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Network Capacity and Energy Consumption: Transparent C+L-band vs Translucent C-band

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Abstract: The capacity and energy consumption of a transparent C+L-band network is compared to a translucent C-band. Although exploiting L-band needs doubling amplifiers, it is shown that C+L upgrade is more beneficial than deploying additional regenerators.
Keywords- *Multi-band, Transmission Modeling, High-capacity Optical Systems*

1. Introduction

In order to support the imminent 5G implementation, it is vital to increase the capacity of optical networks that nowadays mostly operate in C-band only with a spectrum of around 4.8 THz [1]. Elastic optical networks (EON) are already playing a crucial role by allowing to adapt the amount of spectrum allocated and the modulation format used according to the characteristics of each lightpath (LP). Traffic grooming is another key strategy being used to maximize the utilization of the deployed transceivers (TRX)s [2]. Simultaneously, overall power consumption limitations are an economic imperative for network operators, motivating them to use high capacity as well as power-efficient TRXs [3]. Energy consumption for different TRXs has been investigated in [4], also addressing the energy efficiency increase enabled by the envisioned node size decreasing of CMOS integrated circuits. Optical interface technology is progressing in terms of both performance and integration, with the Optical Internetworking Forum (OIF) recently releasing an implementation agreement (IA) for pluggable form factors based on coherent-detection [5]. Despite this progress, the continuous traffic growth will lead to capacity exhaustion. Rolling-out or leasing additional fibers is a solution to cope with this issue, but it is often the last resort, particularly in long-haul and regional networks. Alternatively, operators have two main options to increase capacity in the short-term: (i) upgrade their line systems to support C+L-band; or (ii) make use of regenerators to increase the capacity and spectral efficiency of LPs, thereby adopting a translucent design approach. In [6], optical power adaptation in translucent optical networks has been investigated by extending the generalized multiprotocol label switching (GMPLS) to support optical regeneration. In this work, we compare the capacity and energy consumption of two main network designs: C+L-band transparent and C-band translucent. A traditional transparent network design is analyzed with Flex rate TRX, via adapting the modulation format to the LP quality-of-transmission (QoT), whereas a translucent network design is used with Fix rate TRXs, resorting to intermediate regenerators for error-free end-to-end transmission. A statistical network assessment [7] over the German reference network topology with uniform traffic distribution [8] is reported. In order to show the network capacity limit, we also investigate the network performance when employing ideal elastic TRXs operating at the Shannon limit for the transparent network in the C-band only. The transparent network design (Flex) is considered for both C- and C+L-band scenarios, whereas translucent network design (Fix) is evaluated only for the C-band case.

2. Methodology and Results

We model transparent LP by considering two Gaussian disturbances: the amplified spontaneous emission (ASE) noise from amplifiers and the nonlinear interference (NLI) from nonlinear crosstalk in fiber propagation. In this scenario, the QoT at the end of each fiber span can be estimated by the generalized signal-to-noise ratio (GSNR) [8]. Following a disaggregated approach [9], the QoT of the LP can be determined by: $\text{GSNR}_{i,\text{total}} = 1/\sum_{s\in L}(\text{GSNR}_{i,s})^{-1}$, where $\text{GSNR}_{i,s}$ denotes the GSNR degradation for the i_{th} channel under test over the LP element s. In Fig. 1 we present the GSNR profile for a 75 km span of a standard single mode fiber (SSMF) for the C- and C+L-band transmission scenarios. It is clear that in the C-band only scenario the value of QoT is about 1 dB higher than in the C+L-band case. This is because of the stimulated Raman Scattering (SRS) [10], which transfers power from the C- to the L-band channels. Table 1 presents the TRXs characteristics. Flex TRXs support three different modulation formats with different power consumption depending on the reach, while Fix TRXs supports only the 16QAM, with two different power compensations. Flex TRXs are used in the transparent solutions and Fix TRXs are used in the translucent scenario. In the translucent case and using SNAP framework [11], regenerator assignment between source and destination nodes is done when the LP exceeds either the reach limitation (set by the max chromatic dispersion the TRX compensates for) or the minimum required GSNR of 16QAM modulation format [12].

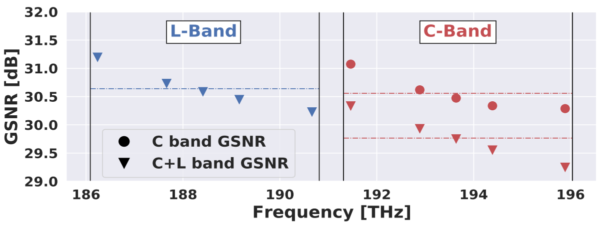

Fig. 1. GSNR profiles for a single 75 km span in C and C+L band transmission.

Table I: TRXs modelling assumptions

TRX	mod. form.	Data rate [Gb/s]	Typical reach [km]	P[W]
Flex	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
Fix	16QAM	400	L<120	15
	16QAM	400	120<L<450	20

Fig. 2 shows the total allocated traffic as well as the average consumed energy for the considered network design scenarios. The energy consumption is calculated based on the number and type of deployed TRXs, on the format they are operating and on the number of amplifiers in use. Noteworthy, the number of sites with amplifiers is 72 when considering the DT network [15] with 75 km spans. We assume each C- and L-band amplifier consumes 20 Watt [13, 14]. Transparent Flex C is assumed to be the reference case, in both Fig. 2(a) and Fig. 2(b), having the highest blocking probability (BP) and the lowest energy consumption, respectively. As can be seen, C-band translucent enlarges the capacity of the network slightly but at the expense of adding regenerators, which further increases energy consumption. Conversely, enabling the L-band decreases the BP significantly and with a relatively minor increase of energy consumption. For example, at the BP of 1% the total allocated traffic is about 70, 100, 170, and 200 Tbps for the transparent C-band, translucent C-band, transparent C+L band and Shannon limit, respectively. In other words, using transparent C+L-band allows to increase capacity by more than $\times 2$ times and by 70% when compared to using the C-band only with a transparent and translucent design strategy, respectively. Implementing a translucent network design in the C-band enables to increase capacity by approximately 43%. When observing Fig. 2(b), it is clear that adding the L-band amplifiers increases the energy consumption by a fixed value. It is considerably smaller than the increase of around 4 dB observed when additional TRXs are used for signal regeneration as a means to improve spectral efficiency.

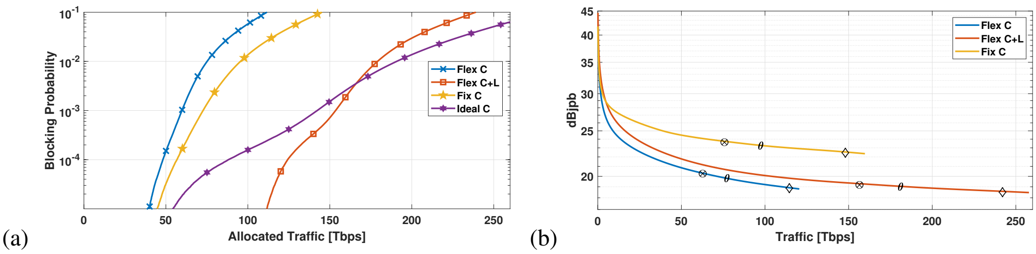

Fig. 2. a) Total allocated traffic [Tbps] in the BP range of 10^{-5} to 10^{-1}; b) energy consumption [dBjpb] in different network designs. $\otimes$, θ, and $\diamond$ indicate the BP of 0.1, 1, and 10%.

3. Conclusions

In this work, we provided evidence that adopting a translucent network design to enable higher order modulation formats via intermediate signal regeneration has a limited impact in capacity increase and leads to a significant increase of power consumption. Exploiting the C+L-band and flexible transceivers is shown to be clearly more effective, enabling a capacity increase of at least two-fold, while demanding a minor increase of energy consumption due to having to deploy dedicated L-band amplifiers.

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