. Ordonez-Lucena, J., Ameigeiras, P., Lopez, D., Ramos-Munoz, J.J., Lorca, J., Folgueira, J.: Network Slicing for 5G with SDN/NFV: Concepts, Architectures, and Challenges. IEEE Communications Magazine **55**(5), 80–87 (2017). DOI 10.1109/MCOM.2017.1600935
21. Sundari, K.G., Gunasundari, R., Jayanthi, K.: Prioritized dynamic multitraffic scheduler for downlink in lte. In: 2015 2nd International Conference on Electronics and Communication Systems (ICECS), pp. 1469–1473. IEEE (2015)
22. Tsai, C.C., Lin, F.J., Tanaka, H.: Evaluation of 5G Core Slicing on User Plane Function. Communications and Network **13**(3), 79–92 (2021)