A Software Simulation for Multi-Channels WDM System by Hybrid EDFA/RA Based Optical Communication Network

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Abstract
This paper provide a software simulation to enhancement performance system using hybrid Erbium doped fiber amplifier/Raman amplifier (EDFA/RA), by the way, RA provides a continuous amplification along the fiber. The (8×10Gb/s) wavelength division multiplexing (WDM) system show successful transmitter work at (193.1 to 193.8 THz) all input channels have the same power with (-6.66dBm) these signal are amplified through EDFA and RA of (20km), two pump laser used. The total output signal is (29.36dBm), total output noise is (-13.53dBm), and output optical-signal-to-noise ratio (OSNR) is (0dB). The average maximum Q-factor for all 8-channels is (4.79), and the average of minimum BER is(3×10^{-7}), this mean the optical network is exploiting for high speed network communication with low error rate, and the major contribution is the development of the multi-destination communication over the lightwave WDM system. The system is simulated, tested, and verified using OptiSystem Software Package.

Key words: EDFA, RA, pump laser, WDM, OSNR, BER, noise figure, and Q-Factor.

Introduction
The Stimulated Raman scattering (SRS) nonlinearities with optical fiber provide an optical amplification process. The development of transparent optical amplifier the erbium doped fiber amplifier (EDFA) technology are adopted the amplification modules are placed after 40-50km of link, this due to initial power and attenuated signal after propagate it in fiber, Raman effect is a scattering effect of light. Light scattering occurs as a consequence of fluctuations in optical properties of a medium. There are three types of scattering: (Rayleigh, Brillouin, and Raman scattering) [1].

The main features of the Raman amplifier (RA) is continuous amplification along the fiber, bidirectional in nature are offers more stability, insensitivity to reflections [2]. The use of RA allows the confinement of the signal inside the limits imposed by the signal-to-noise-ratio (SNR) degradation as a result from higher link distances this is an advantage of the distributed Raman over lumped amplification [3, and 4]. As the traffic increases, wavelength division multiplexing (WDM) technology arises to expand transmission capacity, in turn, requires flexible and broadband architectures with enforcement the interest in RA [5].

To amplify an optical signal with a conventional repeater, one performs photon to electron conversion, electrical amplification, retiming, pulse reshaping, and then electron to photon conversion. These processes are work well in single wavelength systems, but at high speed optical network can adopted all-optical amplifiers such as EDFA, and RA to overcome conversion from electron-to-photo vice-versa [6].

Whereas an EDFA requires a specially constructed optical fiber for its operation, the input powers to EDFA vary as slowly as their gain relaxation time in WDM networks because wavelength channels which pass through the EDFA can change as a result of network configurations or any other partial failure [7]. To implement RA using optical fiber as gain medium requires that the pump and information signals must be injected into the same fiber. A basic scheme for RA architecture is illustrated in Figure 1.

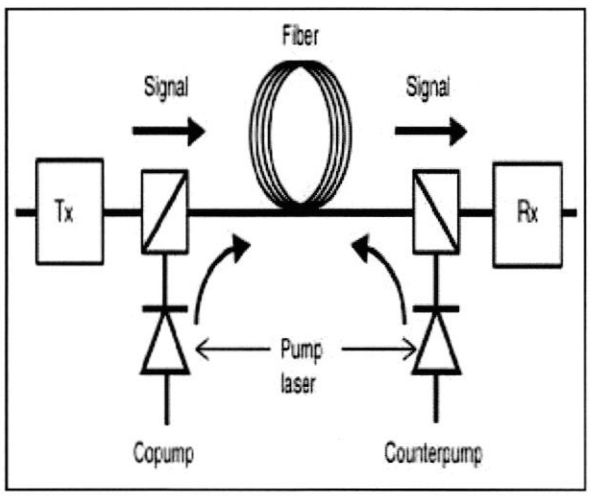

Figure 1: Optical communication system employing Raman amplification.

In general approach the power evolution of pumps signals and amplified spontaneous emission (ASE) in forward and backward directions with time along the fiber distance is given by the following set of equations [8, and 9]:

$$\frac{dP_s}{dz} = g_R\, P_p - \alpha_s P_s \dots (1)$$

and

$$\mp \frac{dP_p}{d_z} = -\frac{\omega_p}{\omega_s}\, g_R\, P_p\, P_s - \alpha_p P_p \dots (2)$$

Where g_R ($W^{-1}m^{-1}$) is the Raman gain coefficient of the fiber α_s *and* α_p are the attenuation coefficient at signal and pump wavelength respectively, ω_s *and* ω_p are the angular frequencies of the signal and pump, P_s *and* P_p are signal power and pump power.

By integration Eq. 1 to obtain Eq. 3

$$P_s(L) = G(L)P_{s(0)} \dots (3)$$

Where $G(L)$ is the signal gain, L is the amplifier length.
The relation between on-off Raman gain and the Raman gain efficiency is given as [8]:

$$G_A = \frac{P_S(L) with\ pump\ on}{P_S(L) with\ pump\ off} \ \ldots (4)$$

The noise figure can be calculated as:

$$\text{NF (dB)}=10\log\left(\frac{S_{in}/S_{in}}{S_{out}/N_{out}}\right) \ldots (5)$$

Amplifier spacing has opposite effects on nose generated due to the fiber nonlinearities effects SRS, four wave mixing (FWM), and the ASE noise introduced by in-line optical amplifications. Decreasing in the amplifier spacing the SRS and FWM effects increase, while the ASE noise reduces [10, and 11]

Based on the nature of Raman physics it has many advantages: (i): Raman gain exist in every fiber that is mean existing link can be upgrade even though they are already installed, (ii): gain is available over the fiber ranging from 0.3 to 2 microns, and (iii): RA is that the gain spectrum can be tailored by adjusting the pump wavelengths, multiple pump can be used to increase the optical bandwidth [12, 13 and 14]. The major contribution of this work is to development the multi-destination communication over the lightwave WDM system by hybrid EDFA/RA. Section II illustrate the simulation model, section III present some results and general discussion, and finally, section IV demonstrate some conclusions and suggested possible for future works.

Simulation model

The system simulation consists of three main parts: (i) optical transmitter, (ii) optical transmission link, and (iii) optical receiver. In the following subsections we demonstrate them in details. Our simulation are designed, tested, and verified using OptiSystem software package it is Canadian corporation license product [15].

Table 1, illustrate the main components properties that used in simulation. The first component of transmitter is the WDM transmitter with 8-channels, and modulation format is non-return to zero (NRZ), all channels are multiplexed by 8×1 equal spacing multiplexer, then the output signal from multiplexer are entered into the transmission link to post-amplified by EDFA, after amplification process the optical signal lunched into the Raman amplifier (RA), the power combiner 2 × 1 used to combine two signal (origin, and pump laser signal with frequency of 980nm, and power is 100mw), after round trip signal are entered into the WDM equal spacing demultiplexer. After demultiplexing process each signal are separate on its port, and filtered by Bessel optical, then at the receiver side are detected by optical receiver with positive intrinsic diode (PIN), and filtered by low pass to add-signal-noise, add ASE noise, add shot noise, and add thermal noise, and finally each signal are monitored by bit error rate (BER) analyzer to calculate Q-factor, and minimum BER. The bit rate of this simulation is 10Gb/s, sequence length is 128bits, sample per bit is 64, and number of samples is 8192. The schematic diagram for the hybrid EDFA/RA simulation is shown in Figure 2.

Table 1: Illustrate The Main Components Properties.

WDM	
Frequencies (THz) (1 to 8)	193.1to 193.8
Frequency Spacing (GHz)	100
Power (dBm)	6.66
Bandwidth (GHZ)	10
EDFA	
Noise Figure (dB)	6
Gain (dB)	10
RA	
Length (Km)	20
Attenuation (dB/km)	0.2
Effective Area (μm^2)	55
Raman Gain Peak	$4.5*10^{-14}$
Raman Gain Reference Pump (nm)	1000
Temperature (K)	300
Polarization Factor	2
Rayleigh Back Scattering (1/km)	$5*10^{-5}$
Upper Pump Reference (nm)	1500
Noise Center Frequency (nm)	1540
Noise Bandwidth (nm)	80
Noise Bins Spacing (nm)	4
Noise Threshold (dB)	-100
Noise Dynamic (dB)	3
Backward Pump Laser Frequency (nm)	1450
Power (nm)	800
WDM Demultiplexer	
Frequency (THz)	193.1
Bandwidth (GHz)	10
Bessel Optical Filter	
Frequency (THz)	193.1
Bandwidth (GHz)	10
Insertion Loss (dB)	0
Depth (dB)	10
Order	1
Low Pass Filter	
Depth (dB)	100
Order	4
Thermal Noise	$1*10^{-22}$

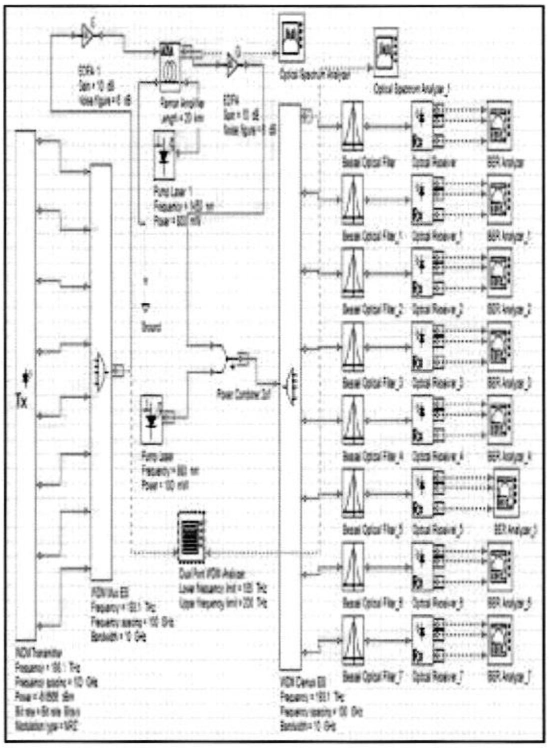

Figure 2: The schematic diagram for hybrid EDFA/RA system.

Results and general discussion

The numerical data (set of controlling parameters) of our system model are employed to obtain the performance of multi-pumped, Raman amplifiers, and EDFA in WDM optical networks as to improve the OSNR, and reduce the nonlinear effects in transmission system. Through Fig. 3"to Fig. "14" will be demonstrating some results of this work:

1) Fig. "3": show all input signal spectrum before launched into the transmission link.
2) Fig. "4": illustrate all signals after RA, red color (signal), and green (noise).
3) Fig. "5": show Raman gain versus frequency, the high peak appear between 10THz and 20THz.
4) Fig. "6": demonstrate output signal (193.1THz) after demultiplexer, there are some noise added by amplifiers.
5) Fig. "7": gain (dB) versus wavelength iteration for all channels (gain increase when wavelength increases).
6) Fig. "8": show noise figure (NF) (dBm) versus wavelength for all signals (NF decrease when wavelength increase).
7) Fig. "9": demonstrate power (dBm) versus wavelength iteration (power increase when wavelength increases).
8) Fig. "10": output channels power versus wavelength, there is some degradation in power this is due to nonlinearities problem.
9) Fig. "11": show Q-factor for output channel_1 (193.1THz) from BER analyzer.
10)Fig. "12": show the minimum BER for the output channel_1 from BER analyzer.
11)Fig. "13": show Q-factor for output channel_8 (193.8THz) from BER analyzer.
12)Fig. "14": show the minimum BER for the output channel_8 from BER analyzer.

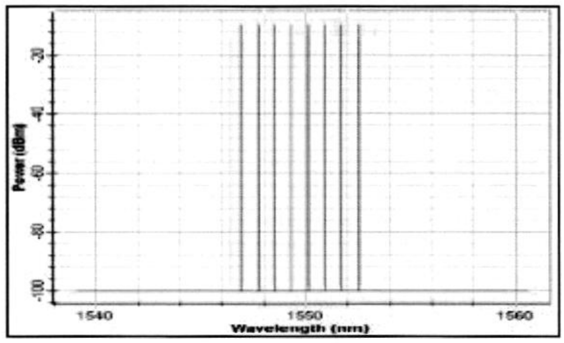

Figure 3: Input Spectrum Signal Iteration

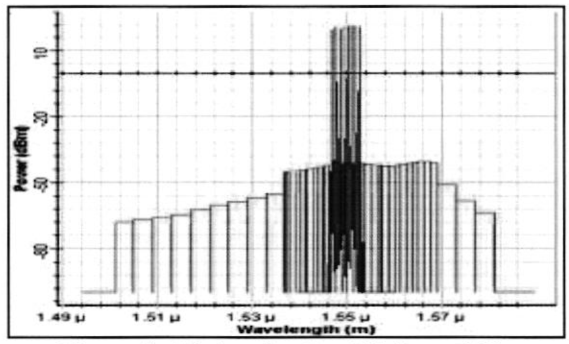

Figure 4: All signals after RA from OSA.

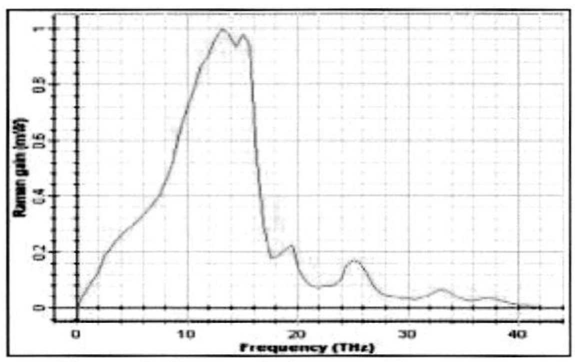

Figure 5: Raman Gain versus Frequency.

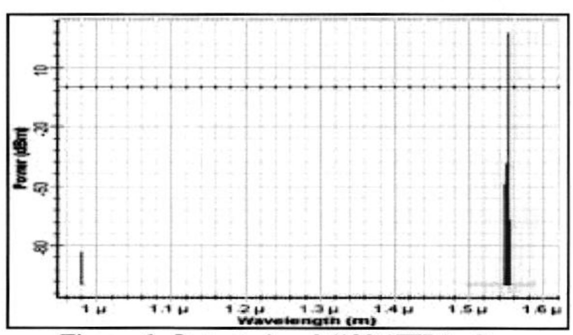

Figure 6: Output signal (193.1THz) after demultiplexer from OSA_1.

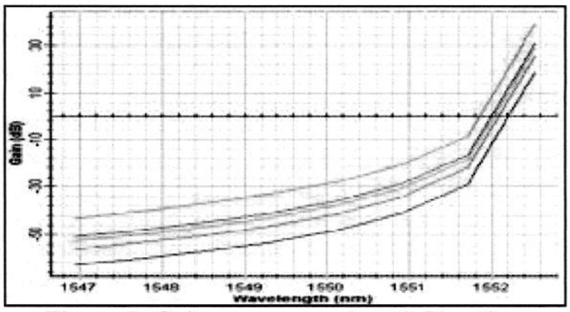

Figure 7: Gain versus wavelength Iteration

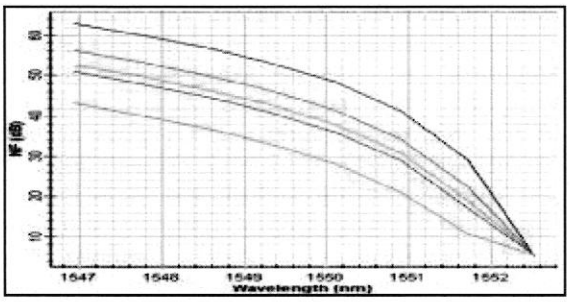

Figure 8: Noise figure versus wavelength iteration

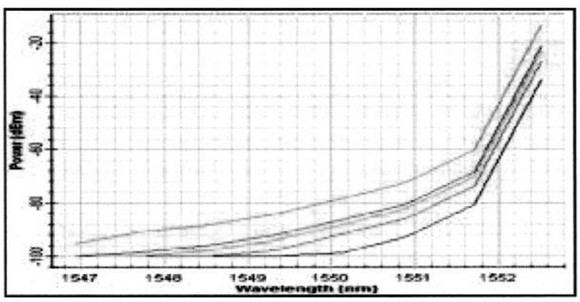

Figure 9: Output Noise Spectrum Iteration.

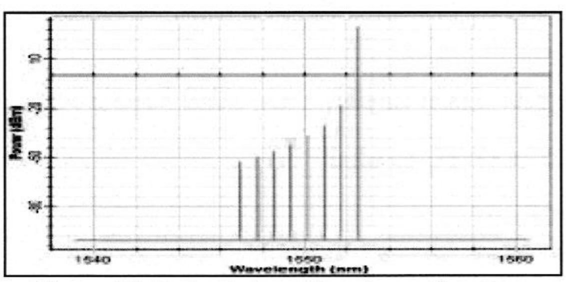

Figure 10: Output signal Spectrum Iteration.

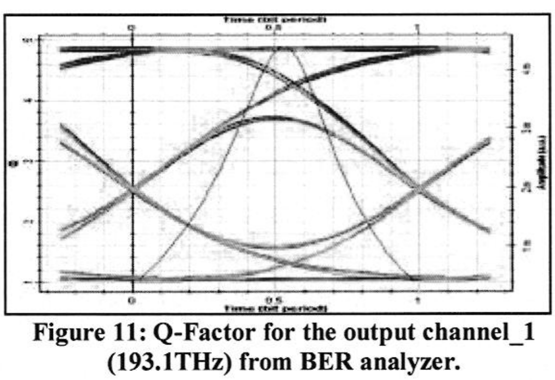

Figure 11: Q-Factor for the output channel_1 (193.1THz) from BER analyzer.

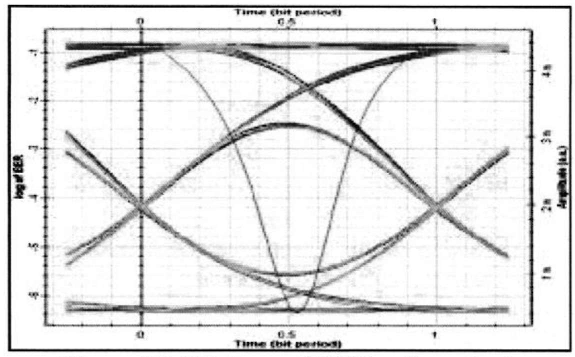

Figure 12: Minimum BER for the output channel_1 (193.1THz) from BER analyzer.

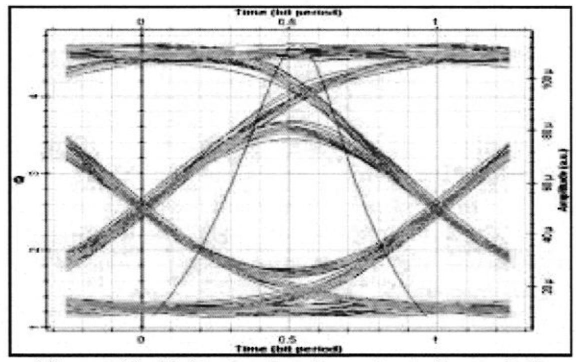

Figure 13: Q-Factor for the output channel_8 (193.8THz) from BER analyzer_7.

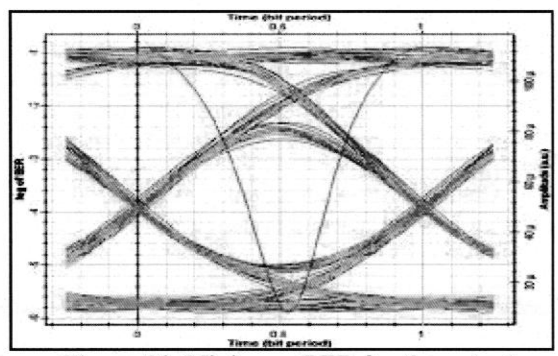

Figure 14: Minimum BER for the output channel_8 (193.8THz) from BER analyzer_7.

From the dual port WDM analyzer the total output signal is 29.3643dBm, and ratio Max/Min is 82.101, the total output noise is -13.5326dBm, and ratio Max/Min is 81.7984 and the total output optical signal to-noise- ratio is 0dB, and the ratio Max/Min is 81.7984.

Conclusion

Through this paper there are simulated systems of 8×10Gb/s WDM transmission over 20km of RA with EDFA. The main benefit of this work is to use hybrid amplification process over WDM optical communication network. To reduce the fiber nonlinearities the NRZ format was adopted. The gain of multi-pumped RA in WDM is affected by two important parameters (wavelength, and power). The EDFA/RA improves the OSNR this lead to maximum bit rate or capacity over optical network. The average maximum Q-factor for all 8-channels is 4.8, and the average of minimum BER is 3×10^{-7} . No architecture changes were needs for the existing infrastructure. Also, can be modified this work to involve network reconfiguration by add optical add-drop multiplexer (OADM), or discrete RA.

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محاكاه برمجية لنظام متعدد القنوات بوجود مازج الاطوال الموجيه المقسمه بواسطة مكبر رامان/ايربيوم المشوب بالاعتماد على شبكة اتصالات ضوئيه

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الملخص

يقدم هذا البحث محاكاه برمجية لتحسين أداء النظام باستخدام مكبر الايربيوم المشوب و رامان لعملية التكبير، بالمناسبة فان مكبر رامان يوفر تضخيم مستمر على طول الليف البصري. وعرض النظام نجاح العمل لجميع القنوات (8*10جيجا بت/ثانية) (193.1 الى 193.8 تيرا هيرتز) جميع قنوات الإدخال لها نفس الطاقه (-6.66 ديسبل ملي وات) وتتضخم هذه الإشارات من خلال مكبر الايربيوم المشوب و رامان بطول (20 كيلومتر) ، واستخدمت مضختي ليزر وكانت الاشاره الكليه الخارجه هي (29.36 ديسبل ملي وات) والضوضاء الكليه الخارجه هي (−13.53 ديسبل ملي وات) ونسبة الضوضاء الى الاشارة الضوئيه هي (0 ديسبل) ومعدل معامل النوعيه الاعلى لجميع القنوات (4.79) ومعدل اقل نسبة خطأ في البت هو ($3*10^{-7}$) وهذا يعني ان الشبكه الضوئيه استثمرت اعلى سرعه باقل معدل خطأ وان المساهمه الرئيسيه للنظام هي تطوير منظومة الاتصالات الضوئيه بوجود المازج المقسم للأطوال الموجيه. تم نمذجة واختبار وتحقيق النظام بالمنتج البرمجي (النظام – البصري).