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C+L-band Network Upgrade: Capacity and Energy Analyses with Different Transceivers

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***Abstract*—We investigate the trade-off between network capacity and energy consumption in optical transport networks with three different transceiver implementations. Also, we provide evidence that C+L-band systems have similar energy consumption while attaining comparable network capacity as adding a second optical fiber and using C-band only.**

***Index Terms*—Optical fiber communication, multi-band, transmission modeling, optical amplification**

I. Introduction

To cope with the continuous increase of network traffic boosted, for example, by the worldwide COVID-19 pandemic [1] and simultaneously limit the overall power consumption of telecommunication networks [2], high capacity as well as power-efficient transceivers (TRXs) are required. Furthermore, to increase the capacity of Wavelength-Division Multiplexing (WDM) systems – that nowadays operate in C-band only with a spectrum of around 4.8 THz – two techniques have been proposed: (a) spatial division multiplexing (SDM) and (b) band division multiplexing (BDM), which has also the potential to reduce the capital expenditure (CAPEX) [3]. The latter aims to exploit the full low-loss spectrum of the widely deployed ITU-T G.652.D optical fiber, which exceeds 50 THz [4]. Analyses have already been carried out regarding the power consumption of TRXs. In [5], the authors showed that the scaling of Intel's integrated circuit CMOS node size decreases every two years; and the CMOS power consumption depends on the node size, with an energy reduction of $\sim$30% in each process step [6]. In one of its latest implementation agreements (IA), the Optical Internetworking Forum (OIF) defined the 400ZR [7], which specifies a power-efficient and cost-effective coherent interface to support 400 Gbps using a symbol rate of 59.84 GBaud.

In this article, we compare the network capacity as well as energy consumption achieved by using SDM or BDM as well as different TRX implementations.

II. QoT Abstraction and Network Analyses

In this work, the COST network topology is considered, which consists of 28 nodes and 41 links [4]. A disaggregated abstraction of the physical layer based on the GSNR as QoT criteria is exploited in this network [8]. The launched optical power is first optimized to maximize the GSNR [9], calculated using the open-source library GNPy [10]. As a result, the average GSNR for the C-band only system (i.e., assuming the L-band is not used) is 30.28 dB; if both bands are used, the average GNSR decreases to 29.61 dB in the C-band and is 29.32 dB in the L-band. The statistical network assessment (SNAP), which is a Monte-Carlo-based software, is applied to derive the networking traffic and energy metrics [11].

TRX	mod. form.	Data rate [Gb/s]	Typical Reach [km]	P[W]
ZR [7]	16QAM	400	L<120	15
	16QAM	400	120<L<450	20
	8QAM	300	450<L<1500	18
	QPSK	200	1500<L<2500	16
	QPSK	100	2500<L	13
FF16 [12]	32QAM	500	L<200	42.5
	16QAM	400	200<L<1000	38
	8QAM	300	1000<L<2000	35
	QPSK	200	2000<L<4000	32
	QPSK	100	4000<L	35
FF20 [12]	32QAM	500	L<600	27
	16QAM	400	600<L<1500	22
	8QAM	300	1500<L<3500	20
	QPSK	200	3500<L<6000	18
	QPSK	100	6000<L	50

TABLE I: Transceivers modelling assumptions.

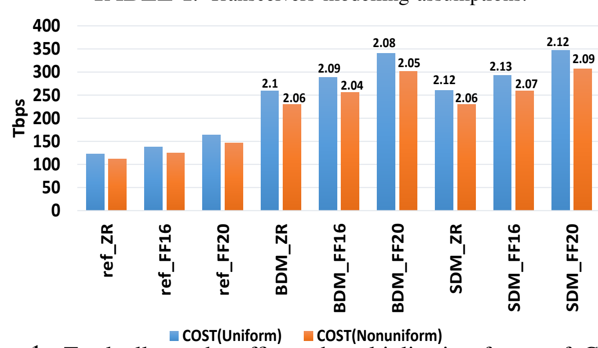
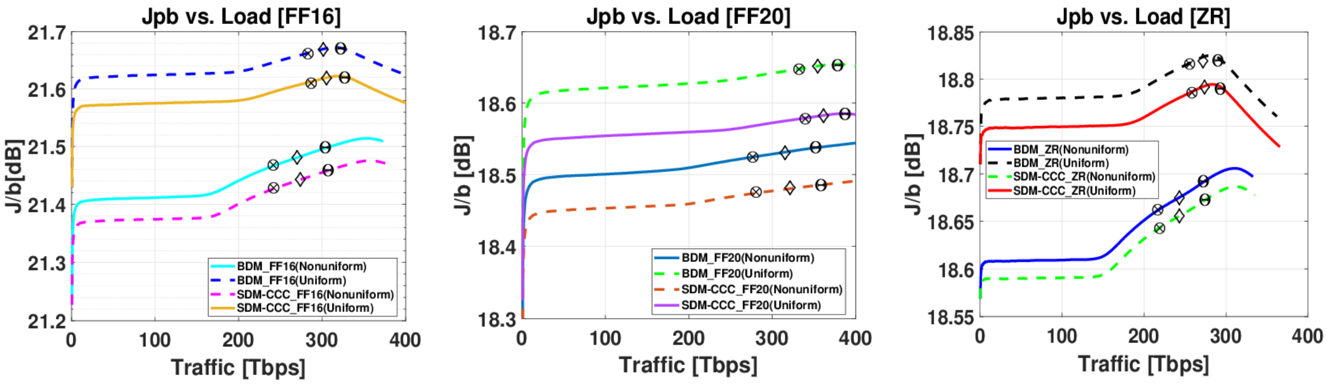


Fig. 1: Total allocated traffic and multiplicative factor of COST topology for different capacity upgrades and JPDFs at BP of 1%.

The network is progressively loaded with traffic following either a uniform or a nonuniform Joint Probability Density Function (JPDF) [4]. The number of SNAP Monte-Carlo runs was 30000, with the QoT-based First Fit (FF) wavelength assignment and the K-shortest path algorithm (with $K_{max} = 15$ as the number of alternative shortest paths between source and destination nodes) being used to solve the routing and wavelength assignment (RWA) problem. Table I reports the capacity and energy consumption for the three considered TRXs implementations (considering the operation of each TRX with different data rates and reaches): TRX Flex Format 16 (FF16) [12] models a TRX from the year 2016; FF20 is the prediction for a standard TRX in the year 2020 [12] and, finally, the ZR TRX is as defined in 400ZR IA of OIF [7]. As shown in Table I, the ZR[1] TRX supports 16QAM, 8QAM, and

[1]400ZR IA defines only 400G transmission with 16QAM < 120km. Nevertheless, it is a common assumption in the industry that the other modes will be possible and this is often designated as OpenZR+.



(a) (b) (c)

Fig. 2: Energy consumption per bit – as dB Joule per bit – versus total allocated traffic for (a) FF16, (b) FF20 and (c) ZR TRXs for SDM and BDM with uniform and nonuniform JPDF traffic distribution in COST topology. ⊗, ♢ and Θ identify the BP of 0.1%, 1% and 10%, respectively.

QPSK modulation formats characterized by different required OSNR (ROSNR) [13]. Maximum energy consumption of 20 W is assumed for this TRX when using 16QAM modulation format to reach a distance between 120 km and 450 km. However, FF16 and FF20 are assumed to support also 32QAM for shorter reach applications. Consequently, a maximum data rate of {400, 500, 500} Gb/s are attainable by ZR, FF16, and FF20 TRXs, respectively. For FF16, the maximum power consumption of 42.5 W is attained when using the most aggressive modulation format (32QAM) designed for short distances, i.e., $<$ 200 km. On the contrary, the maximum predicted energy consumption for FF20 is 50 W which is reached when using QPSK modulation format to bridge distances exceeding 6000 km, as a consequence of the increase of DSP power requirements to compensate for the transmission effects, such as the accumulated chromatic dispersion. Please note that both FF16 and FF20 TRXs are assumed to have an FEC overhead of 28%, but this parameter decreases to 15% for ZR TRX. During operation, the optimal modulation format with respect to the distances that they support is selected taking into account the lightpath (LP) QoT. Figure 1 reports the capacity of COST network with different capacity upgrades, namely SDM and BDM, with uniform and nonuniform JPDFs traffic distributions for all TRX implementations and compared with the reference case at the blocking probability (BP) of 1%. According to this figure, the increase of the average distance between nodes leads to a decrease in the network capacity in nonuniform JPDF or, in other words, increases the BP for the same offered traffic load. The analysis of Fig. 1 shows that nonuniform JPDF results in a decrease of capacity of around 40 $Tbps$. Importantly, the difference between using BDM and SDM as capacity upgrade strategies and the energy consumption is negligible. For instance, Fig. 2 presents the energy analysis for the COST network with different capacity upgrades and JPDFs. It is observable that the average energy consumption when using FF16, FF20, and ZR TRXs are {21.6, 18.6, 18.8} and {21.4, 18.47, 18.65} dBjpb in uniform and nonuniform JPDFs. This shows that the energy consumption difference between the two upgrade strategies is smaller than 0.2, 0.13, and 0.15 dBjpb in FF16, FF20, and ZR TRXs, respectively. This figure highlights that FF20 and ZR TRXs consume less energy in comparison to the older TRX (FF16) (about 3 dBjpb), which results from the node size decrease overtime [12]. Specifically, the ZR, FF16, and FF20 TRX implementations require a constant amount of energy to transfer a bit until reaching a total traffic load of about 170, 200, and 250 $Tbps$ in the uniform JPDF case, and of about 140, 162, and 200 $Tbps$ in the nonuniform JPDF traffic distribution. At BP = 1% all solutions approach the maximum required energy per bit: {18.8, 21.65, 18.6} Jpb and {18.7, 21.5, 18.54} Jpb [dB] for ZR, FF16, and FF20 using uniform and nonuniform JPDFs for traffic distribution, respectively.

III. Conclusions

We analyzed the COST network topology in terms of capacity and energy consumption per bit for two SDM-CCC (2×fiber) and BDM (C+L-band) capacity upgrade strategies and using ZR, FF16, and FF20 transceiver implementations. We showed that BDM and SDM have practically the same effect on the network capacity (more than doubling it when compared to single-fiber C-band); and energy consumption.

Acknowledgment

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