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Flexible and Autonomous Multi-band Raman Amplifiers

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***Abstract*—We propose an embedded controller able to autonomously manage Raman amplification in software-defined optical networks. The conceived structure allows the system to work both in single and multi-band transmission, achieving a large range of amplification constraints. A set of experiments validates this proposal.**

***Keywords*—Raman amplification, multi-band transmission, optical networks, SDN**

I. INTRODUCTION

In the field of optical communications, Raman amplifiers have become essential devices to realize broadband, long-haul transmission systems [1]. Indeed, Raman amplification allows to achieve a lower noise contribution with respect to erbium-doped fiber amplified (EDFA) only system, having a remarkable impact on transmission performance [2], [3]. Furthermore, this technique seamless applies to multi-band transmission, bringing to the exploitation of very dense input spectra [4]. It is also possible to create hybrid high-performance amplification systems that can handle multi-band optical transmissions by adopting the combination of Raman and EDFAs [5], [6].

This work aims to provide a possible architecture of a local embedded controller capable to autonomously handle Raman amplification within an optical network based on multi-band C+L line systems with a high degree of flexibility and adaptability. The proposed system is addressed to the implementation of the software-defined networking (SDN) paradigm [7] down to optical transport, and relies on an optimization software developed for coping with amplification requirements coming from the control plane in order to autonomously manage both single and multi-band transmission. This prospect has been implemented in laboratory and validated through a set of measurements to test the operating behavior of the proposed Raman amplifier architecture.

II. CONTROLLER ARCHITECTURE & EXPERIEMNTAL SETUP

In this section, the conceived embedded controller architecture and the experimental setup built to emulate and validate the operating behavior are illustrated. Within an optical network, the control plane computes and imparts the required amplification constraints at each amplification site (Fig. 1a). In order to uniquely define the required gain mask, we assume that a mean gain target and a tilt target are provided to each Raman amplifier. Raman cards (Fig. 1b) are equipped with an on-board software that is composed by two different units: the Raman Design Unit (RDU) and the Raman Control Unit (RCU). The RDU defines the Raman pump power configuration that achieves the gain mask target computing the optimal working point of the Raman amplification site on the base of physical layer data acquired during an appropriate probing procedure. In the optimization procedure, only inter-pump effects are considered, neglecting the contribution of the channel spectral load. Consequently, the RCU sets Raman pumps and tracks the mean gain operating an analytical linearization around the optimal working point that relies on the evaluation of power gradients with respect to the gain variation. This function allows the system to be self-adaptable in case of spectral load variations or scenario modifications, such as fiber cuts or component aging. In this way, the RCU controls Raman pumps in order to match the mean gain with the target one thanks to telemetry data received by optical channel monitors (OCMs). The proposed controller architecture gives noticeable advantages as the adaptability to physical link

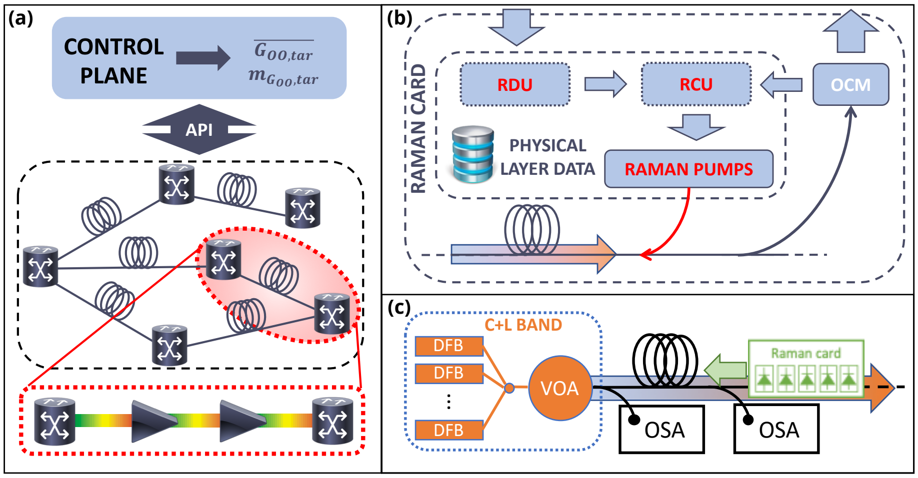

Fig. 1. Representation of the embedded controller architecture: (a) network contextualization, (b) amplification site scheme, (c) experimental equipment.

characteristics and a high flexibility in relation to channel spectral load variations. The optimization framework enables the system to work both in multi-band and in single-band transmission depending on the network request. In addition, the controller is able to obtain a received channel spectrum with a specific tilt, in order to have a pre-tilted power launch in the next fiber span.

The experimental set-up built to test the operation of the controller architecture on a single fiber span is sketched in Fig. 1c. The input wavelength division multipling (WDM) spectrum is composed by a distributed feedback (DFB) laser comb of 38 channels in L-band and 36 channels in C-band. Variable optical attenuators (VOAs) allow to shift the power level of the C+L WDM spectrum and to switch off the L band in order to emulate single-band transmission. The comb has been configured to obtain a flat WDM spectrum with lauch power equal to 0 dBm per channel. The standard single mode fiber (SSMF) span link has a nominal length of 85 km. 5 counter-propagating Raman pumps with frequencies between [200 - 210] THz are installed at the receiver terminal. An optical spectrum analyser (OSA) has been used to collect and provide the telemetry feedback.

III. RESULTS & CONCLUION

After the required probing procedure, several experiments have been carried out in order to verify the operative behavior of the controller upon the equipment both in multi-band and in single-band transmission, imparting different amplification constraints. In particular, we tested the system in multi-band transmission (C+L band) reaching the gain target ($G_{oo,tar}$) to 10 dB, i.e. almost half of the link loss (about 18 dB), and modifying the tilt target in order to restore the flatness of the WDM spectrum or to obtain a pre-tilt for the hypothetical next fiber span. Then, the L band has been turned off and the Raman pumps have been optimized to work in C-band only with the target of achieving flat output WDM spectrum and recovering 7 dB of the fiber loss. The outcomes collected after the completion of the control sequence are reported in Fig. 2. Having set the tracking tolerance equal to one tenth of the gain target, we observe that the optimized gains (G_{oo}) strictly match the relative requirements. Then, considering the tilt (m), defined as the angular coefficient of the linear regression of the output WDM spectrum, the required tilt target (m_{tar}) constraint is achieved in all the cases both for multi-band and single-band transmission.

In conclusion, we propose an embedded local controller that allows to autonomously manage Raman amplification within optical networks in any amplification site. The architecture enables the optical communication system to work both in single or multi-band transmission, avoiding issues related to depletion effects of the spectral load or modifications of the installed equipment. The proposal has been validated by means of an experimental campaign that proves the fulfilling a large range of amplification constraints from the conceived control system.

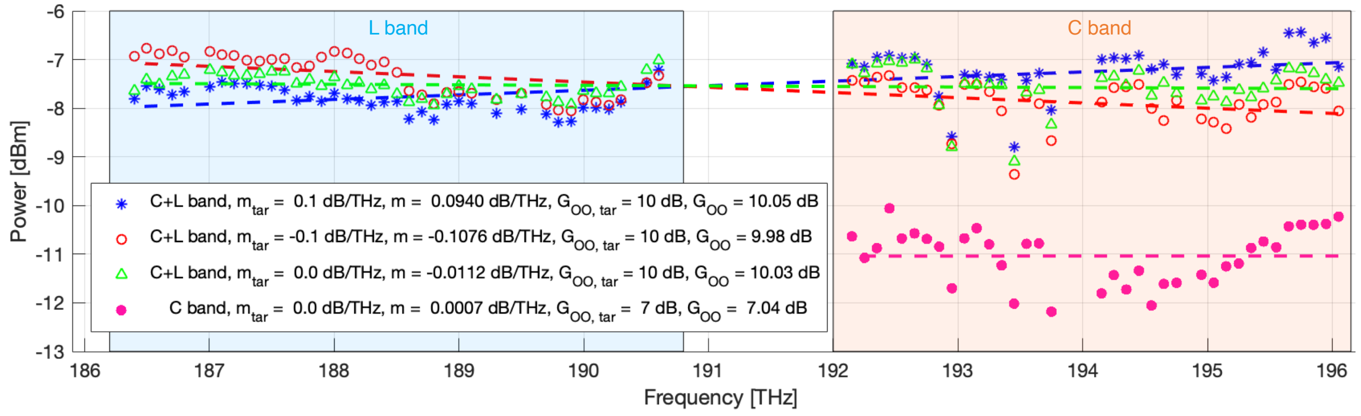

Fig. 2. Experimental results: received power spectrum for different amplification constraints both in multi-band or in single-band transmission.

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