Enabling Quality-on-Demand and Service Differentiation on a Novel Network-as-a-Service Platform Using Slicing Technology for Control and Management of Optical Networks

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***Abstract*—This paper presents a comprehensive Network-as-a-Service (NaaS) platform designed to enhance the deployment and management of all-optical access and transport networks. We demonstrate our platform with a use-case of cloud-based AR/VR gaming service that requires high bandwidth and ultra-low latency, through the slicing of Passive Optical Network (PON) and optical transport network. Building on our previous work that detailed the overall architecture of our solution and the fine-grain Optical Transport Network (fgOTN) technology, this paper introduces the novel aspect of automated PON slicing, achieving a fully end-to-end solution. Leveraging ETSI F5G and ETSI ZSM standards and integrating with ETSI TeraFlowSDN and ETSI Open-Source MANO (OSM) for orchestration and management, our platform offers a seamless and immersive experience for latency-sensitive applications.**

***Index Terms*—CAMARA, F5G, ZSM, Network Automation.**

I. Introduction

In recent years, the demand for high-performance network services has surged, driven by applications that require high bandwidth, minimal latency, and low jitter. One prominent example is cloud-based augmented reality/virtual reality (AR/VR) gaming service, which demands robust and flexible network infrastructure to deliver seamless and immersive experiences. Traditional gaming infrastructures often involve local game consoles or computers, which, despite offering high performance, limit accessibility and flexibility. With the advent of cloud-based gaming services, game processing and rendering are offloaded to powerful remote servers, which stream the game content to users' devices in real-time. This paradigm shift allows users to access high-quality gaming experiences on a variety of devices without the need for high-end local hardware. Lower latency and higher bandwidth are crucial to offer a guaranteed Quality of Experience (QoE) for such demanding applications. To meet these requirements, Network-as-a-Service (NaaS) platforms have emerged as a viable solution, offering on-demand network services that can dynamically allocate resources based on user needs. Our novel NaaS platform presented in our previous work [1] is designed specifically for optical networks and uses the capabilities of the underlying Fixed-5G Advanced (F5G-A) [2] optical networks, providing high quality transmission with ultra-low end-to-end (E2E) latency, guaranteed bandwidth and minimized jitter to ensure the QoE for cloud-based services. This platform empowers network operators to offer premium services that can be activated by users when needed and therefore enabling the concept of Quality-on-Demand (QoD) and Bandwidth-on-Demand (BoD), ensuring optimal resource utilization and superior user experiences. In our previous work, we introduced the architecture of our NaaS solution and we focused on the slicing of the optical transport network only. However, the present paper shifts the focus towards the slicing of both the optical transport network and the Passive Optical Network (PON) access equipment and, thereby offering a comprehensive end-to-end solution. This paper details the architecture and implementation of our NaaS platform, with a particular emphasis on the slicing of the PON access network. We discuss how our platform enables dynamic and on-demand network service provisioning, enhancing the overall user experience and providing new opportunities for network operators

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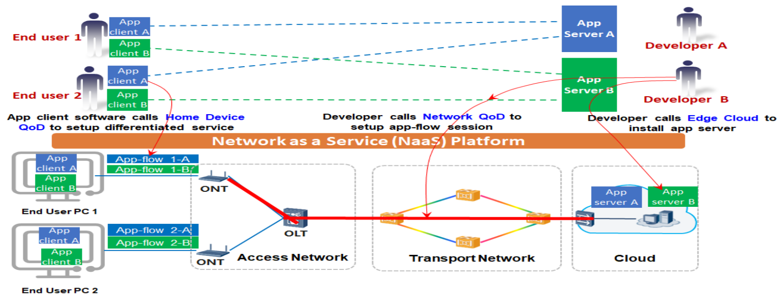

Fig. 1. Our demo use-case built on our NaaS platform

and service providers. To the best of our knowledge, the framework presented in this paper is the first of its kind open-source, model-driven and standards-based development effort in NaaS platforms. The remainder of the paper is organized as follows. Section II explains the details of this NaaS platform and the technologies we used. Section III is devoted to the transport network slicing part of this platform. The PON access network slicing is explained in section IV followed by an illustration of the access network data-plane described in section V. The demo setup is explained in section VI, and our conclusions are discussed in section VII.

II. Overview of our NaaS platform

A. NaaS Platform Architecture

The architecture of our NaaS platform operates on a hierarchical model, leveraging standardized data models and interfaces to ensure seamless integration and interoperability. Fig. [1] illustrates our demo use-case built on top of our NaaS platform, showcasing our end-to-end slicing technology for both access and transport network. The core components include: CAMARA APIs [3], ETSI OSM [4], ETSI TeraFlowSDN [5], ETSI ZSM [6], and ETSI F5G-A network architecture. The following sections briefly explains each component. By integrating these components, we have created a robust and flexible NaaS platform that meets the requirements of AR/VR gaming services, offering a scalable and efficient approach to network resource management and service delivery.

B. CAMARA

The GSMA's Open Gateway initiative uses APIs defined in the CAMARA open-source project to access telecom network capabilities. Our Network-as-a-Service (NaaS) platform employs two types of CAMARA APIs: Quality-on-Demand (QoD) and Edge-Cloud. QoD APIs let users customize traffic profiles for their home WiFi, while Edge-Cloud APIs allow application developers to manage and deploy applications on the operator's network. This enables on-demand virtual machines and gaming resources for game developers and over-the-top (OTT) applications.

C. ETSI ZSM, ETSI F5G, ETSI Open-Source MANO (OSM), ETSI TeraFlowSDN Controller

In this project, we collaborate with ETSI ZSM and F5G communities to enhance our design using their standards. The ZSM Framework's Management Domains (MDs) include the End-to-End (E2E) Service MD for service orchestration. Our NaaS platform integrates the ETSI Open-Source MANO (OSM) project as the E2E MD and the ETSI TeraFlowSDN (TFS) controller as the F5G Network MD. ETSI OSM configures cloud resources via OpenStack APIs and manages connectivity between user VR equipment and cloud gaming servers through the F5G-A network using the TFS controller [1].

III. fgOTN-Based Transport Network Slicing

The core of our solution is the capability to deliver end-to-end optical network slices (modeled using the IETF Network Slice Service Model [7]), realized through an end-to-end Layer 3 VPN (L3VPN) service (modeled using the IETF L3 Service Delivery Model or L3SM [8]). These slices are supported by the underlying Fine-Grain Optical Transport Network (fgOTN) technology that operates at a high granularity, allowing for more efficient and flexible allocation of optical network resources. A key feature of fgOTN is its ability to enable the concept of "Bandwidth-on-Demand" by allowing dynamic adjustment of the container size based on real-time bandwidth needs, enabling service providers to deliver more flexible and elastic services to their customers [9]. fgOTN achieves this by dividing the optical network into smaller, more manageable units, allowing for: A) Efficient Bandwidth Utilization: Dynamically allocates bandwidth based on real-time demands for optimal network capacity use. B) Enhanced Flexibility: Provides granular control and management of network resources to meet diverse user needs. C) Bandwidth-on-Demand: Adjusts container size in real-time to deliver flexible and elastic services to customers [10].

IV. PON Access Network Slicing

Passive Optical Networks (PONs) are widely used for providing high-speed internet access due to their efficiency and cost-effectiveness. However, traditional PON configurations are static and require manual intervention, limiting their ability to adapt to changing network demands. Automated slicing of PON access networks addresses these limitations by enabling: 1) Dynamic Resource Allocation: Resources can be allocated in real-time based on current network conditions and user demands. 2) Service Isolation: Ensuring that different services and tenants do not interfere with each other, maintaining high

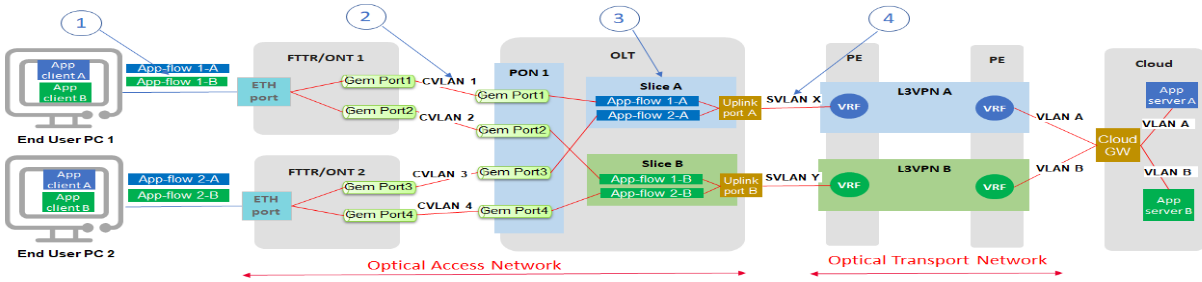

Fig. 2. Access network data-plane illustration

QoE. 3) Scalability: Supporting a larger number of users and applications without significant manual intervention. To achieve effective PON slicing, several technical components and processes are employed. We leverage novel features on access network equipment to support QoD service differentiation. To achieve this, the following three aspects are implemented in our solution. 1) Slice Creation and Management: A PON access network consist of an Optical Line Terminal (OLT) or a central office node, as well as one or more user nodes called Optical Network Terminals (ONTs) or Optical Network Units (ONUs). In our NaaS platform, we divide these ONTs and OLTs into multiple virtual slices. Each slice is treated as an independent virtual network, allowing for tailored resource allocation and management. We classify an application-flow traffic based on its QoS parameters and assign it to one slice. This capability needs to leverage novel features on the ONT. A slice is a dedicated resource partition which contains specific QoS constraints. It may contain multiple application-flows which belong to a same service class. OLT also needs to have the ability to choose the next hop (e.g., the PE router of the fgOTN network) based on the slice's QoS setting. 2) QoS Policies: Implementing Quality of Service (QoS) policies to ensure that each slice meets the specific performance requirements of its associated application. This includes setting priorities for latency, bandwidth, and jitter. 3) Real-Time Monitoring and Adjustment: Continuously monitoring network performance and making real-time adjustments to the slices to maintain optimal performance. This involves feedback loops and machine learning algorithms to predict and respond to network conditions.

V. Access Network Data-Plane Illustration

Fig. [2] illustrates how application-flow connections are configured on the data-plane of the access network. Note that the data-plane configuration of the transport network (i.e. configuring L3VPN instances) has already been discussed and implemented in our previous work. The following four steps are summarizing the details of our implementation: 1) an application-flow is first uniquely identified by 5-tuple: src IP, src port, dest IP, dest port, and protocol. 2) ONT tags each application-flow, based on its 5-tuple, with a unique C-VLAN tag. Separate (i.e., non-over-lapping) C-VLAN pools are allotted to the ONTs which belong to a same OLT. Thus, OLT distinguishes application-flows sent from ONTs by C-VLAN tags. 3) OLT assigns application-flows to particular slices based on their QoS settings. i.e., a slice on OLT is used for service differentiation. It may contain a collection of application-flows that belong to a same service class. 4) OLT binds an S-VLAN to a particular slice. i.e., application-flows which belong to the same slice are tagged with a same S-VLAN. S-VLANs can be used for service differentiation and isolation in L3VPN instances (e.g., virtual routing and forwarding or VRFs) in transport network.

VI. Demonstration Showcasing

The attending users will have the opportunity to see a live demonstration of the proposed solution. The presenting author connects to our testbed and showcase (a) the deployment of the gaming service, and (b) the request of the gaming application flow. Due to logistics and limitations, the real VR gaming application will not be showcased; instead, a mocked game enabling the user to request the app-flow will be used.

VII. Conclusion

This paper presents a significant enhancement to our previously proposed NaaS platform by introducing automated PON access network slicing. This new capability enables a fully end-to-end solution, offering improved flexibility, QoE, and scalability for high-bandwidth, low-latency applications such as cloud-based AR/VR gaming.

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