Capacity Enhancement of Fiber Using Proposed Wavelength Assignment Scheme

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Abstract— In WDM network, routing and wavelength assignment schemes plays paramount role in allocation and utilization of available spectrum efficiently. Various wavelength assignment schemes such as least used, most used, adjacent are employed in present day WDM (wavelength division multiplexing) network to route and establish lightpath between source and destination such that it minimizes cost and network delay of the system. In this paper, proposed FWM (four wave mixing) aware fixed wavelength assignment scheme is investigated and is compared with other fixed channel assignment scheme known as adjacent channel assignment scheme. Until the network channels are not at full load, the enhancement in performance of link with the use of FWM aware channel wavelength assignment scheme is utilized opportunistically to send more data. The enhancement in capacity is clearly presented during the comparison of proposed wavelength assignment scheme with that of adjacent scheme in the results and discussion section.

Key words: BER, Four Wave Mixing, RWA, WDM

I. Introduction

WDM and routing and wavelength assignment schemes [1] are rapidly becoming the present day technologies in present day optical backbone network to meet current bandwidth requirements. Wavelength assignment scheme are of two types static which is offline method [1, 2] and dynamic which is online method of wavelength assignments. In in case of dynamic wavelength allocation [1] scheme, whenever the request is generated, the routes and wavelengths are tested prior to allocate to meet highest performance level while in offline method the nodes does have prior knowledge of fixed order of channels to be assigned and does not waste the transmitter resources that are used to calculate FWM effect each time before allocating new channel. Hence, the network delay for offline scheme is very less compared to real time dynamic scheme. Moreover as the order of the channel assignment scheme is predetermined, the complexity for implementation can also be reduced. Both the adjacent [2] and proposed fixed wavelength allocation scheme belong to offline category. In this paper, the offline purposed channel scheme defining fixed channel order is compared with adjacent channel scheme to show the betterment in terms of performance. Furthermore, this enhancement in performance with proposed scheme is being utilized opportunistically send more data on the same number of channels. The selection of data rate of individual cannels has been done in such a way so that the performance could not drop in comparison to adjacent scheme. The summary of the paper is it present the channels order in such a way that combats FWM nonlinearity and enhance the performance and that further utilized to increase the total data to be sent on same number of channels to be assigned.

II. Theory

In WDM optical network, linear effects such as attenuation [3] and dispersion [3] can be externally controlled and mitigated by using additional passive components. But Non-Linear effects [4] such as FWM cannot be eliminated completely but can be controlled to some extent. Out of all non-linearities, FWM is most serious form of non-linearity as it become effective even at low input power .Thus, it becomes necessary to minimize the effect of FWM in WDM based optical network to achieve highest level of performance in terms of BER [4] and OSNR [4]. Several techniques are employed from time to time to minimize the effect of FWM. Before focusing on minimization techniques, a brief introduction of FWM and its model is presented here.

Four Wave Mixing-it is process of third order mixing of different optical spectral (wavelength) components and generation of new components which may or may not fall on the original spectral components. These sideband spectral components are termed as FWM products. Mathematically, suppose three distinct wavelengths f_i, f_j, f_k is launched and co-propogating inside optical fiber. The resulting FWM products in the system can be calculated using:

$$f_{ijk} = \pm f_i \pm f_j \pm f_k \quad \text{for} \quad i \neq j \neq k \;\; \& \;\; i \neq j = k$$

Among these signals, the most troublesome are the signals corresponding to

$$f_{ijk} = + f_i + f_j - f_k$$

Further in general, for N wavelengths input channel there will be M cross mixing products and are given by: [5]

$$M = \frac{1}{2}\left(N^3 - N^2\right)$$

This equation is applicable for any number of channels satisfying the above two constraints.

The FWM power generated products, denoted as P_{ijk}, in a link, can be expressed as[9]

$$P_{ijk} = \frac{\eta}{9} D_{ijk}^2 \gamma^2 P_{ijk} e^{-\alpha L} L_{eff}^2$$

Where Pijk is the FWM light power at frequency fijk =fi + fj - fk , P_i, P_j , P_k are input light power of frequencies f_i , f_j and f_k frequencies , η represents dependence of FWM efficiency on the phase matching ,D_{ijk} is the degeneracy factor ,which takes value of D = 3 for I = j and D= 6 for i ≠j. The terms of γ and α are respectively, the nonlinear and attenuation coefficients of the fiber. L is the fiber length and L_{eff} denotes the effective length, given by [6]

$$L_{eff} = \frac{1 - e^{-\alpha l}}{\alpha}$$

The term γ can be calculated as: [7]

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}}$$

But FWM efficiency is given by: [8]

$$\eta = \frac{\alpha^2}{\alpha^2 + \Delta\beta^2}\left[\frac{1 + 4e^{-\alpha l}\, sin^2(\Delta\beta, L/2)}{(1 - e^{-\alpha l})^{\ 2}}\right]$$

separation, fiber chromatic dispersion D_c (dispersion slope $dD_c/d\lambda$), and the fiber length as shown by the phasematching factor.[8]

$$\Delta\beta = \left(\frac{2\pi\lambda_0^2}{c}\right)(f_i - f_k)(f_i - f_k)\left(\left[\left(\frac{\lambda_0^2}{2c}\right)\ \left(\frac{dD_c}{d\lambda}\right)[(f_i - f_o)(f_j - f_o)]\right]\right)$$

where c is the speed of light in vacuum and λ_0 is the zero dispersion wavelength. FWM power, efficiency and total number of FWM products falling on original spectral componnets can be calculated by using the equations which are written above.

III. METHODOLOGY

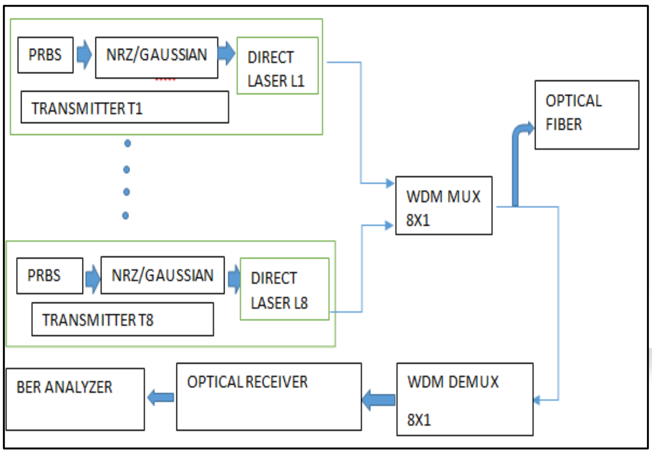

Fig. 1: Schematic model of setup used in optisystem

The experimental setup used to study comparison between both channel allocation scheme and subsequent enhancement of capacity of fiber is shown above. For this simulations are performed in optisytem 14.0 Experimental setup consists of transmitter, optical fiber and receiver section. The transmitter section consists of PN sequence generator, directly modulated laser Gaussian/NRZ pulse generator. In receiver section, optical receivers and BER analyzers are used. FWM non-linearity is added by the fiber which is used. The wavelength of various channels is set by keeping the difference equal to the spacing as required for particular scheme. The demultiplexer is used to split the signal to same number of signal as input channels. BER analyzer is used to study the performance of each wavelength assignment scheme .Further, At transmitter side, optical null is used to disable ports of multiplexer only when number of channels assigned are less than full load. Similarly, ground is used to disable demultiplexer ports corresponding to that of transmitter side. After making experimental setup in optisystem as stated above, simulation parameters are assigned which are similar for both offline channel scheme –fixed and proposed. These simulation parameters are listed below in table for both schemes.

Parameters	Value
System	20 Gbps
Number of channels	2-8
Data rate per channel	2.5 Gbps
Length of optical fiber	50 km
Bandwidth of MUX & DEMUX	11 Ghz
Dispersion, Receiver noise, SRS noise	Turned off
Channel Spacing	0.2nm
Laser Frequencies	1540 nm - 1541.4nm
Power of Laser	1 mW
Linewidth of Laser	0 MHz

Table 1 – Simulation Parameters.

After making experimental layout in optisystem and specifying parameters for experiment, the order for assigning channels for both offline schemes is specified. For adjacent channel assignment scheme, channel assignment order is given by {0, 1, 2, 3, 4, 5, 6, 7}. Channel spacing between each two channels is taken as 0.2 nm. For proposed wavelength assignment scheme, the channel order is taken as {0, 7, 4, 6, 1, 2, 5, 3}. For each channel system starting from 2 upto 8,BER values are noted for each channel within given system for both offline schemes and is compared in the end.

IV. RESULTS & DISCUSSION

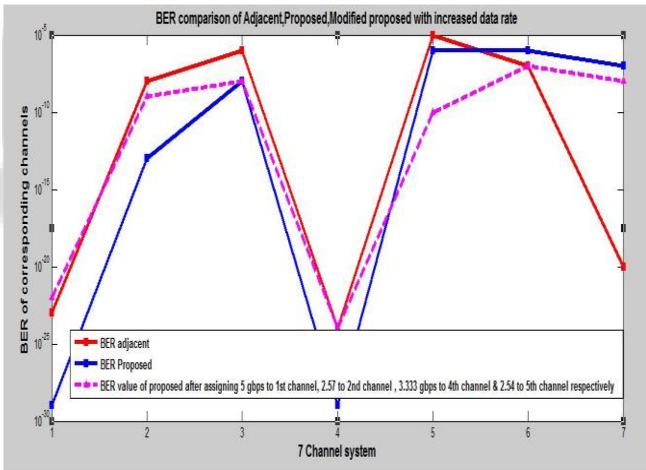

Fig. 2: Performance comparison of both schemes in terms of BER and corresponding enhancement of data rate when 7 channels are already assigned in system.

As shown in the figure ,BER values obtained for each channel in 7-channel system in case of adjacent and that of corresponding channels as per channel order in propsed scheme are plotted.After that , data rate is increased in case of proposed scheme for those channels whose margin in BER value can be made nearly equal to that of adjacent scheme.After assigning 1st channel (1540 nm) in both scheems,2nd channel is assigned which is 1540.2 nm && 1541.4 nm in adjacent and proposed method respectively.This assignment is as per channel order (0,1) & (0,7) for adjacent and poposed shemes is respectively.After assigning subsequent channels in this order,setup is simulated and BER values for corresponding channel as per channel order is noted one by one.As an example,BER value for 1540.2 nm channel & 1541.4 nm which is 2nd channel as per both schemes (adjacent and proposed respectively) is noted and plotted.This is done after assigning all channels in system.Similarly for other channel system,same procedure is followed.Modified proposed is proposed scheme but with increased data rate.

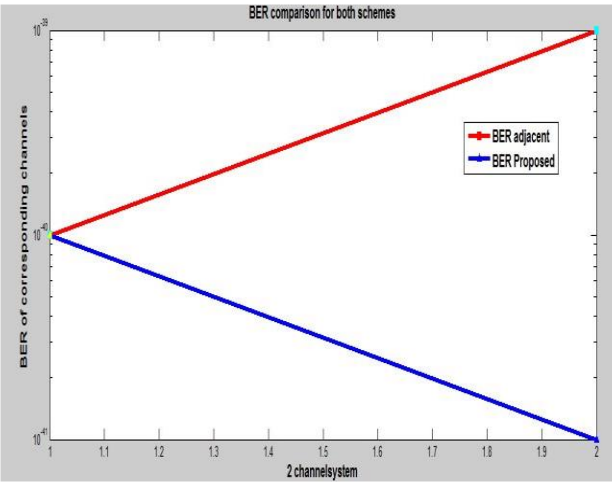

Fig. 3: Performance comparison for 2 channel system for both scheme in terms of BER.

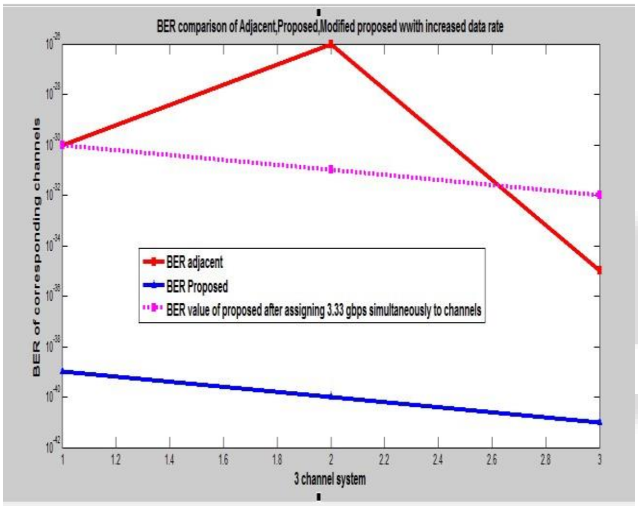

Fig. 4: Performance comparison for 3 channel system for both scheme in terms of BER and corresponding enhancement of data rate when 3 channels are assigned in system.

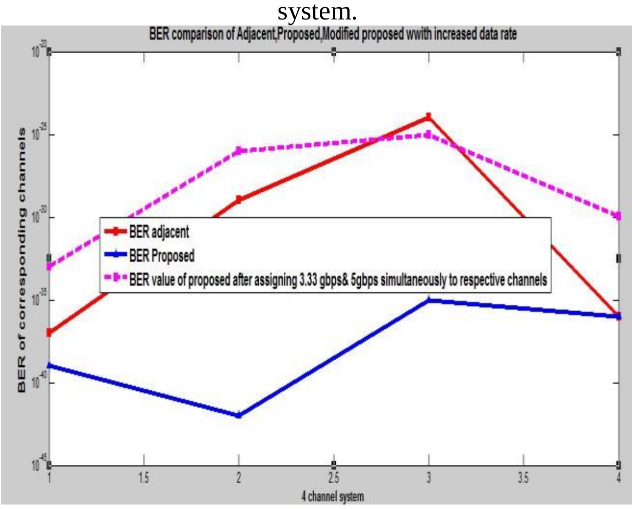

Fig. 5: Performance comparison for 4channel system for both scheme in terms of BER and corresponding enhancement of data rate when 4 channels are assigned in system.

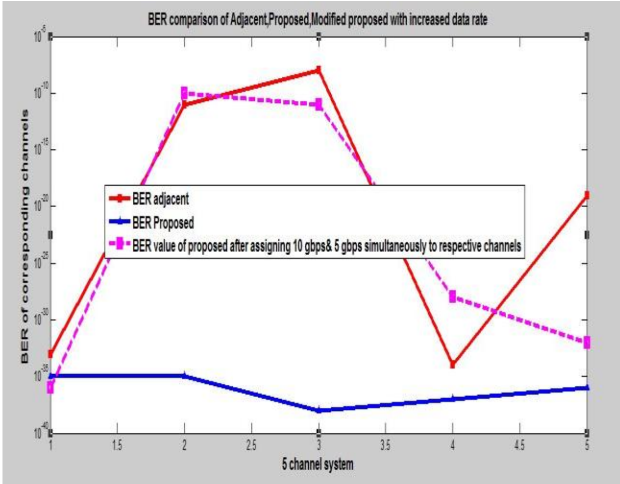

Fig. 6: Performance comparison for 5 channel system for both scheme in terms of BER and corresponding enhancement of data rate when 5 channels are assigned in system

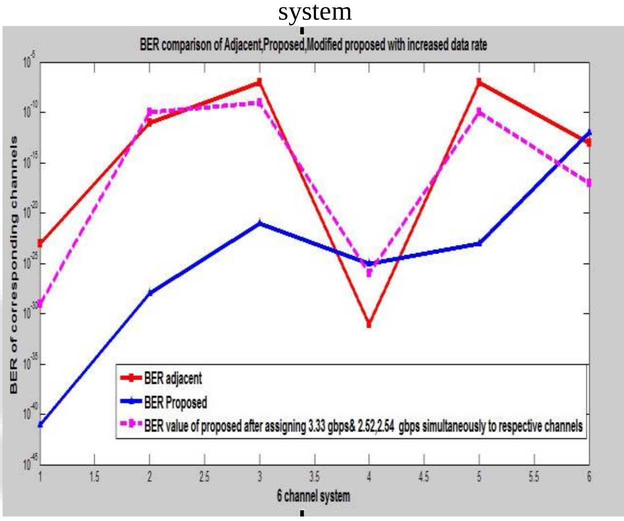

Fig. 7: Performance comparison for 6 channel system for both scheme in terms of BER and corresponding enhancement of data rate when 6 channels are assigned in system.

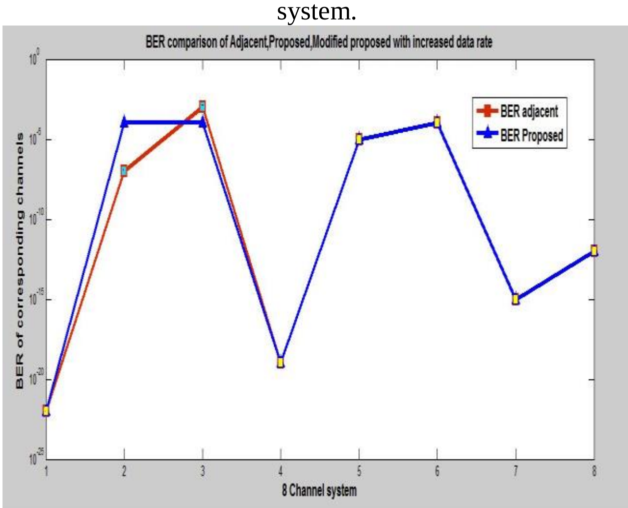

Fig. 8: Performance comparison for 8channel system for both scheme in terms of BER

From above figures, it can be interperated that FWM aware fixed proposed scheme provides better performance for the system until it is not working at full load. In addition to it, for 2 channel system and 8 channel system, both schemes are equivalent to each other in terms of their performance. This is because for 8 channel system both schemes become adjacent equal channel allocation scheme. For 2 –channel system, BER performance is nearly same due to absence of overlapping of FWM products on it.Better performance in terms of BER is achieved due to presence of lesser number of overlapping products in FWM aware proposed scheme as clear from the figure below:

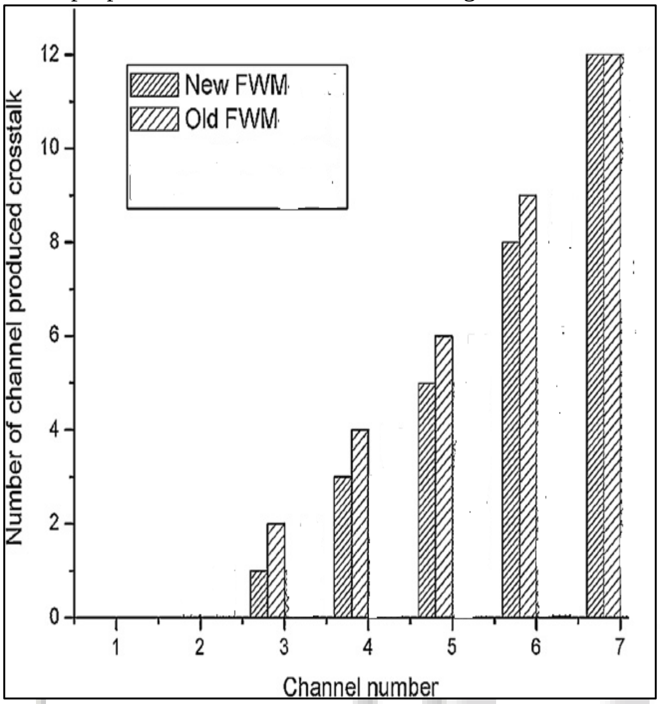

Fig. 9: Number of in-band FWM components vs number of channels assigned (0 to 7) [2]

New FWM corresponds to newly proposed FWM aware channel scheme and old FWM corresponds to adjacent channel scheme. Thus FWM effect is minimized to an extent. The reason for minimization of FWM is that adjacent channel scheme is equal channel spacing scheme [10] whereas in FWM aware proposed scheme behaves like unequal channel allocation scheme [10] until all wavelengths are not assigned. Further it is well known fact that unequal channel spacing has lesser number (in some cases zero of overlapping FWM products than equal spacing channel scheme. Apart from minimization of FWM, capacity enhancement of fiber is done in a bid to make BER nearly equal for both schemes.

V. Conclusion

In this paper, capacity enhancement of fiber in terms of data rate is done. In future, this methodology can be extended for 16 or higher order of channels. This capacity enhancement is possible until fiber is not working at full load. In present day scenario, this is going to serve increasing users demand of increased data rate. Further, FWM minimization is done by using wavelength assignment scheme which has inherent advantage of lesser number of overlapping FWM products.

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