Design Considerations for an Energy-Aware SDN-based Architecture in 5G EPON Nodes

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ABSTRACT

In the evolution of telecommunication industry towards 5G, Ethernet Passive Optical Networks (EPON) technology, with some unique features such as high capacity, low latency, and minimum cost per bit, positions itself as an interesting option for backhauling solution in the Multi-access Edge Computing (MEC) scenarios. It is expected to see the converged optical-radio nodes play a crucial role in future networks. To maximize the benefits of the 5G EPON networks, besides all other challenges, it is essential to address two main issues, namely softwarization and energy efficiency. To this end, in this paper, initially we introduce a framework to have an open control layer based on SDN (Software-Defined Networks), able to prepare the EPON backhaul to deal with the 5G applications and services. Then we introduce a solution that minimizes the energy consumption of EPON networks without imposing additional packet delay.

Keywords: Software Defined Networking (SDN), Passive Optical Network (PON), Ethernet Passive Optical Network (EPON), OpenFlow protocol, 5G Network, Energy Saving.

1. INTRODUCTION

Mobile data traffic forecasts predict an enormous growth of traffic volume driven mainly by the increase in the number of connected devices and popularity of traffic hungry applications such as personalized media mobility in urban environments, augmented reality location based gaming and/or collaborative interactive transmedia narratives [1]. This calls for a fundamental change in network infrastructures to offer features such as extremely high data rates and capacities, on-demand service-oriented resource allocation and automation [2]. 5G technologies attempt to address these issues and are expected to overcome the challenges of next generation communication systems, featuring capabilities such as extraordinarily high speeds and capacity, multi-tenancy, on-demand service-oriented resource allocation, and coordinated automation. Heterogeneous technologies convergence is one of the main aspects of 5G where different technologies come together in an orchestrated way to realize 5G vision. A good example of this is the field of access networks.

The concept of 5G Multi-Radio Access Technology (RAT) introduces a new access network paradigm which combines several radio access technologies to deliver the service to users (e.g. UMTS, LTE, Wi-Fi). It will significantly enhance per-user throughput and overall system capacity. Nevertheless, demands for higher capacities and more scalability at the network access pose a serious challenge for future backhauling systems. Converged optical/wireless networks have emerged as a strong candidate to fulfill the stringent 5G requirements [3]. The proposed solutions are novel architectures consisting of radio access nodes together with an optical fiber backhauling system (for example, Ethernet Passive Optical Networks - EPON), controlled by a suitable network management logic able to support 5G use cases. Software Defined Networking (SDN) [4] is a key technology for managing the network, adopted with the aim of increasing flexibility and achieving cost/energy efficiency in the converged optical/radio networks. By orchestrating the network resources SDN improves the end user's Quality of Experience (QoE), enhancing energy efficiency and creating new business opportunities for service providers.

This paper presents a framework to have an open control layer based on SDN, able to prepare the EPON backhaul to deal with the 5G applications and services, together with a solution that minimizes the energy consumption of EPON networks without imposing additional packet delay. The paper is organized as follows: Section II describes the EPON network architecture, 5G Radio Access Network and the SDN/NFV concept. Section III defines the novel SDN-based 5G EPON architecture and solution for minimizing energy consumption in 5G EPON networks. Section IV concludes the paper.

2. BACKGROUND

2.1 EPON Architecture

Ethernet Passive Optical Network (EPON) [5] is one of the variant of Passive Optical Network (PON), which combines the high bandwidth of optical networks with the well-known Ethernet technology and frame format. The

EPON architecture defines a tree-like topology with 1) an Optical Line Terminal (OLT) located at the service provider that controls and manages the access to the shared medium, 2) a set of Optical Network Units (ONUs) located at the customer premises that dialogue with the OLT to request and be allocated transmission timeslots, and 3) a set of passive optical splitter/combiners connecting the OLT to the ONUs. The Medium Access Control (MAC) module running at the OLT allocates timeslots and arbitrates the access to the shared medium by following a Dynamic Bandwidth Algorithm (DBA).

2.2 SDN Architecture

Software Defined Networking (SDN) is a novel paradigm that opens the way for a more efficient operation and management of the networks, allowing centralization of control functions and mechanisms that are distributed in the current network architectures. It decouples the software-based control plane from the hardware-based data forwarding planes, thus introducing many advantages such as programmability, centralized network view and global optimization of the network operations. OpenFlow protocol [6] is a commonly used southbound interface for communication between the control plane and the data-forwarding plane. OpenFlow allows the SDN remote controller to specify the path of network packet through the network of switches. It allows the SDN controller to define a set of rules and actions to be executed on the matched packet.

2.3 SD-RAN

Software-defined Radio Access Networks (SD-RANs) [7] is a solution for RAN network, which allows decoupling the control and data-forwarding planes for achieving a flexible control. SD-RAN opens a lot of possibilities for the optimization of the resources such as network sharing, slicing, mobile edge computing capabilities, improved security, cloud abstraction and guaranteed content delivery, to name a few possibilities. 5G enables service provider to assign different slices to different tenants with the functionalities specific to the services in order to satisfy their business requirements, thus turning technology CAPEX into service OPEX.

3. SDN-BASED 5G EPON ARCHITECTURE

The aim of this paper is to describe a novel architecture based on the SDN and NFV concepts for the 5G EPON network, where multiple Radio Access Networks (RANs) are converged to EPON nodes at the network edge. Recently, an initiative to realize converged SDN-enabled wireless-optical networks has introduced schemes to implement ONU-eNB [8], while [9] demonstrates the need of a joint resource orchestration over a realistic 5G access use case. The proposed framework reduces the complexity and increases the efficiency of the network operations, while it is capable to decrease the energy consumption of the edge network.

Our solution is built based on [10] and [11], where the OLT functionalities are partially virtualized and migrated to the centralized controller to reduce the complexity of the network, while the rest of functionalities remain at the OLT to be integrated with the OpenFlow-enabled switch. The idea is to build the OLT around an OpenFlow-enabled switch and add 5G EPON functionalities. In this way, a single SDN controller will be able to manage both optical and radio resources in a holistic way. As illustrated in Figure 1, the elements of the SDN-based 5G EPON network architecture are 1) the SDN controller, 2) the OLT, 3) the ONUs, and 4) the RANs that are connected to the ONUs.

3.1 SDN Controller

The SDN controller is the "intelligent" element that manages one or several 5G EPON nodes in the network. It has a centralized view of the network, and can be run in a data-center of the access provider or located at the dedicated server in the network backbone. It communicates with the OLT in order to manage and configure the parameters of the MAC Control Client, MAC Client, Dynamic Bandwidth Allocation (DBA), Energy Management, 5G RAN and Quality of Service (QoS). In this architecture, those functions that can work at the long time-scales are migrated to the controller, while the functions that deal with the short time-scales remain at the OLT to keep the synchronous nature of their operation. The SDN controller modules are:

- The MAC Control Client Manager is responsible for configuring the initial parameters of the MAC control client such as Logical Link Identifier (LLID) for each ONU, and processing the GATE, REPORT and DISCOVERY GATE messages. In addition, it provides a database for the OpenFlow switch to keep information regarding the ONU MAC addresses.
- The MAC Client Manager is responsible for provisioning services, flow management, data forwarding services, bandwidth allocation policy, and ONU registration in the OLT.
- The DBA module is responsible for arbitrating the forwarding of data between the core network and the user. It manages the general policy of the network by changing the DBA parameters and policies, and transmission priority for each ONU.
- The Energy management module is responsible for managing the power consumption of optical network access, specifically the ONUs and their connected RANs.

- The 5G RAN Manager module is responsible for providing a database for the OpenFlow-enabled switch to keep information about admission control for connecting different RANs and frequency bands to the backhaul. In addition, it allows third parties to deploy their applications and services for the mobile users.
- The QoS module manages the different level of QoS on multi-tenant 5G networks. It defines different access and control privileges among multiple tenants. This can be done via the OpenFlow meter functionality, which monitors and measures the rate of packets assigned to each entry flow and applies QoS and DiffServ policies (ex. rate limiting). It also assists per-port queue to scheduling packet on the output port according to their priority.

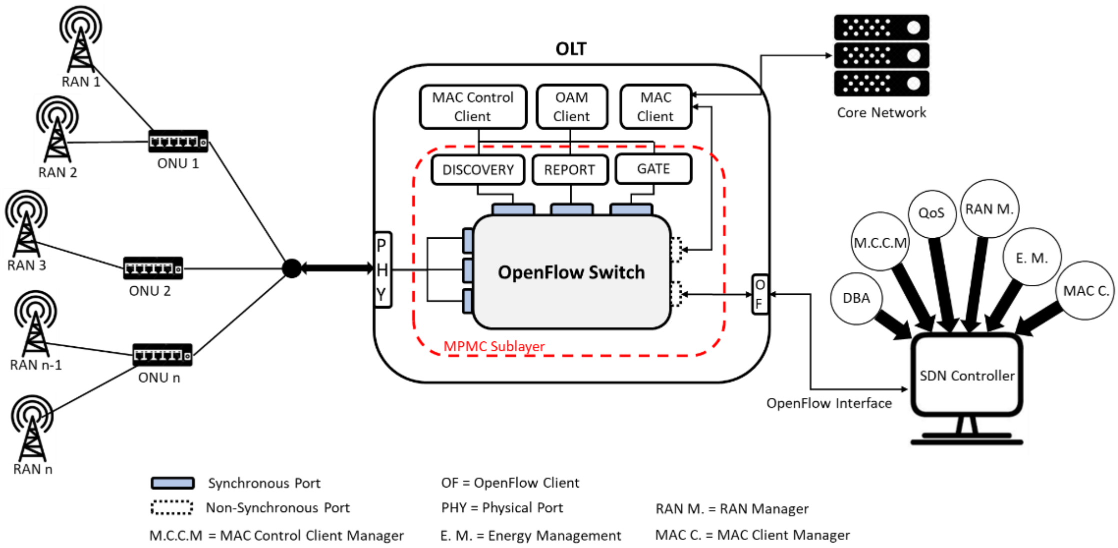

Figure 1. SDN-based 5G EPON Architecture.

3.2 OLT

The second element is the OLT, which concentrates the management functionalities of the 5G EPON network. The OLT is built around an OpenFlow switch and its tasks include the emulation of forwarding functions of the MultiPoint MAC Control (MPMC) sublayer and the internal operations of the legacy EPON architecture (such as Control Parser, Control Multiplexer and MultiPoint Transmission Control elements).

Due to the synchronous nature of the EPON, the OLT is added a set of synchronous logical ports in order to connect to the internal entities of the OLT (such as gate, report and discovery management) and manage the tight timing communication between OLT and ONUs. To this end, three registers are designed to keep the synchronization between the OpenFlow switch and the MPMC sublayer. The OpenFlow switch coordinates the forwarding of the packets to the downstream channel through the DBA agent via dialogue to the P (transmitPending), I (transmitInProgress) and E (transmitEnable) registers. The non-synchronous ports are setting to connect the OLT to 1) the SDN controller via the OpenFlow client (OF-client) and 2) to the core network via the MAC client. Our design simplifies the OLT architecture by setting the OpenFlow switch as a single coordinator for all the entities in the OLT in order to arbitrate the access to the downstream and upstream channel. It is executed via implementing a set of rules and flow entries in the flow table of the OpenFlow switch.

Power saving can be obtained by switching the transmitters and the receivers of the OLT, ONUs and RAN to a sleep state when there is no traffic load in the network. The SDN controller enables the service provider to modify the behavior of the DBA and use the GATE and REPORT messages to switch the state of the ONU between sleep, doze, and active mode. The decision can be taken with the information transported in the REPORT messages about the queue status of the ONU for the upstream channel, and the OLT queue information for the downstream channel [12]. The action of switching off the PON transmitters affects the traffic patterns by transmitting the data frames in bursts, thus introducing delays and jitter, and affecting the QoS. This is the reason for developing a global approach in which the SDN controller has both the control over the QoS and the energy saving, and can reach an appropriate trade-off.

3.3 ONUs

In this architecture ONUs are not modified with the SDN solution. ONUs are just involved in the power-saving mechanism, where every ONU calculates its own bandwidth request by monitoring the queue size and the amount of traffic received by the end user. This process is complete via exchange of REPORT and GATE messages between the ONUs and the OLT. Based on the information conveyed on the REPORT message, the OLT (with the coordination of the SDN controller) can decide whether to keep the ONU in active mode or switch it to the sleep mode, following an algorithm such as those described in [12].

3.4 5G RAN

5G RAN is the radio side of the 5G EPON network, which connects the user terminals to the core network via the ONU and OLT. As mentioned earlier, some functionalities of the RAN (such as support for various traffic types (e.g. IoT), QoS guarantees and latency optimization for the end users, to name a few possibilities) are migrated and performed in the SDN controller and managed via the OpenFlow switch. In addition, the proposed framework is capable to align the DBA power saving mechanism of the ONU with the RAN scheduler in order to perform the adequate power saving. For example, when traffic load is low and is not affected by latency guarantees (e.g. data from IoT sensors) and can thus be delayed and "packed" into bursts, it would be feasible to switch off the Remote Radio Units (RRUs) during the inactivity periods between bursts. This solution could minimize energy consumption across the wide range of the network, while maintaining the penalty introduced in terms of channel utilization and packet delay at a suitable level.

4. CONCLUSIONS

This paper describes a novel architecture design for SDN-based 5G EPON networks to minimize the complexity of the management and operation of the network, while improving dynamically the use of resources. We define an extension for the MultiPoint MAC Control sublayer in the OLT and splitting its functionalities between the SDN controller and the OLT. The management and control part of the OLT and RAN are migrated to the SDN controller, while other functional blocks remain in the OLT to be integrated with the OpenFlow switch. Those functions that work at the longer time-scales migrated to the SDN controller, while the functions related to the short time-scales keeps in the OLT and the RAN.

This framework allows integrating the EPON and RAN power saving techniques. In addition, it enables network provider to minimize the expenses associated with capital expenditure by deploying new services over different slice for several tenants. We are currently working on the evaluation of the proposed architecture via simulation and emulation with the OPNET simulator [13] and OpenDayLight controller [14].

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