Optimizing Radio Resource Allocation in 5G using Transport Network-Aware Intelligent RAN

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***Abstract*—The high cost of 5G deployment, driven by the need for more cell sites, has led to new business models such as Neutral Hosting, where a neutral third party offers a shared network infrastructure to be used by multiple MNOs. In these environments, where infrastructure and spectrum sharing are combined, cross-optimization across the 5G network domains is beneficial for effective resource management. In this paper, we present the work done in the 5GECO project, which aims to harmonize decision-making between the 5G Radio Access Network (RAN) and the Transport Network (TN). We define two interfaces, in line with the Open RAN (O-RAN) and Software-Defined Networking (SDN) specifications, between the controllers of the RAN and TN to enable the exchange of telemetry data between these two domains while maintaining their logical separation. We validate our approach through a real-world experimental setup, demonstrating the benefits of exchanging telemetry data to optimize radio resource allocation in the RAN.**

***Index Terms*—5G, 5GECO, resource management, resource optimization, neutral hosting, RAN, transport network**

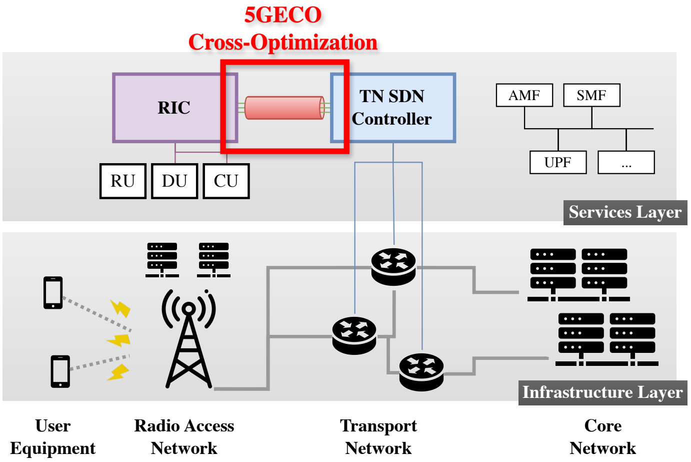


Fig. 1: 5GECO's intelligent RAN-TN cross-optimization.

I. Introduction

The advent of 5G has introduced unprecedented opportunities in the telecommunication industry, enabling a wide range of new capabilities, markets, and applications [1]. However, 5G mobile networks require significant cell densification to meet the stringent requirements of these emerging services, with some areas needing up to ten times more cells than 4G [2]. Increasing the cell density in 5G requires scaling up the entire network infrastructure, from additional base stations to expanding fiber backhaul networks, leading to high deployment costs and a longer time to market [3]. This makes it difficult to provide ubiquitous 5G coverage in dense urban environments, where a large number of cells are needed, and in rural areas, where cell deployment costs cannot be justified.

To mitigate these challenges, various forms of network sharing have been employed across multiple generations of mobile networks, from 2G to 5G [4]. Over the years, this has led to the development of innovative new concepts and business models for network sharing. One such concept is Neutral Hosting (NH), which allows multiple Mobile Network Operators (MNOs) to use a single physical network infrastructure managed by a neutral third party. In the NH paradigm, a neutral host owns the Radio Access Network (RAN) infrastructure, providing a fully virtualized RAN to its tenants (i.e., MNOs). This contrasts with traditional MNO deployments, where 1) MNOs own their own vendor-specific RAN; and 2) MNOs often overprovision resources (e.g., Transport Network (TN) providers) to meet their service requirements.

To that end, NH can significantly reduce the Total Cost of Ownership (TCO) of 5G networks by virtualizing expensive cell and network infrastructure, allowing MNOs to pay only for the resources they need. The 5G Standalone (SA) architecture perfectly fits this concept, as the service-based architecture, Network Function Virtualization (NFV), and network slicing inherently enable network virtualization. However, resource management becomes challenging when both infrastructure and spectrum sharing are combined, as each type of sharing is performed independently of each other in different network domains.

The work carried out during the 5GECO (*5G intelligent radio and transport Edge Network Cross-Optimization*) project [5] aims to address this problem. As shown in Fig. 1, 5GECO aims to make RAN and TN aware of each other and intelligently harmonize their decision-making capabilities, improving resource management in deployments where 1) the TN and RAN have different owners, and 2) the TN and RAN belong to the same owner. To achieve this, 5GECO proposes to exchange enrichment information (e.g., telemetry data, user and flow statistics, etc.) between the RAN and TN, all while remaining isolated and independent. In this paper, we focus on a network deployment where the RAN can intelligently manage its radio resources (e.g., using data-driven approaches like Machine Learning (ML)), while the TN is limited to providing monitoring data.

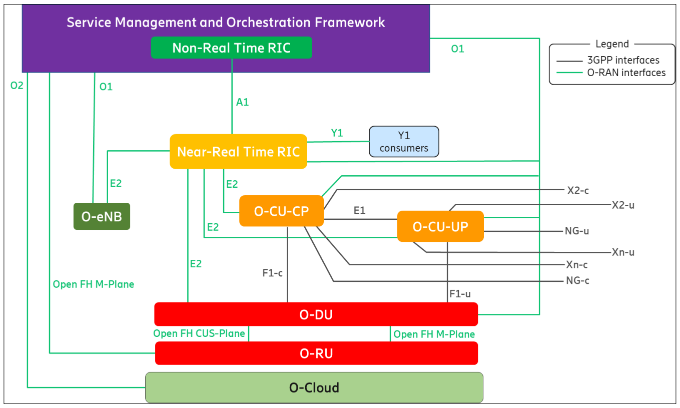
Recent advances in cross-optimization between the RAN and TN have shown promise for improving network performance [6]. However, significant gaps remain in the literature, particularly regarding how the RAN can leverage monitoring data from the TN to optimize resource management without direct control over the TN resources – a core assumption of the network slicing architecture proposed by 3GPP [7], [8]. Existing approaches for Software-Defined Networking (SDN)-based mobile backhaul architectures [9] and multi-tenant dynamic slicing frameworks [10], [11] typically enable cross-domain resource provisioning through centralized control. These solutions are not suitable for NH environments, where independent control of the RAN and TN is required due to the separation of ownership between the NH and the TN provider. Other work, such as [12], explore cross-optimization while maintaining independent control in RAN and TN, but do not address the telemetry exchange between these domains. The lack of standardization to integrate controllers across different domains hinders seamless coordination and interoperability, which are essential for efficient cross-optimization among decentralized network domains [6], [13].

To address these challenges, this paper discusses the work carried out within the 5GECO project to enable effective information sharing between the RAN and TN controllers, enhancing their awareness of each other without compromising their independent control mechanisms. Our contributions are threefold: 1) we provide a detailed overview of the current state and capabilities of RAN and TN controllers, including their standardized interfaces and functionalities; 2) we define two interfaces, the North-South Interface (NSI) and the East-West Interface (EWI), to enable information exchange between RAN and TN while maintaining the independence of the controllers; and 3) we deploy and use a real-life experimental setup of our proposed interfaces, demonstrating the practical advantages of these interfaces in terms of radio resource optimization.

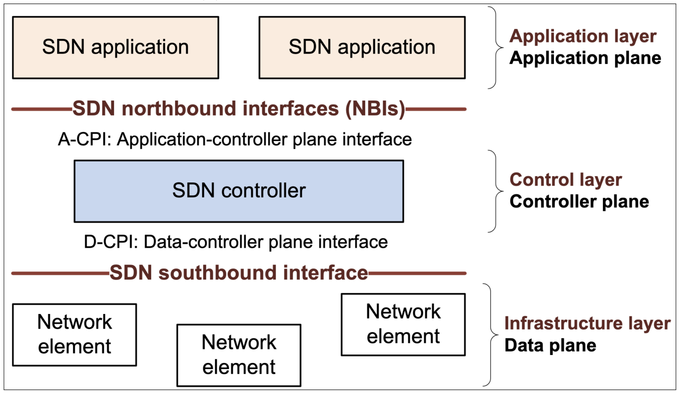
II. RAN & TRANSPORT CONTROLLERS

In this section, we provide an overview of the existing controllers and frameworks for the RAN and the TN, together with a brief description of their functionalities and standardized interfaces. More specifically, we describe the principles and architecture of Open RAN (O-RAN) for the RAN and SDN for the TN.

A. RAN Intelligent Controller (RIC)



(a) O-RAN architecture [14].



(b) SDN architecture [15].

Fig. 2: Logical architecture for O-RAN and SDN.

The O-RAN Alliance[1] has made significant contributions towards standardizing the management and control entities related to the RAN. The general O-RAN architecture, shown in Fig. 2a, is composed of O-RAN Network Functions (NFs), a Service Management and Orchestration (SMO) framework to manage the O-RAN NFs, and an O-RAN Cloud (O-Cloud) that hosts many of these NFs. For radio management, the O-RAN architecture defines the RAN Intelligent Controller (RIC), a critical component that provides advanced control and optimization capabilities to manage the complex and dynamic nature of RAN deployments.

The RIC is logically separated into two distinct components: the Non-Real-Time RIC (Non-RT RIC), housed in the SMO framework, and the Near-Real-Time RIC (Near-RT RIC), a NF in the O-Cloud cloud computing platform. The Non-RT RIC handles long-term Quality of Experience (QoE) optimization and policy management functions using different applications called rApps, performing network planning and training Artificial Intelligence (AI) and ML models. In contrast, the Near-RT RIC uses so-called xApps to perform tasks that require near-real-time execution, such as dynamic resource allocation and interference management. Simply put, the Non-RT RIC generates policies for the RAN, while the Near-RT RIC executes those policies. As shown in Fig. 2a, the following standardized interfaces interact with the RIC:

- **E2 interface**: connects the RIC to the E2 nodes (e.g., gNodeBs (gNBs)) to exchange control messages and data required for the RIC to manage RAN elements. Through this E2 interface, the RIC receives real-time data from RAN elements, which can then be analyzed using AI/ML algorithms to optimize the network. The RIC then sends

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[1] O-RAN: https://www.o-ran.org

control commands back to the RAN elements to execute these optimizations.

- **A1 interface**: connects the Non-RT RIC to the Near-RT RIC. This interface is used for policy management, intent-based control, and conveying ML model updates from the Non-RT RIC to the Near-RT RIC. The Non-RT RIC, typically located in the cloud, performs longer-term analytics and ML model training, after which these models and policies are passed to the Near-RT RIC via the A1 interface.
- **O1 interface**: connects the RAN elements to the SMO framework. This interface is used for the management and orchestration of the RAN elements, providing data necessary for functions such as fault management, configuration management, and performance management.

B. Transport Network SDN Controller

The TN is the backbone of various types of network infrastructure. In the context of cellular networks, the TN interconnects the disaggregated O-RAN elements with the Core Network (CN) toward the Internet. To facilitate the control and management of these types of networks, the notion of SDN was introduced, separating the control plane and the data plane as shown in Fig. 2b. This separation has proven to be an effective solution to reduce both Capital Expenditures (CAPEX) and Operational Expenditures (OPEX) by increasing flexibility and facilitating innovation [16]. The SDN controller is a crucial component of SDN, centralizing the control of multiple network devices (e.g., switches and routers in a TN) into a single entity and providing functions for SDN applications to interact with a global view of the network.

Fig. 2b presents the two interfaces of the SDN controller:

- **Southbound Interface (SBI)**: enables communication between the SDN controller and the physical network devices. This interface provides a standardized method for the SDN controller to manage and regulate the data plane of the underlying devices.
- **Northbound Interface (NBI)**: allows applications to interact with the SDN controller, facilitating the development of network applications that can leverage the abstracted network state that SDN provides. These interfaces typically use RESTful Application Programming Interfaces (APIs), enabling easy integration with various network management and orchestration systems.

III. RIC-SDN INTERFACES

As described in the previous section, the control entities of both the RAN and the TN are already well established, each providing fine-grained control over each of their network domains. However, the information exchange between these two entities is not specified. Since the RIC and the SDN controller of the TN operate in different areas of the network, 5GECO proposes to keep their decision-making processes independent so that they do not exert control over one another. While the existing NBI of the SDN controller could be connected to the SMO to provide the necessary information to the RAN, this would also allow the SMO to control the TN, which is undesirable.

TABLE I: Interfaces used to share information from one component to another

From component	**To component**	**Interface name**
Near-RT RIC	Non-RT RIC	A1
Near-RT RIC	SDN Controller	Y1
Non-RT RIC	Near-RT RIC	A1
Non-RT RIC	SDN Controller	DME[*]
SDN Controller	Near-RT RIC	/[**]
SDN Controller	Non-RT RIC	/[**]

[*] Using the Data Management and Exposure (DME) of the SMO, the Non-RT RIC can indirectly expose enrichment information to external entities. However, this interface is not fully standardized yet.

[**] SDN Apps can be used to collect and expose telemetry data to the SMO's Enrichment Information (EI) interface, indirectly reaching the RIC.

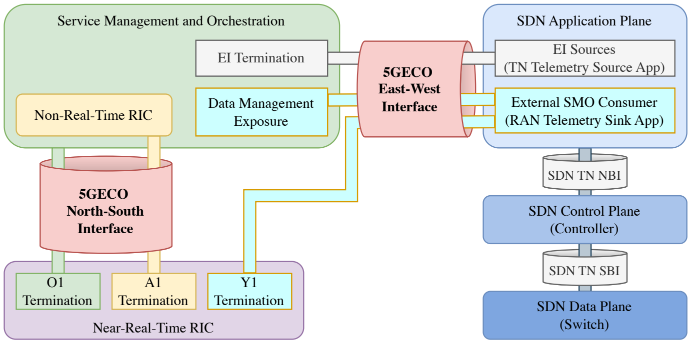

Fig. 3: Definition of North-South and East-West interfaces. These interfaces enable the RAN and the TN to exchange telemetry data with one another in a non-hierarchical way, meaning that neither one of the domains can control the other.

Keeping control of the RAN and TN logically separated has several benefits. On the one hand, existing control applications and infrastructure in each domain can be reused, minimizing cost and additional development overhead, which means that this approach is suited not only for Neutral Hosting, but also for more traditional network sharing deployments. On the other hand, the neutral host is not limited to this logical separation and may therefore still add a lightweight management entity (which may be housed in the SMO) on top of our proposed approach if required.

Table I provides an overview of the existing interfaces that enable information sharing between the RAN and the TN. This clearly shows 1) the lack of telemetry interfaces on the SDN controller for external entities; and 2) the lack of a unified interface for this kind of information exchange. Consequently, we propose and discuss some of the architectural changes and interfaces required to enable information sharing between the RAN and the TN, while maintaining independent control over each domain. Fig. 3 depicts two interfaces that enable this behavior: the East-West Interface (EWI) and the North-South Interface (NSI).

A. East-West Interface (EWI)

First, we define the EWI, as shown in Fig. 3, as an interface to expose and consume information between the SMO containing the Non-RT RIC and the TN SDN controller. We define the EWI in line with the existing standardization efforts of interfaces at the RIC, the SMO, and the SDN controller.

1) RIC: the Near-RT RIC can expose data to external entities through the O-RAN Y1 interface [17]. This interface plays a key role in sharing RAN telemetry with both internal and external entities within the trust domain of the MNO. Functionally, the Y1 interface exposes various types of RAN analytics that can be used to support key tasks, such as traffic steering, mobility management, and interference management.

To consume data from external entities, the RIC can use the external Enrichment Information (EI) interface of the SMO [18]. This interface allows the SMO to consume enrichment information from external sources and pass it to the Non-RT RIC via the internal Non-RT RIC-SMO interface. The process of gathering such enrichment information is thoroughly described in the O-RAN use cases specification [19], providing sequence diagrams of the required message exchange to collect enrichment information from external applications (e.g., a telemetry data App running on the TN SDN controller). Furthermore, the EI interface also allows the Non-RT RIC to exchange handshake messages (e.g., request and response messages) with external enrichment information sources. When required, enrichment information can also be exposed to the Near-RT RIC through the A1 interface of the NSI.

Additionally, O-RAN is studying new external SMO terminations, such as the Data Management and Exposure (DME) interface, to expose data from the SMO and Non-RT RIC to external entities [20]. Although these terminations have not yet been fully standardized in the O-RAN specifications, they provide the functionality required to exchange enrichment information with external entities.

2) SDN: on the SDN TN side, there is no standardized interface like that of O-RAN to consume data from and expose data to external entities. However, custom applications can be deployed in the application plane of the TN, with functionalities similar to the xApps and rApps of the RIC. To this end, as shown in Fig. 3, we create two SDN Apps: the *TN Telemetry Source App* and the *RAN Telemetry Sink App*. The *TN Telemetry Source App* monitors the TN, collects enrichment information (e.g., packet loss, link throughput, etc.), and exposes this information to external entities. The SMO in the RAN can then connect to this App through the EI interface and consume data from the TN. The *RAN Telemetry Sink App* serves as an endpoint for the TN to collect telemetry data from the RAN, coming from both the Y1 interface of the Near-RT RIC and the DME of the SMO.

B. North-South Interface (NSI)

To complement the EWI, we define the NSI as an interface to allow information sharing between the Non-RT RIC and the Near-RT RIC. As shown in Fig. 3, the NSI is composed of two existing interfaces: 1) the O1 interface between SMO and Near-RT RIC [21]; and 2) the A1 interface between Non-RT RIC and Near-RT RIC [22].

The established O1 and A1 interfaces already enable the necessary data exchange between the Non-RT RIC and the Near-RT RIC, eliminating the need for additional components or interfaces. Nevertheless, the functions provided by these interfaces are essential for RAN-TN cross-optimization. They allow the Non-RT RIC to communicate TN-aware enrichment information and policies to the Near-RT RIC. By combining the NSI and the EWI, we achieve information exchange among the Near-RT RIC, the Non-RT RIC housed within the SMO, and the SDN controller of the TN.

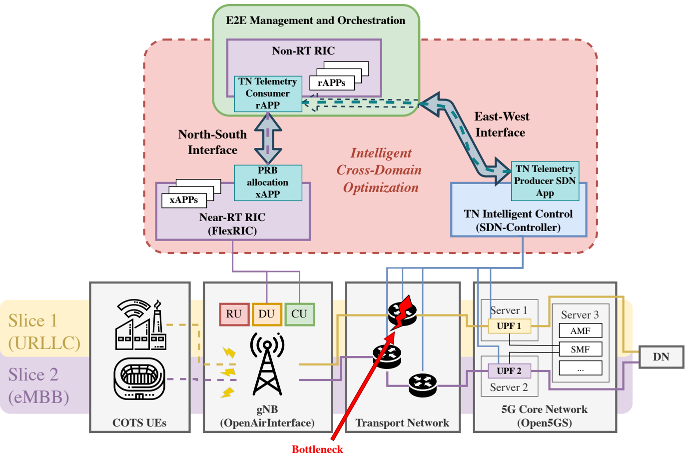

Fig. 4: Experimental setup for TN-aware intelligent RAN experiment. Two UEs are connected to a single gNB over 5G New Radio (NR). Each UE is connected to a different slice, reaching its distinct UPF over different TNs.

IV. EXPERIMENTAL SETUP

To showcase the benefits of sharing information between the RAN and the TN, we develop and analyze a proof of concept (PoC) of a TN-aware intelligent RIC on top of our Open5G@TheBeacon 5G SA testbed [23]. Our objective is to demonstrate how an intelligent RAN can more efficiently reallocate radio resources (i.e., Physical Resource Blocks (PRBs)) when it is aware of possible problems in the TN.

A. Testbed

Our O-RAN compliant testbed runs open source software solutions to deploy a fully end-to-end 5G SA network. We use OpenAirInterface (OAI)[2] for the RAN, Open5GS[3] for the CN, and FlexRIC[4] for the RIC. Additionally, we use our spectrum license, encompassing 50 MHz in band n77 (4035 MHz - 4085 MHz), in order to perform real-world over-the-air tests. A detailed description of the hardware components used in our testbed is provided in [23].

B. Setup

Fig. 4 represents the experimental setup and the network architecture deployed on our testbed. As shown in this figure, we add three new major components on top of our existing testbed to enable a TN-aware intelligent RAN: 1) a telemetry-producing app for the TN that records various metrics; 2)

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

[3] Open5GS: https://open5gs.org

[4] FlexRIC: https://gitlab.eurecom.fr/mosaic5g/flexric

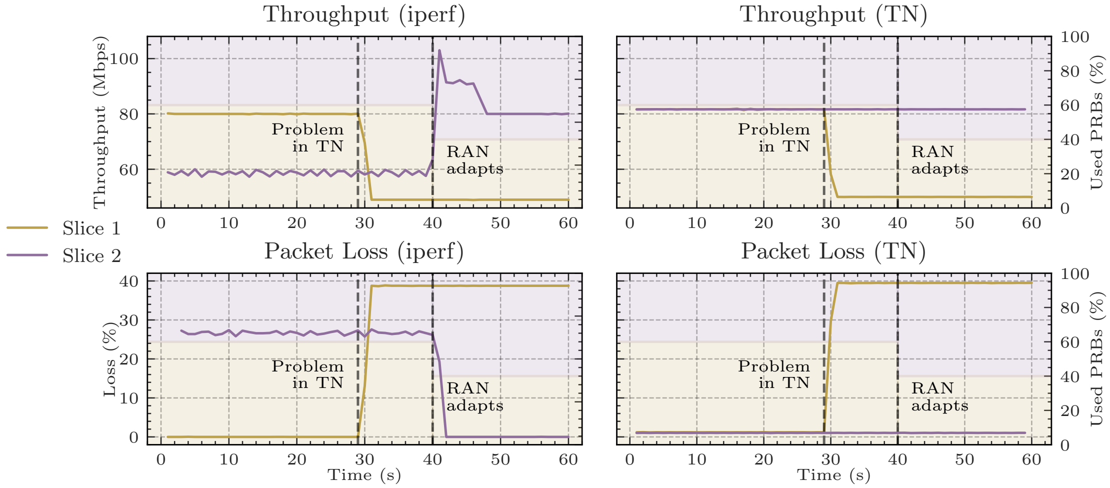

Fig. 5: Throughput and packet loss results at the application level (left) and at the TN level (right) for the TN-aware intelligent RAN scenario. Each plot marks the time at which the TN congestion problem was induced and the time at which the RIC reallocates PRBs. The background colors depict the distribution of PRBs between users across the experiment run.

a telemetry-consuming rAPP for the RIC that fetches the monitoring information from the TN; and 3) an xAPP that can dynamically (re)allocate PRBs for each slice in the network.

These components interact as follows. First, the TN telemetry producer, which can be deployed on a switch-by-switch basis, allows us to capture hop-by-hop performance metrics (link throughput and packet loss) throughout the TN. Our captured metrics are then saved in PostgreSQL databases deployed on the same machine as the User Plane Functions (UPFs), allowing them to be consumed by external entities. Then, the telemetry consumer rAPP in the RIC periodically collects these metrics, analyzes them, and uses them to create policies regarding the allocation of PRBs. More specifically, our rAPP currently contains a simple algorithm that decides to reallocate radio resources whenever packet loss in the TN exceeds a user-defined threshold. Finally, these policies are then executed by the PRB allocation xAPP, which is based on an existing FlexRIC xAPP that allocates PRBs at the slice level. This xAPP can dynamically reallocate PRBs between users, based on the policies created by the rAPP.

C. Scenario

Using this experimental setup, we deploy a scenario with two User Equipments (UEs), each using a different slice. UE 1 is assigned to a Ultra-Reliable and Low-Latency Communications (URLLC) slice called Slice 1, while UE 2 is assigned to an enhanced Mobile Broadband (eMBB) slice called Slice 2. Both UEs are connected to the same gNB, but their data planes run over two different TNs, each of which ends up in a different UPF. As shown in Fig. 4, UPF 1 serves UE 1 on Slice 1, while UPF 2 serves UE 2 on Slice 2. The UPFs are connected to the same 5G CN, providing the remaining NFs required to run a functional 5G SA network.

In this scenario, both UEs start with a fixed PRB allocation: 60 % of PRBs are allocated to UE 1, while the remaining 40 % are assigned to UE 2. This kind of fixed allocation is extremely useful in the context of network slicing, as resources can be dedicated to a specific slice to ensure Quality of Service (QoS) requirements. Then, we generate 80 Mbps of downlink traffic over User Datagram Protocol (UDP) for each UE using iperf, after which we emulate a congestion problem in the TN by rate-limiting the interface of UPF 1 connected to the TN. This causes the throughput of UE 1 to drop and the packet loss at the TN to increase. Based on this sudden increase in TN packet loss, the RIC should dynamically reallocate radio resources, since UE 1 cannot fully utilize its assigned PRBs anymore.

V. RESULTS & DISCUSSION

The results shown in Fig. 5 present the throughput and packet loss of each slice, from the application level (left) and from the TN (right). Two important events are marked on the graphs: the time at which the congestion problem occurred in the TN, and the time at which the RAN dynamically adapted the assigned PRBs because of that problem.

At the first mark, a bottleneck in the TN of Slice 1 causes the TN-level and application-level throughput of UE 1 to drop from 80 Mbps to 50 Mbps and the packet loss to increase to 40 %. As a result, the radio resources allocated to UE 1 are not being fully used, since the PRBs are allocated in a fixed way to each slice. As a result, the fixed amount of PRBs allocated to UE 1 cannot be fully used, resulting in inefficient use of radio resources. By the second mark, the RIC detects the sudden increase in packet loss using telemetry data from the TN and reallocates the PRBs, assigning more resources to UE 2. We observe a throughput peak over 100 Mbps caused by buffered packets in the RAN, after which the throughput settles back to the 80 Mbps generated by the application. At the same time, the application-level packet loss of UE 2 significantly decreases. It is important to note that the packet loss of UE 2 was high in the first place because we use UDP, which does not have any congestion control mechanisms. By dynamically reallocating PRBs across the UEs, the RIC optimizes spectrum usage based on telemetry data from the TN.

Our results empirically prove that the RAN can benefit from TN telemetry data. Similarly, a RAN-aware TN could make better management decisions by using information from the RAN. For example, the TN could predict congestion based on the number of connected UEs or the average throughput, provided by the RAN's Y1 interface [24]. This increased awareness can be exploited by the TN to improve network management, which is crucial in a network sharing context.

VI. CONCLUSION & FUTURE WORK

In this paper, we show the importance of cross-optimizing RAN and TN control to improve resource allocation in 5G. By defining and implementing the North-South Interface (NSI) and East-West Interface (EWI) proposed in the 5GECO project, we provide a way to exchange information between the RAN and TN while preserving the logical separation of each domain, and we demonstrate that a TN-aware RAN can allocate radio resources more effectively, improving spectrum usage and enabling cost-effective Neutral Hosting services.

In future work, a combined TN-aware RAN and RAN-aware TN approach should be investigated to improve resource usage in each domain. In addition, more advanced ML-based algorithms for the RIC and SDN controller that use external enrichment information can further enhance decision-making.

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