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Abstract
We experimentally transport the 5G backhaul interface over an OVS-DPDK based OLT in a generic server. Our SDN solution provides the flexible residential and 5G-mobile converged PON for different scenarios such as 5G self-healing in optical access network by means of dynamic SLA coordination.

Introduction and Proposition

In access networks, optical fibers are deployed massively to reach all types of end customers. On one hand, with more than 500 million Fiber To The Home (FTTH) customers in the world[1], Passive Optical Network (PON) technology is a mature technology mainly deployed with a Point-to-Multi-Point (PtMP) architecture which starts from Optical Line Terminal (OLT) in the Central Office (CO) and ends at Optical Network Units (ONUs) at or very close to the customers premises. Different marketing offers are provided to meet customers' need including bitrate, availability and are translated into Service Level Agreements (SLAs). PtMP topology of PON is enabled by Time Division Multiple Access (TDMA). The ONUs emit traffic for a short (typ. µs) and scheduled timing, orchestrated by the OLT. Five classes of services corresponding to different Transmission Containers (T-CONT) characteristics are defined for uplink streams[2]. The Dynamic Bandwidth Allocation (DBA) maps the bandwidth distribution according to the T-CONT priority.

On the other hand, the macro antenna sites are traditionally connected by optical fibers with a Point-to-Point (PtP) topology. With massive antenna deployments and the more than 99.999 % availability requirements of some 5G services[3], a protection solution, such as a second optical link should be taken into consideration for new antenna sites. A natural answer for the operators is to reuse the widely deployed FTTH infrastructure based on PON technology. As shown in Fig. 1a), Orange's (a principle operator in France) deployment in Rennes, the density of FTTH access points (red marks) is larger than the antenna sites around one CO. Moreover, there are always links available on Optical Distribution Networks (ODNs) to connect antenna sites since FTTH deployment is over-provisioned to facilitate operational management. Besides, two main challenges arise when one ODN serves both FTTH customers and antenna sites. Firstly, the complexity of sharing the PON infrastructure and the management tool for two separated operators (one for mobile, the other one for residential services) and this consequently needs an appropriated and dynamic multi-tenancy strategy[4]. Secondly, optimized DBA strategies has to be applied for critical-time mobile services[5][6].

Virtualization technologies can provide very interesting tools to address these challenges through an optimized fixed-mobile convergence strategy empowered by Software Defined Networking (SDN) and Network Function Virtualisation (NFV). SDN separates the data plane from the control plane and couples with the standard YANG data model[7] in the SDN controller to coordinate the configuration of all network equipment. Many organizations made efforts to introduce SDN in access networks such as the Open Networking Foundation (ONF) and the Broadband Forum (BBF)[8][9] and this encourages equipment manufactures to develop their access equipment with SDN-compatible functionalities[10].

Furthermore, research teams all around the world are turning their attention to benefit NFV in access[11][12] like accommodating all OLT functionalities into a generic server to perform vOLT. As a result, configuring the vOLT becomes much easier and the DBA functionalities can be taken to a brand new level. For instance, flexible DBA sharing engineering policies could be achieved, as reported in[5][6]. Uplink latency could be reduced as well by predicting the bandwidth and

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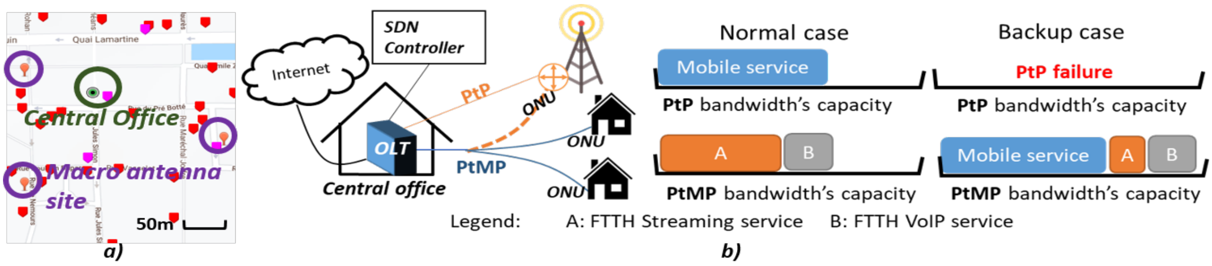

Fig. 1: a)Antenna site and FTTH distribution b)5G self-healing approach with converged mobile and residential architecture

eliminating status reporting from the ONUs[13][4].

In this paper, we focus on the first challenge, namely 5G self-healing scenario that allows for lower service interruption times for mobile services, with regards to SDN control in a convergent fixed-mobile deployment. Related work[14][15] have proposed variety of PON protection and SDN-enabled PON reconfiguration schemes including long-reach passive optical networks (LR-PON) and dynamic wavelength allocation (DWA). However, a redeployment of PON optical fibers closer to core network, or a deployment for the second PtP protection link is way too expensive because the cost of FTTH resides in the deployment of the fiber, and thus will not be the first choice for telecommunication operators. Hence, we propose to re-use the existing PON infrastructure to enable mobile site protection. Moreover, we adapt automatically and on-the-fly the DBA profiles, generally statically programmed, in order to improve the performances.

Our previous work[16] demonstrated the feasibility to send a mid-haul PDCP-RLC[17] mobile functional split traffic between a macro antenna site connected with a PtP link and a small-cell connected with a PtMP link. Here, we experimentally demonstrate a 5G self-healing application following with a dynamic PtMP bandwidth allocation reconfiguration according to prioritization policy when both mobile and fixed clients attached to the PON infrastructure. Fig. 1b) shows an SDN controlled OLT with NFV capabilities serves both mobile and residential clients over PtP and PtMP topologies. The antenna site is connected with both PtP and PtMP links coming from the same CO. When the SDN controller detects a PtP failure, it triggers the reconfiguration of the OLT to redirect the mobile traffic to the PtMP protection link and ensures the continuity of all the services even if its performances are lower than normal. Meanwhile, residential customers could have a minimum assured quality of their services, but it's already the case today to adapt the streaming quality according to instantaneous bandwidth. In case of PtP overloading, the lower priority services could reroute to the PtMP link as well.

Experimental Setup

As shown in Fig. 2, our experimental setup consists of three parts: the generic server in the CO employed as OLT, the SDN controller to control the OLT, and finally the traffic generators and analyzers. The mobile traffic has two sources. The first is a 5G backhaul traffic between a 5G New Radio core[18] and an emulated Radio Access Network (RAN) and User Equipment (UE)[19]. The second is generated by a traffic generator and is received by an analyzer in order to have a precise latency analysis. The generator emulates two residential traffic flows representing streaming and VoIP services as well.

A generic x86 Linux server accommodates a modular, pluggable SFP+/OLT[20]. The latter directly embeds OLT functions, allowing for an alternate solution to custom, dedicated hardware PON system based on conventional OLT chassis. Open Virtual Switch (OVS) with Data Plane Development Kit (DPDK) is integrated in the server to allow switching capabilities at high bit-rate and low latency for the generic server based OLT. Our SDN controller has a real time control of the

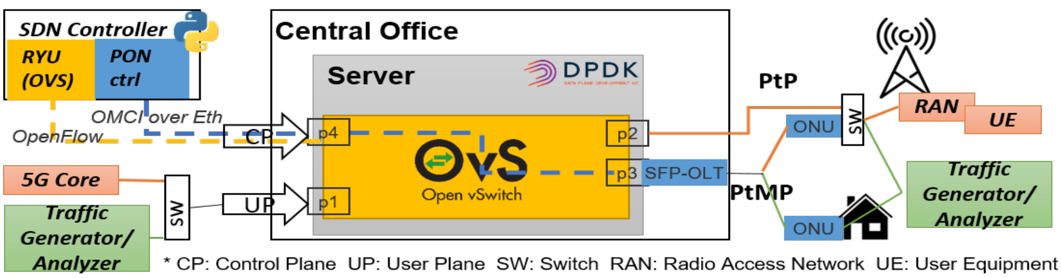

Fig. 2: Experimental setup

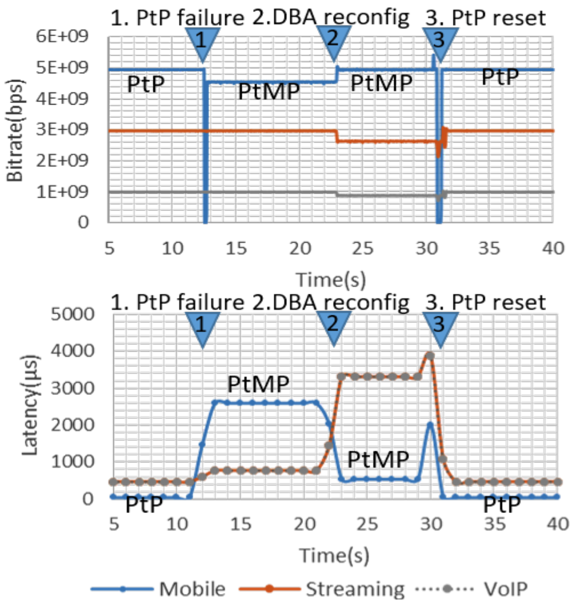

Fig. 3: Bitrate (top) and latency (bottom) measurement for mobile and fixed traffic in time

bridges in OvS and the T-CONT parameters of the PON. Two protocols are used as control plan messages between the controller and the access equipment. The first one is OpenFlow protocol[21] and is used for OVS management. Based on RYU[22], our controller detects the main mobile link failure, the throughput of each flow in real time and re-configures flows' priority and bandwidth via OpenFlow protocol. The second one is ONU Management and Control Interface (OMCI) over Ethernet and is used for PON management. Based on the Tibit-API[23], we developed our functions to dynamically configure DBA parameters of each ONU termination. The abstraction layer with a YANG model and RESTCONF interface for the overall system exists since our last work[24].

Results and Discussion

As mentioned previously, our scenario has two key procedures: the self-healing mechanism for 5G mobile services and the reconfiguration of DBA input parameters (fixed rate, guaranteed rate, best effort rate) to prioritize the mobile traffic SLA during the emergency backup period.

A 5Gbps flow was generated to emulate the mobile traffic, and 4Gbps flow were for residential traffic that includes 3Gbps streaming and 1Gbps VoIP for both up and downlink from the generator to construct the proposed scenario. We analyse in Fig. 3 the bitrate and latency evolution over time for each traffic flow since DBA could play a major role on latency performances. Furthermore, the mobile traffic's self-recovery time was evaluated according to bitrate variations on Fig. 3. At the beginning, the mobile traffic goes through PtP link and only the residential traffic uses the PtMP PON. At the first arrow on Fig. 3 (12 seconds) we cut down the PtP fiber. It triggers the self-recovery procedure to reroute the mobile traffic to the PtMP PON. Because of the Forward Error Correction, the maximum upstream bitrate of PON is limited to 8.4Gbps and a congestion occurs when the 5Gbps mobile traffic comes in. That's why the reader can notice a 4.5Gbps rate and a 2.5ms latency for the mobile traffic from 13 seconds to 23 seconds on Fig. 3. The reconfiguration of the DBA parameters is performed at the time tag corresponding to 23 seconds (arrow 2 in Fig. 3), from which a 5.1Gbps guaranteed rate is allocated to the mobile traffic. We can see that mobile traffic's rate is increases back to 5Gbps, and its uplink latency is dramatically reduced to about 500µs. Besides, the typical uplink latency of our SFP+/OLT is about 400µs. At the third time tag, corresponding to 31 seconds (arrow 3 in Fig. 3), we reestablish the PtP fiber connectivity and the mobile traffic is rerouted back automatically to PtP link in less than 200ms. Meanwhile, since the PON bandwidth is released, a reconfiguration of DBA parameter is done and both streaming and VoIP services go back to their initial status in terms of bit rate and latency.

Additionally, when the total PON uplink bandwidth is not saturated, 319µs stream latency is observed for all traffic in PON with T-CONT parameter as following: fixed rate 0kbps, guaranteed rate 128kbps and best effort rate 10Gbps. Besides, Fig. 3 gives an idea of 5G availability aspect since a really short self-recovery time based on automated control plane on SDN controller is made possible.

Conclusion

We experimentally demonstrated a 5G mobile and residential convergence scenario that allows FTTH infrastructure re-utilization to increase the availability of mobile networks antenna sites. We also demonstrated an unavailability of less than 200ms, the time for the traffic to be rerouted to the protection link by the SDN controller and intelligent link management algorithm. Our setup also reconfigures on-the-fly the DBA profiles of the PON, prioritizing the mobile traffic flow, but guaranteeing a minimum service for the residential flows.

Acknowledgements

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