Performance of Hybrid Optical Amplifier and Conventional Optical Amplifier in the Scenario of Long Haul Ultra-Dense Wavelength Division Multiplexed System

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***Abstract*— A Hybrid Raman-Erbium Doped Fiber Amplifier (Raman-EDFA) is employed for increased distance in an Ultra Dense WDM (U-DWDM) system of 96 channels transmitted at ultra-narrow channel spacing of 0.1nm. It is reported that with the optimal span of 60km of Single Mode Fiber the offered Raman-EDFA achieves the total link distance of 2070km as compared to 1794km obtained by EDFA. The acceptable BER and Quality Factor (15.43dB) is reported. It is recommended that Raman-EDFA does perform well even in extended long haul communication in an Ultra-DWDM system for better performance and high capacity.**

***Index Terms* — Raman-EDFA, Hybrid Optical Amplifier (HOA), Erbium Doped Fiber Amplifier (EDFA), Dense Wavelength Division Multiplexed System (DWDM), Long Haul Communication**

I. INTRODUCTION

The advanced high capacity Dense Wavelength Division Multiplexing transmission easily utilizes the entire low loss wavelength region of fibers [1], [2]. This technology solves the problem of increasing the communication channels without deploying new cables. The conventional optical amplifiers, such as, an Erbium doped fiber amplifier (EDFA), Semiconductor optical amplifier (SOA) and Raman amplifier are the vital components for DWDM system [3-5].

Raman amplifiers comes as a solution for high capacity systems as it has attracted huge attention in recent years as an enabling technology for future long haul high capacity optical systems due to range of its practical and potential advantages [6]. Also SOAs and EDFAs are attractive in WDM networks since they feature the extremely high on-off ratios and increase the transmission distance [7].

Hybrid Optical Amplifiers (HOA) are an enabling and promising technology for future DWDM systems as it allows for larger spans and closer channel spacing [8]. The HOAs are designed in order to maximize the bandwidth of optical communication system. Unfortunately, the investigation of Hybrid Optical Amplifiers at U-DWDM system at ultra-narrow channel spacing over long haul transmission distance is more to be investigated. Various experiments have been conducted using HOAs for short and long haul DWDM system with different channel spacing. A long-haul transmission of 16 × 10 Gbit/s over single-mode fiber (SMF) of 1040 km using combined Raman and linear optical amplifiers as inline HOAs was demonstrated [9]. This work was limited to number of channels with channel spacing of 100 GHz. Error-free DWDM transmission of 43 Gbit/s DPSK signals over 1200 km of NZ-DSF with 50 GHz channel spacing and no inline dispersion compensation was conducted [10].

Super-DWDM system was investigated and a transmission experiment with a channel spacing of 25 GHz over 320km (80 km × 4 span) of standard SMF without dispersion compensation was conducted[1]. This experiment was limited by the transmission distance and number of spans. These reported models cannot be used to design Ultra- high capacity DWDM system as they are limited to the number of channels or channel spacing (> 0.2 nm) and mostly are with conventional amplifiers only. The above quoted work is extended by transmitting 96 optical channels at 0.1nm spacing for extended distances and comparing the system performance using both Hybrid Optical Amplifier (HOA) and with a Conventional Optical Amplifier (COA).

In this paper, the above researches are extended by illustrating the Raman-EDFA HOA in scenario of large closely spaced channels over extended/increased long haul communication.

The paper is organized as follows. After the introduction, Section II describes the system set up .Section III discusses the results and section 1V gives the conclusions.

II. SYSTEM SETUP

The system setup for long haul communication using Hybrid Raman-EDFA and conventional EDFA is shown in Fig.1. Each DWDM transmitter transmits 96 x 2.488Gbps optical channels with channel spacing of 12.5 GHz (0.1 nm) starting from 1536nm. The data stream from a pattern generator (2^7-1) with a NRZ binary sequence is pre-coded

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and drives a sine squared amplitude modulator. The pseudo random binary sequence generator (PRBS) sequence is rotated between each of the output ports so as to decorrelate them from each other for all the 96 user channels. Each input probe is optimized and launched with input power of -10dBm to balance the OSNR (optical signal to noise ratio) and nonlinear effects. A long haul system composed of N spans is considered.

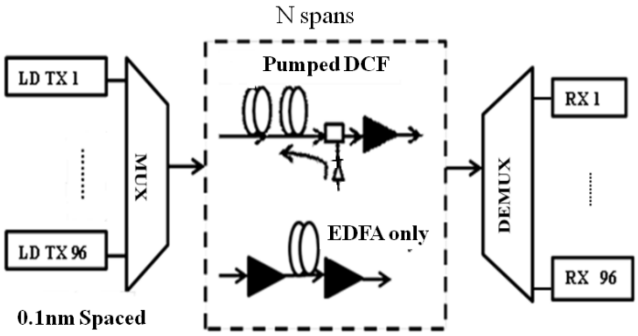

Fig.1. Setup for long haul 96 channel DWDM with Raman-EDFA HOA

The fiber length parameters are L_{span} for the Standard Single Mode Fiber (SSMF) and L_{DCF} for the Dispersion Compensated Fiber (DCF). DCF is used to compensate for the link dispersion. The total link length is given as in (1) below.

$$L_{total} = N_{span}(L_{span} + L_{DCF}) \quad (1)$$

The loss of 0.25dB/km exists in Raman pumped DCF (RDCF) with pump wavelength at 1449nm and pump power of 600mW.The effective area of DCF is 21µm^2. A pumped DCF establishes amplification and dispersion compensation in one entity [8]. Each span has SSMF with dispersion of 16ps/nm/km and DCF with negative dispersion of 106.56ps/nm/km and EDFA with fixed gain of 22dB and noise figure of 4dB. The DWDM system with conventional amplifier includes SSMF followed by two stages EDFA with DCF for dispersion compensation. The length of DCF to rightly compensate for the dispersion is calculated based on the following as in (2) below.

$$L_{DCF} = -\frac{D_{span}}{D_{DCF}} L_{span} \quad (2)$$

where D_{span} and D_{DCF} are dispersion values for SSMF and DCF considered. From [11] we use the following equation to get the length of DCF and SSMF.

$$\frac{L_{span}}{L_{DCF}} = 6.66 \quad (3)$$

Using the (2) and (3) the dispersion can be adjusted as

$$D_{DCF} = -6.66\, D_{span} \quad (4)$$

The receiver includes PIN photo detector with dark current of 0.1nA and with responsivity of 0.875 A/W.

III. RESULTS AND DISCUSSION

The various combinations of DCF and SMF lengths are indicated as in Table I. The span cases are taken same as in [12] to draw a comparative analysis and show the improvements. A total of 98 channels with 0.2nm are considered in [12] for long haul calculations. In this paper a performance test on 96 channels at 0.1nm spacing with offered hybrid Raman-EDFA is reported. The previous work quoted work is extended by reducing the inter channel spacing to lesser value while maintaining almost the same number of user channels for extended distance.

TABLE I
Different Variations of SSMF spans and DCF

Cases	SSMF (km)	DCF (km)
1	24	3.6
2	36	5.4
3	48	7.2
4	60	9.0
5	72	10.8
6	84	12.6

The DWDM system is tested under varying span cases. The first channel is taken for analysis. With different span cases the maximum approachable distance $L_{approach}$ as the function of L_{span} is calculated to get Q factor >15dB for Bit Error Rate, BER< 10^{-9}. The Table II and Table III lists out all the spans and maximum distances reached for both Raman-EDFA and EDFA.

TABLE II
$L_{approach}$ with EDFA with TARGET Q >15dB

Cases	Spans	$L_{approach}$(km)	Q factor	BER
1	18	496.8	15.52	1.30×10^{-9}
2	24	993.6	15.47	2.19×10^{-9}
3	21	1159.2	15.41	$2.7\text{x}10^{-9}$
4	26	1794	15.73	2.4×10^{-9}
5	21	1738.8	15.5	1.02×10^{-9}
6	17	1642.2	15.63	1.09×10^{-9}

TABLE III
$L_{approach}$ with Raman-EDFA with TARGET Q >15dB

Case	Spans	$L_{approach}$(km)	Q factor	BER
1	21	579.6	15.10	5.07×10^{-9}
2	26	1076.4	15.19	3.92×10^{-9}
3	23	1269.6	15.31	1.7×10^{-9}
4	30	2070	15.43	1.61×10^{-9}
5	25	1904.4	15.16	1.19×10^{-9}
6	19	1835.4	15.21	1.06×10^{-9}

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It is observed that the span case 4 corresponding to SSMF length of 60km gives maximal approachable distance. The other cases reach less number of spans to achieve the target of >15dB Q factor. Moreover the number of spans also starts to reduce after case 4. So to calculate the long haul distance span case 4 is considered. The Q factors and BER values are also quoted for the 96 channel U-DWDM system.

The total appreciable distance reached is 2070km obtained with maximum number of spans 30 with Raman-EDFA Hybrid Optical Amplifier. The maximum distance obtained with Raman-EDFA HOA with that of distance obtained with EDFA standalone (1794km) for this span case is compared. It is observed that total distance achieved with EDFA is quite less as compared to distance achieved with Raman-EDFA HOA.

Figure 2 shows the results of the maximum approachable distance $L_{approach}$ as a function of L_{span} given a target Q factor > 15 dB, bit rate < 10^{-9}. Results of system based on EDFA and Raman-EDFA are reported for comparison. At L_{span} of 60 km the L_{total} is around 1794kKm (26 spans) when EDFA is used, while it is increased up to 2070 km (30spans) when Raman-EDFA is used. It is observed that all the different span cases gives target quality of signal but after the span case4, corresponding to 60km of Standard Single Mode Fiber, the distance covered starts to decrease as shown in Fig.2.

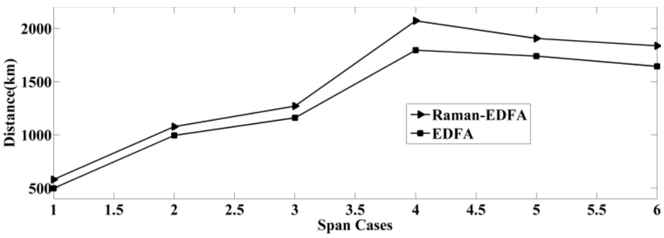

Fig.2. Maximum Approachable distance versus different span cases for Raman-EDFA HOA and Conventional EDFA

It is shown that Raman-EDFA HOA used in long haul communication links at optimal span distance (L_{span}) gives better performance even in an Ultra DWDM system. Hence hybrid Raman-EDFA does serve to increase the overall capacity of the U-DWDM system with maximized channels at very dense channel spacing whilst increasing the distance of transmission.

IV. CONCLUSION

Raman-EDFA Hybrid Optical Amplifier is employed in the scenario of a total of 96 channels Ultra Dense Wavelength Division Multiplexing System with 96 × 2.488 Gbps transmission for extended distances. The U-DWDM system has been investigated for long haul communication in the presence of both the hybrid and conventional amplifiers for comparison. It is reported that 60km of SSMF forms an optimal span distance amounting to 2070km (30 spans) achieved by Raman-EDFA Hybrid Amplifier as compared to EDFA which obtains a maximum distance of 1794 km, which is much lesser than the Hybrid Amplifier. A Quality factor of 15.43 dB is obtained with Raman-EDFA with a high distance. From the reported results it is recommended that Raman-EDFA is right choice in extended long haul communication at optimal span distance for better performance and to achieve high capacities even in U-DWDM systems.

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