An End-to-End Real-Time Connectivity Testbed Exploiting Standardized Dynamic Data-Plane PON Technologies

E. Kosmatos(1), C. Matrakidis(1), D. Uzunidis(1), P. Kostopoulos(2), A. Stavdas(2), A. Lord(3)

(1) OpenLightComm Ltd, United Kingdom; vkosmatos@openlightcomm.uk
(2) Dpt of Informatics and Telecoms, University of Peloponnese, Tripolis, 22100, Greece
(3) Applied Research, BT, Polaris House, Adastral Park, Ipswich, IP5 3RE, United Kingdom

Abstract *To avoid the cost of overprovisioning in dedicated connectivity schemes, we developed a real-time reconfigurable connectivity platform spanning Metro and Access by utilising the dynamic data-plane of commercial PON technologies and a novel SDN control-plane. We demonstrated end-to-end orchestration of < 10 seconds in all cases.*

Introduction

With the advent of 5G, connectivity needs are growing relentlessly. So far, the primary goal of 5G is to provide ‘local’ (wireless) connectivity. However, to satisfy the performance objectives set by Industry 4.0, connectivity between end-user terminals and/or processing/storage devices (centralized or distributed) has to be provided over a much wider geographic scale. These extended Metro and Access network segments have become the new research arena for richer connectivity and lower cost solutions.

As of today, the predominant connectivity paradigm is one of “overprovisioning” where connectivity resources are dedicated to point-to-point (P2P) links regardless of their utilisation. This approach, indeed, solves connectivity challenges but with a cost that escalates rapidly with the number of connecting nodes. Alternative paradigms exploiting optical burst/packet switching have not flourished yet, as no standardised data-plane technology has made it to market for these technologies.

We recently reported: a) a real-time connectivity platform for Metro[1] exploiting an SDN-enabled XGS-PON/GPON data-plane featuring point-to-multipoint (P2MP) connectivity with service restoration of a few seconds; b) the abstraction methodology for a bare-metal GPON access system[2]. Through ‘virtualisation’, this system supported multi-tenancy while allowing bandwidth provisioning in real-time.

In this work, we integrate and extend these two systems and we report - for the first time to our knowledge - the implementation of an SDN-enabled control-plane that orchestrates in real-time an end-to-end connectivity platform across Metro and Access. This experimental solution exploits standardised data-plane technology.

A real-time end-to-end connectivity testbed

The Metro and Access testbed is schematically illustrated in fig.1. In[1] a Nokia ISAM 7330 GPON system was employed as a real-time connectivity Metro platform. However, as the capacity requirements in Metro have already exceeded the capability of this system, here a state-of-the-art Nokia ISAM 7360 XGS-PON is employed instead. This is an intermediate step for Metro as in the long term, TDM line-rates will scale to 50G[3] and beyond while TWDM will provide the necessary scalability (fig.1). Hence, the end-to-end testbed consists of: a) XGS-PONs serving as a Metro connectivity platform; b) GPONs to inteconnect end-user terminals; c) an Edge node that is emulated by a L2-switch. The Edge node may also include IT resources as in[4] while a larger number of L2 switches can be hosted in the node following the CORD[5] architecture or a next-generation CORD scheme[6] when optical multi-band technology matures. Moreover, the Edge node is either collocated with a Metro node or it is placed closer to the end-user[3] (as in fig.1).

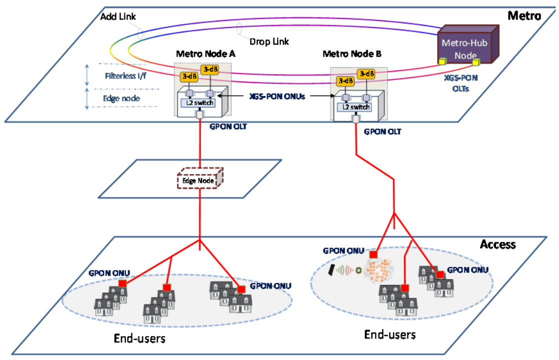

Fig. 1: Overview of the end-to-end platform

The Metro network in fig.1 exploits a filterless dual-bus configuration[7],[1] where two different fibre segments are used to implement the P2MP ‘add’ and ‘drop’ sections, respectively. Strictly speaking, a dual bus set-up is not necessary with an XGS-PON, the two symmetric traffic flows are transported in different optical bands; a single bidirectional bus will suffice in this case. However, as a real-time connectivity platform may co-exist with (C-band only) dedicated P2P resources (with overprovisioning), the dual bus architecture was selected (further details in[7]).

The connectivity interfaces of the Edge node are shown in fig.2: the northbound physical interfaces (towards Metro) are the XGS-PON ONUs while the southbound physical interfaces (towards Access) are GPON's OLT. The end-user terminals are interfaced to GPON's ONUs.

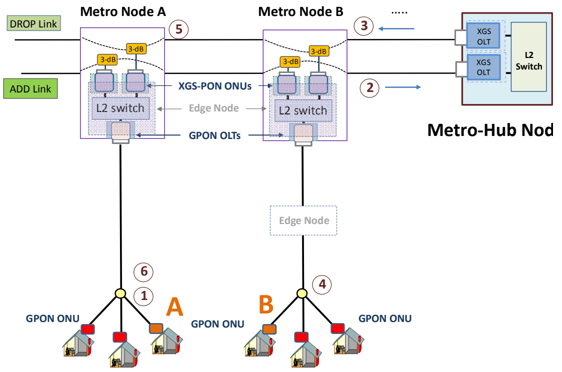

Fig. 2: Configuration details of the end-to-end testbed

To set up an end-to-end path between two remote end-user terminals A and B in fig.2, a traffic flow emanates from the GPON ONU "A" towards GPON's OLT at Metro Node A via path (1). Then, the L2 switch forwards the flow to the (left in fig.2) XGS-PON's ONU. The Metro Nodes A and B, TDMA-share the "add" link capacity through the filterless architecture based on 3dB couplers (fig.2). The flow on path (2) is terminated to the (bottom in fig.2) XGS-PON OLT. The L2 switch in the Metro-Hub node forwards the flow to the other (upper in fig.2) XGS-PON's OLT. Again, Metro Nodes A and B, TDMA-share the "drop" link capacity. Then, the flow following the symmetric paths (3) and (4) is terminated to the GPON ONU of the end-user B. To establish a connection from B to A, the flow via (4) and (2) reaches Metro Node A via the (5) in the drop segment and then via path (6) terminates to GPON ONU of the end-user A. The Metro network architecture is as in[1].

To orchestrate an end-to-end service set-up/release in real-time between two remote end-user terminals (like A and B in fig.2), an SDN-enabled control plane is necessary to seamlessly forward flows between the Metro (XGS-PON) and Access (GPON) segments via the corresponding Edge Nodes. In this particular implementation, no dedicated L2 switch was used at the Edge Nodes as the Nokia ISAMs offer Ethernet switching functionality .

An SDN-enabled control-plane for the testbed

The control plane architecture exploits the SDN approach and it has been developed based on the standardized Netconf and OpenFlow (OF) protocols to ensure interoperability. A set of agents is responsible for configuring the network elements of the infrastructure as instructed by a set of controllers (fig.3). For this purpose, there is a GPON and an XGS-PON agent (forming the agent layer), responsible for configuring the corresponding infrastructures in fig. 2, through the corresponding CLI interfaces.

The agents are managed by the Management Agent Software Framework (MASF) based on the ConfD[8] platform. The MASF in the northbound interface exposes the abstracted XGS-PON and GPON schemes to the controllers and acts as a Netconf Server enabling the configuration of XGS-PONs and GPONs using the Netconf protocol. The MASF exploits the abstraction scheme described in[1],[2],[4] where the the OLTs and ONUs are represented as legacy OF/Netconf L2 switches. In detail, the abstractions was realised using the legacy-switch YANG model to which the BroadBand Forum's GPON QoS queue models[9] were incorporated. This allows us to capitalize on both standard OF/Netconf protocols without extensions and the abstraction of vendor specific details.

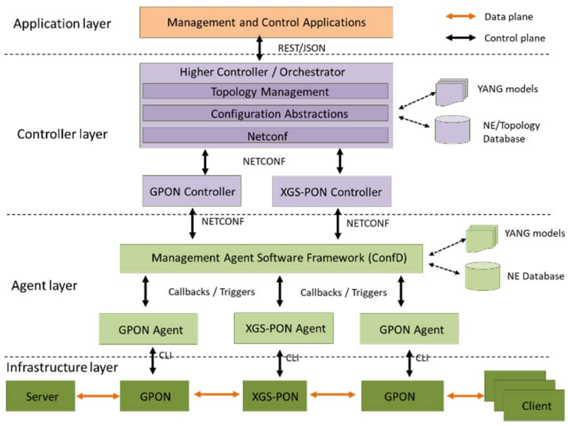

Fig. 3: The control-plane architecture for the testbed

In MASF, the appropriate YANG models are generated and exposed for the elements in the XGS-PONs and GPONs. MASF communicates via southbound interfaces with the necessary agents to realise the configuration of XGS-PON and GPON systems.

At the controller layer, the XGS-PON and GPON controllers communicate with the MASF using Netconf. In addition, a higher- hierarchy-controller (HHC) is developed which is responsible for the orchestration of all controllers. The HHC acts as Netconf client and communicates with the lower controllers through the southbound interface, while it enables the actual configuration of the whole network through the northbound interface's REST API.

Validation and Performance

By means of the SDN architecture of fig.3, the end-to-end platform is orchestrated either in a coordinated way or sequentially. In the former option, the XGS-PON and GPON platforms are orchestrated concurrently while in the latter, they are orchestrated independently of each other. Our claim for a real-time connectivity platform is validated in both cases by injecting a TCP flow and measuring: a) the response times of the control-plane; b) the service recovering time using the iperf traffic generator. In particular, in both configurations, a 150 Mb/s TCP flow is generated from A to B (fig.2) with a DBA profile shown in Table I.

Table I: The DBA profile of the TCP flow

Upstream queue configuration profile	TCONT type	Fixed BW (Mb/s)	Assured BW (Mb/s)	Maximum BW (Mb/s)
GPON profile GP1	TCONT-5	20	200	500
GPON profile GP2	TCONT-5	10	40	70
XGS-PON profile XP1	TCONT-5	20	200	500
XGS-PON profile XP2	TCONT-5	10	40	70

In the sequential orchestration set-up, we preconfigure the queues of both the GPON and XGS-PON with GP1/XP1 profiles respectively. Then, the GPON queue is reconfigured to the lower bandwidth profile of 70 Mb/s (GP2). The corresponding total control-plane latency is reported in Table II (first column) and it is 5.1s. This latency consists of three components: i) the latency at the agent layer (fig.3); ii) the controller-agent communication and MASF processing. The latency at the agent layer is 4.2s which is split into 1) the authentication; 2) queue manipulation (deactivation, modification and re-activation), an operation that results in data transmission interruption; and 3) configuration and processing delays. The actual TCP flow performance is illustrated in fig.4(a) featuring a service recovery time of around 6.4s.

Table II: The control-plane latency of the testbed

Control plane latency		Individual configuration of GPON	Individual configuration of XGS-PON	Orchestrated configuration of GPON and XGS-PON
GPON Agent	Authentication latency	2387		1399
	Latency in GPON Agent for GPON reconfiguration causing DATA interruption (ms)	1449		1293
	Configuration preparation, communication and processing latency	339		337
	Total latency in GPON Agent (ms)	**4175**		**3029**
XGS-PON Agent	Authentication latency		2229	2156
	Latency in XGS-PON Agent for XGS-PON reconfiguration causing DATA interruption (ms)		1316	1314
	Configuration preparation, communication and processing		351	355
	Total latency in XGS-PON Agent (ms)		**3896**	**3825**
Total	Controller-agent communication latency, MASF processing latency	958	839	1459
	Latency of whole reconfiguration cycle (controllers-agents-controllers)	**5133**	**4735**	**8313**

Then the XGS-PON is configured to the profile XP2 to match the adjustments made at the GPON. As shown in Table II (second column) the latency of the agent layer is 3.9s, while the total latency is 4.7s. The service recovery time is far lower than the previous case at ~1.6s. Apparently, the service recovery time is a fraction of control-plane activation time as the latter includes the aforementioned (1)-(3) processes. For the sequential orchestration set-up, the total control plane latency sums up to ~ 9.9s, while the service recovery time to ~8s.

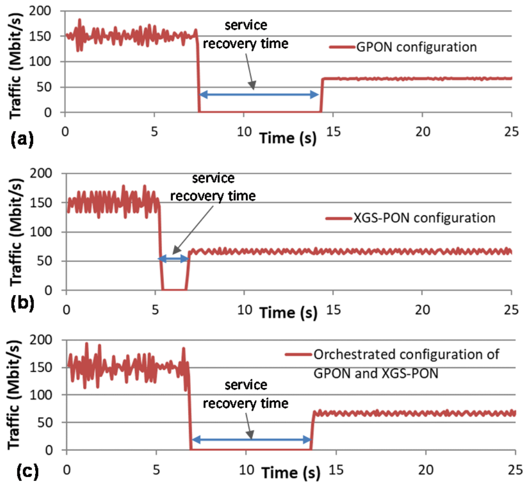

Fig. 4: TCP flow responce in the segmented (a) GPON (b) XGS-PON reconfiguration, (c) coordinated reconfiguration

In the second configuration set-up, the SDN orchestrator in fig.3 is orchestrated in a coordinated manner. In particular, the queues of the GPON and XGS-PON profiles are simultaneously reconfigured from the GP1/XP1 values, respectively, to the GP2/XP2 values. In this case, the control plane latency is ~8.3s (third column in Table II) a value that is 15% lower than the corresponding figure in the sequential set-up. In addition, a very interesting observation is that the service recovery time (fig.4c) is ~6.4s, which is 20% lower than the corresponding sequential set-up case. This result shows clearly the benefits of coordinated orchestration for an end-to-end platform.

Conclusions

We report the proof-of-concept validation of an end-to-end connectivity platform spanning Metro and Access that is reconfigured in real time making use of the dynamic data-plane of PONs. We have elaborated the details of a novel end-to-end SDN control-plane that orchestrates the two PON systems and we showed the benefits of coordinated orchestration for the testbed systems. Reconfiguration of < 10 seconds is reported in all cases.

Acknowledgements

The authors are grateful to Sebastian Horlitz, Thomas Pfeiffer and Jochen Maes for their invaluable support. The XGS-PON is a generous donation of Nokia Bell Labs. The GPON was kindly provided by Nokia-Hellas.

References

[1] E. Kosmatos, C. Matrakidis, A. Stavdas, S. Horlitz, Th. Pfeiffer, A. Lord; “Building a Truly Dynamic Filterless Metro Network by Reusing a Commercial PON's Data-Plane and a Novel SDN-Enabled Control-Plane”, *OSA/IEEE Journal of Lightwave Technology*, Vol.37, issue 24, pp. 6033 - 6039, 2019.

[2] E. Kosmatos, C. Matrakidis, A. Stavdas, T. Orfanoudakis; "An SDN Architecture for PON Networks Enabling Unified Management using Abstractions"; *ECOC 2018*, Rome, Italy.

[3] D. Zhang, D. Liu, X. Wu, D. Nesset, “Progress of ITU-T higher speed passive optical network (50G-PON) standardization”, IEEE/OSA Journal of Optical Communications and Networking, Vol.12 (10), D99 - D108, 2020 C.Matrakidis,

[4] E. Kosmatos, T. Orphanoudakis and A. Stavdas, "Building a Converged Access Network Based on OpenFlow", *IEEE SDN Newsletter*, July 2016

[5] “CORD: Central Office Re-architected as a Datacenter”, https://www.opennetworking.org/cord/

[6] E. Kosmatos, C. Matrakidis, D. Uzunidis, A. Stavdas, S. Horlitz, Th. Pfeiffer, A.Lord; "Architectural Foundation and Control-Plane Integration of a Novel Metro-Access, Cloud-Integrated, Node", ECOC 2019, Dublin, Ireland

[7] D. Uzunidis, C. Matrakidis, A. Stavdas, A. Lord;"DuFiNet: Architectural Considerations and Physical Layer Studies of an Agile and Cost-Effective Metropolitan Area Network", OSA/IEEE Journal of Lightwave Technology, Vol.37, issue 3, pp.808 - 814, 2019.

[8] ConfD platform, http://www.tail-f.com/management-agent/

[9] "ITU-T PON YANG Modules", BroadBand Forum, WT-385, May 2017