Remotely Reconfigurable Remote Node for Hybrid Ring-Tree Passive Optical Networks

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***Abstract*—An improved passive remote node (RN) configuration for hybrid ring-tree passive optical networks is presented. This novel RN is remotely reconfigurable allowing minimizing the total power in the fiber and increase resilience to fiber cuts.**

I. INTRODUCTION

Passive optical networks (PONs) are becoming consistent alternatives to offer access solutions in a fiber-to-the-home (FTTH) environment. Flexibility, scalability, resiliency, higher user density and bandwidth, robustness and extended reach are important features for the next generation PONs (NG-PONs), while maintaining simplicity to make the network economically practicable [1]. Scalable Advanced Ring-based passive Dense Access Network Architecture (SARDANA) is an attempt to demonstrate how to exploit NG-PON in a cost effective and reliable way, allowing migration from the current deployed Ethernet PON (E-PON) and Gigabit PON (G-PON). SARDANA network is able to reach more than 1000 users spread over 100km, with symmetric 100Mbit/s per user [2]. This network consists on a hybrid wavelength division multiplexing (WDM) double ring and time division multiplexing (TDM) tree topology connected by means of a remote node (RN) which guarantees the scalability of the network. The RNs are transparent to all wavelengths but the ones to be dropped for its fed trees, providing low passing losses. Dropping wavelengths that require optical amplification to bypass the splitting losses, will be regenerated using erbium doped fibers (EDFs) remotely pumped from the central office (CO) [3]. The high amount of pump power required to the CO is a critical parameter of the network and the resiliency of the network in case of fiber cut in the ring is not still completely guaranteed.

In this paper we analyze the impact of different doped EDFs on the efficiency of the network and we propose an optimized RN able to reduce the total pump power demanded to the CO.

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II. NETWORK AND RN ARCHITECTURE

The SARDANA topology is presented in Fig. 1.a). SARDANA WDM is implemented by a fiber pair to optimize the spectrum and avoid the Rayleigh Backscattering distortions [4]. One fiber carries the downstream (DS) WDM signals and the other the upstream (US) WDM signals. The light generation and control are centralized at the CO leading to a completely passive outside plant.

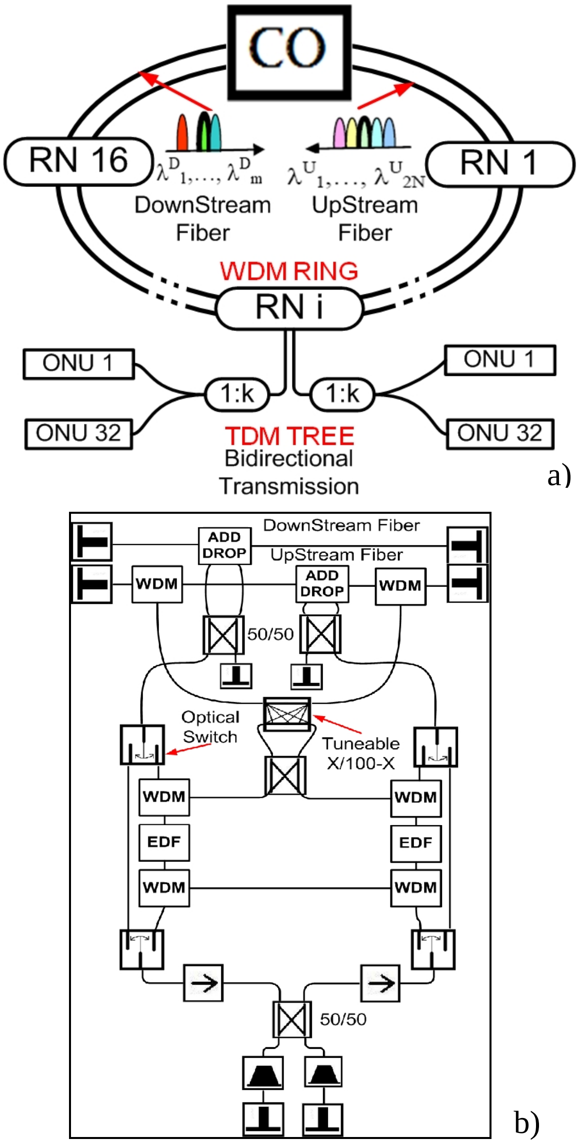

Fig. 1.a) SARDANA architecture
b) RN topology proposed in [5]

The RNs establish the connection between the double-fiber-ring and the single-fiber-trees and are able to Add&Drop and distribute to each access tree the assigned wavelengths being transparent to the other WDM channels on the ring. The RNs are able to compensate distance from the CO, Add&Drop and filtering losses providing gain by means of EDFs, remotely pumped from the CO. Simple Optical Network Unit (ONU) implemented with a colorless Reflective Semiconductor

Optical Amplifier (RSOA) provides US remodulation at the same wavelength as for the DS signal [3].

Figure 1.b) presents the RN topology proposed in [5]. For RNs close to the CO, the DS signals can reach the ONU with power enough that amplification is not required. In case of extreme fiber cut, at one of the sides of the ring, those RN will be no longer the closest to the CO but the farthest and amplification must be provided to the signals. This configuration has in mind the distance from the CO being possible the selection between amplification and a non amplification module by means of latched optical switches. Other characteristic of this RN topology is the introduction of a tunable power splitter responsible for a fairer and adjustable pump power distribution among the RNs [6].

III. EDF EFFICIENCY

The total amount of pump power demanded to the CO is an important limitation of the network. The RN topology presented in fig.1.b) has demonstrated significant efficiency improvement [5]. Thus, in order to further improve the system it is necessary to optimize the EDF characteristics to operate at the highest efficiency leading to lower pump power requirements to the network.

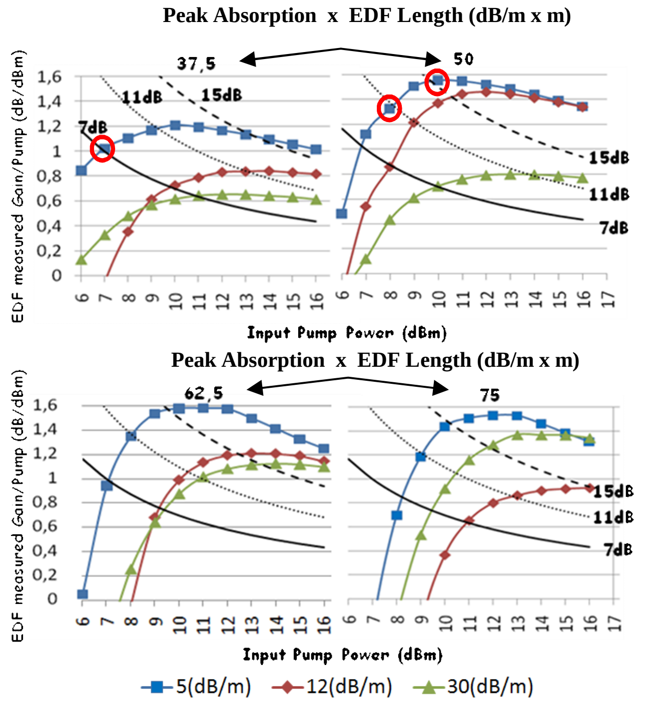

Fig. 2 Signal gain efficiency and remaining pump power as a function of the supplied pump power for EDFs with peak abortion of 5, 12 and 30 dB/m. Highest efficiency for 7, 11 and 15dB of signal gain.

Figure 2 presents the gain efficiency characteristics of three EDFs with different peak absorption of 5, 12 and 30dB/m. The lengths of the EDFs are adjusted to satisfy the product between the Peak Absorption and the EDF length to the constant values of 37.5, 50, 62.5 and 75.

Three scenarios were identified: the tree needs 7, 11 or 15 dB of gain. The optimized operation points to achieve highest efficiency for signal gain of the referred scenarios are marked in the figure. The highest efficiency for the three cases is achieved with the EDF with lower peak absorption of 5dB/m.

Since the EDF with 5dB/m is the most efficient a more extensive analysis is presented in the figure 3. The figure presents the signal gain and the reminiscent pump power in dependence of the input pump power for EDFs lengths of 7.5, 10, 12.5 and 15m.

For 7dB of gain, the most efficient length is for 7.5m, requiring 7dBm of pump power leading to a reminiscent pump power of 3dB. For 11 and 15dB of gain the most efficient length is for 10m requiring 8 and 10dBm leading to reminiscent pump power of 3 and 7dBm respectively. From these results, it can be seen that the reminiscent pump power from the 7 and 11dB of gain is not enough to supply a second EDF, although the reminiscent pump power from the 15dB gain is able to be redirected to a second EDF. This is an important factor developing the amplifiers configuration since it can lead to an optimal low pump requirement multiple amplifiers.

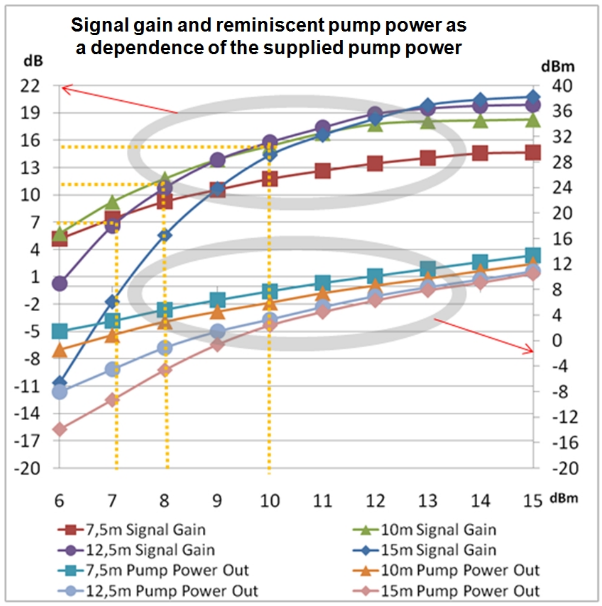

Figure 3: Signal Gain and pump reminiscent in function of the input pump power and EDF length.

Comparing the operation points with highest efficiency with the operation points used in [5] it can be noticed that it requires less 4dB of supplied pump power to obtain the same gain of 15dB, due to an increase in the efficiency of the amplifier resulting from the usage of a different fiber.

IV. IMPROVED RN

Considering the operation points with highest efficiency, some improvements can be applied to the RN proposed in [5].

Despite of the ability of the RN to select between amplification and non amplification module, for different distances from the CO, different gain is required. Having in mind the previous goal, an improved RN topology is presented in the Fig. 4.a).

This proposed RN topology is able to select a different EDF optimized to the necessary gain for the operation mode of the network, reducing the total amount of pump power required per RN, increasing the total efficiency of the network. Other improvement presented is related to the usage of circulators instead of power splitter at the tree side of the RN saving an extra 3dB thinning the required gain per RN.

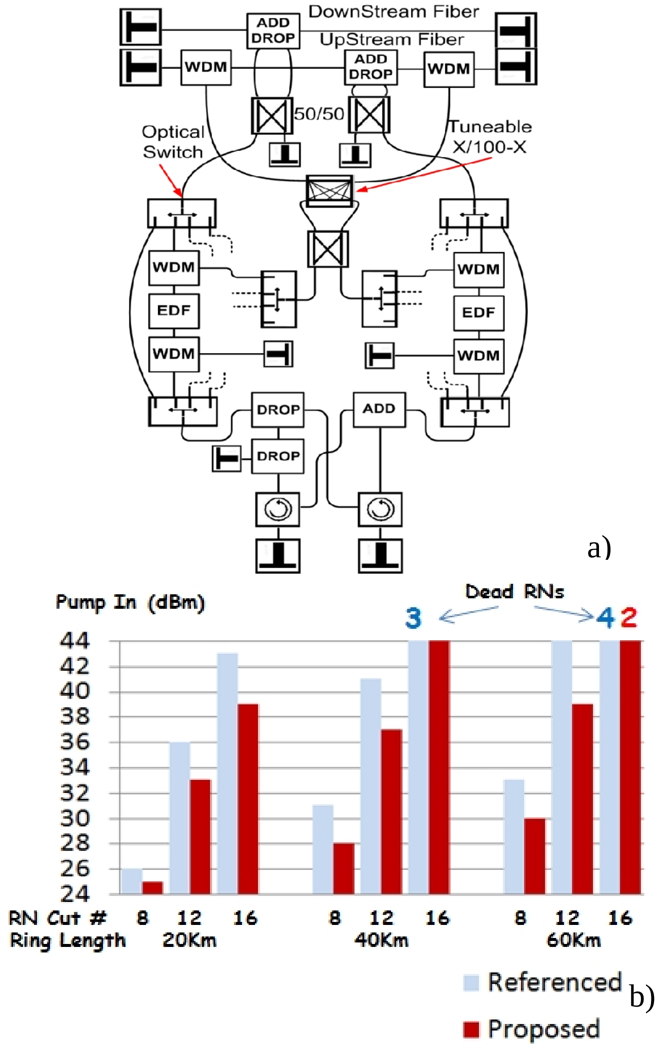

Fig. 4.a) Proposed RN topology b) Pump Power supplied by the CO and the number of Dead RNs (RN with not enough pump power for amplification for different network operations).

For the optimized operation points with 7 and 11dB of gain, the remaining pump power is 3dBm. It is low pump power to reintroduce in the network or to supply to other EDF, so it is used to convert to electrical power by a special harvesting device and stored electrically in order to be used to control the switches not requiring any external power source, keeping the network fully passive[5,6].

V. RECONFIGURABILITY

An important component in the reconfigurability of the network is the power converter, control and harvesting module [6-7].

The figure 5 represents a block diagram of the equipment in the module and the states of operation. An optical signal is supplied to the photodiode present on the module being part of the converted electrical signal lead to a control unit by means of an RF component and the mainly part of the energy is supplied to an Energy Reclamation Circuit to be stored and used to control the switches.

For these power convertor and harvesting modules the efficiency is higher for input optical powers between -7 and 0dBm and the output electrical power is higher for higher input optical power, so, the best operation point of this conversion unit is for 0dBm [8]. Experimental tests made on this modules demonstrated the a possibility to control the unit with power as low as -25dBm, although, the minimum power for harvesting is much higher than that, what can be difficult to achieve if multiple modules of those are implemented in a very large network. Different topologies are being considered in order to increase the efficiency of the module and allow harvesting with lower input powers. Some similar equipment had been proposed in [6].

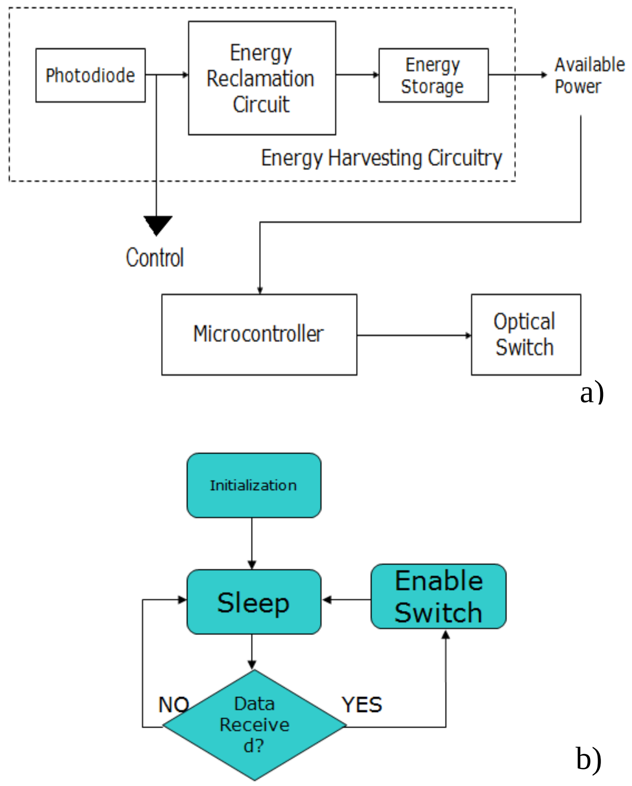

Figure 5 a). Schematic of the harvesting and control module and b) the micro controller states.

VI. SYSTEM SET-UP AND RESULTS

In order to compare the impact of each configuration on the network, the pump power supplied by the CO and the number or dead RN's (RNs with not enough pump power to provide amplification) are calculated for the different networks operations as fiber cut at RN 8, 12 and 16 (considering the network presented in fig 1.a). The proposed compared RN topology can provide 7, 11 or 15dB of signal gain depending on the distance from the CO and the operation of the network.

In Fig. 4.b), a comparison between the referenced and the proposed RNs topologies is presented for 20, 40 and 60Km ring length. For normal operation of the network, or fiber cut at RN 8, there is a reduction of the supplied pump power in 1, 3 and 3dB and for fiber cut at RN12 a reduction of 3, 4, and 5 dB respectively for 20, 40 and 60km. For extreme resilience operation, or fiber cut at RN 16, there is a reduction of 4dB for 20km and a reduction of dead RNs of 3 and 2 respectively for 40 and 60Km.

VII. CONCLUSIONS

The SARDANA project architecture provides flexibility, scalability, resiliency, higher user density and bandwidth, robustness and extended reach that are important features for next generation dense FTTH networks also called NG-PONs.

EDFs are important components in the RNs, since they limit the efficiency of the network. An analysis to different EDFs with different parameters has been demonstrated. Low doped erbium concentration (5dB/m of peak absorption) is the most efficient solution to provide 7, 11 and 15 dB of signal gain.

The characterization of different EDF's pump usage efficiency led to the conception of an improved RN design, able to select the adequate EDF length to the required gain, improving the pump usage and decrease the total power in the fiber for granting full resilience and improved functioning.

With the implementation of this novel topology, the network can be totally resilient for 20 and 40Km, and reduce in 2 the number of dead RNs for 60km in extreme resiliency. At normal operation mode, the network demands less 1, 3 and 3dB of pump power from the CO respectively for 20, 40 and 60km.

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