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REVIEW ARTICLE ON THE MITIGATION OF FOUR WAVE MIXING IN OPTICAL COMMUNICATION SYSTEM

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ABSTRACT

The main challenge faced in today's telecommunication is the ever increasing demand for bandwidth and data rates. The desire to expand the capacity of fiber optic communication to accommodate this demand accelerated the development of high capacity Dense Wavelength Division Multiplexing (DWDM) transmission equipment. However, nonlinear impairments are the fundamental limiting mechanisms to the amount of data that can be transmitted in DWDM. In DWDM, Four Wave Mixing is the most critical of nonlinear effects in fibre optics communication. This effect limits the DWDM's channel capacity. There are numerous researches on nonlinear impairments that show the intricacy of FWM phenomena in DWDM system. This article present review of the several measures which have been carried out by researchers to overcome nonlinear effects in DWDM. Such measures include Modulation Formats, Channel Spacing, Channel Shuffling Algorithm and Electro-Optic Phase Modulation. The review provides insight into the methods, parameters and approaches used by other researchers. This will pave way for can thus lead to significant improvement in the design of DWDM system.

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1.0 INTRODUCTION

Optical communication is the transmission of communication signals in the form of light over a thin glass or plastic (Fiber) guided through glass fibers to move huge blocks of data over long or short distances. On one hand, the main equipment used in optical transmission is Wavelength Division Multiplexing (WDM). WDM can be classified into two different wavelength patterns: Coarse Wavelength Division Multiplexing (CWDM) and Dense Wavelength Division Multiplexing (DWDM). The CWDM provides up to 16 channels across multiple transmission windows of fibres. However, DWDM uses two different light bands, red and blue, for transmission window but with denser channel spacing. Channels designs vary, but typical DWDM system uses 40 channels at 100GHz spacing or 80 channels with 50GHz spacing. CWDM and DWDM are based on similar principle of using multiple wavelengths of light on a single fibre but differ in the spacing of the wavelength, channels number, and the capacity to amplify the multiplexed signals in an optical environment. DWDM has been proven to be

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one of the most capable technologies for optical communication systems.

On the other hand, the nonlinear effect of optical fiber plays a negative role in the information carrying capacity of DWDM system since it degrades its performance and reduces bandwidth capacity of the equipment. The limitation of nonlinear effects in DWDM cannot be compensated but instead it accumulates.

Four Wave Mixing (FWM) occurs when two co-propagating wave produce two new optical sideband waves at different frequencies to cause severe cross talk between channels propagating through an optical fiber. The two most important classes of nonlinearity effects are nonlinear effect due to refractive index and nonlinear effect due to scattering Fizza *et al.,* 2016). Nonlinearities that occur due to optical changes in the refractive index are Self-Phase Modulation (SPM), Cross-Phase Modulation (XPM), and FWM. Also, nonlinearity effects that occur as a result of scattering include Stimulated Raman Scattering (SRS) and Stimulated Brillouin Scattering (SBS). This is as shown in Figure 1. SBS and SPM can only be examined in single channel link whereas SRS, XPM and FWM are introduced in multi-channel link (Lavingia *et al,* 2015). In DWDM, FWM is the most critical of nonlinear effect. This is caused by the nonlinear attribute of the refractive index of an optical fibre interacting among amid DWDM channels to create sideband which causes inter-channel interference. The major effect of FWM is to limit the DWDM's channel capacity.

This limit becomes more severe for large number of DWDM channels with small spacing (Tawade *et al*, 2010). In addition, the nonlinear effects depend on transmission length. The longer the fibre link length, the more the light interaction and the greater the nonlinear effect.

The aim of this article is to review some of the methods used by researchers in mitigating FWM effect in a DWDM system. The article is organized as follows. Section II described the theory, concept and mathematical analysis of FWM. Sections IV chronologically showcase methods proposed by researchers for mitigating FMW. The strengths and weaknesses of the methods suggested for mitigating FWM, the choice of parameters used was discussed, from the farthest to the earliest. The role of enumerated methods and

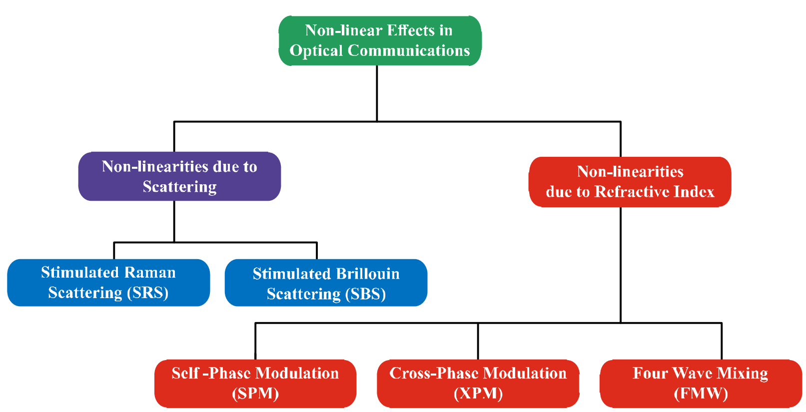

Figure 1: Classification of Nonlinear Effect in fibre Optics Communication

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their effectiveness in reducing FWM in optical transmission was highlighted. Section V is the conclusion. Finally, section IV describes the further opportunities and challenges in the context of this article.

The demand for higher bandwidth has skyrocketed due to exponential growth of the internet traffic. Nonlinear effects on fibre optic system pose a serious limitation for the existing carrier technologies. In principle, the capacity of optical communication systems can exceed 10Tbps which can enable service providers to accommodate consumers' demand for ever-increasing amounts of bandwidth (Agrawal, 2006). However, in practice, the bit rate of 100Gbps is hard to come by with the use of DWDM transmission equipment due to limitations imposed by the nonlinearity attributes on optical fibre link.

These effects impede the transmission capacity and performance of optical communication system. There are numerous researches on nonlinear impairments which show the intricacy of such phenomena for DWDM Alvarez-Chavez *et al*. (2018). Also, several measures have been proposed by researchers to overcome the impact of nonlinear effects in DWDM, such as Modulation Formats (Tawade *et al*. 2010; Iyer and Singh, 2011; Prabhpreet and Kulwinder, 2014; Abd *et al* 2018) Channel Spacing (Sharma, and Kaur, 2012; Singh and Singh, 2016) Channel Shuffling Algorithm (Jain and Kaur, 2016) and Electro-Optic Phase Modulation (Waidi *et al*. 2018).

Although these proposed methods contributed towards improving the effect of FWM, yet these methods are inadequate since they do not totally take care of nonlinear characteristics of FWM on DWDM systems' Quality Factor (Q-Factor). There is a need to suggest useful approaches that will make more significant difference in bridging the knowledge gap that exists from the previously used methods.

2.0. FOUR WAVE MIXING (FMW): THEORY AND CONCEPT

The Four Wave Mixing (FWM) is a nonlinear phenomenon that plays dominant role in distant transmission of signal. FWM can be detrimental for DWDM systems that must be designed to reduce its impact. FWM mixing process results in power transfer from one channel to other. This FWM attribute results in power drain of the channel, which degrades the performance of the channel, in order to achieve original BER, some additional power is required which is termed as power penalty. Since, FWM itself is inter-channel crosstalk it induces interference of information from one channel with another channel. This interference of information again degrades the system performance. To reduce this degradation, channel spacing must be increased. Also, FWM imposes limitations on the maximum transmit power per channel (Singh and Singh, 2007).

If the channel spacing is decrease, the number of channels increases; consequently increasing the transmission capacity of DWDM system. However, the closer the spacing, the more new wave are generated, resulting in channel crosstalk due to FWM. In another word, decreasing the channel spacing increases the FWM effect and so does decreasing the dispersion. Similarly, smaller spacing also limits the maximum data rate per wavelength.

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FWM arises when two co-propagating waves produce two new optical sideband waves at different frequencies. Severe cross talk between channels propagating through an optical fiber occurs when new frequencies fall in the transmission window of original signal. It can induce crosstalk in DWDM communication systems and limit the performance of such systems. Figure 2 is an illustration of the process, consider the interaction of two strong waves at frequencies ω_1 and ω_2, which mix to produce a downshifted (Stokes) wave at ω_3 and an upshifted (anti-Stokes) wave at ω_4. The frequencies have equitable spacing. This article highlighted methods used in mitigate FWM in DWDM systems.

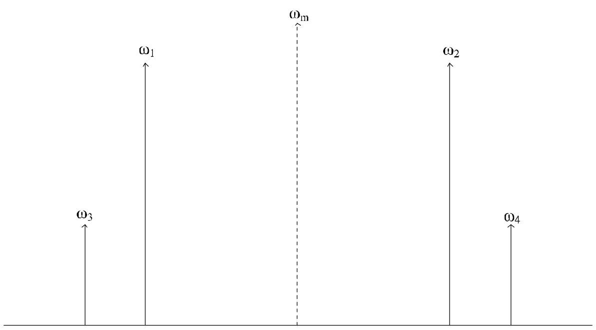

Figure 2: Frequency diagram for FWM with Pump frequencies (ω_1 and ω_2) and sideband frequencies (ω_3 and ω_4)

Mathematical Analysis of FWM

The origin of nonlinear reaction can be traced to harmonic motion of bound electrons under the influence of an applied field. As a result, the total polarization P induced by electric dipoles is not linear in the electric field E, but satisfies the more general relation (Agrawal, 2002).

$$P = \varepsilon_0 (X^{(1)} \cdot E + X^{(2)} : EE + X^{(3)} \vdots EEE + ...) \qquad 1$$

where ε_o is the vacuum permittivity and is j^{th} order susceptibility. The linear susceptibility represents the dominant contribution to P vanishes for silica glasses since optical fibers do not normally exhibit second-order nonlinear effects

The main features of FWM can be best understood from the third-order polarization term in (1). DWDM signal is considered to be a sum of n monochromatic plane waves and the nonlinear polarization, P_{nl}, is given by

$$P_{nl} = \varepsilon_0 X^{(3)} E^3 \qquad 2$$

and the electric field signal can be expressed as

$$E = \sum_{p=1}^{n} E_p \cos(\omega_p t - k_p z) \qquad 3$$

substituting (2) into (3)

$$P_{nl} = \varepsilon_0 X^{(3)} \sum_{a=1}^{n} \sum_{b=1}^{n} \sum_{c=1}^{n} E_a \cos(w_a t - k_a z) E_b$$
$$\cos(w_b t - k_b z) E_c \cos(w_c t - k_c z)$$

further expansion of (iii) gives

$$P_{nl} = \frac{3}{4} \varepsilon_0 X^{(3)} \sum_{a=1}^{n} E_p^2 + 2 \sum_{b \neq a} E_a E_b E_c$$
$$\cos(\omega_a t - t_a z)$$

$$+ \frac{1}{4} \varepsilon_0 X^{(3)} \sum_{a=1}^{n} E_p^3 \cos(3\omega_a t - 3k_a z)$$

$$+ \frac{6}{4} \varepsilon_0 X^{(3)} \sum_{a=1}^{n} \sum_{a>b} \sum_{c>b} E_a E_b E_c \cos[(2\omega_a + \omega_b + \omega_c)$$
$$t - (k_a + k_b + K_c) z]$$

$$+ \frac{3}{4} \varepsilon_0 X^{(3)} \sum_{a=1}^{n} \sum_{b \neq 1} E_a^2 E_b \cos[(2\omega_a + \omega_b)$$
$$t - (2k_a + k_b) z]$$

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$$+[(2\omega_a+\omega_b+\omega_c)t-(k_a+k_b+K_c)z]$$

$$+[(2\omega_a-\omega_b+\omega_c)t-(k_a-k_b+K_c)z]$$

$$+[(2\omega_a-\omega_b-\omega_c)t-(k_a-k_b-K_c)z] \quad 4$$

The first terms of (4) represents the effect of SPM and CPM while the 3rd and 4th terms will be overlooked because of phase mismatch and contribute little. The last term of (4) represents the FWM effect. The term also explains that if three Electromagnetic (EM) Waves co-propagating in a fibre will generate new waves with frequency.

3.0 METHODOLOGY

a. An overview of methods used in mitigating FWM

Analytical research conducted by Singh and Singh (2007), discussed the origin, application and thresholds management of nonlinear effects of FWM in optical fibers was discussed. It noted that nonlinear effects of FWM on a communication system depend on the effective area, effective fiber length, and the intensity of transmitted signal. Also, using Non-zero Dispersion Shifted fibre, ahead of Dispersion Shifted fibre, of large effective area and small effective length with reduced transmitted signal power resulted in reduction of penalty due to FWM process.

In Tawade *et al.*, (2010) Binary and Duo-binary Modulation Format was used to investigate FWM effect on BER in two-channel WDM for 100km long Optical Communication System. In the research it was observed that duo-binary encoding scheme can reduce significantly the level of FWM but only considered two channel WDM in a world where there is huge demand for large number of channels in data communications. The Duo-binary modulation was compared with binary modulation and observed that that BER is more reduced by using Duo-binary modulation compared to binary modulation.

The quality factor deterioration due to combined nonlinear effects and Amplified Spontaneous Emission (ASE), noise for system parameters was investigated in (Iyer and Singh, 2011). The authors emphasizes on SRS and FWM. The research was carried out using 8 and 16 channels WDM system. The channels were modulated using NRZ modulation format. The frequency distribution was based on the 100 GHz and 50 GHz ITU-T G.692 Recommendation frequency grid. In their proposed model, performance of the worst affected channel due to FWM and SRS was compared. The result indicated that the worst affected channel due to SRS performs better and hence suggested for preferred and efficient transmission over worst affected channel due to FWM. But the authors were not specific about the transmission distance which is one of the major parameters that must be considered when designing optical transmission network.

Sharma and Kaur (2012) investigated 80Gbps DWDM system over 100km to calculate the BER-Bit Error Rate- Q-factor and received power in the presence of FWM under equal and un-equal channel spacing was carried out. The result shows that the unequal spacing between the channels helps the system perform better. Conversely, the researchers probed FWM on 16 channels WDM with different modulation format at different values of dispersion, core effective area and channel spacing in terms of FWM power, BER and Q-

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factor.

The effects of FWM was investigated using different modulation formats on 16 channel WDM at various values of dispersion, core effective area and channel spacing by Prabhpreet and Kulwinder (2014). The system performance was evaluated in terms of FWM, power, BER and Q-factor. In their simulated result, it was concluded that with increase in the channel spacing, core effective area of fiber, signal interference between input signals decreases; FWM effect also decreases. Also, it was concluded that duo-binary modulation format, if compare with NRZ, RZ, is the best suitable technique to reduce FWM. However, Single mode fibre of 100km was considered which cannot completely describe the characteristics of FWM in DWDM over long transmission distance such as 200km.

In the research study of Boštjan *et al.* (2014), an overview of future research activities in the field of optical telecommunications towards 2020 and beyond was presented. It was forecasted that continuous development and sophistication will apparently overcome new boundaries in WDM systems. Adding that future research efforts in the field of optical backbone networks will be aimed at tackling the problem of physical limitation called fiber wall, with two trends from the field of spatial multiplexing in sight. Some of the fibre wall can be liken to FWM. However, it was difficult to predict time needed for spatial multiplexing to become commercialized since the very successful WDM technology required 10 years from first laboratory experiments to an implementation in practice.

Agalliu and Lucki (2014), highlighted the benefits and limitations of modulation formats for optical communications. Non-Return to Zero, Return to Zero, Chirped Return to Zero and Carrier-Suppressed Return to Zero modulation formats were compared in terms of BER and spectral efficiency to find the limits for selected transmission network topologies using Time Domain Split Step method. It was observed that phase modulation formats offer many advantages compared to intensity formats. In the final analysis, they concluded that Differential Phase-Shift Keying and Differential Quadrature Phase-Shift Keying improve the Bit Error Rate and transmission reach.

In the research study of Kothari *et al* (2014), FWM in WDM optical fibre systems was analyzed using LABVIEW. The input of FWM was investigated on the design and performance of WDM optical communication system using power and efficiency for different channel spacing of transmitted signals, dispersion and core affective area as parameters. It was concluded that FWM decreases with the increase of the channel spacing of transmitted signals, dispersion and core effective area of fibre.

Ndujiuba and John (2015), discussed different kinds of optical nonlinearities encountered in fibres. The essential materials and fibre parameters that determine them were identified. Two channel WDM optical communication systems in single mode fibre over long haul of 100km were simulated to investigate the effect of SPM, XPM and FWM. Dispersion management technique was used to suppress FWM and performed comparison of nonlinearities using eye pattern with respect to Bit Error Rate and Q-factor. It was concluded that FWM nonlinear effect is more advantageous and effective as compared

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to SPM and XPM.

An experimental analysis carried out by Fizza *et al*. (2016), relates the use of optical rectangular filter to reduce FWM for WDM system. The parameters used in the design are four channels with 10nm spacing, 10Gbps data rate and fibre link of 150km. Electro Absorption Modulator with optical rectangular filter was used in their proposed model. In the model, the filter eliminates all frequency harmonics above a given cutoff frequency, without affecting lower frequencies. It was concluded that possible solutions, increase channel spacing and the use of optical filter, are the two methods of escaping FWM. The result was reported in the form of Q-factor, minimum BER and Eye diagram. However, only four channels were considered in the model developed which does not totally reflect behaviour of DWDM that had been designed to accommodate many channels. In practice, it is not economical to be transmitting over four channels in a longhaul of 150km.

Hybrid modulation formats for the implementation of flexible transponders for Fixed-Grid Optical Networks has been proposed Guiomar *et al* (2016). Two disparate hybridization approaches were engaged, Time-Division Hybridization Modulation Formats (TDHMF) and Quadrature-Division (Flex-PAM) Hybrid Modulation Formats (QDHMF). The researchers, theoretically and numerically, compared back-to-back signal propagation performances of two flexible modulation techniques; TDHMF and Flex-PAM. From a general system performance perspective, it was observed that both TDHMF and Flex-PAM were shown to approach the GN-model predictions in terms of maximum signal reach, incurring small penalties, provided that the appropriate non-linear propagation counter measures are applied. Accordingly, Flex-PAM is an alternative to the widely studied TDHMF, since it offers bit-rate flexibility without requiring time-dependent modulation.

Singh and Singh (2016) compared the effect of FWM for different channel allocation schemes such as Equal Space Channel Allocation (ESCA) and Unequal Space Channel Allocation (USCA) schemes for a DWDM system. The research was analysed under eight (8) channels and evaluated based on the Quality-factor (Q-factor) of the DWDM system for different parameters such as optical fibre length varied from 25 to 125km, Laser power, channel spacing and data rates. The researchers noticed that decrease in the channel spacing between input channels, mutual interference increases; hence the effect of FWM also increases. Similarly, FWM effect decreases with an increase in channel spacing for the DWDM system. The result of the simulative observation shows that USCA offered better Q-factor for DWDM than ESCA.

The performance of DWDM system for symmetric dispersion compensation scheme for 32-channel 40Gbps at RZ modulation scheme over 480km optical fibre link was analysed by Mallick *et al* (2016). The researchers observed from their results that RZ is preferable for long distance communication to minimize FWM effects and concluded that 32-channel DWDM system gives optimum performance if the input power is 3dBm, modulation format is RZ and channel spacing of 200GHz.

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In a research conducted by Jain and Kaur (2016), the use of Dynamically Channel Shuffling Algorithm towards the elimination of FWM was proposed. The method was simulated on OPNET. The results were formulated in terms of Bit Error rate, Quality element, and Optical Signal to Noise Ratio (OSNR). DWDM system with channel spacing of 200GHz and 12 channels was considered. The researchers work towards eliminating FWM in DWDM system while forgetting that FWM can only be mitigated but cannot be eliminated. The channel spacing proposed is not only wasteful but also uneconomical in real world. In addition, huge channel spacing of 200GHz is enough to greatly reduce FWM but with limited bandwidth capacity to accomplish bigger data rates for service providers to accommodate enormous demands from customers.

The connection between modulation format and the efficiency of Multi-Channel Digital Back-Propagation (MC-DBP) in an ideal fibre optics communication system was investigated by Xu *et al.* (2017). The performance and the optimization of MC-DBP was investigated with respect to both SNR and Achievable Information Rates (AIRs) using modulation formats, such as Dual Polarization Quadrature Phase Shift Keying (DP-QPSK), Dual Polarization 16-Quadrature Amplitude Modulation (DP-16QAM), DP-64QAM, DP-64QAM. The numerical simulation and analytical modeling was carried out on a WDM system of 9-channel and 32GHz channel spacing. The simulation results show that the nonlinear distortions, such as FWM, show considerable dependence on modulation format.

In a comprehensive analysis carried out on 10Gbps DWDM system with 32 channels spaced at 100GHz by Paliwal (2017). The system designed was optimized for a long haul optical link for RZ and NRZ modulation formats using opti-system simulator. The performance parameters for NRZ and RZ modulation formats revealed that NRZ is superior if compared to RZ when dealing with FWM. It was also observed that RZ causes significant eye closure penalty near end channels.

The impact of major nonlinearities in optical fibre such as SRS and FWM in cascaded amplifier was conducted by Ali *et al.* (2018). High speed data rate transmission scheme were investigated at different data rates over optical long reach DWDM system. Mathematical methods were used to investigate the nonlinear issues at different data rates, such as 10, 40 and 100Gbps. In the research, 16 different data of optical signals were fed to 16 channels long reach and high data rate DWDM optical network with central frequency of 193.1 THz. In order to compensate for FWM, channel spacing technique and launch power behavior with 200GHz frequency space was used. The limitation about the work is that two figures of merit, Signal to Noise Ratio (SNR) and Bit Error Rate (BER) were used to assess the success of the research.

Electro-Optic Phase Modulation (EOPM) method was used by Waidi *et al.* (2018) to suppress the effect of FWM. This was placed after a 64-channel DWDM multiplexer. The DWDM system was simulated at 10Gbps using two types of fibres, Single Mode Fibre and Dispersion Shifted Fibre (DSF). The simulated results confirmed the ability of the EOPM at improving the system performance,

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and concluded that EOPM module has good performance in terms of Bit Error Rate (10^{-24}) in comparison with the one without EOPM (10^{-18}) in total of transmitted power.

Alipoor *et al.* (2018) studied nonlinear effects in the optical communication fibres such as DWDM using Optical Double Side Band (ODSB) configuration with direct and external DSB modulation was proposed. In this study, external ODSB modulation for 10dB input power, 100GHz channel spacing, 10Gbps bit rate and 20km optical fibre link were considered. It was concluded that with increase in data transfer rates, output results such as Optical Signal-to-Noise ratio, BER, and Q-factor, deteriorated under the influence of FWM-effect but more channel spacing of the transmitter, lead to better performance of the system parameters.

Investigation on the transmission performance of Pulse Amplitude Modulation-based Wavelength Division Multiplexing (WDM) operating in the O-band with 112Gbps channel data rate and 200 GHz channel spacing and without using optical amplification was carried out by Ahmed and Fyath (2018). It was observed from the research work that the effect of FWM on the performance of O-band WDM interconnect is more severe if compared with C-band counterpart in a 200 GHz channel spaced WDM system. The limitation of the work is that the performance of 224Gbps per channel PAM-WDM interconnects and 16-PAM modulation was not addressed in their investigation.

In a research conducted into the effectiveness of modulation formats to nonlinear effects in optical fibre transmission systems under 160Gbps data rate. The durability of normal Non-return-to-zero (NRZ), Return to Zero (RZ) and modified-Duobinary-Return-to-Zero (NDRZ) modulation formats to FWM were investigated Abd *et al.* (2018). The suggested model was implemented with different parameters such as transmission distance of 700km and input signal power around 10dBm. It was observed from their results that RZ modulation appears better tolerant to FWM crosstalk. It was concluded that modulation behavior with high values of both data rate and distance; RZ modulation reveals more adequacies to nonlinear effects than NRZ and MDRZ. The limitation in the research is that it is practically impossible to transmit an optical signal over 700km distance without a repeater stations.

Alvarez-Chavez *et al.* (2018) utilized theoretically studies to explore the limitations imposed by nonlinear effects on the optimum power in a multi-span DWDM system. The effects probed are FWM, ASE, dispersion and SRS. The degree of power transmission per channel was appraised for different number of channels or inter-channel spacing. Also, determined is the prerequisites under which DWDM performance will be narrowed by FWM, ASE and SRS.

b. Artificial Intelligence

Another research focused on end-to-end deep learning techniques for designing optical fiber communication transceivers with focus on the supervised offline training was presented by Boris *et al.* (2018). The proposed method enables a communication system to be adapted for information transmission over any type of channel without requiring prior mathematical modelling and analysis. In the

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research, a fiber-optic system was modelled as a deep fully-connected feed forward Artificial Neural Network (ANN). A reliable communication below Forward Error Correction (FEC) thresholds was achieved through the deep learning system which includes transmitter, receiver, and nonlinear channel. The simulation results obtained from the end-to-end deep learning IM/DD system operating at 42Gbs was validated experimentally.

Javier *et al*. (2018), presented a review on the application of Artificial Intelligent (AI) based techniques in improving performance of optical communication systems and networks. The enumerated AI-based approaches cover optical transmission in view of characterization and operation of network components to performance monitoring, quality of transmission, and mitigation of nonlinearities. The authors also highlighted subdivisions of AI that have been successfully engaged in optical networking, stating the motivation behind their choice. It is obvious from the literature study that AI techniques has been used to mitigate nonlinearity with attention to where Maximum a posteriori, was proposed (Taylor, 2009); Maximum-likelihood (Karinou *et al.*, 2017); combination of the two techniques earlier mentioned (Rottenberg *et al.*, 2017) and, Bayesian filtering and expectation by (Zibar *et al.*, 2016). The review study presented by Javier *et al*. (2018) highlighted some of the benefits of AI in the context of optical communication to include.

i. attack and intrusion detection in optical networks,
ii. automation of network management operations,
iii. ability to adapt to changing conditions, to learn from them and to propose solutions to unexpected situations, turning them into promising candidates to meet changing demand patterns.

End-to-end (E2E) learning method to minimize error between the transmitted and received bits was proposed by Zibar *et al*. (2016). In the approach, multilayer neural networks were placed at transmit and the receive ends, to represent an encoder and decoder, respectively. The transmitter and the receiver neural networks were jointly enhanced to learn the encoding and decoding strategies that would reduce the error between the transmitted and received bits, and thus to maximize Achievable Information Rate (AIR). E2E learning finds application in ultra-wideband optical communication systems for the reason that it is independent of channel model. Since the fiber optic channel is nonlinear, maximizing AIR will require operating in a nonlinear region, making the approach for linear channels inefficient.

4.0 CONCLUSION

This paper has provided a survey of the current research on methods for mitigating nonlinear effect of FWM in Optical Communication System. The paper discussed an overview of opportunities and challenges arising in this context. A clear and general vision of methods used in mitigating FWM is presented. Also, pointed out the AI field which is still adequately uncovered. Also, this paper reveals gaps in the organized knowledge in optical communication system in the contest of DWDM system.

5.0 FUTURE OF DWDM AS REGARD FWM

In the nearest future, machine learning should bring more benefit to optical communication systems and networks, by introducing some degree of intelligence into optical measurement systems (Zibar *et al.* 2020). It is also envisage that complexity of next-generation optical communication systems will greatly depend on machine learning to optimizing the physical layer. Apart from this, the machine learning techniques will provide a path towards intelligent optical networks that are autonomous, self-healing, and able to predict traffic demands

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