

C+L Band Gain Equalization for Extended Reach WDM-Ring PON Using Hybrid Raman / in Line EDFA Amplification

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ABSTRACT

In this paper, we investigate by simulation the feasibility of gain enlargement and equalization on extended reach WDM-ring PON by means of hybrid Raman/EDFA amplification. The system under analysis is composed by a bidirectional pump at 1480 nm and 16 channels (8 C band + 8 L band). The simulation describes an 80 km WDM ring with 8 nodes in which 2 channels are added/dropped. The results demonstrate gain equalization with a ripple of 2.54 dB over a bandwidth of 50 nm by using a 1480 nm bidirectional pump with 1 W and spans of EDF with a total length of 22 m.

Keywords: Extended reach access networks, optical amplification, Erbium Doped Fiber Amplifiers (EDFA), Raman Fiber Amplifiers (RFA), gain enlargement and equalization.

1. INTRODUCTION

Access solutions have become an important research topic in telecommunications as they can provide low cost services operating over high bandwidths. The full utilization of C band has pressed out the development of optical amplification technologies that provide wider optical bandwidth, namely the C +L band, which are nowadays under intensive research [1]. In the context of access networks, such as WDM ring Passive Optical Networks (PON), (see Fig. 1), extended reach and high splitting ratios require amplification between Optical Line Terminal (OLT) and the Optical Network Units (ONU), performed remotely in conjunction points at the ring, referred to as the Remote Nodes (RN) [2]. Hybrid Raman/EDFA are eligible solutions to work in such scenarios because they can maximize the span length and enhance the bandwidth of the EDFA.

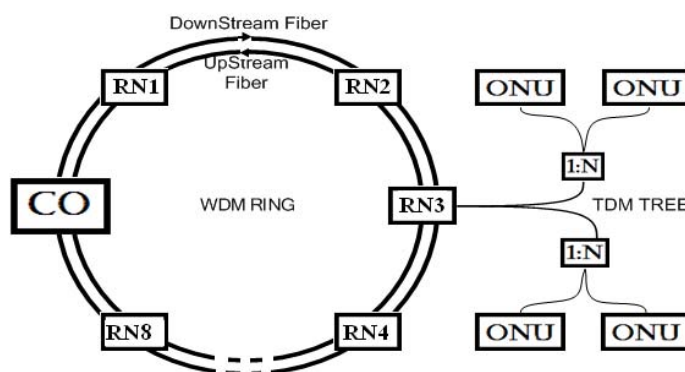


Figure 1. WDM ring PON scheme.

The system under analysis is a WDM ring 80 km long with 8 equally spaced nodes conceived for rural scenario in normal operation mode. In the central office (CO), a bidirectional laser emitting at 1480 nm is used to pump 16 channels spaced by 400 GHz (8 C band + 8 L band) comprised between 192.5 THz to 186.3 THz. The channels leave the central office with 0 dBm of optical power. The transmission has accounted for that the bypass losses are 0.53 dB for channels and 1.01 dB for the pump, being the attenuation of channels and pump are 0.20 dB/km and 0.25 dB/km, respectively. The channels drop losses are 3 dB. In the above described frame, two situations are analyzed, one with Raman amplification and the other with a hybrid amplification scheme composed by in line EDF with Raman. Hence, an optimized span of Erbium Doped Fiber (EDF) is inserted in the mid length of each link according to the dropping channels powers. This procedure was performed with total pumping power equal to 1 W (500 mW in each direction). The results are compared in terms of gain ripple and total amount of EDF span, being their suitability for practical PON analyzed.

2. METHODS AND RESULTS

The 16 analyzed channels with the exception of the last two rely on the maximal bandwidth of Raman gain efficiency; see Figure 2 where the Raman gain efficiency spectrum is plotted for a Standard Single Mode Fiber (SSMF) pumped at 1480 nm, being the C and L channels represented by black and red arrows, respectively.

The strategy followed for the optimization is then the following: (i) drop the channels with the higher gain firstly to settle a maximal gain level and decrease the effect of pump depletion, (ii) whenever the channel power reduction surpasses a predefined value, try several span of EDF fiber in the mid-link to minimize the gain ripple. The obtained optimized results were also compared with simple Raman amplification. The simulation is based on the implementation of Raman propagation equations [3] and the Saleh [4] model for EDFA using the semi-analytical average power analysis method [5-6]. This method enables us to obtain quick and accurate solutions.

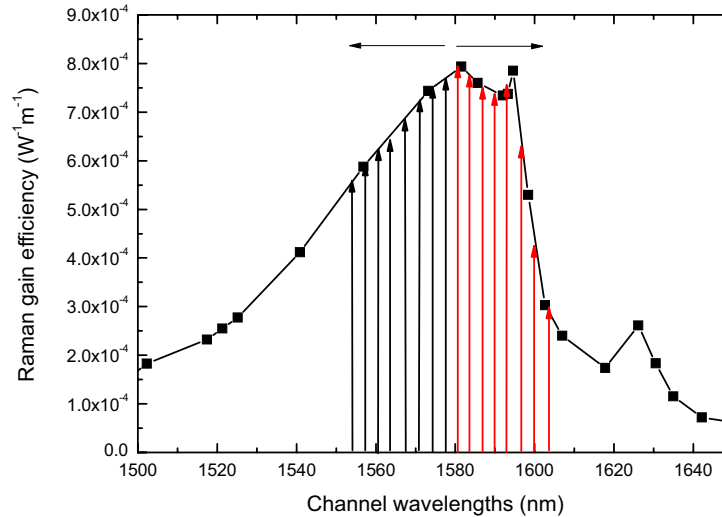


Figure 2. Raman gain efficiency for pumping at 1480 nm. The channels are represented by arrows (black-C band and red-L band). The curve was obtained by interpolation of experimental data [7].

The optimal dropping order is listed in table 1, which corresponds by dropping firstly the channels in the maximal Raman gain efficiency and then move outwardly, as assigned in Figure 2.

Table 1. Channel dropping order along the ring (2 channels per node).

	RN #	f_1 (THz)	f_2 (THz)
C band	1	190.1	190.5
	2	190.9	191.3
	3	191.7	192.1
	4	192.5	192.9
L band	5	189.3	189.7
	6	188.5	188.9
	7	187.7	188.1
	8	186.9	187.3

The results for total pumping at 1 W (500 mW for each direction) are depicted in figure 3. The top graph displays the power after dropping spectra for optimized hybrid Raman/in line EDFA and simple Raman, being the middle graph the optimized EDF span and their position in the ring (in relation to the central office CO). The bottom graph displays the power available to pump the spans of EDF. On looking at the simple Raman results, we verify that just by choosing a dropping order compliant with the maximal Raman gain efficiency, the power is considerably flat in the 1567 – 1590 nm range and then decreases as the channels wavelength move away from the maximal gain efficiency. On those aparted links, the insertion of span of EDF fiber is able to increase to power above the 0 dBm threshold. It must be noted that in order to provide gain in L band higher spans of EDF are used. On looking at the pump power results, we notice that due this methodology, the available pump power in distant links is still high enough to pump the EDF spans. Hence, in the hybrid approach a total span of EDF equal to 22 m is used (2 m for C band amplification and 20 m for L band amplification) to attain a ripple of 2.54 dB over a bandwidth of 50 nm.

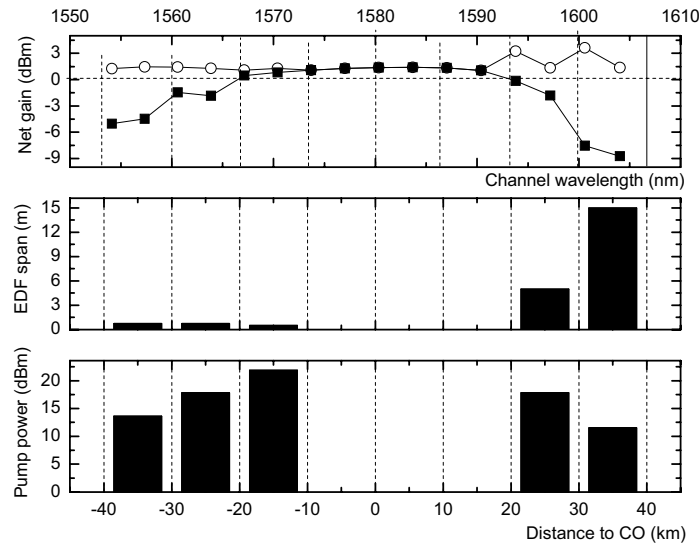


Figure 3. (Top)- Net gain dropping spectrum after dropping. Squares- simple Raman. Circles- optimized hybrid Raman/ in line EDFA. The horizontal dashed line settles a detection threshold. (Middle)- Optimized spans of EDF and their positions along the ring. The vertical dashed lines are used to place the dropped channel wavelength along the ring. The total pump power is equal to 1 W. (Bottom) – Available power to pump the EDF along the ring.

3. CONCLUSIONS

We investigated the feasibility of gain enlargement and equalization for hybrid Raman/EDFA amplification solutions in a 80 km WDM ring scenario working in normal operation mode. This survey employs 16×400 GHz channels for a rural scenario in the C + L transmission bands. The methodology uses a dropping order that explores the potentialities of Raman gain efficiency and optimizes the necessary EDF spans in order to have equalized gain. The method was able to obtain a ripple of 2.54 dB over a bandwidth of 50 nm using a bidirectional pump at 1480 nm with a total power of 1 W and 22 m of EDF

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