Combating Stimulated Raman Scattering Nonlinear Effect on 8-channels DWDM Systems

Hefans Akhmed Arafat¹, Eko Fajar Cahyadi¹,², Dodi Zulherman¹, Dadiek Pranindito¹, Min-Shiang Hwang²,³
¹Faculty of Telecommunication and Electrical Engineering, Institut Teknologi Telkom Purwokerto, Purwokerto, Indonesia
²Department of Computer Science and Information Engineering, Asia University, Taichung, Taiwan
³Department of Medical Research, China Medical University Hospital, China Medical University, Taichung, Taiwan
E-mail: ²ekofajarcahyadi@ittelkom-pwt.ac.id

Abstract. The performance of dense wavelength division multiplexing (DWDM) system in optical fiber network communication is influenced by various factors, one of them is called a nonlinear effect. Stimulated Raman Scattering (SRS) is one of the nonlinear effects that occur due to a high-power level utilization, causes a signal scattering phenomenon that grown exponentially as the power increases. This works aimed to analyze the bit error rate (BER) and Q-factor performance of DWDM systems that suffer from SRS nonlinear effects on optical power launch, channel spacing, and bit rate variations. Observations were made on a model of 8-channels DWDM, over 100 km optical fiber cable with channel spacing variations of 50, 100, and 200 GHz. The DWDM system was designed using the erbium-doped fiber amplifier (EDFA). The system performance was observed with optical power launch variations of -6, -4, -2, 0, 2, 4, 6 dBm, and bit rates for 10 and 40 Gbps. Based on the result, the 6 dBm optical power launch, with 200 GHz channel spacing, and 10 Gbps data rates, provides the best performance of 1.78 x 10⁻¹⁵ BER values, and Q-factor of 48.57. The observation of nonlinear systems performance is measured with an optical spectrum. Changes in the value of optical power launch, channel spacing, and data rate had affected the performance of the DWDM nonlinear system.

1 Introduction

Utilizing a different wavelength as an information channel to transmit data through an optical fiber link can improve the system performance, especially in bandwidth capacity. The dense wavelength division multiplexing (DWDM) systems can transmit several different wavelengths with large quantities of traffic through the same optical fiber channel. It could be applied in the long-distance telecommunication networks which require a large bandwidth consumption. Despite its superiority in efficiency and scalability, DWDM also has some disadvantages, one of which is the presence of the nonlinear effects [1, 2]. The nonlinear effects are events that could decrease the performance of a system while transmits the signals. There are several types of nonlinear effects on DWDM links, such as Stimulated Raman Scattering (SRS), stimulated Brillouin scattering (SBS), self-phase modulation (SPM), carrier-induced phase modulation (CIP), and four-wave mixing (FWM). SRS is a stimulating effect induced by the inelastic scattering phenomenon at a higher power level and grown exponentially along with the increasing power. When a high power light beam propagates throughout the fiber, the SRS emerges because of an interaction between vibrational mode of the fiber silica molecules with the light beam.
This work analyzes the performance of DWDM system with the SRS nonlinear effect scenario in OptiSystem 15 simulator. To analyze the performance, we use a variety of optical power launch, bit rate, and channel spacing scenarios to obtain BER and Q-factor values. For a better understanding, the rest of this paper is organized as follows. In section 2, we cover the related works. It is followed by the proposed method in section 3, and the results of the simulation are discussed in section 4. Finally, the conclusions are presented in section 5.

2. Related Works
In recent years, several research that analyzes the nonlinear effect on optical communication has been published [1, 2, 3, 4, 5, 6, 7, 8, 9]. Aldila et al. [3] in 2015 examined the impact of linear and nonlinearity of CWDM optical fiber link systems. They employ a wavelength variation from 1,460 nm to 1,625 nm with 20 nm of channel spacing. In this work, the CWDM link was varied by length. The erbium-doped fiber amplifier (EDFA), as an optical amplifier, was observed by Q-factor and bit error rate (BER) parameter. Based on the discussion, the CWDM link with EDFA has a better performance than both linear and nonlinear link without reinforcement.

Firnandya et al. [4] in 2015 study the effect of the FWM nonlinear effect in DWDM link with three scenarios. The first scenario was conducted by varying bit rate and optical fiber length. Followed by analyzing the effect of channel spacing. Finally, in the last scenario, they vary the optical power launch. The results in these works were the FWM nonlinear effect can have a detrimental impact on the DWDM system. It caused by the parameter such as Q-factor for all scenarios did not meet the ITU-T standard. Ditya et al. [5] in 2017 examined the effect of three-wave mixing in the DWDM system with three scenarios. The first scenario in this work was changing the bit rate and length of the optical link. The second one changed the channel spacing variable, and the last scenario was to change the transmitter power variable. The results of this study are nonlinear effects of three-wave mixing (TWM) can cause adverse effects on DWDM systems because almost all values of Q-factors are below the standard set.

In 2016, Pamukti et al. [6] published a paper that discusses the impact of the nonlinear effect on soliton transmission in DWDM link. The result of these work showed an influence on DWDM performance caused by the soliton transmission and proved the channel reducing can overcome the nonlinear effect in DWDM. Kumari et al. [7] in 2015 showed the SRS effect could occur on the WDM system using the variation of channel spacing. In these work, the SRS effect on WDM system was influenced by optical power launch. Another works by Kaur et al. [8] and Patni et al. [9] in 2016 discussed the performance improvement on the DWDM system using an optical amplifier and dispersion compensator. Those works can be used to overcome the linear effect in the DWDM system. The results of this study indicate an escalation of signal quality in DWDM systems with EDFA amplifiers since the implementation of higher pump power value.

3. Proposed Method
This study uses a model to analyze the performance of DWDM systems that suffer from SRS nonlinear effect. In this section, we elaborate on how the simulation is conducted.

3.1. System Design
Fig. 1 shows the block diagram of the systems comprised of a transmitter, transmission, and receiver. In the transmitter block diagram, located CW laser, Mach-Zender modulator, nonreturn to zero (NRZ) pulse generator, pseudo-random bit sequence (PRBS), and multiplexer, as depicted in Fig. 2. The simulation is performed on 10 and 40 Gbps 8-channels DWDM system, with EDFA optical amplifier over a transmission distance of 100 km. As shown in Table 1, the channel spacing used in this study is the standard of ITU-T G.694.1 of 50 GHz, 100 GHz, and 200 GHz [10]. The input power varied to -6, -4, -2, 0, 2, 4 and 6 dBm. CW laser has a role as an optical transmitter. Table 2 summarizes several different frequencies (in THz) for 8-channels DWDM system, with 0.05, 0.1, and 0.2 THz channel spacing variations.
Figure 1. Block diagram of the system.
The transmission block consists of two types of the optical link; single-mode fiber (SMF), and dispersion compensating fiber (DCF). Table 3 shows the parameter of SMF and DCF. We use 80 km of SMF, and 20 km of DCF to reach 100 km of transmission distance. Meanwhile, as the last mile systems, the receiver block diagram comprises of the demultiplexer, APD photodetector, low pass Bassel filter (LPBF), and BER analyzer, as shown in Fig. 3. The details parameters value of the APD and LPBF are summarized in Table 4. It shows the responsivity and gain value of the APD photodetector are 1 A/W and 3 dB, respectively. Meanwhile, the LPBF cut-off frequency value is set in 30 and 7.5 GHz.

| Parameter          | Value | Unit |
|--------------------|-------|------|
| Power of CW laser  | -6, -4, -2, 0, 2, 4, 6 | dBm  |
| Channel spacing    | 50, 100, 200 | GHz  |
| Bit rate           | 10, 40 | Gbps |
| Input ports mux    | 8     | Ports|

| Channel | 0.05 | Channel Spacing (THz) | 0.1 | 0.2 |
|---------|------|-----------------------|-----|-----|
| 1       | 193.15 | 193.20 | 193.10 |
| 2       | 193.20 | 193.30 | 193.30 |
| 3       | 193.25 | 193.40 | 193.50 |
| 4       | 193.30 | 193.50 | 193.70 |
| 5       | 193.35 | 193.60 | 193.90 |
| 6       | 193.40 | 193.70 | 194.10 |
| 7       | 193.45 | 193.80 | 194.30 |
| 8       | 193.50 | 193.90 | 194.50 |
3.2. Scenarios

The performance parameters tested in this simulation are the BER and Q-factor. These two variables are then simulated towards channel spacing, power launch, and bit rate variations. The detailed scenarios of this work are summarized in Table 5.

| Scenario | Parameter             | Performance | Simulated on       |
|----------|-----------------------|-------------|--------------------|
| 1        | Channel spacing       | BER & Q-factor | 6 dBm, 40 Gbps    |
|          | 50, 100, 200          |              |                    |
| 2        | Power launch (dBm)    | BER & Q-factor | 200 GHz, 40 Gbps  |
|          | -6, -4, -2, 0, 2, 4, 6|              |                    |
| 3        | Bit rate (Gbps)       | BER & Q-factor | 6 dBm, 200 GHz    |
|          | 10, 40                |              |                    |

Table 3. Transmission block specifications

| Type   | Parameter       | Value   | Unit |
|--------|----------------|---------|------|
| SMF    | Length          | 80      | km   |
| Attenuation | 0.3          | dB/km   |      |
| Dispersion | 17            | ps/nm/km|      |
| DCF    | Length          | 20      | km   |
| Attenuation | 0.5          | dB/km   |      |
| Dispersion | -85           | ps/nm/km|      |
| Noise figure | 4             | dB      |      |

Table 4. Receiver block specifications

| Type        | Parameter          | Value   | Unit |
|-------------|--------------------|---------|------|
| WDM demux   | Channel spacing    | 50, 100 | GHz  |
|             | Output ports mux   | 8       | Ports|
|             | Dispersion         | 17      | ps/nm/km|
| APD         | Responsivity       | 1       | A/W  |
|             | Gain               | 3       | dB   |
| LPBF        | Cut-off frequency  | 30 & 70.5| GHz |

Table 5. Scenarios
4. Results and Discussion

In this section, we evaluate the effect of channel spacing, optical power launch, and bit rate variations towards BER and Q-factor parameters based on the arrangement in section 3. As a comparison of error bits ratio that relative to the total number of received bits, the BER value in the DWDM system is restricted to a maximum of $10^{-12}$. Meaning that out of 1,000,000,000,000 bits transmitted, only one of them suffered in error, as expressed in (1).

$$BER = \frac{nc}{nb}$$ ................................. (1)

where, $n_c$ is a number of bits error, while $n_b$ is a received bit in a defined time interval [11]. In a simple transmission channel model with the assumed data source, the BER value could be calculated analytically [12]. However, in this work, the BER value is determined through stochastic computer simulations. As mentioned earlier in section 3.1, and depicted in Fig. 3, the BER value was obtained by utilizing the BER analyzer instrument. Aside from BER, another key parameter in this study is Q-factor. Q-factor characterizes two digital SNRs (electrical and optical) that combined into a single convenient measurement of overall system quality. Q-factor could be determined from (2).

$$Q = \frac{y_{opt} - i_L}{\sigma i_L}$$ ................................. (2)

where $y_{opt}$ is the optimal threshold level, $i_L$ is optical power level, and $\sigma i_L$ is the standard deviation of the noise. However, similar to BER value, in this work, we also determined the value of Q-factor through the simulation results.

Before discussing BER and Q-factor, we provide input and output of the optical spectrum images in the transmitter block with 8 data channels. As shown in Fig. 4 to Fig. 9, the SRS nonlinear effect is portrayed at the output of the optical spectrum (Fig. 5, 7, and 9). From the obtained results, the SRS nonlinear effect is actually affected by the optical input power, bit rate, and channel space variations. The utilization of higher input power value will consequence to the escalation of the SRS effect in the DWDM system. On the other hand, the nonlinear effect of SRS will get smaller when a more significant bit rate is employed. This thing happens since during the signal transmission process, the transmitted optical light experiences scattering. Hence, some of the scattered light would lose energy (Stokes shift) or gain energy (anti-Stokes shift) [13].
4.1. The Effects of Channel Spacing Variation
As summarized in Table 5, scenario 1 performs a channel spacing variation (50, 100, and 200 GHz) to obtain BER and Q-factor value, simulated in 40 Gbps optical link with 6 dBm power input.

4.1.1. Bit Error Rate (BER) The impacts of channel spacing variation in 8-channels DWDM system on BER value is depicted in Fig. 10. The graphic shows, by employing a higher channel space, it will generate a better BER value. The best BER value results in 200 GHz channel space utilization for $1.78 \times 10^{-15}$, located on channel 1. Meanwhile, the worst BER value is experienced at 50 GHz channel spacing, located on channel 4 and 6.
4.1.2. **Q-factor** Similar to BER value, the Q-factor also gain an improvement along with the escalation of channel spacing (shown in Fig. 11). The best Q-factor value appears on 200 GHz channel spacing for 26.18, located on channel 1.

4.2. **The Effects of Optical Power Launch Variation**

4.2.1. As summarized in Table 5, scenario 2 performs an optical power launch variation (-6, -4, -2, 0, 2, 4, 6 dBm) to obtain BER and Q-factor value, simulated in 200 GHz channel spacing, and 40 Gbps of bit rate.

4.2.2. **Bit Error Rate (BER)** Fig. 12 depicts the impacts of optical power launch variation in 8-channels DWDM system on BER value. As the input power increase, the BER value also gaining an improvement. The best BER value results in 6 dBm power launch for $1.78 \times 10^{-15}$, that located in channel 1. Meanwhile, the worst BER value is experienced at -6 dBm optical power utilization for $2.17 \times 10^{-18}$, located on channel 2.

4.2.3. **Q-factor** The Q-factor value is relatively similar to BER, as the power level increase, so both of them will gain improvement, as shown in Fig. 13. The best Q-factor value appears on 6 dBm of power variation is 43.34, located on channel 7. Meanwhile, the worst value occurs in channel 5 with -6 dBm of input power, for 17.71.

4.3. **The Effects of Bit Rate Variation**

As summarized in Table 5, scenario 3 performs a bit rate variation (10 and 40 Gbps) to obtain BER and Q-factor value, simulated with 6 dBm optical power, and 200 GHz of channel spacing.

4.3.1. **Bit Error Rate (BER)** Fig. 14 depicts the impacts of bit rate variation in 8-channels DWDM systems on BER value. The best BER value in 40 Gbps bit rate occurs for $1.78 \times 10^{-15}$, located on channel 1. Meanwhile, the worst outcome is for $1.50 \times 10^{-14}$. 

![Figure 8. BER on 50, 100, and 200 GHz of channel spacing.](image1)

![Figure 9. Q-factor on 50, 100, and 200 GHz of channel spacing.](image2)
4.3.2. Q-factor

In contrary, the best value of Q-factor is reached when employing a 10 Gbps of bit rate rather than 40 Gbps. The 48.57 of Q-factor value is located in channel 6, resulted by 10 Gbps bit rate with 6 dBm of input power, and 200 GHz channel spacing, as shown in Fig. 15. Meanwhile, the worst Q-factor value occurs in channel 7, for 22.70 with 40 Gbps bit rate.

4.4. Discussion

From all three examined scenarios, the detailed summarize of BER and Q-factor best and worst value affected by channel spacing, power launch, and bit rate variations, are presented in Table 6.

5. Conclusions

In this paper, we have simulated an 8-channels DWDM system that suffers from SRS nonlinear effect in OptiSystem 15 simulator environment. Based on the results and discussion in section 4.

| Table 6. Summary of Performance Parameters |
|---------------------------------------------|
| Scenario | Value | BER | Q-factor |
|----------|-------|-----|----------|
| 1 | Best | 1.78 x 10^{-151} | 26.18 |
|        | Worst | - | - |
the nonlinear effect of SRS on DWDM systems is resulted by the emergence of new wavelengths in the spectrum analyzer. In each scenario, the solution to overcome the SRS nonlinear effects could be obtained by increasing the input power on the transmitter block, adding channel space values, and raising the bit rates. The system performance results in the BER parameter have the best value of $1.78 \times 10^{-151}$ at 6 dBm of optical power launch, with 40 Gbps bit rate and 200 GHz channel space. Meanwhile, the worst BER values occur when using 40 Gbps of bit rate on 50 GHz channel spacing. The Q-factor parameter has the best value of 48.57 at 6 dBm of optical power launch, with 200 GHz channel spacing and 10 Gbps bit rate. Meanwhile, the worst value occurs when using 50 GHz channel spacing with 40 Gbps of bit rate.

**Acknowledgment**

The author’s thanks go to Lembaga Penelitian dan Pengabdian Masyarakat (LPPM), Institut Teknologi Telkom Purwokerto for funding this project.

**References**

[1] Nawawi N M, Anuar M S, Rashidi C B, 2015, Aljunid S A, Rahman A K, Junita M N, Abdullah S R, *Int. Conf. on Computer, Comm., and Control Tech. (IfC'T)* p 346.

[2] Sabapathi T, Poovitha R, 2017, *Int. Conf. on Electronics and Comm. Systems (ICECS)* p 38.

[3] Aldila P, Hambali A, and Irawati I D, 2015, *e-Proc. of Eng. (Bandung)* vol 2, no 2 p 3078.

[4] Firmandya A R, Hambali A, and Pambudi A, 2015, *D e-Proc. of Eng. (Bandung)* vol 2, no 2 p 2596.

[5] Ditya H D, Hambali A, and Pambudi A D, 2017, *e-Proc. of Eng. (Bandung)* vol 4, no 2 p 1839. 2017.

[6] Pamukti B and Perdana D, 2016, *Int. Conf. on Information Technology, Information Systems and Electrical Eng. (ICITISEE)* p 26.

[7] Kumari P and Tiwari A, 2015 *Int. J. of Adv. Research in Computer and Comm. Eng.* 4 p 195.

[8] Kaur R and Singh M IOSR, 2016, *J. of Electronics and Comm. Eng.* 11 p 122.

[9] Patni A and Kumar D, 2016, *Int. Conf. on Recent Adv. and Innovations in Eng. (ICRAIE).*

[10] ITU-T, 2012 Spectral grids for WDM applications: DWDM frequency grid Recommendation G.694.1.

[11] Ivaniga T, Ivaniga P, 2014 *IOSR J. of Electronics and Comm. Eng.* 9 p 1.

[12] Alam S M J, Alam M R, Hu G, Mehrab M Z, 2011 *Int. J. of Machine Learning and Computing* 1 p 435.

[13] Singh S P., 2007, *Singh N Progress In Electromagnetics Research* PIER 73 p 249. 2007.