American Journal of Applied Sciences and Engineering | *ISSN 2766-7596*
Published by AIR JOURNALS | *https://airjournal.org/ajase*
12011 WestBrae Pkwy, Houston, TX 77031, United States
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Research article

# Mitigating the Effect of Chromatic Dispersion in Shared Path Optical Network using Intelligent Dense Wavelength Division Multiplexing Techniques

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| Accepted: August 21st, 2022 | Published: September 30th, 2022 |
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*Citations - APA*

Ogili, S. N., Onuigbo, C. N., & Abonyi, D. O. (2022). Mitigating the effect of chromatic dispersion in shared path optical network using intelligent dense wavelength division multiplexing techniques. *American Journal of Applied Sciences and Engineering, 3(5), 24-34, DOI: https://doi.org/10.5281/zenodo.7886683*

ABSTRACT

*This paper presents mitigating the effect of chromatic dispersion in shared path optical network using intelligent Dense Wavelength Division Multiplexing (DWDM) technique. The study reviewed literatures and identified that DWDM currently in use to compensate for losses due to chromatic dispersion, also experience technical problems of collision, and affects quality of data transmission. To solve this problem an intelligent rule-based optimization algorithm was developed to improve the DWDM. This was implemented with Optiwave software and used to improve the optical network. Result of signal strength at 50km distance was -55.161dBm for a transmit power of 3.047W. While that of the network with IDWDM recorded for power 3.523W and signal strength -54.530dBm. The result implied that with IDWDM, the percentage in noise reduction is 13.5% when power is considered and 1.14% when signal strength is considered.*

***Keywords:*** *Optic Fiber; Chromatic Dispersion; Shared Path Optical Network; Intelligent Dense Wavelength Division Multiplexing Techniques; IDWDM*

## Introduction

Over the years the needs for increased speed of data routing and data transmission rate at minimum time, low cost, less complexity, etc. have remained the driving force behind the rapid changes and transformation in the Information and Communication Technology (ICT) sector. However, increased number of new users day by day, high data demands for certain internet applications, need for real time transmission, etc. have presented a major challenge to the present day ICT facility in achieving desired user experience. According to Guizani et al. (2006) one major reason which made the conventional ICT network infrastructure unable to meet the desired user requirement is the limited spectrum channel available for data transmission, which in most cases are not sufficient to manage the capacity of data rate available for transmission, and hence affects the real time experiences of users.

One solution which has the potential to solve this problem is the optic fiber technology. This fiber is characterized by data transmission at the speed of light, large data transmission and immunity to electromagnetic interference which is one of the challenges of the existing radio frequency-based transmission network (Costa et al., 1983). In fiber transmission, data can be sent through single mode or multi-mode. In the single mode, data is transmitted through one direction only, while in the multi-mode, data can be transmitted in bi-directional form. During the process of data transmission many characteristics of light particles like scattering effect, chromatic dispersion, etc. exist. (Costa et al., 1983; Cohel,1985).

Most especially, chromatic dispersion has remained a major problem for optical fiber transmission. Chromic dispersion is as a result of dynamic transmission of frequency or wavelength components within an optical signal at varying speed (Christensen, et al., 1993). The problem affects the optical signal transmitting distance, especially for single mode fibers (Chen, et al., 2022). In addition, it also produces delay time deterioration, fading of signal, accumulation of dispersion, attenuation (Morito, et al., 1999), polarization Nielsen and Chandrasekhar (2005), which all affects the quality of data transmission.

This impact of dispersion on the signal quality broadens laser pulse till in most case it overlaps resulting to increased error rate. Dense Wavelet Division Multiplexing (DWDM) technique is a strategy which is employed generally to help compensate for chromatic dispersion. The approach allows the transmission of multiple data streams into a single fiber channel. However, there is need to provide quality of data transmission which can go beyond quality of service, but also address quality of user experience.

To this end, many techniques have been proposed for the compensation and optimization of service quality in optic fiber. Ali et al (2019), Proposed a feed forward equalizer for the optimization of signal losses due to chromatic distortion. Chen, et al. (2022) used applied frequency and vector network for the analysis of the problem. The visualization of the data employed Fourier transform and tested over 10km. Other studies such as (Ranzini et al 2019, Bobruk, 2021, and Ranzini et al 2020) applied employed filter for the chromatic compensation and the three results showed that delay was reduced. However, there is need for an intelligent solution for the mitigation of chromatic dispersion in optic fiber network. This will be achieved in this paper using an intelligent DWDM approach which mitigates the impact of chromatic dispersion on the quality of optical data and ensure quality of service.

## Literature Review

Chen, et al. (2022) presented the application of frequency domain method and vector network analyzer for the measurement of chromatic dispersion on a single-mode fibers, polarization maintaining fibers and few-mode fibers. The transfer function of the fiber transmission is obtained using the vector network analyzer, then uses the inverse Fourier transform for measuring the complex transfer function obtained and to determine the group delays for each of the fiber modes. The result of the system identified that the technique can be used to measure very low optical power and very long fibers of about 10km in length.

In Ali et al. (2019), adaptive equalization for dispersion mitigation in multi-channel optical communication networks, was presented. The system uses a feed forward equalizer and decision feedback equalizer for the investigation of the optical downlink of the network system and then uses the acquired data to achieve maximum performance of the optical communication networks with the adaptive equalizer. The result of the study presented that the technique has a key impact in mitigation of dispersion on a multi-channel optical transmission. The bit error rate is below $10^{-5}$ and quality factor is above 5.

Ranzini et al. (2019) presented the mitigation of chromatic dispersion in a direct detection system using optoelectronic signal processing. The work considers the application of feed forward neural network equalizer and recurrent neural network with reservoir computing for the investigate the filters in the network signal. The filters include the arbitrary waveguide grating filter and a series of cascaded Mach-Zehnder delay equalizer. The result of the work calculated the transmission with respect to transmission without equalization, A 32GBd transmission presented 0dB penalty at 25km transmission distance with reservoir computing and feed-forward neural network procession at 40km, while Bobruk (2021), researched on the compensation of chromatic dispersion in a fiber optic telecommunication line with the growth needs of the bit rates in the dense wavelength division multiplexing. The fiber optics lines considered in the research is the ITU G.652 A and B fibers. The methods presented in this work are dispersion compensation single mode fiber, dispersion compensation grating and double cladding-photonic optical fibers. The result of the study presented that the method that gives the best compensation performance by obtaining the lowest line attenuation is the dispersion compensation single mode fiber. It guarantees effective compensation of dispersion to about level 0ps/nm.

Ranzini et al. (2020) researched on machine learning based tunable optoelectronic chromatic dispersion compensation for transmission on a short-reach. The hybrid structure applied for the mitigation of the fiber chromatic dispersion is achieved by sharing the complexity among optical and digital domain. This is done by slicing the signal into smaller bands and applying delay on them accordingly, then later regroup the signals again. It calculates the delay in each scenario to mitigate the rate of bit errors. The result of the study is presented that the 32GBd transmission with 0dB penalty of the hybrid solution presented a mitigation of 200ps/nm for chromatic dispersion (equivalent to 12km standard of the single mode fiber length).

Trujillo et al (2020) presented an algorithm for chromatic dispersion compensation dynamically on XGS-PON network architecture. The study applied the OptiSim and Matlab tools to develop an algorithm for the dynamic mitigation of chromatic dispersion and reduce the degrading effects brought to the optic fiber network system. The result of the system simulation identified that the there is need for additional amplification on the system in order to meet up with the target parameters on the designed modules. Roumelas et al (2019) researched on chromatic dispersion and time jitter experienced on underwater optical wireless communications. The work investigates the influence of time jitter and chromic dispersion on an underwater optical wireless connection system. The work identified that the chromatic dispersion makes the network pulse to be temporary broadened of narrowed, while the jitter makes the detection process at the receiver to be complicated. The work extracted a mathematical expression for the probability of fade on the time jitter. Zhang et al (2022) presented the mitigation optical layer impairments of a multi-band optical networks using G.652 and loss minimized G654 fibers. The work also paid attention on other optical layer impairments like LP01-LP11 mode coupling, the negative impact of the Simulated Raman Scattering (SRS) with the use of optical supervisory channel and optical domain reflectometer in all types of fiber and four wave-mixing issues. The work identified that the technique applied can be used for optimal satisfaction of resource utilization in optical fiber networks.

**Formulation of Fiber Propagation Impairment**

The propagation path of fiber is described according to Govind (2002) as a light pulse through optic fiber in a nonlinear Schrodinger state presented in equation 1 as;

$$j\frac{dA}{dz} = \frac{B_2 d^2 A}{2dt^2} - j\frac{x}{2}A - Y|A^2|A \qquad 1$$

Where A is the electric field, $B_2$ presents the dispersion parameters, while x is the attenuation coefficient and Y the nonlinear coefficient. The equation 1 describes the nonlinear characteristics of data when it travels through an

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optical path. The power loss which occurs due to the fiber impairments like attenuation and dispersion are presented as equation 2;

$$\frac{dP}{dz} = -aP \qquad 2$$

Where a is the attenuation coefficient, expressed in $Km^{-1}$ and z is the direction of data transmission. The relationship between the input and output is presented as equation 3;

$$P_{out} = P_{in}.e^{-aL} \qquad 3$$

While the attenuation, A in dB/km is defined by equation 4 [16];

$$A\left[\frac{dB}{km}\right] = \frac{-10.\log(\frac{P_{out}}{in})}{L} \approx 4.343.a \qquad 4 \text{ define this alpha?}$$

**Chromatic Dispersion**

This is one of the most affecting quality of service constrain for optic fiber transmission. The chromatic dispersion occurs when the flashes of optics spread its pulses after traveling though distance (Km) in an optical medium (Ali, 2019). During the transmission of packet in the optic fiber, the various wavelength travels at speed which varies from one another due to the core refractive index, thus resulting to the chromic dispersion problem. Li et al. (2018) added that during the data transmission process, the optical pulse end propagates through the cladding fiber which varies the traveling wave speed from the normal speed of light. In some other cases the dispersion results in the break of the optic transmission, resulting to signal degradation.

**Dense Wave Division Multiplexing**

Wave Division Multiplexing (WDM) is a multiplexing strategy where many optical signals with variations in wavelength are channeled towards a single optical fiber (Wang 2019). As shown in the figure 1, the multiple input of data is multiplexed and channeled into a single fiber link, then at the receiving end, the data are demultiplexed and then sent to the receiver. Furthermore, the optical network architecture is equipped with Erbium Doped Fiber Amplifier (EDFA) which is used to boast the signal strength and re-routed after being coupled to the channel using optic coupler until the pulse gets to the final destination.

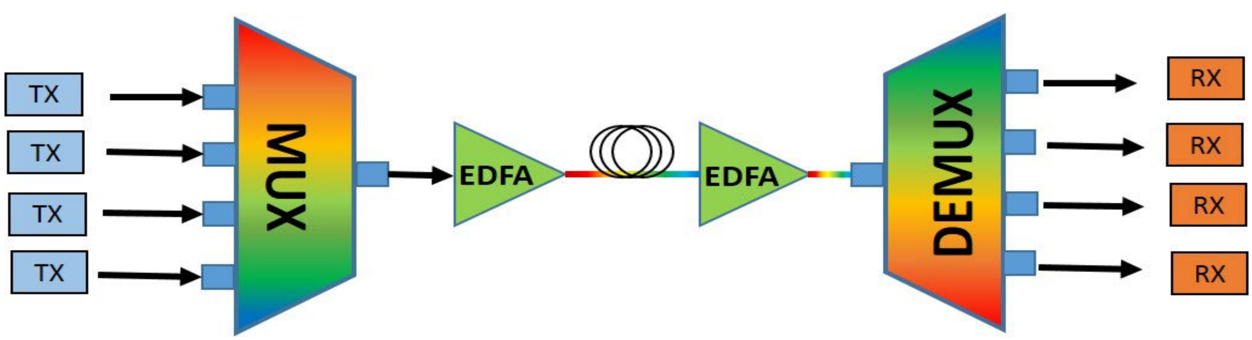


Figure 1: Basic diagram of WDM (Wang, 2019).

The application of WDM has been able to improve the problem of chromatic dispersion in optic fiber, however in the case of dense WDM, large pulse is merged and transmitted on the same optical channel, which is good as speed and capacity is achieved at low cost, but Panda and Debani (2014) revealed that challenges such as interference and cross talk, due to many wavelengths with different channels in the same fiber still exist. (Costa et al., 1983), Posited

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that these collusions are inevitable as dispersion due to scattering particles of light results to variation in optical speed and results to losses and degradation of signal quality at the receiver end. To solve this problem, the paper proposed an intelligent algorithm which helps solve the optimization problem.

**Intelligent Dense Wave Division Multiplexing (IDWDM)**

The need for an IDWDM is vital to manage the problem of collision which occurs in the dense WDM. The intelligence approach employed a rule-based optimization algorithm to ensure that optical pulse merged with different channels do not collide with each other during transmission of data. To achieve this, rule-based algorithm used frequency and time control function to identify the number of available channels in the optical spectrum and also the number of wavelengths which is available for the transmission of data using frequency control function. The figure 2 presents the flow chart of the RO, while the figure 3 presents the flow chart of the IDWDM. Below is the algorithm;

**Rule Based Optimization Algorithm (RBO)**

1. Start
2. Initialize frequency (f) and time (t) functions
3. Generate the number of channels available as (1, 2, 3…….y)
4. Determine the number of wavelets (1, 2, 3……..x)
5. Load pulse (z) and align with wavelet x
6. Initiate data transmission process
7. Search for y and align with x
8. If z is true and y =0
9. Set t = 50ms
10. Activate delay and return to step 7
11. Else
12. Align z with y
13. Transmit data
14. End if
15. Return

**American Journal of Applied Sciences and Engineering | AJASE**
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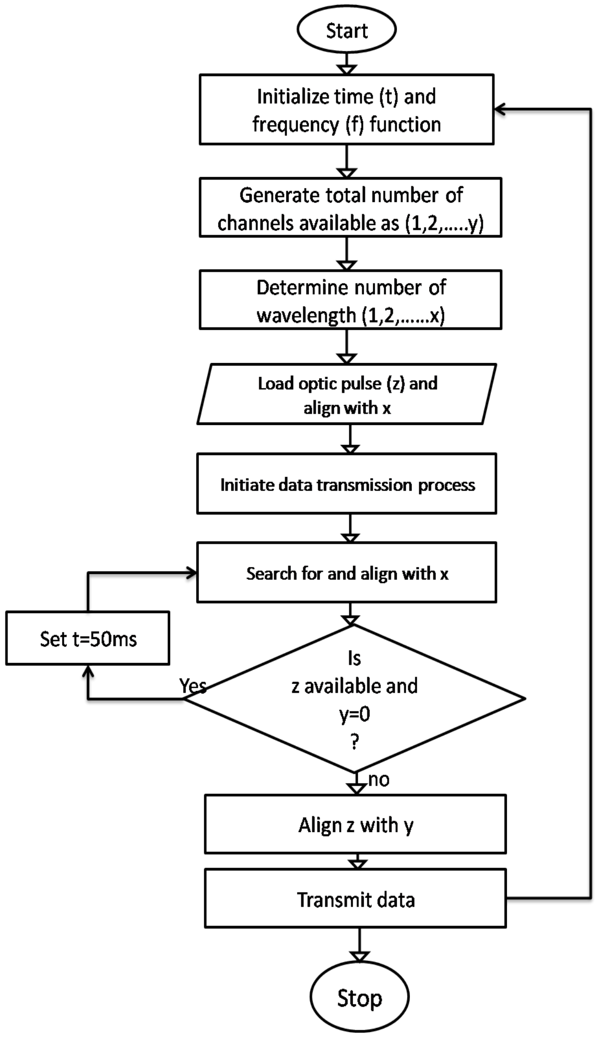


Figure 2: Flow chat of the RBO

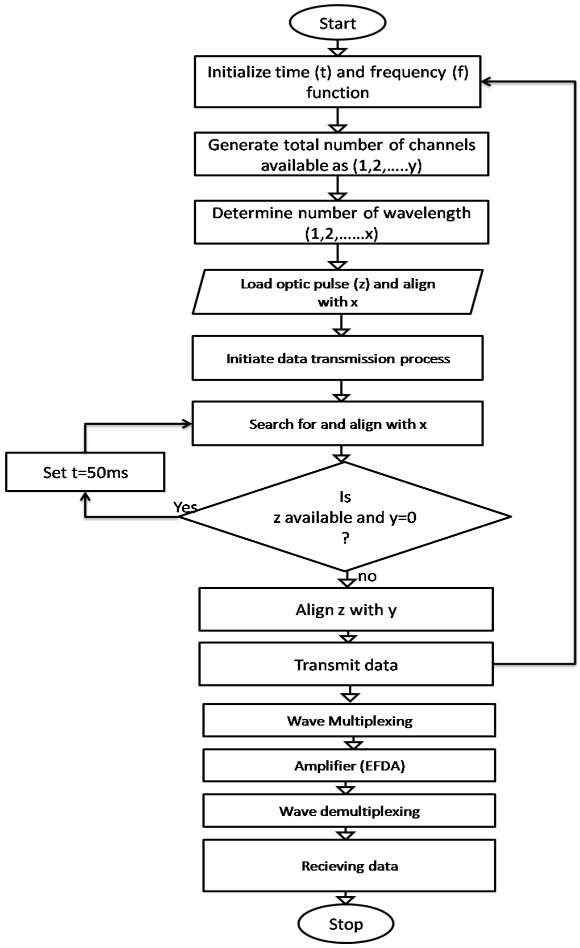


Figure 3: Flow chart of the IDWDM

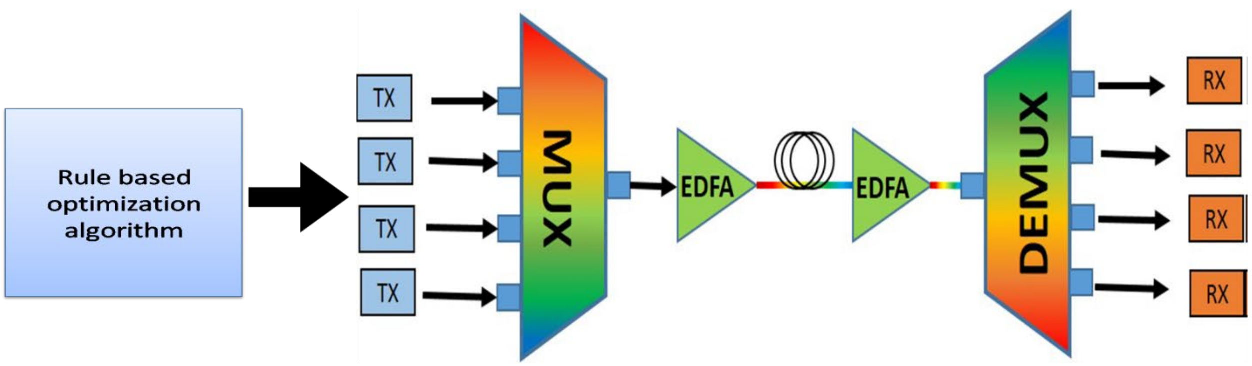


Figure 4: Architecture of the IDWDM

The figure 2 presented the flow chart of the intelligent algorithm developed to mitigate the impact of chromatic dispersion in the optical fiber network, while the IDWDM model was presented in the flow chart of figure 3. The diagram shows the intelligent DWDM system was used to coordinate the wavelet and channels of the optical network to avoid collusion which has been the problem with the existing system. This was achieved via the coordination of the wavelet and channels appropriately, while the wavelet available with no channel or allocation is delayed in 50 ms and then retransmitted when channel is available as shown in the architectural model of the IDWDM in figure 4.

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Simulation and Results

The model of the IDWDM was integrated on optical fiber network using optiwave software as shown in the figure 5 and the performance analyzed with the parameters in table 1;

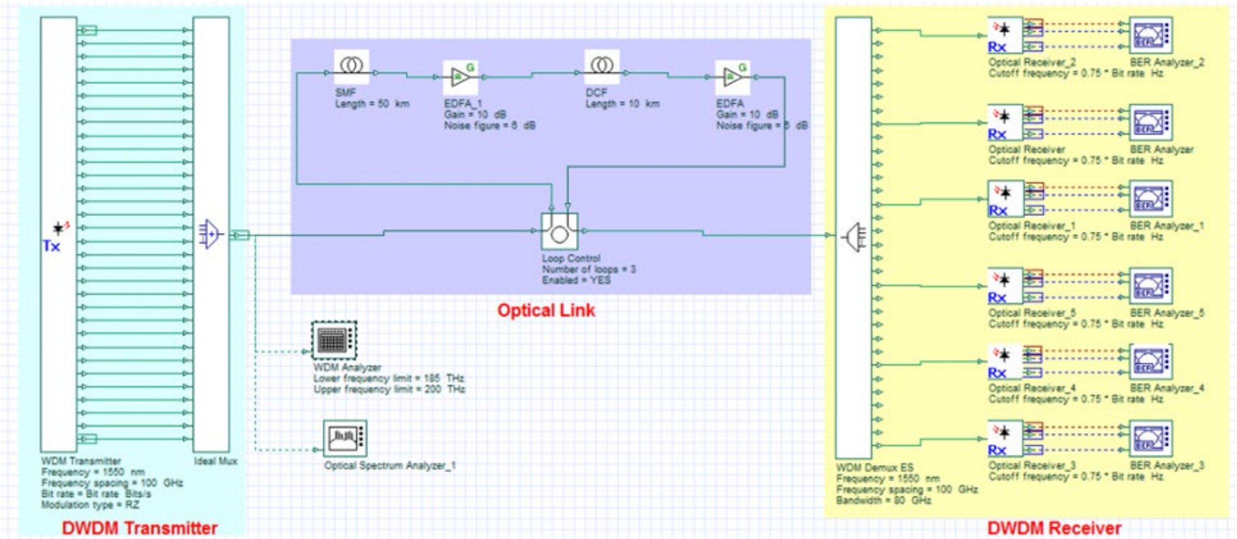


Figure 5: Optical transmission network

The figure 5 showed the network which the IDWDM model, embedded with the transmitter and was used to generate and transmit optical signal, while the performance analyzed with power meter. The network was simulated with the IDWDM active and also without the algorithm active and their performance was evaluated considering signal strength and power.

**Table 1: Simulation Parameters**

| Parameters | Values |
|---|---|
| **Length** | 50km |
| **EDFA gain** | 10Db |
| **Noise figure** | 8Db |
| **Loop** | 3 |
| **Frequency spanning** | 100GHz |
| **Frequency** | 1550nm |
| **Cutoff frequency** | 0.75 |
| **Bandwidth** | 80GHz |
| **Distance** | 50km |
| **Software** | Optiwave |

Figure 6 presents the performance of the optical network signal strength without IDWDM, while figure 7 presented the signal strength with IDWDM. Also figure 8 showed the noise without IDWDM and the noise with IDWDM in figure 9 respectively;

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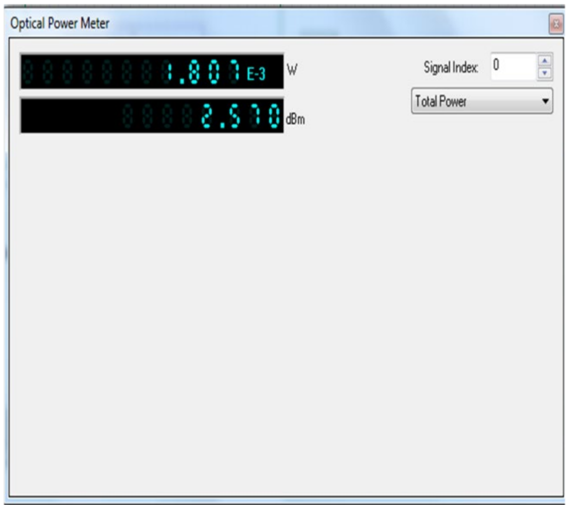


Figure 6: Signal without IDWDM

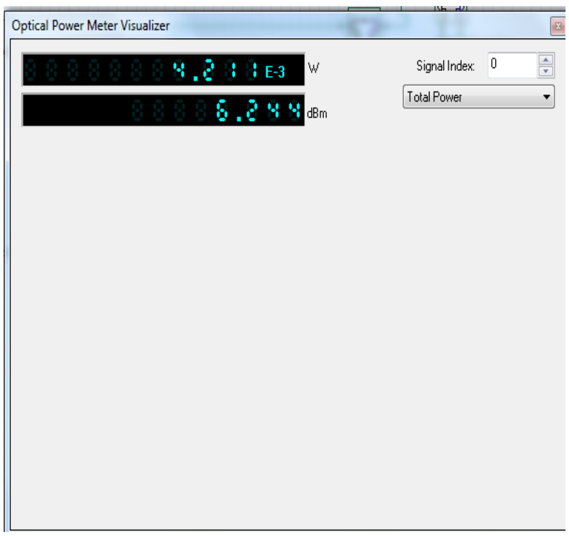


Figure 7: Signal with IDWDM

The figure 6 presented the performance of the optical network with IDWDM considering the total power received after data has been transmitted. The result without IDWDM for power on the same network parameters is 1.807W and 2.570dBm signal strength. Result of figure 7 showed that the power recorded is 4.211W and the signal strength is 6.644dBm. The implication of the result showed that the quality of service achieved with the IDWDM is better as the problem of interference with the DWDM has been minimized and the wavelength coordinated to prevent collusion. The performance improvement of the optical network using 1DWDM and considering power is 57%, while with signal strength an improvement of 58.84% was recorded. The next result presented the noise performance analysis with power meter.

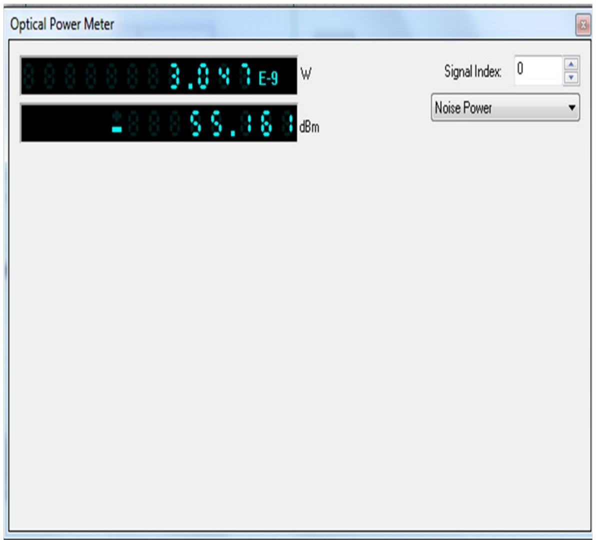


Figure 8: Noise without IDWDM

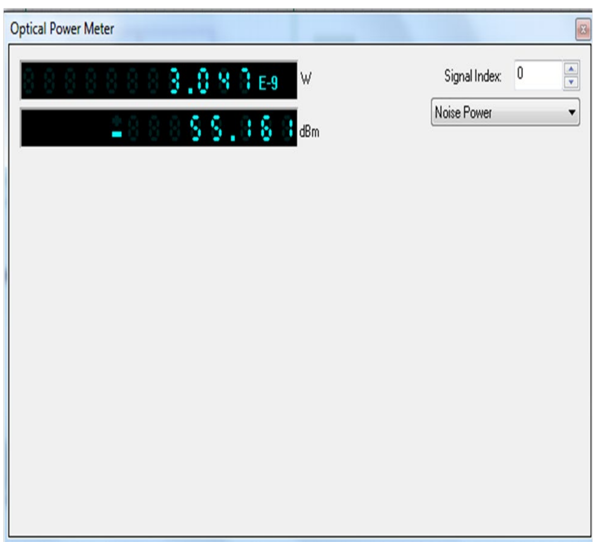


Figure 9: Noise with IDWDM

The figure 8 presents the noise value without IDWDM considering the power and signal strength. The valued of the power is 3.047W and the signal strength recorded -55.161dBm. While that of the network with IDWDM recorded for power 3.523W and signal strength -54.530dBm. The result implied that with IDWDM, the percentage in noise reduction is 13.5% when power is considered and 1.14% when signal strength is considered.

**Conclusion**

Over the years, the impact of chromatic dispersion has continued to impair on the quality of service in optical network transmission. The application of WDM which was meant to compensate for the problem, result to issues of collision or interference especially during the transmission of large data files, and has remained another technical problem. To address the issues, IDWDM was developed and deployed in an optical network transmitter using simulation approach in Optiwave software. The result when tested over an optical distance of 50km showed 13.5% reduction in signal degradation.

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**References**

Ali, F., Ahmad, S., Muhammad, F., Abbas, Z., Habib, U., & Kim, S. (2019). Adaptive equalization for dispersion mitigation in multi-channel optical communication networks. *MDPI Electronics,* 8, 1364. https://doi.org/10.3390/electronics8111364

Bobruk, T. (2021). Chromatic dispersion compensation in existing fiber optic telecommunication lines with the growing bit rates needs of DWDM system. *IAPGOS*, 4, 38-41. https://doi.org/10.35784/iapgos.2805

Boris, A. (2002). Variation methods in nonlinear fiber optics and related fields. In Process in Optics.

Costa, B., Puleo, M., & Vezzoni, E. (1983). Phase-shift technique for the measurement of chromatic dispersion in single-mode optical fibres using LEDs. *Electronics Letters,* 19, 1074-1076. https://doi.org/10.1049/el:19830729

Cohen, L. (1985). Comparison of single-mode fiber dispersion measurement techniques. *Journal of Lightwave Technology,* 3, 958-966. https://doi.org/10.1109/JLT.1985.1074509

Christensen, B., Mark, J., Jacobsen, G., & Bødtker, E. (1993). Simple dispersion measurement technique with high resolution. *Electronics Letters,* 29, 132-134. https://doi.org/10.1049/el:19930094

Chen, X., Hurley, J., Stone, J., & Li, M. (2022). Chromatic dispersion measurements of single-mode fibers, polarization-maintaining fibers, and few-mode fibers using a frequency domain method. Photonics, 10, 215. https://doi.org/10.3390/photonics10020215

Govind, P. A. (2002). Fiber-optic communication systems (3rd ed.). Wiley.

Guizani, S., Razzak, M., Hamam, H., Bouslimani, Y., & Cheriti, A. (2006). Effect of chromatic dispersion on fiber over wireless systems. *IEEE*, 1-7. https://doi.org/10.1109/ICTTA.2006.1684512

Li, F., Zou, D., Ding, L., Sun, Y., Li, J., Sui, Q., Li, L., Yi, X., & Li, Z. (2018). 100 Gbit/s PAM4 signal transmission and reception for 2-km interconnect with adaptive notch filter for narrowband interference. Optics Express, 26, 24066-24074. https://doi.org/10.1364/OE.26.024066

Marial, S. (2009). Digital pre-compensation of chromatic dispersion in QPSK high-speed telecom systems (Master's thesis). TRITA-ICT-EX-2011:209.

Morito, K., Sahara, K., Sato, R., & Kotaki, Y. (1999). Penalty-free 10 Gb/s NRZ transmission over 100 km of standard fiber at 1.55 µm with a blue-chirp modulator integrated DFB laser. *IEEE Photonics Technology Letters,* 8, 431-433. https://doi.org/10.1109/68.750369

Nielsen, T., & Chandrasekhar, S. (2005). OFC 2004 Workshop on Optical and Electronic Mitigation of Impairments. *Journal of Lightwave Technology,* 23.

Panda, A., & Debani, P. (2014). Nonlinear effect of four wave mixing for WDM in radio fiber system. *Journal of Electronics and Communications Engineering Research*, 2(4), 1-6.

Ranzini, S., Da-Ros, F., Bulow, H., & Zibar, D. (2019). Tunable Optoelectronic Chromatic Dispersion Compensation Based on Machine Learning for Short-Reach Transmission. *MDPI Applied Sciences,* 9(20), 4332. doi:10.3390/app9204332

**Vol. 3, No. 5 | 2022 | pp. 24-34 |** *DOI: https://doi.org/10.5281/zenodo.7886683*

Ranzini, S., Da-Ros, F., Bulow, H., & Zibar, D. (2020). Optoelectronic signal processing for chromatic dispersion mitigation in direct detection systems. European Union's Horizon 2020 research and innovation programme European Research Council through the ERCCoG FRECOM project (grant agreement no. 771878).

Roumelas, G., Nistazakis, H., Stassinakis, A., Volos, C., & Tsigopoulos, A. (2019). Underwater Optical Wireless Communications with Chromatic Dispersion and Time Jitter. *Computation,* 7(3), 35. doi:10.3390/computation7030035. https://www.mdpi.com/journal/computation

Trujillo, A., Gomez, G., & Zemanate, A. (2020). Algorithm for the dynamic compensation of Chromatic Dispersion in XGS-PON network architecture. In Expotecnología 2019 "Research, Innovation and Development in Engineering IOP Conf. Series: Materials Science and Engineering 844 (pp. 012048). IOP Publishing. doi:10.1088/1757-899X/844/1/012048

Wang, R. (2019). Resource Allocation and Optimisation of Elastic Optical Networks in Nonlinear Regime. Explore Bristol Research. http://research-information.bristol.ac.uk

Zhang, C., Liu, X., Li, J., Zhang, A., Liu, H., Feng, L., Lv, K., Liao, S., Chang, Z., & Zhang, J. (2022). Optical Layer Impairments and Their Mitigation in C+L+S+E+O Multi-Band Optical Networks with G.652 and Loss-Minimized G.654 Fibres. *Journal of Lightwave Technology,* 40(11), 3415-3424