

# First international SDN-based Network Orchestration of Variable-capacity OPS over Programmable Flexi-grid EON

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**Abstract:** The first experimental demonstrator of 46-108Gb/s discrete-multi-tone (DMT) fixed-length variable capacity OPS over programmable, flexi-grid elastic optical path network (EON), orchestrated via multiple OpenFlow controllers in the framework of SDN is presented.

**OCIS codes:** (060.4250) Networks

## 1. Introduction

Optical packet switching (OPS) can potentially provide a solution to ultrafast, energy- and resource-efficient data transport. OPS can provide times-sliced sub-wavelength logical path preferably in metro area network (MAN) and intra data center network. On the other hand, Elastic Optical Network (EON) can adopt the flexi-grid, which uses 12.5GHz spectrum slices for adaptively allocating bandwidth variable connections and, thus, improves the spectrum usage. A bandwidth variable transceiver (BVT) is one of the enablers to provide both fixed-length variable-capacity (FL-VC) optical packet [1] and elastic optical path [2]. Moreover, the BVT plays a key role in interfacing between such OPS and EON to convert FL-VC optical packet to the elastic optical channel signals.

This paper introduces for the first time the network orchestration of multiple OpenFlow (OF) controllers through the SDN-based Application-Based Network Operations (ABNO) [3] architecture in an OPS-EON demonstrator (Fig. 1), although several international multi-technology testbeds have been presented by extending a single SDN controller [4]. To the authors' knowledge, the orchestration of end-to-end transport services through OF control on the OPS-EON coexisting data plane has not yet been experimentally demonstrated on a network testbed. In the data plane 100Gb/s discrete multi-tone (DMT), a direct-detection (DD) OFDM, transmitter [5] is adopted for distance-adaptive (2-40km) FL-VC packet transmission at up to 108Gb/s in short-reach OPS network, followed by the data transport over flexi-grid optical connection in the EON network.

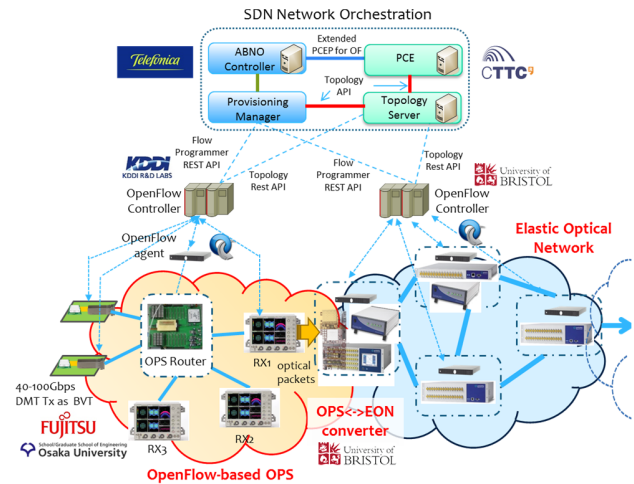


Fig.1 Orchestration in OF-based OPS-EON network demonstrator

## 2. OPS Data Transport Plane: Distance-adaptive Optical DMT Payload Packet

100Gb/s-class DMT packet transmitter (DMT-TX) is developed which exploits its flexibility to generate fixed-length distance-adaptive optical packet. The packet length is fixed to ease the buffer scheduling algorithm while 1024 subcarriers in each payload are adaptively modulated to maximize the payload capacity according to the transmission distance [5]. The flow control technique in OF naturally fits to such variable-capacity OPS, e.g., the OF controller informs DMT-Tx of the possible routes to the destination and DMT-Tx determines the bit rate for a given distance, while the intermediate OPS node switches the packets according to the OF-enabled switching (SW) table.

Fig. 2.a shows the experimental setup. Two DMT-Txs are used as source nodes and a  $2 \times 3$  PLZT ((Pb,Lu)(Zr,Lu)O<sub>3</sub>) SW is as an OPS router. No buffer is employed here for simplicity, but the contention resolution of the FL-VC packets could be done by fiber delay line buffers with simple scheduling [1]. One DMT-Tx consists of a 65GS/s DAC and an electro-absorption modulated laser (EML) at 1540.5 nm, while the other is with a 12GS/s DAC and for generating dummy packets. The each DMT-Tx output is packetized and appended 2Gbaud OOK-formatted optical label via a gate switch. The packet has 283.5ns payload and 16ns label which contains the repetition-coded 8-bit address (Fig. 2.b). The guard interval is 50 ns while the rise and fall time of the SW is ~10ns.

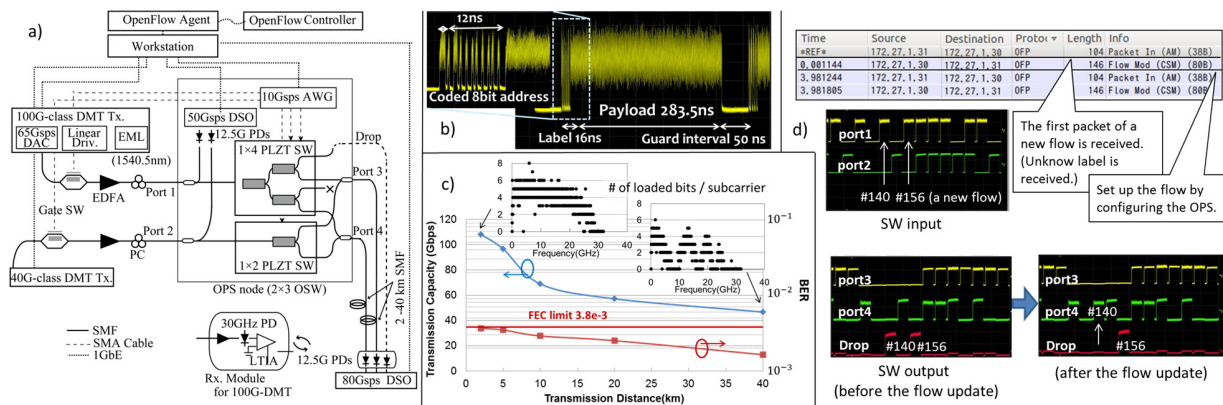


Fig. 2 a) OPS domain experimental setup, b) DMT packet waveform, c) BER and achievable capacity versus transmission distance, and d) demonstration of OF table and SW table update

At the router, the labels are detected via the digital storage oscilloscope (DSO) and sent to an OF agent through the 1GbE connection. The agent is introduced in order to support OF protocol and translates the Flow table into the SW table, which will be uploaded to the memory of the 10 GS/s arbitrary waveform generator (AWG). The  $2 \times 3$  SW is used as a  $2 \times 2$  crossbar SW with a dropping port. The router output is then transmitted over 2–40km SMF links and received via the destination node implemented by a 30GHz PD and an 80GS/s DSO. The received packets are demodulated in an offline manner, and then the raw data are uploaded to an Ethernet traffic generator at the OPS/EON interfacing demonstrator. The BER and the achievable raw bit rate within a 7% FEC limit ( $BER = 3.8 \times 10^{-3}$ ) are represented in Fig. 2.c. We achieve 108.2Gb/s for < 2 km and 46.7 Gb/s even with 40km. Fig. 2.d shows an example of the OF control over the 46–108G/s FL-VC OPS network where a new flow is configured when the unknown label (#140) is detected at the OPS router. The flow update time is 1.1ms except the AWG memory update.

### 3 EON Data transport Plane and Interface with OPS

The OPS networks and EON are inter-connected by an OPS-EON interface card. Fig. 3 shows the transport plane of EON. An Ethernet traffic generator encapsulated the raw data from OPS networks to optical Ethernet signals, to emulate the link between Japan and UK. The OPS-EON interface card, implemented using high performance FPGA (HTG Xilinx V6 PCIE board), receive Ethernet traffic using multiple 10GE SPF+ modules, and then process and groom the traffic to drive a sliceable, programming BVT. The BVT can adopt 10Gbaud PM-QPSK, 20Gbaud QPSK or 20Gbaud 16QAM signal formats for variable scenarios. An 8-subcarrier super-channel signal is generated with modulation format programmability for each subcarrier in a 50GHz grid, to provide bandwidth from 80Gb/s to 1.28 Tb/s and more flexibility. Another 8-subcarrier programmable super-channel (SC) signal with 10Gbaud PM-QPSK signals are generated in a 40GHz grid. The Node 1, based on architecture-on-demand (AoD) concept, reconfigure the capacity of BVT for different application scenarios. As shown in the inset, two SC signals

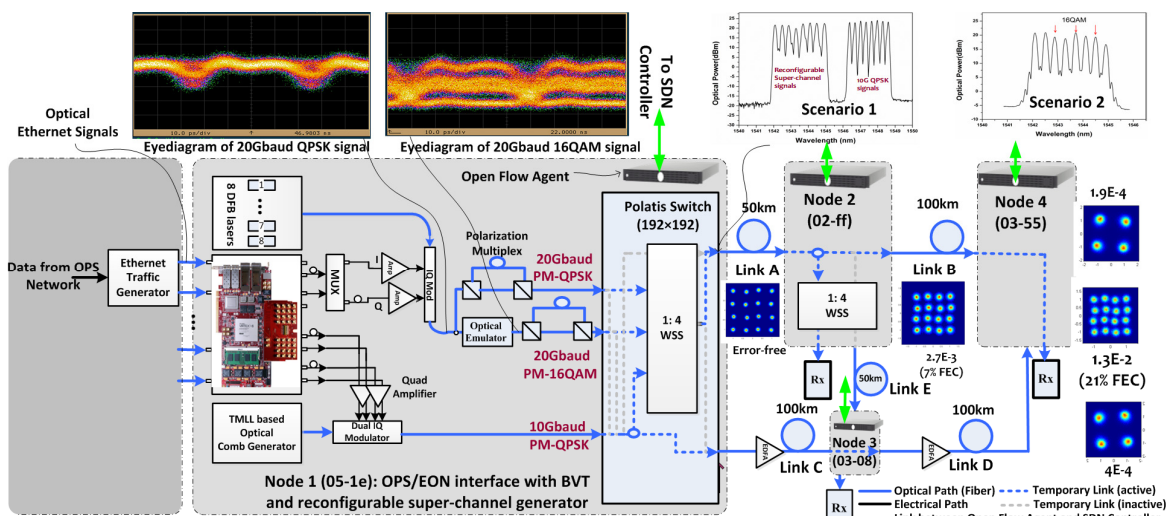


Fig. 3 Reconfigurable, programmable and flexi-grid EON with OPS/EON interface

can be launched to the link A in scenario 1 for large capacity requirements. In scenario 2, we only use an 8-subcarrier SC signals with carrier 3, 5 and 7 using PM-16QAM to provide 880Gb/s bandwidth.

The EON consists of four AoD-based optical nodes, based on several polatis beam steering fiber switches.. The SC signals can be programmed based on network request, link situation and even adopted FEC coding in 16QAM signals. We test channel 7 (16QAM signals) in scenario 2. The received constellations are shown in Fig. 3. An ECL is used to replace the DFB laser for the tested 16QAM channel. Due to short link length, we decreased launched OSNR to degraded performance. At Node 2, the dropped 16QAM signals show a BER about  $2.7 \times 10^{-3}$  below the 7% FEC threshold and the BER goes to  $1.3 \times 10^{-2}$  at Node 3 with more transmission length, which is below the 20% FEC threshold. Providing the link situation, FEC encoding, the data plane can provide more flexible service. For the QPSK subcarriers, all signals dropped at Node 4 show BERs around  $4.0 \times 10^{-4}$  and a recovered constellation is also shown in the inset.

#### 4. Multi-domain Orchestration

The ABNO architecture [3] is proposed as a multi-technology and multi-domain network orchestration solution. The ABNO controller is the main component of the architecture and is responsible for controlling the workflows for both OF-controlled OPS and EON domains, which are run by KDDI and University of Bristol, respectively (Fig. 1). The Topology Server recovers the topology exposed by each OF controller North-Bound Interface (NBI), and it is fed both to the PCE and the Provisioning Manager. The PCE is the network element which handles the path computation across the network graph provided by the Topology Server (Fig. 4.b) and it has been extended for OF [6] (Fig. 4.c). The Provisioning Manager is responsible for the actual flow establishment request to the OF controllers through each specific controller's NBI. In Fig. 4.a. the different messages exchanged are detailed.

We propose three different scenarios where an OPS node (00-01) is connected to EON through an OPS/EON edge node (05-1e), where OPS-EON interface card is placed. In the first scenario, a bit rate of 800Gb/s for transporting aggregated OPS frames (each of them up to 108.2 Gb/s with a distance of 2km) is requested end-to-end. The PCE computes a path from node 00-01 to receiver at 02-ff. Then, the Provisioning Manager requests the required flow establishment towards each domain. At the reception of the flow request, the OPS OF controller assigns OPS label 140 to the output port connected to edge OPS/EON node. The EON OF controller calculates that 800Gb/s require 2 QPSK 4QAM sub-carriers which are setup at the S-BVT by choosing the spectrum range and slots (i.e., 193.627-194.027 THz with 50GHz). The setup delay for this first scenario is around 26s (Fig. 4.d). The setup delay has been decoupled in path computation time (including topology request,  $T_{pce}$ ), OPS flow ( $T_{ops}$ ) and EON flow ( $T_{eon}$ ) setup delays. The second scenario consists of an aggregated request of 300Gb/s from 00-01 to receiver at 03-08. The behavior of OPS OF controller is similar to the three scenarios, while the EON OF controller assigns 2QAM sub-carriers, which are setup at S-BVT, with a global setup delay of 34s. Finally, the third scenario requests 100Gb/s, which on the EON requires 2QPSK sub-carriers. The setup delay is around 36s.

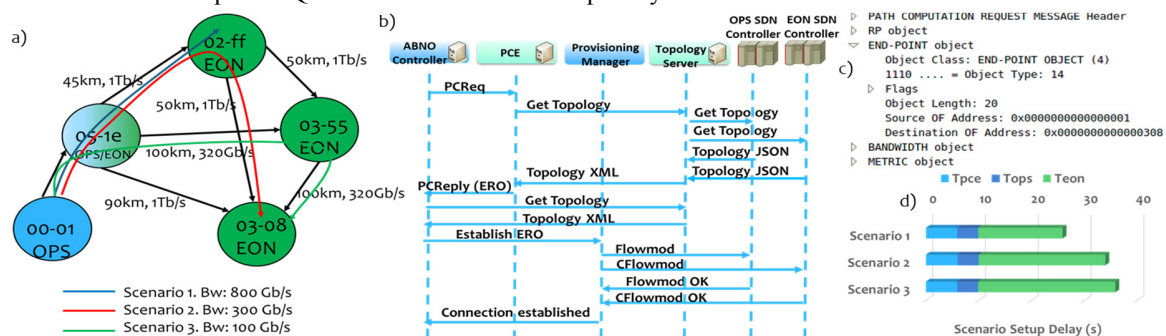


Fig. 4 a) PCE network graph including OPS and EON domains, b) ABNO controller message exchange, c) Wireshark capture of PCRequest with OF end-point objects, and d) Scenarios Setup Delay (s)

#### 5. Conclusion

46-108Gb/s DMT-based FL-VC OPS over programmable, flexi-grid EON, orchestrated via multiple OF controllers in the framework of SDN has been experimentally demonstrated for the first time. This could serve as a milestone architecture for elastic-bandwidth slice provisioning with the finest data granularity for SDN applications.

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