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Fiber Bragg Grating based an Optimal OADM for Performance Enhancement in DWDM using Artificial Neural Network

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Abstract

Objectives: This paper proposed a new method for performance enhancement of Optical Add or Drop Multiplexer (OADM) with the Dense Wavelength Division Multiplexing (DWDM) based on the artificial intelligence. **Methods/Statistical Analysis**: The FF-NN is trained and tested in the MATLAB platform from the parameters obtained from simulation. The NN is trained for 70 signals with different number of channels and with different data rates as well as it is tested with 30 signals. The classification of the signals to be added or dropped is determined by the FF-NN. The DWDM network is initially modeled with the OptiSystem software tool with different number of channels with different data rates and channel spacing. **Findings:** The parameters BER, OSNR, Jitter and Chromatic Dispersion have been calculated. The training and testing of the neural network is carried out on the MATLAB platform and based on this, the signal will add/drop or allow the signal to pass. The result shows that the proposed method achieves the accuracy of 97.28% on classifying the signals to be dropped from the fiber or passed through it without any interruption regarding its ability to make the transmission with minimum error. The performance of the proposed method is also analyzed in terms of Transmitted & Received Signal Power and compared with the conventional OADM system with multiple filters. **Applications/Improvements**: The proposed method offers a viable solution to increase the performance of OADM with the DWDM. The improvement includes the use of hybrid algorithms, to further increase the performance.

Keywords: Dense Wavelength Division Multiplexing, Feed Forward Artificial Neural Network, Fiber Bragg Grating, Optical Multiplexer, Performance Enhancement, Signal Power

1. Introduction

Optical networks have to face some technical challenges which are very important in case of increasing traffic. Fortunately the rapid evolvement of the optical transmission technology proven to be a provision for the increased demand of Internet-based services worldwide in the past decade[1]. The optical communication network employs different techniques for the efficient routing of information via the optical signals among number of users among those Wavelength Division Multiplexing (WDM) is the most famous approach for optical transmission systems. WDM network is defined as a method for improving the transmission capacity and for designing the foremost path[2]. With the use of WDM network the signals with moderate and high data rates can be transmitted over a single fiber together at different wavelengths[3]. The WDM network has ability to transmit a big amount of data/signals through its various channels, and as soon as channels increases, total bandwidth of the system also increases

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without increasing the speed of clock[4]. But it requires complex transmitters and receivers for the data transmission. Also they must be wideband i.e., the channel spacing will be very large which results in more expensive and possibly less reliable network.

The Dense WDM (DWDM) developed in which the channel spacing was very narrow and thus more number of channels can be transmitted over the single fiber compared to the WDM network. The problem of increasing communication channels solved easily without requirement of new cables or by using limited cables by DWDM technique making this system very attractive not only for communication purposes, but also for design of real time systems when the required bandwidth is on the order of many gigabits per second[5]. By using DWDM technique, 132 colors or wavelength can be combined or multiplexed through single mode fiber[6]. DWDM employs semiconductor optical amplifier (SOA) in conjunction with an arrayed waveguide grating (AWG) based multiplexing and de-multiplexing scheme and it improves the overall power budget[7]. Even though the DWDM network may be suspected to some impairment related to the system level they can be tackled with the help of some special type of modulators[8].

Now- a- days SONET has been displaced by DWDM technique and primarily chosen by fast growing telecom & metro networks. Organization of DWDM over single mode optical fiber in moderately little stages-100 m and less gives numerous intrinsic favorable circumstances in that setting including substantial transmission limit consolidated with littler size and power utilization in respect to copper wiring; future evidence versatile communication backbone that gets rid of costly link; and the capacity to supportive networks with diverse transmission rates and configurations on the same cable infrastructure[9]. With the latest remarkable advancements in connectors & switches, OADM plays a vital role in empowering more connectivity and adaptability in DWDM systems for the signals to be added or dropped along with reconfiguration at HUB & access node[10]. For making ease of optical switching, a group of researchers implemented a new technique called terabit interferometric drop, add and extract multiplexer[11]. Lot of techniques was employed to multiplex and de-multiplex the signals within the Optical Add/Drop Multiplexer (OADM), out of which the Fiber Bragg Grating (FBG) is the most attractive one[12].

FBG can be used as a wavelength multiplexer/demultiplexer in OADM for adding/dropping of number of wavelengths[13]. The signal riding on one of the wavelength channels may be started at one edge and leave the system at other point in optical networking. That specific wavelength may be passed through various optical elements like optical cross-connects or optical add-drop multiplexer along with any other particular route[14]. The wavelength that has to be leaving or entering into the network will be controlled by the FBG based on its nature of the reflectivity. The desired wavelength reflection can be achieved by designing the FBG in several optimized ways. Fiber Bragg gratings with maximum reflectivity can also be used as notch filters in communication systems[15]. The reflection spectrum of the FBG can also be optimized using the Harmony Search Algorithm for achieving maximum reflectivity[16]. Another one method optimizes the reflection spectrum of FBG by considering different phase shifts of the grating[17]. The performance of the FBG can also be improved with some advanced techniques. The add/drop capability of the OADM can also be optimized by means of some artificial intelligence based method such as artificial neural networks (ANN). Based on algorithms or actual hardware, ANNs are processing devices and can estimate an element of different combination of inputs and outputs[18].

In this paper, we have developed an artificial intelligence based OADM is developed based on the parameters obtained from the simulation of the DWDM network in OptiSystem software. In section 2, related work has been discussed. The motivation for considering the present work and proposed methodology is given in section 3. The simulation results and the comparison of the proposed method with other existing technologies for improving performance of the OADM is presented and discussed in section 4. Finally, section 5 concludes the paper.

2. Related Works

In[19], a technique has been proposed to sensor network named improved DE algorithm for identifying the Bragg wavelengths of fiber Bragg gratins when the wavelength moves connected with one completely sensor overlaps the other. Two-FBG sensor system used in simulation & experimental setup whose results demonstrates that the Bragg wavelength can be rapidly and precisely identified when the reflectivity's of both FBGs are somewhat or totally overlapped. This system beats the restrictions of the customary CPD procedure and can be utilized to amplify the estimation scope of each FBG sensor.

In[20], an idea has been proposed for all optical add/drop multiplexing (OADM) hub. The hub was intended to go work as passage hub between optical system fragments that show differing properties as far as multiplexing frameworks, granularity and modulation format. The general building design of this OADM hub demonstrated that the hub has the capacity to work as a "language translator" between network sections taking into account OTDM and WDM frameworks misusing distinctive modulation formats to transport NRZ-DPSK and RZ-OOK individually.

In[21], a method has been proposed for solving the problem of low-dispersion FBG filter. This problem can't be solved by using traditional methods due to availability character. To satisfy the criterion of target design, Cross-Entropy Optimization (CEO) method has been used and this method approached the target values. Simulation result shows that CEO method has better grating structures as compared with Particle Swarm Optimization. These grating structures are most suited for designing of low-dispersion fiber Bragg grating filters.

In[22], an effective optimization method based on self-adaptive differential evolution (DE) algorithm has been proposed to design fiber Bragg grating (FBG) filters with high-channel-count. They have numerically presented a 1037-channel 50-GHz spaced FBG filter to cover the whole bands.

In[23], a scheme was proposed based on Pareto-based multi-objective optimization technology for designing a wavelength-division-multiplexing (WDM) fiber Bragg grating (FBG) sensor network. Effectively enhance the multiplexing capability of the WDM network in this methodology was demonstrated in the simulation results.

In[24], the cross-entropy optimization (CEO) method was proposed in searching down the optimal index modulation profiles. Various continuous multi optimization issues were solved using an effective algorithm called CEO that solves and shows robustness as for beginning conditions. When compared with the traditional Covariance Matrix Adaptation Evolution Strategy (CMAES), an improved index modulation profile was created in this method. A proof of idea Few-mode fiber (FMF) compatible OADM was demonstrated in[25], which empowers add/drop functionality for MDM super channels.

In[26], a phenomenon has been demonstrated of optical switching over a 100Gbps multiband optical frequency division multiplexing (MB-OFDM) based on a experimental setup. Flexible types of optical add/drop multiplexer is used for whole process. Cascading of five OADM made possible here without affecting the transmission performance. Through this demo, the authors have opened a different way to optically meshed networks with flexibility of high degree. The proper combination of optical switching (sub-band) and MB-OFDM technique permits the fiber output in a significant manner. Consequently bandwidth of optical fiber managed properly. One important benefit of this method is its capability to optimize the aggregation process making saving of cost & energy.

3. Optical Add or Drop Multiplexer with Feed Forward Neural Network

This work proposes a new artificial intelligence based methodology for the desired wavelength selection that has to be added or dropped from the OADM in DWDM network and thus optimizes the reflectivity of the FBG to yield higher modulation index profile without reconfiguring the filter at each node. The method consists of three phases:

- Initial data generation
- Training the ANN and
- Testing the ANN

At first the initial data for the ANN will be generated by designing the DWDM network in the OptiSystem software. In the training phase the ANN will be trained for the parameters obtained from the previous stage and in the testing phase the ANN will work effectively for adding or dropping the wavelength from the device based on the parameters associated with that wavelength. The proposed work can be implemented on MATLAB platform and the performance will be analyzed with the existing methods. The block diagram of the proposed work is shown below in Figure 1. The block diagram shown in Figure 1 is self-explanatory about the sequence of our proposed work. The FFNN is trained with the estimated parameters from the simulation of DWDM network and the signal is classified as either to be passed through the fiber or to be dropped from it based on the capacity of the fiber with which it can carry the required number of channels at maximum data rate and symbol rate. In the testing phase the incoming optic signal at the entrance of

OADM is processed by the trained neural network and then the signal is either dropped from the fiber or passed through the fiber without any hindrance based on the knowledge obtained from the training phase. Thus finally a performance improved OADM is produced using the feed forward type of NN.

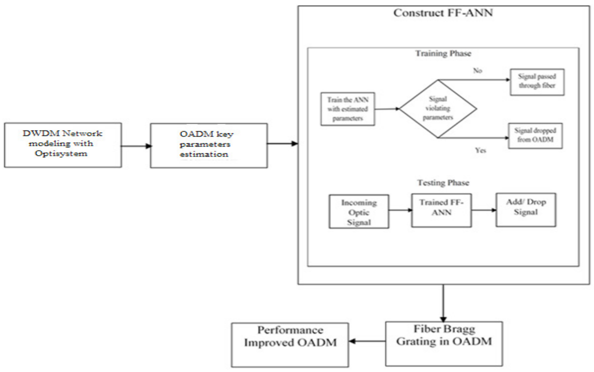

Figure 1. Functional Block diagram of the proposed method.

3.1 DWDM network simulation with OptiSystem

Number of closely spaced signals can be transmitted through Dense Wavelength Division Multiplexing (DWDM) as compared to wavelength division multiplexing (WDM). WDM fully utilizes the large bandwidth provided by optical fiber by permitting huge amounts of data in different channels to be transferred at different wavelengths[27]. There are various simulation tools are available for simulating the optical networks among them OptiSystem is found to be an efficient one for the simulation of all kind of optical networks.

OptiSystem software is used for the simulation and design of various optical communication systems and especially it is designed for the higher propagation schemes such as OFDM (Orthogonal Frequency Division Multiplexing), PM-QPSK (Polarization Multiplexed Quadrature Phase Shift Keying) and D (Q) PSK (Differential Quaternary Phase Shift Keying). Optical communication systems can be simulated to check their performance. Optisystem software is very easy to use GUI & user friendly simulation method making it flexible and easily usable. OptiSystem works by interconnecting different blocks of different optical components. Each block is connected graphically as an icon having own set of parameters which can be modified by user. By changing the parameters by user, each & every block is simulated independently and the information is passing from one block to other. This is also named as a block-oriented simulation methodology. Thus each optical component including optical MUX/DEMEUX, Optical amplifiers, OADM, Optical transmitters/transponders and Optical receivers in the DWDM network can be simulated as a block and the fiber used for carrying the signal is simulated using either Split step Fourier technique or time domain split step fiber model in the simulation engine. The parameters used for the simulation are given as input such as data rate, symbol rate, carrying capacity of the fiber, length of the fiber, type of network used for transmission and transmission distance for which the signal to be transmitted in designing the DWDM network. After designing the DWDM network with the OptiSystem the parameters used for constructing the ANN is measured from the performance analysis of the network here we are considering the BER and OSNR (Optical Signal to Noise Ratio) of the signals in order to achieve error free transmission, jitter to ensure reliable data transmission and chromatic dispersion which will vary depends on the bit rate of the signal.

3.2 Parameters Estimation

The parameters used for constructing the ANN are obtained from the performance analysis of the DWDM network in the simulation. The parameters considered in the formation of ANN based OADM are BER for each channel, OSNR, jitter measured from the eye diagram and chromatic dispersion calculated from the spectra of the signal. Each of these parameters are having some acceptable values with which the signal can be transmitted through the fiber without any interruption. The signals those violating these parameters are considered to be dropped from the fiber for achieving efficient optical transmission. The detailed description about these parameters is as follows.

3.2.1 Bit Error Rate (BER)

Bit error is referred as the process in which the received bits of a transmitted stream is altered when passing through the fiber because of noise, interference and distorted conditions. Thus the bit error rate is generally defined as the number of bit errors occurring per unit time, it is the ratio of number of signals received without any alteration to the total number of bits transmitted[28]. The general formula for the calculation of BER is given in equation (1).

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

The probability of error (P_e) can also be used to define the BER of the signal[29] as in equation (2),

$$P_e = \min\left[\frac{1}{2}(1-erf)\sqrt{\frac{E_b}{N_o}}\right] \quad (2)$$

Where N_o is the noise power spectral density, *erf* is the error function and E_b is the one bit energy. For various modulation methods, different error functions exist. The probability of error is directly proportional to E_b/N_o, which is the ratio of signal-to-noise.

3.2.2 Optical Signal to Noise Ratio (OSNR)

Optical amplifier like Erbium Doped Fiber Amplifier (EDFA) reduces OSNR of the signal so these amplifiers are used in limited number in a network. One more option is to use RAMAN amplifier but it also has some intrinsic noise but it is less as compared to EDFA. To ensure the error free operation, the DWDM network must operate above their OSNR limit. This can be achieved by the increase in signal data rate. BER has also its effect on the value of OSNR and the relation between them[30] is shown in the equation (3) & (4)

$$Log_{10}(BER) = 10.7 - 1.45(OSNR) \quad (3)$$

$$OSNR = \max\left[\frac{10.7 - Log_{10}(BER)}{1.45}\right] \quad (4)$$

The OSNR value at the DWDM should be greater than 15 dB but less than 18dB at the receiver. OSNR requirements depend on the location, type of network, data rate and the BER which is targeted.

3.2.3 Location

The OSNR value required will be different at different locations in the transmission through light path. The OSNR value should be higher close to the transmitter and lower close to the receiver. The reason is that the number of optical amplifiers and Reconfigurable add drop multiplexer will degrades the OSNR value because of noise. Because of this reason those elements are to be at minimum number level to achieve maximum value of OSNR at the receiver side.

3.2.4 Type of Network

The OSNR value required to be greater than 40 dB, for the Metro type network.

3.2.4.1 Data Rate

The increase in data rate requires the increase in OSNR value.

3.2.4.2 BER

At the point when the BER value diminishes, the value of OSNR gets increased.

Thus, it said that the increase in OSNR value guarantees the lower BER that implies a lower number of mistakes happen in the transmitted signal and consequently the quality of the system made strides. Thus the signal transmitted through the fiber must have a higher OSNR value other it must have discarded.

3.2.4.3 Jitter

When simulating DWDM in OptiSystem one of the performance evaluation parameters we acquired from that is the eye diagram. An appropriately built eye ought to contain each conceivable bit sequence of basic alternate 1's and 0's to segregated 1's after long keeps running of 0's, and every single other example that may show up weaknesses in the design. Jitter happens when rising or falling edges happen at times that contrast from the ideal time. In these few edges occur early and some take place later[31]. An average eye diagram and the jitter measured from that demonstrated in the accompanying Figure 2.

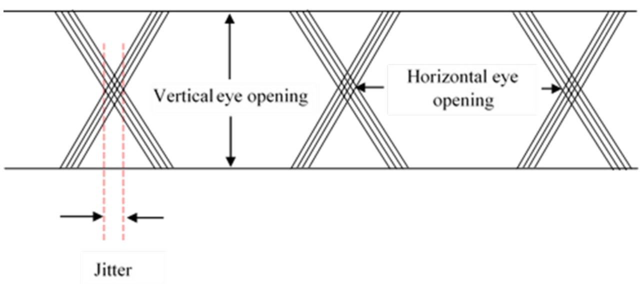

Figure 2. Jitter measured from the eye diagram of the system.

As seen from the Figure 2, the cross section mentioned in the figure denotes the jitter present in the system. The eye diagram well represents the system performance and it is said that more the widening of the diagram is the better signal level. The jitter of the optical channel is denoted as in equation (5).

$$f = \min[Jitter] \tag{5}$$

3.2.4.4 Chromatic Dispersion (CD)

Chromatic dispersion, known as the fiber parameter that limits its transmission capacity when the bit rate of the signal increments, particularly on account of optically amplified medium to long links. CD characterized as the property of an optical fiber that makes diverse light wavelengths to propagate at distinctive speeds as they travel through it. In DWDM the pulse spreading can extend to adjacent bit periods and lessen the signal quality which brings about the reception of poor quality signal. In this manner for guaranteeing the quality of the signal transmission, CD must portray clearly. The primary parameter of the chromatic dispersion is known as chromatic dispersion coefficient which determines the size of the dispersion and it is given by equation (6).

$$D(\lambda) = \frac{dt_g(\lambda)}{d(\lambda)}, \left[\frac{ps}{nm \times km}\right] \tag{6}$$

Where t_g is the group delay per km of the signal change per wavelength.

The chromatic dispersion coefficient for a particular wavelength[32] can be calculated using the formula in equation (7).

$$CD = D(\lambda) = \min\left[\frac{S_0}{4} \times \left[\lambda - \left(\frac{\lambda_0^4}{\lambda^3}\right)\right], \left[\frac{ps}{nm \times km}\right]\right] \tag{7}$$

Where $S_0 = \frac{dD(\lambda_0)}{d\lambda_0}$, Dispersion characteristics slope measured in ps/nm^2×km

λ_0 = Operating wavelength

λ = Considered wavelength

The chromatic dispersion coefficient at wavelength 1550 nm is D(λ)=18 [ps.nm^{-1}km^{-1}][33]. After estimating the parameters from the simulation they are used in the training of the FF-ANN and then the incoming signal is classified based on the training knowledge which is discussed in the following section.

3.2.5 Threshold Formation

The formation of threshold based on three objective functions is given in equation (8). The objective of work is to enhance the OSNR and to reduce the BER, Jitter and Chromatic Dispersion.

$$O_{thres} = \min\left[\frac{f \times CD \times BER}{OSNR}\right] \tag{8}$$

3.3 Feed Forward Neural Network

The parameters estimated from the simulation are then used for the training of the Feed forward method of artificial neural network. An artificial neural network known as one of the efficient classification methods based on artificial intelligence. The information distributed and processed in parallel. The training of such a network with hidden layer gets complicated. That is the reason for an output error; it is difficult to know the amount of error originates from the input nodes, various nodes and how to modify the weights as per their contributions. The problem understood by finding the impact of the considerable number of weights in the network. Then the algorithm changes the weights of every association reached the end goal to diminish the estimation of the error function.

3.3.1 Training

- Define the estimated parameters as input neurons
- Calculation of basis function at input side

For each input neuron *i* calculate the basis function. This can be calculated as given in equation (9).

$$B_{in}(n) = \sum_{i=1}^{n} i_n w_m^i \tag{9}$$

In the above equation (6) the value of *n* represents the number of input neurons (i.e., here four), *m* denotes the number of hidden neurons and w_{nm}^i represents weight at the input links

- Estimate the activation function at hidden neurons

The activation function H_m used in this method is the tan-sigmoid function and it is calculated by the equation (10).

$$H_m = \frac{1}{1 + \exp(-B_{in}(n))} \tag{10}$$

- Calculation of basis function at output side

The basis function for the output side can be calculated with the weight value at output side w_{nm}^i & it is calculated by equation (11)

$$B_{out}(n) = \sum_{m=1}^{n} H_m w_m^o \tag{11}$$

- Calculation of learning error

After measuring the output basis function the learning error in that step is estimated using the equation (12) with respect to the actual value that has to be obtained and the value which we are getting in the previous step.

$$Learning\ \ error, e_l = \frac{1}{2}(Actual\ value - Obtained\ value)^2 \tag{12}$$

- Back propagation error

The back propagation error is calculated as the average of the learning error for all the output basis function. Then the deviation in the weight value is measured using the equation (13) in order to minimize the back propagation error and then the weight is modified with the newly calculated weight as in equation (14).

$$\Delta w = BP_{error} \times \gamma \times \delta, \tag{13}$$

Where γ = Learning rate and it is in the range of [0, 1]

$$\delta = \text{Mean of activation function} = \frac{1}{M}\sum_{m=1}^{M} H_m$$

$$\text{New weight, } w_{new} = \Delta w + w^o \tag{14}$$

3.3.2 Testing

The process in testing the FFNN is similar to that of the training phase. But in testing the fifth and last steps as done in the training will not exists. And the signal is classified to be added or dropped from the fiber.

In this paper the FFNN is trained with the four parameters which are obtained as output from the simulation such as BER, OSNR, Jitter and CD. Thus the neural network we are going to construct has four input neurons, five hidden neurons and one output neuron that specifies the decision of dropping or adding the channel from or to the fiber. It is assigned that the output neuron indicates zero if the channel has to be dropped otherwise indicated the value of one for adding the corresponding channel to the fiber. Figure 3 shown below indicates the Neural Network used in the proposed method.

In this Figure 3, the input layer contains four input neurons which accept the inputs such as BER, OSNR, Jitter and CD respectively. The error resulting from the training phase can be rectified by means of back propagation algorithm and in the testing phase the trained neural network correctly classifies the channel to be dropped or added based on the parameters associated with it.

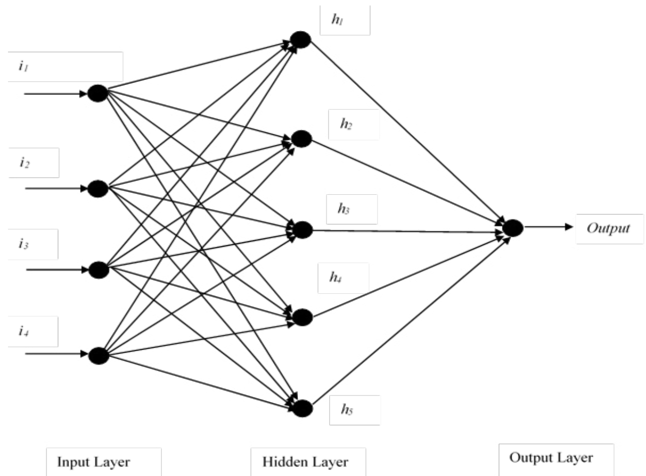

Figure 3. FFNN used for adding or dropping the channel.

3.4 Fiber Bragg Grating (FBG) Principle and Mathematical Modeling

The Optical Add or Drop Multiplexer in DWDM network will add/drop or allow the signals to be passed through the fiber based on FBG design. FBGs can be fabricated by varying the refractive index of fiber core by UV exposure. When light passes through the FBG, only that signal will be reflected who satisfies Bragg's wavelength[34,35] which is given by the Equation (15).

$$\lambda_B = 2\eta_{eff}\Lambda \tag{15}$$

Where Λ is representing the pitch of grating and η_{eff} is showing the effective refractive index of the fiber. Parameters of FBG, such as magnitude of refractive index, period of refractive index perturbation, grating length and numbers of grids give optical properties of FBG.

3.4.1 Mathematical Modeling

For deriving a mathematical model of a FBG[36], we will assume the existence of only two counter propagating guided modes in the FBG of amplitudes A (z, λ) and B (z, λ) respectively for any wavelength λ. The effective refractive index is denoted by η_{eff} and the corresponding propagation constant is denoted by $\beta = 2\pi\eta_{eff}/\lambda$. The refractive effective index along the fiber axis z is given by equation (16)

$$\delta\eta_{eff}(z) = \overline{\delta\eta_{eff}}(z)(1+\nu\cos\left[\frac{2\pi}{\Lambda}z + \varphi(z)\right]) \quad z \in [0, L] \tag{16}$$

Where $\overline{\delta\eta_{eff}}(z)$ is the slowly varying index amplitude change, ν is the fringe visibility and φ(z) is the slowly varying index phase change. In the present work, we assume the fringe of visibility ν = 1 and φ = 0 in the absence of chirping.

In an ideal waveguide, when the modes are orthogonal, the presence of a dielectric perturbation cause coupled modes. Introducing the detuning parameter given by equation (17)

$$\zeta(\lambda) = \beta - \frac{\pi}{\Lambda} = \frac{2\pi\eta_{eff}}{\lambda} - \frac{\pi}{\Lambda} \quad (17)$$

The two coupling coefficients can be approximated by equation (18) & (19)

$$\hat{\sigma}(z,\lambda) = \zeta(\lambda) + \sigma(z) - \frac{1}{2} = \zeta(\lambda) + \beta\frac{\overline{\delta\eta_{eff}}(z)}{\eta_{eff}} - \frac{1}{2} \quad (18)$$

$$\kappa(z) = \frac{\overline{\delta\eta_{eff}}(z)}{\pi\lambda} \quad (19)$$

κ the 'ac' (associated coupling) coefficient and σ is called the 'dc' (demi coupling) .

The two modes coupling model is then completed by the following boundary conditions:

$$R(0,\lambda) = 1 \quad (20)$$

(The forward-going wave is incident from −∞) and

$$S(L,\lambda) = 0 \quad (21)$$

(There is no backward-going wave for z ≥ L/2).

The main characteristic of a FBG is then expressed through its complex spectral response in the transmission band given by equation (22)

$$\lambda \in [\lambda_{min}, \lambda_{max}] \mapsto \rho(\lambda) = \frac{S(0,\lambda)}{R(0,\lambda)} \quad (22)$$

From which we deduce its spectral response at the entrance of a grating given by equation (23)

$$\lambda \in [\lambda_{min}, \lambda_{max}] \mapsto r(\lambda) = |\rho(\lambda)|^2 \quad (23)$$

For calculating equation (22) & (23), two main methods exist that result from two-mode coupling in non-uniform grating: transfer matrix method and direct numerical integration. In presented work, we have optimized the FBG to add or drop the signal through the fiber based on the decision taken from the trained FFNN. Thus the process associated with the proposed method is also given in the form of flowchart as shown below in Figure 4.

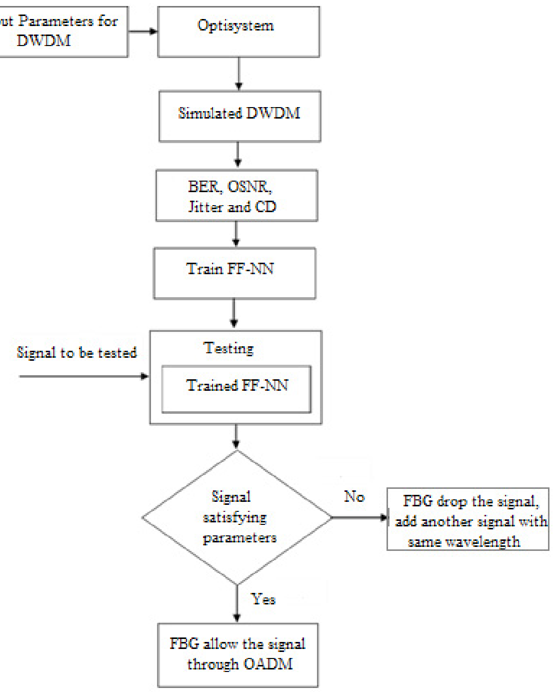

Figure 4. Processes associated with the proposed method for optimizing OADM in the DWDM network.

Table 1. Parameter Setting for OptiSystem

Parameter	Value
Data rate	5 Gbps
	10 Gbps
	20 Gbps
Number of channels(N. ch)	32
	64
	100
Channel spacing	30 GHz
	40 GHz
	50 GHz

4. Results and Discussion

In this paper we have proposed a system for adding or dropping the optical channels with in the fiber by developing the artificial neural network based Optical Add/Drop Multiplexer using feed forward type of neural network. The DWDM network is initially modeled with the OptiSystem software tool with different number of channels (Nc=32, 64,100) each with different data rates of 5 Gbps, 10 Gbps, 20 Gbps and with different channel spacing (Csp) of 30 GHz, 40 GHz and 50 GHz. The initial parameter setting for the Optisystem design is given in

Table 1. The wavelength of the channel used is 1550 nm and a fixed fiber length of 80km by considering the source of CW laser with frequency of 193.1 THz. For the purpose of optical transmission within the network the NRZ type of modulation is considered with Mach-Zehnder modulator. Then the parameters obtained from the simulation are used in the training and testing of the ANN such as BER, OSNR, Jitter and Chromatic Dispersion by interfacing the OptiSystem simulation results to MATLAB with the system configuration of Intel core i3 processor, 4GB RAM and Windows 8 Operating system.

Table 2. Measurements obtained from the simulation of DWDM network using OptiSystem

Parameters			BER	OSNR	Jitter	Chromatic Dispersion
Data Rate= 5 Gbps	Csp=30 GHz	Nc=32	10^{-8}	25.35	0.5	1.2
		Nc=64	10^{-8}	28.17	0.5	1.2
		Nc=100	10^{-8}	31.35	0.5	1.2
	Csp=40 GHz	Nc=32	10^{-9}	34.98	0.5	1.6
		Nc=64	10^{-9}	40.07	0.2	1.6
		Nc=100	10^{-9}	47.06	0.5	1.2
	Csp=50 GHz	Nc=32	10^{-11}	41.05	0.2	1.2
		Nc=64	10^{-11}	43.05	0.5	1.4
		Nc=100	10^{-11}	44.65	0.5	1.6
Data Rate= 10 Gbps	**Csp=30 GHz**	**Nc=32**	10^{-11}	16.89	0.2	-22.8
		Nc=64	10^{-11}	19.53	0.2	-22.8
		Nc=100	10^{-11}	22.69	0.5	-22.8
	Csp=40 GHz	Nc=32	10^{-11}	25.57	0.5	-22.8
		Nc=64	10^{-11}	38.86	0.2	-22.6
		Nc=100	10^{-11}	36.58	0.5	-22.4
	Csp=50 GHz	**Nc=32**	10^{-11}	37.22	0.5	-22.8
		Nc=64	10^{-11}	34.54	0.2	-22.8
		Nc=100	10^{-11}	36.54	0.5	-22.4
Data Rate=20 Gbps	**Csp=30 GHz**	**Nc=32**	10^{-11}	16.89	0.5	-30.8
		Nc=64	10^{-12}	19.53	0.5	-30.8
		Nc=100	10^{-11}	22.69	0.6	-30.8
	Csp=40 GHz	Nc=32	10^{-11}	25.57	0.2	-30.8
		Nc=64	10^{-11}	30.86	0.3	-30.4
		Nc=100	10^{-11}	33.58	0.2	-30.7
	Csp=50 GHz	Nc=32	10^{-12}	37.22	0.2	-30.7
		Nc=64	10^{-12}	39.54	0.2	-30.7
		Nc=100	10^{-12}	49.54	0.2	-30.8

The parameters obtained after simulating the DWDM network in the software tool of OptiSystem is given in the following Table 2**.** With these simulation results next the FF-NN will be trained for the addition or dropping of the optical channel based on the threshold value of the outcome FF-ANN. In this paper, we set the threshold as 0.32×10^{-10}.

Table 3. Signal Classification performance by FF-NN

Parameters	**Signal Classification using FF-NN**
Signals identified as valid (True Positive)	27
Signals correctly identified as not valid (True Negative)	1
Signals incorrectly identified as valid (False Positive)	2
Signals incorrectly identified as not valid (False Negative)	0
True Positive Rate [TP/(TP+FN)]or Sensitivity	89. 84%
False Positive Rate [FP/(FP+TN)]	49%
Accuracy = $\frac{TP+TN}{Total\ number\ of\ signals}$	97. 28%
Positive Predictive value= $\frac{Sum\,of\,TP}{TP+FP}$	97. 05%

The FF-NN is trained and tested in the MATLAB platform from the parameters as given in the Table 1. The neural network is trained by 70 signals with different number of channels and with different data rates from the Table 1 as well as it is tested with 30 signals. The following Table 3 gives the results from the classification of the signals to be added or dropped as determined by the FF-NN**.**

The Table 3 shows that the signal classification results obtained from the FF-NN is given. The performance obtained by the classifier is acceptable. To validate the proposed method, it is compared with the conventional method in which used integrated dense wavelength division multiplexing and Optical-OFDM system with OADM including the fiber nonlinearity effect and analyzed its performance. The comparisons results are shown in terms transmitted signal power are given in the following Table 4 and 5.

Table 4. Comparison of Transmitted signal power of the proposed method and the existing method

WAVE LENGTH (µm)		Transmitted Signal Power (dB)			
	Proposed		Method in [38]		
	200 km	300 km	200 km	300 km	
1.	1.44	1.2703	1.2869	1.2501	0.8314
2.	1.45	1.9652	2.1256	1.0524	0.7148
3.	1.47	2.1821	2.3867	0.8011	0.5412
4.	1.49	1.5143	1.8311	0.6247	0.4143
5.	1.51	1.4487	1.7442	0.5217	0.3541
6.	1.53	2.1355	2.5155	0.4304	0.3082
7.	1.55	2.4444	2.8854	0.4070	0.2590
8.	1.57	0.9357	0.6562	0.3845	0.2199
9.	1.59	0.8233	1.5565	0.2345	0.2116
10.	1.61	1.6222	1.6475	0.2227	0.1823

Table 5. Comparison of Received Signal power of the proposed method and the existing method

WAVE LENGTH (µm)		Received Signal Power (dB)			
	Proposed		Method in [38]		
	200 km	300 km	200 km	300 km	
1.	1.43	3.9487	5.4835	3.9978	4.6512
2.	1.46	2.6887	3.7681	2.7614	3.2512
3.	1.48	0.5747	2.2708	2.2781	2.6514
4.	1.50	1.7001	1.4276	1.7584	2.1451
5.	1.52	1.4386	2.5657	1.5072	1.6547
6.	1.54	1.6188	1.4218	1.3784	1.3142
7.	1.56	0.8564	2.3332	1.2004	1.2471
8.	1.58	1.1247	1.8663	1.1124	1.1112
9.	1.60	0.5113	1.1509	0.9751	1.0047
10.	1.62	0.8645	2.6715	0.8415	0.3458

The received signal power at the received side after optimizing the OADM with the proposed method and the one with existing method[37] is given in Table 5. The comparison chart is shown in Figure 5, 6, 7 and 8 for different fiber length based on the comparison with wavelength and signal power. From the Table 3, 4 and 5 it is obvious that our proposed method based on artificial intelligence technique achieved better performance than the conventional method with other existing methods.

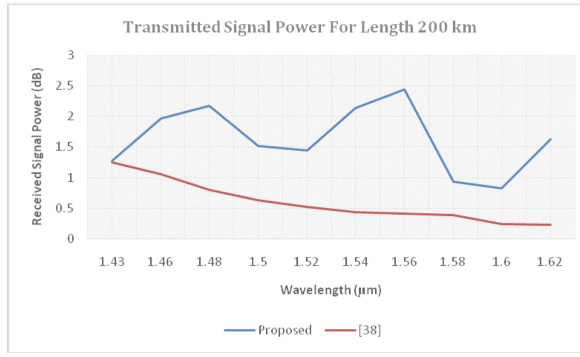

Figure 5. Transmitted Signal Power for Length 200 km.

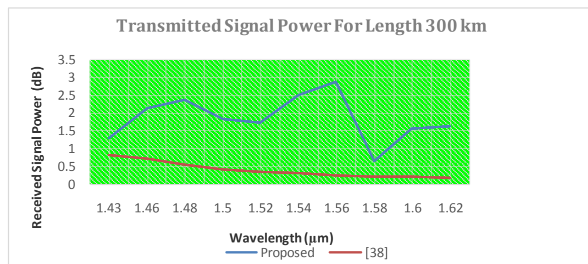

Figure 6. Transmitted Signal Power for Length 300 km.

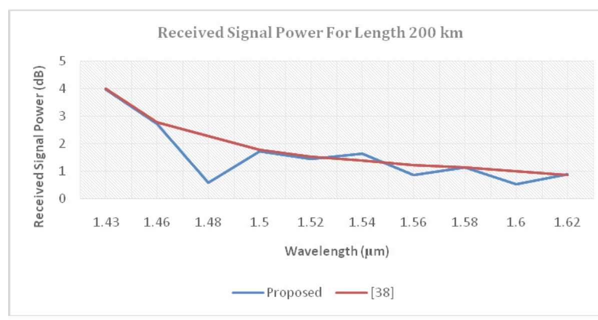

Figure 7. Received Signal Power for Length 200 km.

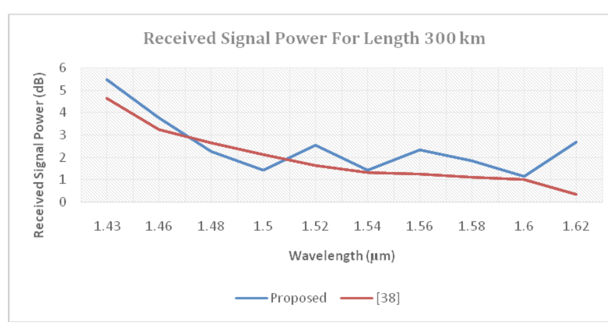

Figure 8. Received Signal Power for Length 300 km.

5. Conclusion

FBG based OADM system was optimized for adding or dropping the optical channels by developing an artificial neural network. The DWDM network was initially modeled with the OptiSystem software tool with different number of channels, each with different data rates and with different channel spacing. Then the parameters such as BER, OSNR, Jitter and Chromatic Dispersion were obtained from the simulation which was further used in the training and testing of the ANN by interfacing the OptiSystem simulation results to MATLAB. As data rate increases; BER decreases. For a particular data rate, with increase in channel spacing and number of channels; OSNR increases. With increase in data rate; chromatic dispersion decreases drastically.

The training and testing of the artificial neural network is carried out in the MATLAB platform based on FBG based OADM will add/drop or allow the signal to pass and the results shows better classification. The result shows that the proposed method achieves the accuracy of 97.28% on classifying the signals to be dropped from the fiber or passed through it without any interruption regarding its ability to make the transmission with minimum error. The performance of the our method is also analyzed in terms of Transmitted & Received Signal Power and compared with the conventional OADM system with multiple filters. In contrast to the conventional system, the transmitted signal power in dBs is higher in the proposed methodology while considering different wavelength and fiber length. Eventually, the received signal power draws a comparative result for shorter fiber length but in case of larger fiber length, it is high as compared to conventional OADM system.

This does imply an enhanced performance of present methodology and has also opened a gateway for future research in increasing the performance which may be carried out by the use of hybrid algorithm.

6. References

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