Experimental Demonstration of a Programmable 400-Gbps DMT Transceiver with Policy-based Control

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Abstract: *We propose a programmable 400-G discrete multi-tone (DMT) transceiver with policy-based control. We experimentally demonstrate the 400-G DMT transceiver enabling either capacity, distance, or energy efficiency priority in a four-node photonic mesh network.*

Keywords: *Discrete Multi-Tone, programmable optical transceiver, policy-based control*

I. INTRODUCTION

Network traffic for wireless back/front-haul and data centers has been increasing every year, and recent research efforts have focused on the efficient use of network resources to support this traffic exponential growth. In particular, for a metro-access/regional network, simple low-cost solutions enabling high capacity are needed. Therefore, in this context, a beyond-100-Gbps-class system is strongly required for cost-sensitive applications. A suitable candidate is the discrete multi-tone (DMT) technology [1, 2]. A DMT transceiver can provide high capacity transmission and rate/distance adaptability by adjusting the number of bits/subcarrier thanks to the DMT features, as it is an OFDM-based multi-carrier modulation with simple configuration/implementation.

In addition, multiple advanced functionalities can be enabled by the DMT transceiver by suitably programming and dynamically (re)configuring specific parameters/characteristics for an efficient and flexible usage and management of the network resources [3]. Particularly, an adaptive DMT transceiver can be remotely programmed according to the network priority (e.g. high-capacity, long-distance and low power consumption) to meet the traffic demand, channel bandwidth/path/state and energy efficiency requirements. Therefore, we propose to enable a policy-based control in the optical transceivers in view of its integration in a software defined network (SDN) based control plane. Figure 1 shows the configurations of the 400-G DMT transceiver according to the proposed policy-based control. The optical transceiver, consisting of four lanes with variable rate up to 100-G each, enables rate/distance adaptability, in order to fulfil the priority target. 75-G, 50-G or either 25-G can be enabled yielding the 3/4, 1/2 or 1/4 of the maximum capacity per lane, to ensure the best effort. In case of capacity priority, the target is maximizing the achievable rate on each one of the four lanes. Whereas, adopting the distance priority policy, the achievable reach is extended at the expense of the capacity per lane, by adaptively loading the transceiver subcarriers with the number of bits suitable for meeting the target performance. Finally, the number of active transceiver lanes is varied according to the energy efficiency policy: the corresponding transmitters and receivers are enabled/disabled to target the power consumption requirement. We demonstrate the functionalities of the proposed DMT transceiver with policy-based control in a four-node photonic mesh network (CTTC ADRENALINE testbed) [4].

For the assessment of the capacity priority policy, we evaluate the transmission of 400-G (100-Gbps x 4-lane) on a 35-km single mode fiber (SMF) link of the ADRENALINE network (Fig. 2). Then, we validate the distance priority policy on 150-km non-zero dispersion-shifted fiber (NZDSF) link. Last, we analyze the priority policy of the energy efficiency, targeting the transmission of 100-G/1-lane on the 35-km SMF link.

II. 400G DMT TRANSCEIVER WITH POLICY-BASED PRIORITY CONTROL

Figure 2 shows the configuration of the DMT transceiver and the experimental setup of the ADRENALINE network testbed. The laser diode (LD) wavelengths set for the four lanes (LD1, LD2, LD3, and LD4) are 1553.33nm, 1552.52nm, 1551.72nm and 1550.92nm, respectively; they are modulated by external Mach-Zehnder modulators (MZMs) and multiplexed. The DMT signal is generated by off-line processing and is converted to an analog signal by a 64 GS/s, 8 bits digital-to-analog converter (DAC). The transmitted DMT signal is received by a photodetector (PD) through the demultiplexer (DEMUX). The received optical power is maintained to +0 dBm by means of a variable optical attenuator (VOA). The received signal is converted to digital by a 64 GS/s, 8 bits analog-to-digital converter (ADC) and subsequently demodulated. The subcarrier number and the cyclic prefix of the DMT signal are 1024 and 16, respectively. The input power to the EDFA1 and the OXC-2 is +4.7 dBm, and +18 dBm, respectively. The dispersion of the transmitted signals is compensated by the tunable dispersion compensator (TDC) at the receiver side.

The priority policy of the transceiver can be set to capacity, distance, and energy efficiency. When the capacity priority policy is adopted, the total capacity is maximized and the target bitrate of each lane is determined by the OSNR reference value based on Fig. 3. If an OSNR is over 43.8 dB, the target is set to 110.3-Gbps. The target bitrate is decreased due to the low OSNR. For this evaluation, we consider a target bit error ratio (BER) of 4.5×10^{-3}, assuming CI-BCH-FEC with 7% overhead (OH) of Ethernet [5].

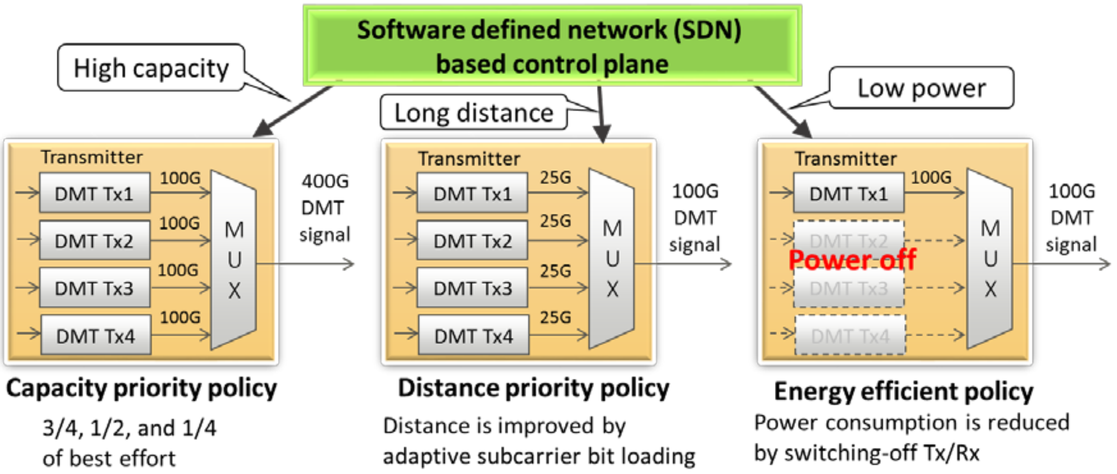

Figure 1. The configuration of the transceiver with policy-based control

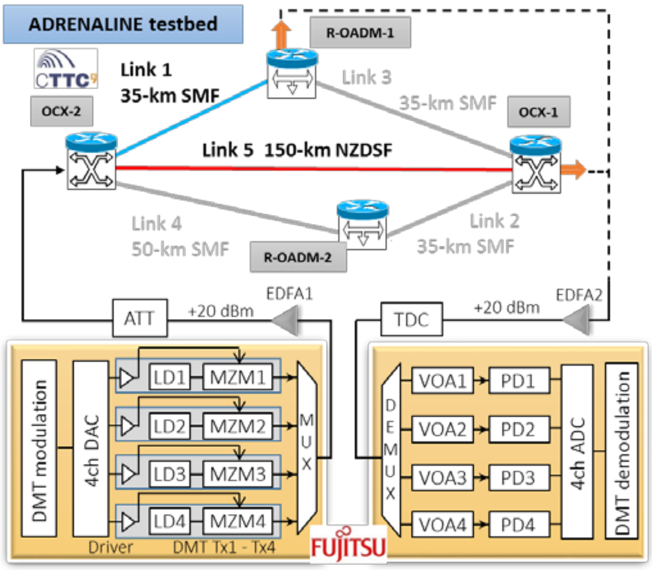

Figure 2. Experimental setup of the ADRENALINE testbed and the configuration of the proposed DMT transceiver

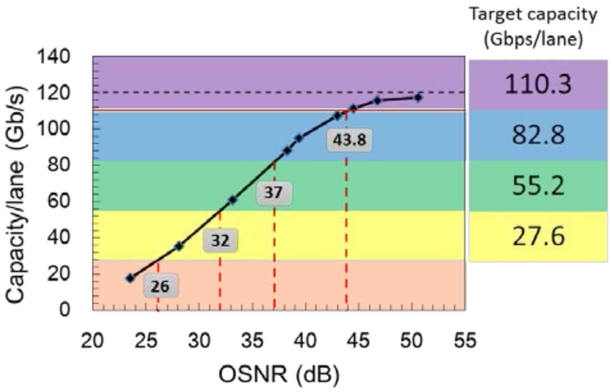

Figure 3. OSNR vs. capacity of the DMT transmission

Table 1. The evaluated scenarios for the priority policy control

Scenario	Priority	Gross capacity (Gbps)	Distance (km)	Power consumption
1	Capacity	441.2/4-lane	35-km Link 1	1
2	Distance	220.6/4-lane	150-km Link 5	1
3	Energy efficiency	110.3/1-lane	35-km Link 1	0.25

III. RESULTS AND DISCUSSION

We evaluate the feasibility of the DMT transceiver with policy-based control when operated in the ADRENALINE testbed. Table 1 shows the evaluated scenarios to demonstrate the priority control capability/policy. Figure 4 shows the received optical spectra before demultiplexing, the bit allocation, SNR profile of lane-1, and the BER characteristic for the (1) capacity, (2) distance, and (3) energy efficiency priority scenarios.

In Scenario 1, the transceiver is set to operate according to the high capacity priority over the 35-km SMF of ADRENALINE link 1. We obtain a high OSNR value of more than 44.8 dB, as shown in Fig 4(a)-(1). Therefore, the net bitrate of the transceiver is set to 400-Gbps (110.3-Gbps gross per lane). We achieve the successful DMT transmission of 400-Gbps/4-lane over 35-km SMF at the target BER, as shown in Fig. 4(d)-(1).

In Scenario 2, the DMT transceiver is configured to operate with the distance priority policy over the 150-km NZDSF of ADRENALINE link 5. Since the obtained OSNR is lower than 37.0 dB, the target bitrate is set to a gross value of 55.2-Gbps/lane, according to Fig. 3. As a result, we achieve a net data rate of 200-Gbps/4-lane over 150-km NZDSF by adaptively assigning the number of bits per symbol per subcarrier.

Last, in Scenario 3, we evaluate the effectiveness of adopting the energy efficient priority policy. When the network traffic is sparse, the power consumption of all 4-lane transmissions is reduced by switching-off the transmitters and receivers of some lanes. According to the traffic, the priority policy can be changed from capacity (Scenario 1) to energy efficiency (Scenario 3). Therefore, in order to assess this case for 100-Gbps transmission, the 3-lanes of the transceiver are disabled (instead of enabling 4 lanes at 27.6-Gbps gross). We achieve successful transmission (below FEC limit) of 100-Gbps with only 1-lane over link 1 (35-km path), as shown in Fig. 4. In this case, the power consumption of the ADRENALINE network elements, such as OXC, ROADM, and EDFAs, is not taken into account. The energy saving achieved with the DMT transceiver operating with scenario 3 policy, where 3 over 4 lanes are switched-off, is 75% compared to the scenarios where all the 4 lanes are enabled, as indicated in table 1.

All scenarios analyzed within the ADRENALINE network are successfully demonstrated, as shown in Fig. 4. Therefore, we confirm the effectiveness of introducing a policy-based control for operating the DMT transceiver with high-capacity, long-distance, and energy efficiency priority, by achieving a transmission of more than 400-G/4-lane, 200-G/4-lane, and 100-G/1-lane, respectively. Thus, a policy-based control of the transceivers enables to flexibly and efficiently manage the available network resources.

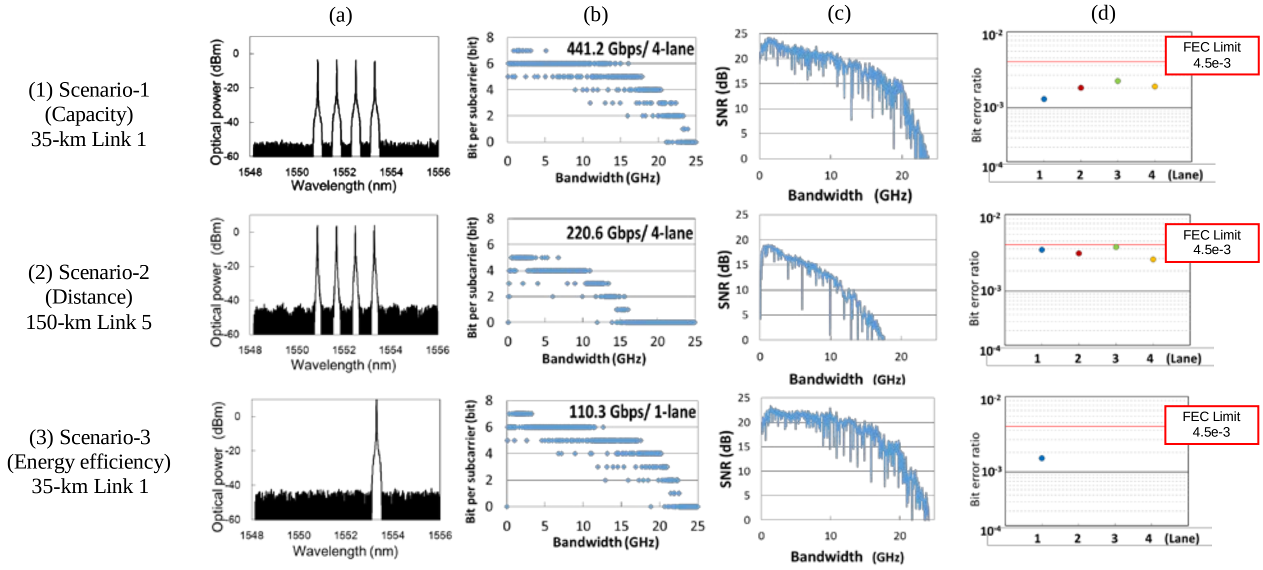

Figure 4. (a) Optical spectra, (b) bit allocation, (c) SNR profile and (d) BER per lane of (1) capacity, (2) distance, and (3) energy efficiency priority scenarios

IV. CONCLUSION

We propose to use a policy-based control in programmable/adaptive optical transceivers. We experimentally demonstrate the functionalities of a 400-G DMT transceiver enabling operation policy within the ADRENALINE network. For the high capacity priority, we achieve a DMT transmission of more than 400-Gbps/4-lane (110.3-Gbps /lane) over 35-km SMF. Next, for the long distance priority, we achieve 200-Gbps/4-lane (55.2-Gbps/lane) over 150-km NZDSF by adaptively decreasing the bits/subcarrier. Last, for the energy efficient priority, we demonstrate that energy saving is achieved proportionally to the number of disabled lanes, by achieving 100-G/1-lane transmission over the 35-km path. Thus, the proposed policy-based DMT transceiver is an attractive candidate for future metro-access networks and data center applications, featuring rate/distance adaptability, energy efficiency and cost-effective architecture.

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