

Optimization of 16 wdm channel of 40 gbps optical link

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Abstract. The demand for higher capacities in fifth-generation networks and upcoming generations can be met with technology such as Wavelength Division Multiplexing (WDM). A study has been conducted to enhance the performance of a system comprising of sixteen light waves that carry high data rates of 40 Gbps for each data source associated with one of the wavelengths. The key focus of this study was to optimize the system parameters, including channel spacing, power levels, and dispersion compensation, to increase the signal-to-noise ratio and reduce signal degradation, which would be compatible with high data transfer speeds. The aim of this work is to improve the efficiency and performance of the proposed system. Using the simulation program OptiSystem, the proposed optical communications system based on 16 WDM channels for the 40 Gbps optical link was improved. Several parameters were adjusted to improve the performance of the proposed system. By carefully treating variables that can significantly affect system performance and striving to maximize the signal-to-noise ratio, minimize signal degradation, including dispersion compensation strategies, and optimize power levels. This work can determine the ideal configuration for the 16 WDM channels by evaluating and comparing the performance of different optimization strategies to obtain better results compared to previous work. The results show the extent of the impact of the optimization process on improving the system performance, which makes the proposed system suitable for communications systems in the next generations.

1 INTRODUCTION

Due to the changing nature of the current user and the expected demand for higher capacities in the next few years, many studies are focusing on fiber optic communications nowadays [1]. Optical communications offer many advantages, making it the focus of attention for researchers in the field of modern communications, as it provides wide bandwidth, higher data security compared to other conventional systems, and longer transmission distances, especially in cases where amplifiers are used to compensate for the attenuation caused by the fiber, and immunity against electromagnetic interference [1].

That makes optical communication technology suitable for supporting high data transfer speeds that suit the needs of the modern user in the 5G and beyond. Indeed, this technology still needs a lot of improvements to make it capable of transmitting a higher data rate [2-7].

The lack of interference that occurs in the WDM system due to the mismatch in the optical-electronic bandwidth makes it possible for many users to participate on one fiber at the same time by sending a group of optical signals in the same optical fiber. This feature can make WDM technology suitable for contemporary communications, increasing the total capacity of a single optical cable and increasing the data rate for each user [8]. Despite all this, WDM signals are very susceptible to optical fiber dispersion, which negatively affects the system's performance [9].

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The Chromatic dispersion occurring in optical fibers leads to varying propagation speeds of light signals at different wavelengths. Therefore, over time, this phenomenon may cause dispersion of certain wavelengths. Which leads to the possibility of WDM signals being more susceptible to interference and distortion. Consequently, signal quality decreases and error rates increase [10]. As this phenomenon negatively affects the continuity of communication quality, to mitigate the effects of this

dispersion and seek to maintain the quality of WDM signals, The dispersion compensation approach can be used to solve this sensitive problem at high speeds and long distances as it is closely related to these two factors. All of this will lead to a non-linear effect on the transmitted signals. In order to mitigate these effects of optical fibers and increase the ability to obtain higher data rates and achieve longer distances in the process of transmitting WDM signals. The power of the optical signal at the input of an optical fiber must be taken into account. These changes can affect the signal directly and thus lead to the loss of data or part of this data [11]. Therefore, it is recommended to use optical amplifiers to enhance signal intensity and compensate for losses that occur over long distances resulting from attenuation in the optical fiber itself.

For communication systems that use WDM technology, optical amplifiers are very useful for increasing signal strength because these signals cannot be transmitted with high power, and with the possibility of amplifying the optical signal without converting it into an electrical signal, which ensures high-quality transmission and reduces the possibility of non-linear effects. One of the most important amplifiers currently in use are Erbium-Doped Fiber Amplifiers, or EDFAs, which are considered essential parts of fiber-optic networks because they are able to enhance the power of transmitted signals over a wide spectrum with increased power conversion efficiency, reduced noise, and better gain [8]. Increasing the data rate requires system components that cause less impact on the quality of data transmission, so EDFA is commonly used in communications networks that are long-range and have relatively high capacity. Indeed, the use of EDFA is crucial to prevent signal degradation and allow massive data transmission over long distances [12]. Depending on the wavelengths used in standard single-mode optical fiber communication systems and since the operational wavelength of EDFA is compatible with the lower bounds of the attenuation window. It is possible to control the network capacity by using an amplifier of different wavelengths at the same time and different distances [13].

On the receiving side, a mechanism can be used to add gain to the power received by Avalanche Photo-Diodes (APDs) to amplify weak optical signals without the need to use amplifiers at the receiving end. APD can be considered suitable for long-range communications systems that use WDM technology with a high data rate due to its ability to deal with low-power optical signals. [14].

To enhance communication systems, optimizing fiber optic systems is very important, and many studies have paid attention to achieving this by using WDM and EDFA together.

Furthermore, some studies focused on using optimized WDM, EDFA, and APD technologies to enhance the capacity and improve the performance of fiber-optic communications networks.

2 RELATED WORK

Many researchers have presented studies on improving optical systems based on WDM technology. In reference [15], the researchers proposed working on a TWDM-PON system that supports two-way data transfer with a very high data rate of 80 Gbps, the study was able to obtain an acceptable error rate with a transmission distance ranging from 20 to 50 km with a BER of 10⁻¹³ as a minimum. Habib Ullah Manzoor et al. studied and analyzed the effect of Polarization Mode Dispersion (PMD) on Four-Wave Mixing (FWM) in a system based on close-spaced WDM and high data rate DWDM-PON. The study worked on optimizing the PMD, which led to improving the efficiency of the system in both the uplink and downlink [3]. The authors of [1] introduced a two-way symmetrical TWDM-PON system based on both Visible Light Communication (VLC) and OFDM, which stands for Orthogonal Frequency Division Multiplexing, the study used Digital Signal Processing (DSP) to improve the performance of the proposed system and reach a fast transfer rate of 200 Gbps. In another study, researchers proposed determining a more effective plan of action by analyzing and optimizing the energy resources and Bit Error Rate (BER) of an optical communications system based on WDM technology [4]. Using multiple types of optical amplifiers, a 40 Gbps DWDM system was studied and analyzed in reference [16]. In this paper the overall performance is evaluated using BER and Q-factor. In another study, a new EDFA structure was proposed based on a four-stage parallel double pump, the results show the impact of using such amplifiers on the optical system in general. This proposal provides an improvement in terms of gain on the system. This optical amplifier can enhance the system with higher gain and lower noise compared to traditional EDFA, this can provide an improvement in the functionality of WDM communication over fiber optic networks [17]. A 16-channel WDM system

using EDFA as an amplifier for free-space optical communications was designed and studied by the authors in reference [18]. In addition, visual simulation software was used to optimize EDFA fiber length and pump power. The results in this study showed the extent to which the noise factor is reduced and the gain is increased in the proposed system that is based on a 16-channel WDM scheme.

As a summary of what was presented in the literature review, these studies focused on the effectiveness of WDM, APD, and EDFA technologies in increasing the capacities provided to each client and improving the performance of the optical communications system in general. Moreover, it clarified the importance of working on collecting these technologies and their role in enabling the transfer of large amounts of data at relatively high speeds and over long distances. This will contribute to the possibility of using such systems in the communications process that support a high data transfer rate.

In this paper, based on the previously reviewed studies, a system that provides a high data rate over long distances will be proposed. The proposed system combines WDM, APD, and EDFA technologies, consisting of 16 WDM channels with a data rate of 40 Gbps. Optisystem is the program that will be used to simulate and build the design and optimize several parameters to achieve the best performance and compare the results that will be obtained.

3 METHOD FOR SIMULATION

As seen in Figure 1, the design model is divided into three sections: transmitter, channel, and receiver. 16 carrier optical waves with a certain strength and frequency within a band of 191.5-194.5 THz and a linewidth of 100 KHz are created by a Continuous Wave (CW) laser array and are utilized as WDM channels. An external modulator, comprising a 40 Gbps information source, a Non-Return to Zero (NRZ) pulse generator, and a Mach-Zehnder modulator, receives each optical wave as input. An ideal WDM multiplexer is employed to multiplex the modulated signals from the 16 channels, and a switch selector is used to pick from several channel scenarios.

Four distinct scenarios were used to evaluate the simulation model in order to identify the optimal choice for the channel in the suggested system. In order to account for dispersion, a 10 km Dispersion Compensating Fiber (DCF) was added after the Single-Mode Fiber (SMF) in the second scenario, whilst 50 km of SMF and EDFA with 10 dB of gain and 6 dB of noise figure were employed in the first. SMF, EDFA, and DCF approaches were coupled in the third and fourth cases. A second EDFA with 5 dB of gain was added at the receiver side in the fourth scenario, while an EDFA with 10 dB of gain was positioned between the SMF and DCF in the third scenario.

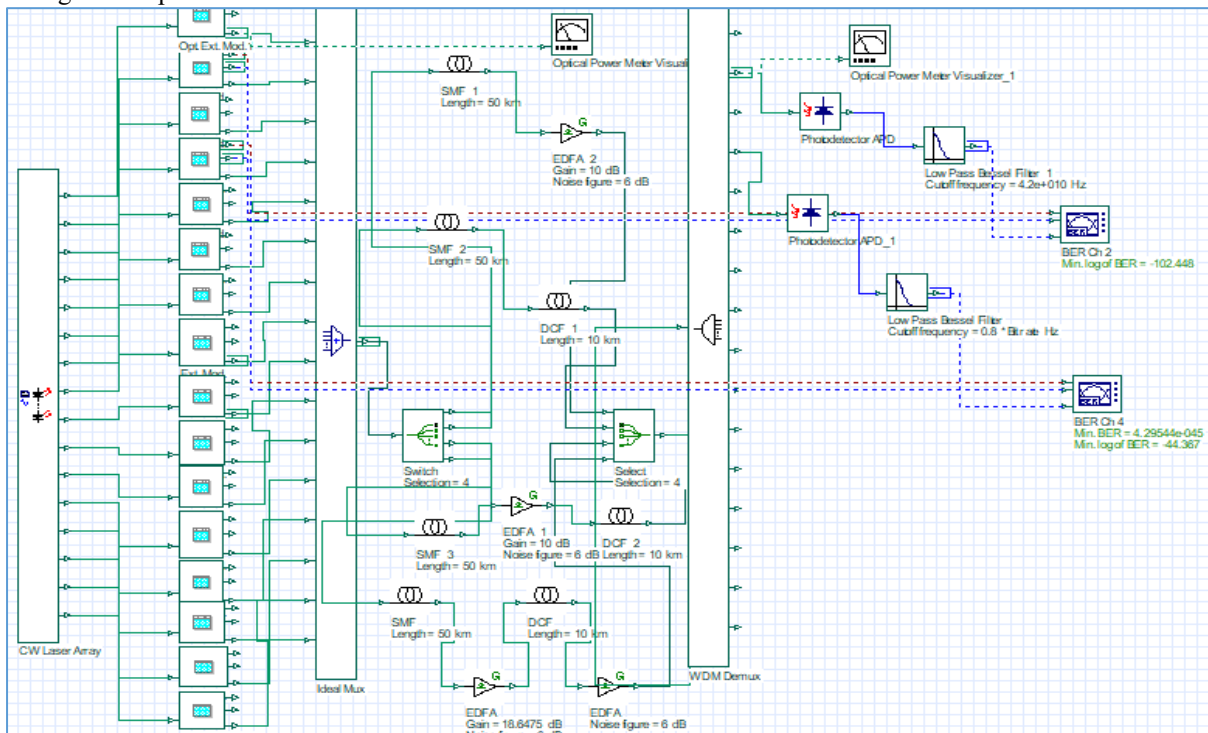


Fig 1. Schematic Design of the Proposed System

While for the receiving side of the proposed system, to convert light waves into electrical signals, it was proposed to use an APD as a photodetector, due to its ability to add gain to the received signal. Then use low-pass Bessel filters that eliminate unwanted frequencies. Also, before the photodetector, to separate the wavelengths mixed in the WDM signal, a WDM demultiplexer is used, which splits the multiplexed optical signal. In addition, a power meter and Bit Error Rate (BER) analyzers were included to measure the received power and system performance where can be calculated as in Equation 1. [19]:

$$BER = \frac{\text{Number of errors}}{\text{Total number bits}} \quad (1)$$

Alternatively, the BER can be derived by evaluating the Signal to Noise Ratio (SNR) of the received information by Equation 2 [20]:

$$BER = \frac{2}{\pi \times SNR} \times e^{\left(\frac{-SNR}{8}\right)} \quad (2)$$

4 OPTIMIZATION TECHNIQUE

OptiSystem software offers several optimization techniques to find the best solution for a set of design parameters in optical communication systems. The software allows defining constraints and then iteratively performs the optimization process, reducing time and cost. Optimization techniques available include particle swarm, genetic algorithms, and gradient-based optimizations. In this paper, an iterative optimization technique that begins with setting termination criteria and constraint boundaries was proposed. The objective of this research is to ensure guaranteed reliability and a high data rate while maximizing the SNR. To achieve this, an iterative optimization problem with the objective of minimizing the BER using a function f with N variables has been proposed, while maximizing the distance or minimizing input power with a function g having M variables. The goal is to find the optimal point x^* that minimizes this problem that appears in Equation 3.

$$f(x^*) \leq f(x), \quad \forall x \text{ close to } x^* \quad (3)$$

5 RESULTS AND DISCUSSION

The results introduced in this section demonstrate the enhancement in the proposed system performance. The results are obtained by using the Optisystem simulator. The relation between different input power and the minimum log of BER of the 40 Gbps 16 WDM channels system is illustrated in Fig.2 where four scenarios were considered for the channel. In the case of SMF with EDFA, zero BER will be received even when the optical power increases. This is happening because the WDM signal is very sensitive to the dispersion of the optical fiber thus a dispersion compensation technique must be used. In the other scenarios, a DCF has been used as a dispersion compensator with or without an optical amplifier. The results show that in the case of using two EDFAs, the system will provide better performance especially when low input power. In contrast, when increasing the input power, the error rate will increase in both last scenarios, this is because of the optical fiber nonlinear effects. However, the proposed optimization algorithm is established to enhance the performance of the system while low power input is considered.

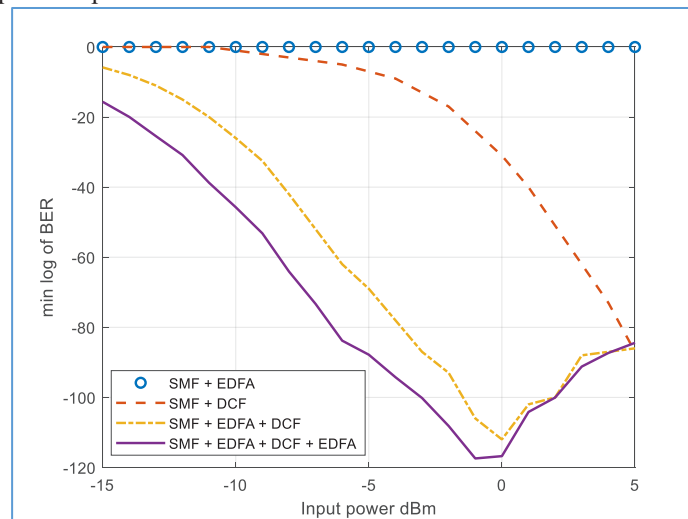


Fig 2. The input power versus minimum log of BER considering four scenarios for the channel.

Fig. 3 shows the eye diagram of the WDM channel 2 in the scenario of SMF + EDFA + DCF + EDFA where 40 Gbps of data rate, 16 WDM channels with -10 dBm of input power, and APD gain of 3 before the optimization.

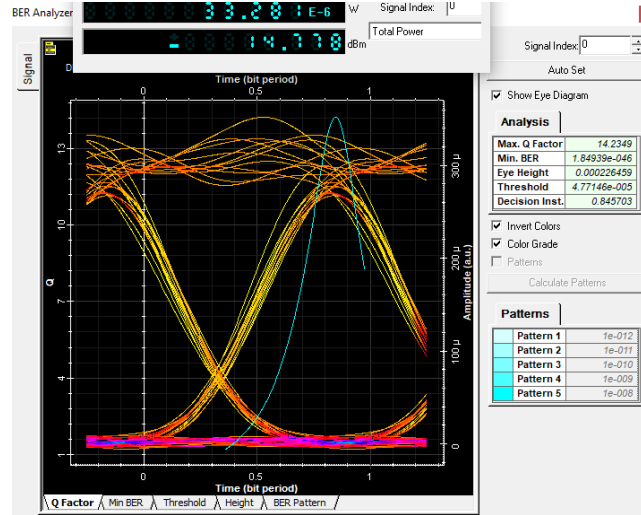


Fig 3. The eye diagram of a WDM channel 2 before the optimization

The cutoff frequency of the low pass Bessel filter, the gain of the photodetector APD, the bandwidth of the WDM de-multiplexer, and the gain of both EDFAs are all optimized. This optimization led to better performance as Fig. 4 shows with a comparison to Fig.3 where the minimum BER is 3.56×10^{-103} . On the other hand, it is less in the pre-optimization case (1.84×10^{-46}). The eye diagram in Fig. 4 is more opening and this means a lower level of Inter-Symbol Interference (ISI) and robustness against noise, as well as the received power of the optimal scenario, is greater (769.59 versus 33.28 mW).

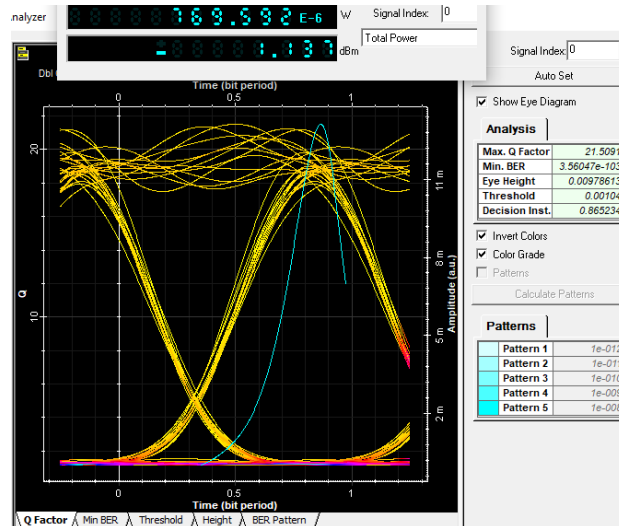


Fig 4. The eye diagram of a WDM channel 2 after the optimization

6 CONCLUSION

The optimization algorithm used in this study improved the performance of a 40 Gbps 16-channel WDM system. This work proposed an iterative algorithm to optimize and improve the optical communication link. The optimization algorithm resulted in a lower Bit Error Rate, improved eye chart

quality, and increased received power. Additionally, it has been noted that dispersion compensation methods, like the employment of optical amplifiers and dispersion-compensating fibers, can assist in lessening the impacts of dispersion and enhance overall system performance.

In summary, the findings show that the WDM system's efficiency may be greatly enhanced by adjusting important parameters including the Low Pass Filter (LPF) cutoff frequency, the APD photodetector's gain, the WDM demultiplexer's bandwidth, and the EDFAs' gain.

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