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Experimenting the Integration of Green Optical Access and Metro Networks Based on SDN

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ABSTRACT

This paper outlines the issues in providing a seamless integration between energy-efficient optical access networks and metro networks that preserves the overall latency balance. A solution based on SDN is proposed and detailed. The proposed solution allows to trade the increased delay in the access section, due the utilization of energy efficient schemes, with a reduced delay in the metro section. Experiments in a geographically distributed testbed evaluate the different delay contributions.

Keywords

energy efficiency, TWDM, PON, SDN, metro.

1. INTRODUCTION

Software defined networking (SDN), originally proposed for Metro Ethernet networks, has emerged as a strong candidate to improve the control of telecommunication networks also in the context of passive optical networks (PONs) [1]. For example, in [2], an SDN-based PON testbed is presented to provide OpenFlow-based service-aware flow scheduling. In [3] the extension of SDN and OpenFlow principles to optical access/aggregation networks for dynamic flex-grid wavelength circuit creation is proposed.

However, so far, SDN has been mainly applied to replace existing technologies and control solutions in specific network segments, without addressing the need to provide a common converged architecture to control metro/access aggregation nodes including heterogeneous technologies, e.g. PON and metro Ethernet.

This paper presents the evaluation of the approach proposed in [4] for the integration of energy-efficient Time and Wavelength Division Multiplexed (TWDM) PON and Ethernet-based metro networks based on SDN. The solution relies on a lightweight network controller solution scaled to operate within a single node, where node cards are operated and monitored as being network nodes in a network.

The proposed solution is demonstrated in a geographically distributed testbed to show its viability in a real network scenario. Experiments show that the contribution to the average frame delay of the reconfiguration time of the aggregation switch at the border between access and metro networks is negligible even when dynamic access network reconfiguration is triggered frequently.

2. INTEGRATED ACCESS-METRO NETWORK ARCHITECTURE IN A GEOGRAPHICALLY DISTRIBUTED TESTBED

Figure 1 depicts the aggregation node architecture proposed in [4]. The Optical Line Termination (OLT) of the Time and Wavelength Division Multiplexing (TWDM) PON is equipped with two Optical Subscriber Units (OSUs), each one transmitting at a different fixed wavelength. Toward the metro network, each OSU is connected to an interface of an Ethernet OpenFlow (OF) switch, included within the aggregation node, that is, in turn, connected to the metro network. The ONUs are assumed to be equipped with tunable transmitters so that they can flexibly transmit/receive traffic to any OSU. The OpenFlow switch is controlled by the aggregation node controller, implemented as a light version of an SDN controller (i.e., Light SDN Controller). The aggregation node controller is in charge of i) configuring the main flow-entries in the OpenFlow switch to forward the flows to the proper OSU, considering both operations of the OLT (normal or sleep-mode); ii) monitoring the status of the aggregation node ports (including the internal ports between OSUs and the OpenFlow switch); iii) installing or modifying the connections through the metro network (e.g., by configuring a proper label stack in the case of metro networks employing Segment Routing). The TWDM-PON features a Dynamic Wavelength and Bandwidth Allocation (DWBA) scheme, which consists of two different phases (i.e., TWDM and TDM) as reported in [6]. In the TWDM phase, each ONU is assigned to a different OSU (e.g., ONU2 is assigned to OSU2 while ONU1 is assigned to OSU1). If reconfiguration is triggered, the TDM phase is entered. The OLT sends a tuning GATE to notify ONU2 that must tune to communicate with a different OSUs (i.e., OSU1). At the same time, the OLT sends a reconfiguration request to the Light SDN Controller.

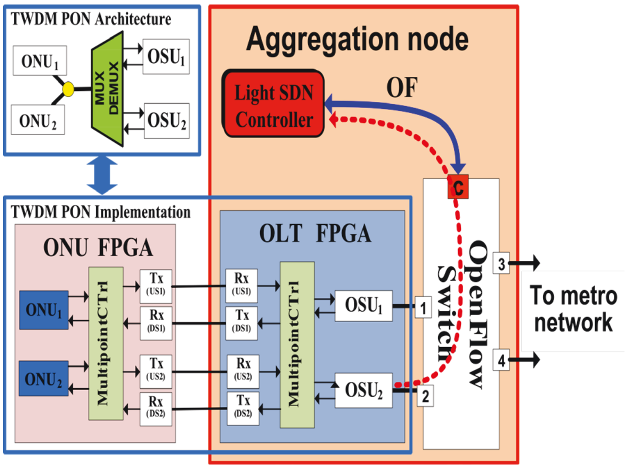
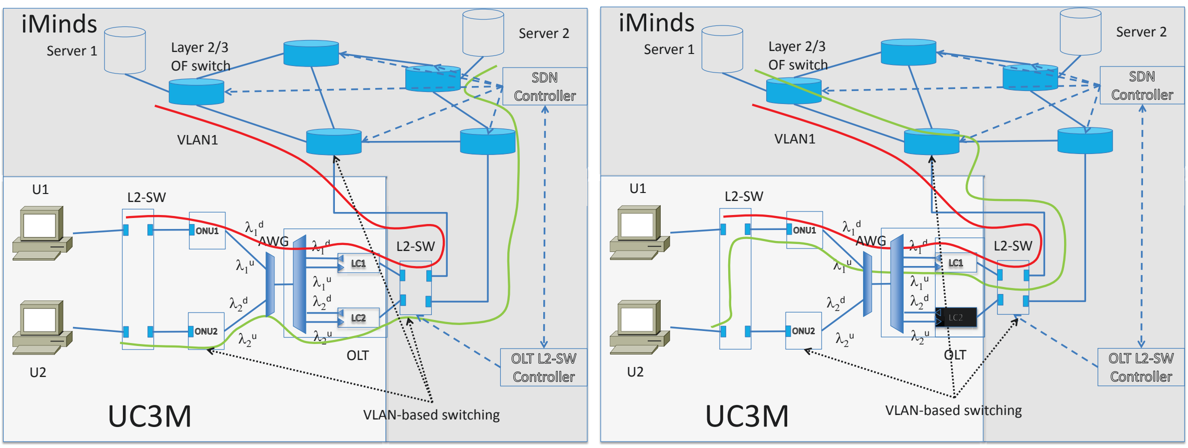


Figure 1. Proposed Access-metro integration based on SDN.

The request triggers the reconfiguration of the OpenFlow switch scheduling priorities and traffic balancing toward the metro network. The communication between the OLT and the Light SDN Controller can be performed either out-of-band or in-band, as in this study. That is, when a change in the status of the OSU occurs (e.g., an OSU is switched OFF) a control frame is sent by the OSU to the Light SDN Controller to notify it. During the tuning process (i.e., for a time, namely the tuning time, required to tune both the ONU transmitter and receiver to a different wavelength), both Downstream (DS) and Upstream (US) traffic are buffered, and the OSU2 enters sleep mode. Contemporarily, OpenFlow-based intra-node reconfiguration is performed within the OpenFlow switch. Once the reconfiguration process successfully completes, the immediate timeslot is assigned to the tuned ONUs (i.e., ONU2). After ONU2 timeslot expires, the immediate timeslot is assigned to ONU1. Hence, both ONUs share the single wavelength in TDM fashion until next reconfiguration is triggered.

3. IMPLEMENTATION OF THE INTEGRATED ACCESS-METRO NETWORK ARCHITECTURE IN A GEOGRAPHICALLY DISTRIBUTED TESTBED

In this study the architecture depicted in Fig. 1 is implemented in a distributed testbed provided by the Fed4Fire project [5]. Figure 2 depicts the distributed testbed implementation of the proposed approach. A WDM PON testbed located at UC3M and an Open Flow Ofelia island at iMinds are utilized. The WDM PON replaces, in this case, the TWDM PON. The experiment consists of implementing dynamic reconfiguration in the WDM PON testbed and dynamic VLAN reconfiguration in the iMinds Ofelia island and the coordination between these actions. Two end-to-end VLANs are set up between two servers connected to Layer 2/3 OF switches in the iMinds Ofelia island and two end-users (i.e., U1 and U2) connected to different interfaces of a L2-SW connected to two ONUs in the UC3M WDM PON testbed. The L2-SW connected to the ONUs is utilized for emulating the possibility, for the end-users, to receive data from VLANs arriving at each of the ONUs. This scenario emulates, for example, a scenario in which the ONU is connected to a small cell antenna and the end users can receive data from both the antennas.



(a) (b)

Figure 2. Distributed implementation of the proposed approach before (a) and after (b) reconfiguration.

If the traffic between the servers and end-users is low, one OLT Line Card (LC) is switched OFF, as depicted with a black rectangle in Fig. 2b, for energy efficiency purposes. Thus one VLAN in the UC3M WDM PON testbed undergoes reconfiguration. In particular the L2-SW connected to the OLT is reconfigured to forward both VLANs to the single LC that is still ON. In addition, the L2-SW connected to the ONUs is reconfigured to emulate, for example, the roaming of U2 to the antenna connected to ONU1.

Simultaneously, OpenFlow-based network reconfiguration is triggered in the iMinds testbed, upon WDM PON reconfiguration. The metro network reconfiguration can be triggered to set up a shorter path to compensate for the increased delay in the optical access network because an LC has entered sleep mode. Alternatively, a decrease in traffic in the access network might allow a resource (i.e., network capacity and server capacity) optimization in the metro-aggregation networks. For this purpose the controller of the L2-SW in the access network communicates with the SDN resource controller of the metro-aggregation network to synchronize reconfiguration upon traffic changes. For example, both the VLAN are connected to the same server.

4. EXPERIMENTAL SETUP AND EVALUATION

As an initial experiment, this paper mainly focuses on verifying the impact of the OpenFlow switch reconfiguration time on the average frame delay. Figure 3 shows a screenshot of the jFed Experimental Toolkit, provided by iMinds which is used to access the testbed. It shows the considered scenario in which four hosts are connected to the OF switch (i.e., Open Virtual Switch, OVS). All the four hosts and the OVS are co-located in the iMinds Ofelia island. As shown in Fig. 2a and Fig. 2b, downstream (DS) data are transmitted from Server 1 and Server 2 to OLT Line Card 1 (LC1) and LC2, respectively. In the performed experiment, as depicted in Fig. 3, host3 and host4 emulate Server 1 and Server 2 while host1 and host2 emulate LC1 and LC2. Figure 4a shows the switching matrix configuration of the OVS (i.e., host3 is connected to host1 and host4 is connected to host2) when both the OLT LCs are ON. Figure 4(b) shows the OVS switching matrix when only one OLT LC is ON (i.e., host3 and host4 both transmit/receive data to/from host1). The OVS reconfiguration is periodically triggered by the controller (i.e., ictonctrl Fig. 3) based on the reconfiguration period T_{rec}, as shown in Fig. 4. This behaviour emulates the LC turn OFF when there is low network traffic as depicted in Fig. 2b. TCP traffic is generated through *thrulay* traffic generator [7] at both host3 and host4 with different traffic loads. The maximum transmission unit (MTU) and link capacity are set to 1500B and 1Gb/s, respectively. The considered performance parameters are the average frame delay and the OVS reconfiguration time. The average frame delay (i.e., Round Trip Time --- RTT) is defined as the interval between the start of frame transmission to the start of reception of the frame acknowledgment, averaged out of all the successfully transmitted frames. The OVS reconfiguration time is defined as the interval between the instant at which OFP_FLOW_MOD message is received by the OVS to the instant at which flow entries are successfully configured in the OVS flow table.

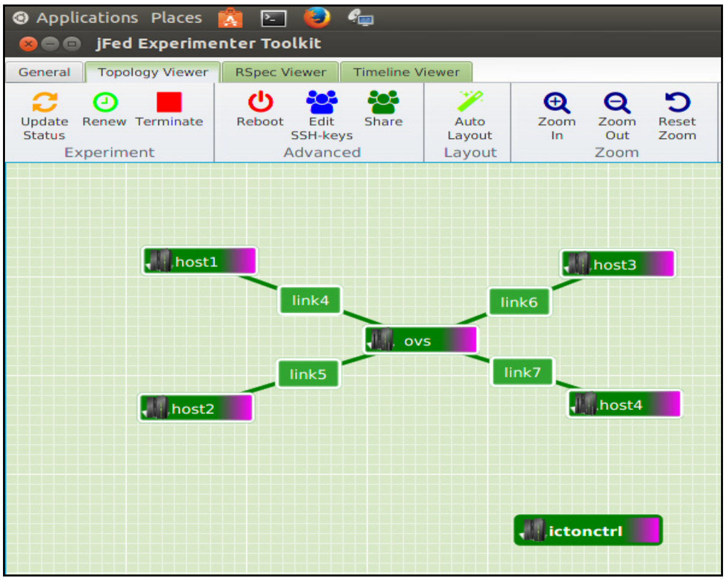


Figure 3. Experimental setup in jFed Experimenter Toolkit.

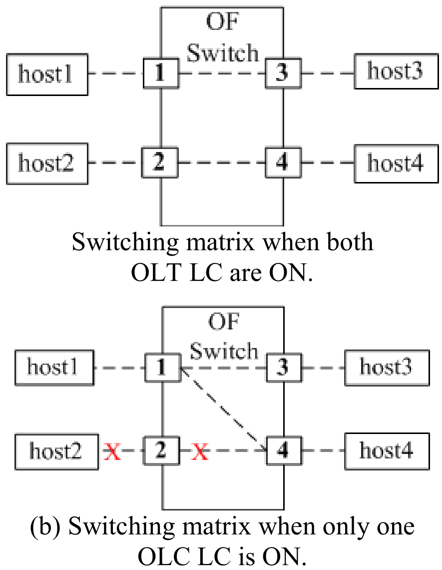


Figure 4. Experimental setup configuration.

5. RESULTS

Figure 5 shows average frame delay as a function of reconfiguration period T_{rec} and of the average TCP throughput $\mathrm{TH}_{\mathrm{avg}}$. When there is no reconfiguration (i.e., $T_{re} = 0$), both host3 and host4 use simple TWDM approach (shown in Fig. 2a), thus average frame delay is low. Note that tuning time T_{t} is set to 0 to observe only the impact of OVS reconfiguration time. As shown in Fig. 5, at a specific average TCP throughput, the average frame delay is almost constant as function of reconfiguration period. This phenomenon is caused by the fact that the OVS reconfiguration time is almost negligible. However, if the optical access network is switching between the TWDM and TDM phases, the behavior is expected to be different as shown by [8][9]. Moreover, as expected, the average frame delay increases with increasing the average TCP throughput. Figure 6 shows the samples probability mass function of the OVS reconfiguration time during a single the experiment with duration of 3600 s. In particular, around 50% of OVS reconfigurations take around 60 µs. Thus, it is experimentally proven that the impact of OVS reconfiguration time on the average frame delay is negligible.

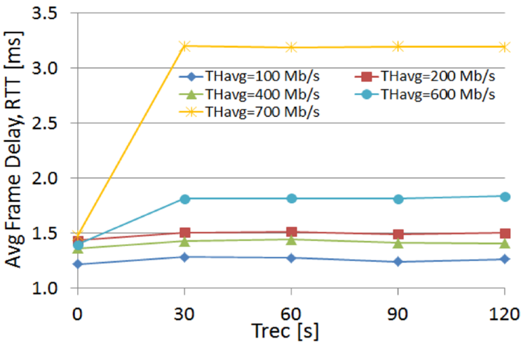


Figure 5. Average frame delay as a function of the reconfiguration period T_{rec}.

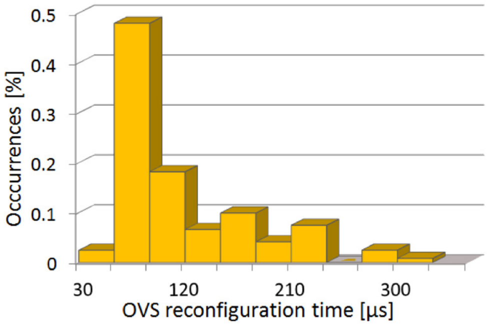


Figure 6. OVS reconfiguration time pmf.

6. CONCLUSIONS

This paper described the implementation of a solution based on SDN to integrate optical access networks and metro networks in a geographically distributed testbed. The initial results showed that the impact of the reconfiguration time of the OVS, which interconnects the optical access network with the metro network, on the average frame delay is negligible.

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