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Single Open Programmable *Packetponder* Element for Access/Metro Aggregation and Network Consolidation

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***Abstract*— In this paper we show, for the first time, an access/metro aggregation and node consolidation by using an open *packetponder* and common-form-factor pluggables, transmitting an aggregated 99.56Gb/s (single channel) over 80km single-mode fibre. We experimentally demonstrate how an open-source Network Operating System (NOS) of a P4 programmable switch can accommodate both point-to-point and point-to-multipoint topologies with emerging pluggables including the XGS-PON (TiBiT) and the industry-first 100ZR coherent pluggable.**

I. Introduction

TELCOs distribute dataplane hardware, with attendant control and management software, across three successive hierarchical network domains: core, metro, and access. Each successor domain has increasing radix/lower bandwidth connections that terminate in residential and business premises. Common, off-the-shelf (COTS) open *whiteboxes* with open hardware, open software and open application programming interfaces (APIs) have been proposed for use in the three domains as an alternative to closed systems via ONF or TIP. Open variations of optical line terminals (OLTs), aggregating switches/routers, transponders, and ROADMs are available across the access, metro and core domains, as exemplified in Fig. 1(a)(i). Previous demonstrations showed a consolidated access node, aggregating 5G mobile and residential services [1]. Also, the control of an *ex-situ* xPonder with coherent module was shown [2]. We recently demonstrated a aggregation/metro node where an open *packetponder* [3] with COTS components and open software can usefully substitute the traditional L2 transponder function in a single open hardware element as shown in Fig. 1(a)(ii). The *packetponder* can accommodate a variety of pluggable transceivers, supporting lineside-to-lineside, optical-to-electrical-to-optical (OEO) re-amplification, re-shaping, and re-timing (3R) with wavelength conversion.

In this paper, we demonstrate, for the first time, how a fully open and programmable *packetponder* can be redefined to serve various purposes, unifying both metro and access networks and simplifying architectures. We show experimentally the feasibility of a *packetponder* at the edge, aggregating the access domain services with common-form-factor (CFF) pluggables and open software/APIs. The use of open-source Network Operating System (NOS) and open, programmable whitebox enables the integration of current and emerging standardised, multi-source agreement CFF pluggables that support access, metro and edge network services. The consolidated platform, depicted in Figure 1(a)(iii), reduces the number of ASICs traversed by packets exchanged between end-users and the network core from three to one, which potentially reduces both the energy consumption and management/control overhead and complexity. Our solution aggregates mixed signals, akin to a *muxponder*, as in Figure 1(b), at the edge of a metro link, enabling transmission of an aggregated 99.56Gb/s signal (single channel) through 80km single-mode fibre. Furthermore, the *packetponder* functionalities surpass those of a *muxponder*, that aggregates mixed rates, but also enables any-to-any forwarding with 3R OEO. Here, we demonstrate C-Band $\leftrightarrow$ C-band wavelength conversion with *in-situ* tunability of pluggable transceivers supporting different standard management interface specifications (SFF, CMIS), and using a single YANG model (by sending a gNMI protocol request to access the registers of CFF pluggables over the I^2C bus); and C-Band $\leftrightarrow$ O-Band *in situ* wavelength conversion.

II. Experimental arrangement

The experimental arrangement is shown in Fig. 2(a). The Keysight/Ixia XGS2-SDL test traffic generator (TTG) chassis contained: I) Novus-S: QSFP-28 port cages supporting 100/50/25/10 GbE; and II) Novus-NP: SFP+ and 10GBase-T port cages supporting 10GbE/1GbE/100MbE load modules. It emitted Ethernet packets of different format e.g. eCPRI, and used the *IxNetwork* software for building test scenarios and viewing statistics. We used Internet MIX (IMIX) of packets for each traffic to resemble a real-world scenario, with 58.33% of the packet distribution being small token size (66-70bytes, such as Session Initiation Protocol traffic), 33.33% of medium size (570 bytes, representing web traffic with http

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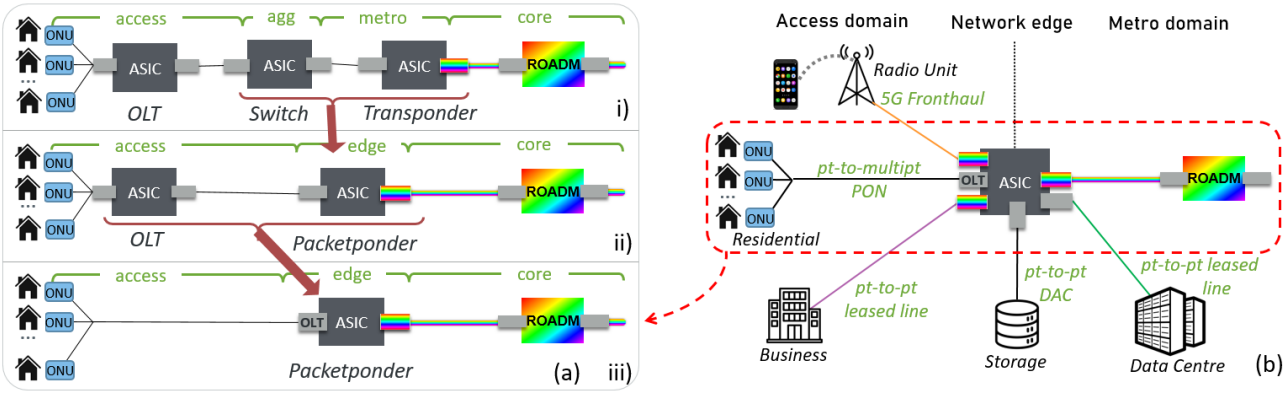


Fig. 1: (a) i) Typical network; ii) *Packetponder* [3]; iii) *Packetponder* with pluggable OLT; (b) *Packetponder* at network edge terminating: 5G fronthaul, PON and leased line *Access* services; coherent optical DWDM metro back-haul transmission via ROADM; local storage and datacentre connectivity.

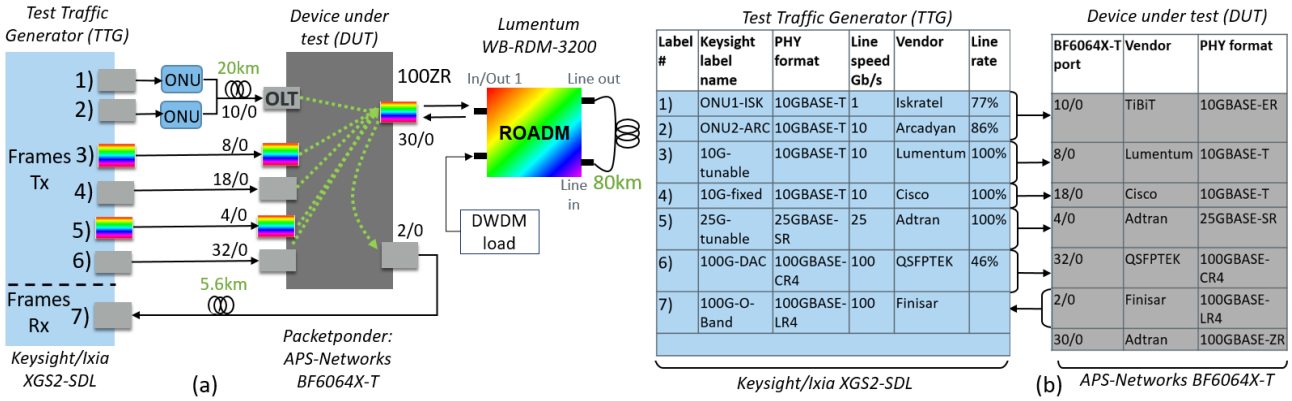
meta data), and 8.33% of size 1518 bytes, illustrating video traffic for example. The device-under-test (DUT) was an APS-Networks switch, deployed as a *packetponder*, where 7 (of 64) QSFP28 port cages accommodated the CFF pluggables tabulated in Fig. 2(b). Where required, a Mellanox SFP-QSFP28 adaptor/converter was used.

The aggregation use-case emulated in this experiment, used TTG traffic emitted by ports 1) and 2) and incident to a pair of independent optical network units (ONUs) which aggregated the two unidirectional flows into a single flow for transmission across a 20km PON and reception by a TiBIT XGS-PON OLT SFP+ pluggable transceiver in the DUT. TTG port 3) emitted pt-to-pt traffic with a (C-Band) Lumentum 10GbE tunable optical SFP+ pluggable transceiver (for leased line emulation). TTG port 4) emitted pt-to-pt traffic (850nm-band short reach) SFP+ using a Cisco SFP-10G-SR. TTG port 5) emitted pt-to-pt traffic (C-Band) with an Adtran 25GbE tunable SFP28 optical pluggable transceiver (with eCPRI for 5G radio unit backhaul emulation). TTG port 6) emitted pt-to-pt traffic QSFP28 100G-direct attach copper (DAC) cable emulated a local traffic within the rack that connect to intra-rack storage array (local content deliver network emulation).

The flow of test traffic is represented by arrows between the Tx ports labelled 1)-6) and the single Rx port labelled 7) of the TTG. Test traffic emitted from the TTG was configured using *IxNetwork* with a unique `IPv4 source address` particular to the Tx ports. A P4 program on the DUT used the 2-tuple `<DUT_ingress_port, IPv4_source_address>` for ingress flow classification. The program was compiled and "written" to the forwarding table of the APS-Networks switch ASIC. At run time, based on their 2-tuple, all packets were forwarded to a single 100GbE port cage, `30/0`, that contained an industry-first 100ZR QSFP28 coherent tunable pluggable transceiver from Adtran (the *incast* forwarding test traffic flows within the DUT to a common egress port cage is shown by the green dotted line of Fig. 2(a)), which fits perfectly in a 100G QSFP28 port, thanks to its purpose-built DSP. Data was emitted from the Tx port at `1524.94nm`, directed through ingress add port `In 1` of an open, optical whitebox ROADM (Lumentum WB-RDM-3200) and transmitted over 80km of single-mode optical fibre, together with a fully loaded DWDM channels (emulating 76×50GHz grid spaced data channels with two 100GHz empty bandwidth slots). The signal was then looped back through port `Out 1` of the ROADM to the Rx port of the Adtran 100G ZR pluggable, emulating an edge to metro node. The P4 program then used the 2-tuple `<DUT_ingress_port_label, IPv4_source_address>` to direct test traffic to port `2/0` which contained an O-band 100GbE QSFP28 pluggable (`1302.35nm`), and transmitted over 5.6km of single-mode fibre. This particular feature is key to demonstrate wavelength conversion between the C-band and the O-band with 3R regeneration. Traffic is finally received to the Rx port labelled 7) of the TTG. During each test run, packet statistics were recorded by the TTG for all test runs.

III. Results

Fig. 3(a)(i) shows the *in-situ* assignment and change of wavelengths via command line interface (cli) arguments sent from the remote ONOS controller console that effected the wavelength tuning of the pluggable particular to each one of three ports in the *packetponder*: port 4/0, 10GbE; port 8/0, 25GbE; port 30/0, 100GbE. The YANG tree structure that reflects the intent expressed from the cli is shown in Fig. 3(a)(ii). The ONOS controller allowed *in-situ* wavelength tuning of each of the tunable pluggables via a gNMI request sent to the NOS to modify the registers of the pluggables via the I^2C bus. We contributed to Stratum and ONL, respectively the NOS and OS of our *packetponder*, to accommodate and control both SFF-based (for 10/25GbE) and CMIS-based (for 100GbE) pluggables. Fig. 3(b) shows successful error-free reception of all 10^{10} packets - that were proportionally divided depending on the line-rate of each Tx port of the TTG - at the conclusion of a ten-hour test run. Fig. 3(c) depicts the throughput from each Tx test packets, from successive TTG Tx ports that were consecutively added at 10 second intervals, and the successful reception of the aggregated throughput at the Rx. We experimentally demonstrated a 99.56Gb/s throughput traffic aggregation in a single wavelength channel, which exclude overheads. The 100Gb/s aggregation limitation is due to



Label #	Keysight label name	PHY format	Line speed Gb/s	Vendor	Line rate
1)	ONU1-ISK	10GBASE-T	1	Iskratel	77%
2)	ONU2-ARC	10GBASE-T	10	Arcadyan	86%
3)	10G-tunable	10GBASE-T	10	Lumentum	100%
4)	10G-fixed	10GBASE-T	10	Cisco	100%
5)	25G-tunable	25GBASE-SR	25	Adtran	100%
6)	100G-DAC	100GBASE-CR4	100	QSFPTEK	46%
7)	100G-O-Band	100GBASE-LR4	100	Finisar	

BF6064X-T port	Vendor	PHY format
10/0	TiBiT	10GBASE-ER
8/0	Lumentum	10GBASE-T
18/0	Cisco	10GBASE-T
4/0	Adtran	25GBASE-SR
32/0	QSFPTEK	100GBASE-CR4
2/0	Finisar	100GBASE-LR4
30/0	Adtran	100GBASE-ZR

Fig. 2: Experimental arrangement: (a) Packet flow to/from TTG via DUT & ROADM. (b) CFF pluggable identification, port-labelling & connectivity mapping scheme between TTG, DUT and ROADM.

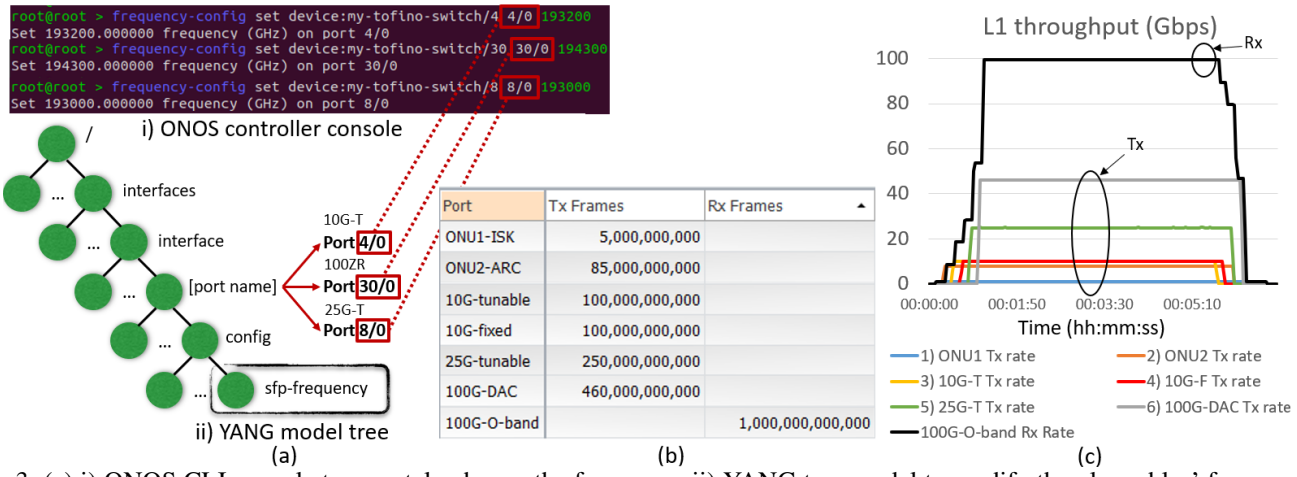


Fig. 3: (a) i) ONOS CLI console to remotely change the frequency, ii) YANG tree model to modify the pluggables' frequencies; (b) extended traffic Tx/Rx 10 hours; (c) throughput - dynamic, sequential addition of traffic

the equipment available to us, but this concept can certainly be expanded to 400G and beyond, with an increased availability of high-port count and high capacity open programmable switches and CFF tunable pluggables. Equally, Stratum was used with ONL (OS) and ONLP (Platform APIs), and again alternative open NOS and OS could be used, such as SONiC.

IV. Discussion and Conclusion

The *packetponder* terminates/aggregates many high-radix, lower speed, access terminations *and* few low-radix, high bandwidth metro/core terminations in a single hardware element. Hence, fewer physical network elements (OLTs, transponders) are needed as they can be merged at fewer singular locations, saving both CAPEX and OPEX. The *packetponder* concept endures at higher bandwidths too, e.g., the next generation Tofino 2 ASIC supports 400GbE port cages and might accommodate low-radix 400G DWDM ZR+ and high-radix 400G XR QSFP-DD coherent pluggables for further CAPEX savings [4], [5]. We anticipate future developments that simplify and consolidate the network architecture for energy efficiency.

In this paper, we presented an open *packetponder* – a singular element – at the network edge to interchange L1 access/metro optical and L2 packet data plane traffic via open hardware/software interfaces and CFF pluggable transceivers. We showed concomitant support for mixed line-erate (1/10/25/100 GbE) convergence/aggregation of pt-to-pt and pt-to-multipt access connections: TDMA PON, fixed & tunable coherent CFF pluggable transceivers enabling Layer 1, 3R OEO for both C-Band ↔ C-band wavelength conversion with *in-situ* tunability; and C-Band ↔ O-Band wavelength conversion – all within a single *packetponder* element.

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