American Journal of Applied Sciences 5 (8): 1059-1063, 2008
ISSN 1546-9239

Impact of Four Wave Mixing (FWM) in Routing and Wavelength Assignment

[1]Tan Saw Chin, [2]F.M. Abbou and [1]Ewe Hong Tat
[1]Faculty of Information Technology, Multimedia University,
63100 Cyberjaya, Selangor, Malaysia
[2]Faculty of Engineering, Alcatel Network Systems, Multimedia University,
50450 Kuala Lumpur, Malaysia

Abstract: The impact of Four-Wave-Mixing (FWM) is investigated using the proposed Assign Shortest Path First (ASPF) algorithm for wavelength assignment in Routing and Wavelength Assignment (RWA). Results show that ASPF algorithm indulges more FWM crosstalk in high optical channels for all input light power and low input power able to reduce he effect of FWM. The blocking probability due to FWM effects is approaching idea case when input power is less than or equal to 10 mW. Furthermore when the input light power is 15 mW, the blocking due to FWM crosstalk is extremely high. Thus, careful optical channel capacity, low FWM crosstalk, low input light power and a FWM-aware wavelength assignment algorithm are strongly desired for the accomplishment of efficient and high capacity WDM transparent optical network.

Key words: Four wave mixing, shortest path algorithm, RWA

INTRODUCTION

Most of the Routing and Wavelength Assignment (RWA) problems have been investigated under the assumption that the optical medium is an ideal one which can carry signals without any bit error. Under this circumstance, the effects of transmission impairments on the signal quality of a connection do not need to be considered. However, in the case of transmission impairments in fibers and optical components, this may significantly affect the quality of a light path[1-2]. Thus, without physical-impairment awareness, a network layer RWA algorithm might provision a light path which cannot meet the signal quality requirement. Generally, impairments can be classified into two categories, linear and nonlinear. Linear effects are independent of signal power and affect wavelengths individually. Amplifier spontaneous emission (ASE), polarization mode dispersion (PMD) and chromatic dispersion are examples of linear impairments. Non linearity is significantly more complex: they generate not only dispersion on each channel, but also crosstalk between channels. These fiber nonlinearities are four-wave mixing (FWM), self-phase modulation (SPM), cross-phase modulation (XPM) and stimulated Raman scattering (SRS). Recently there has been an intensive on-going research on physical impairments in RWA algorithm in Wavelength Division Multiplexing (WDM) optical networks. Some physical impairment that has been studied are: PMD[3-4], ASE[3,5], FWM[6-8]. All the FWM-aware RWA approaches in[6-8] optical network are analyses based on the effect of frequency grid, wavelength set position and connection length. None of them address the issue of correlations of input light power, optical channel and FWM crosstalk power. As careful optical channel, low FWM crosstalk power and optimal input light power are strongly desire4d for the accomplishment of efficient, cost-effective, high capacity WDM transparent optical network. Thus, the goal in this study is to assess how network performance could be affected by FWM crosstalk, input light power and optical channels.

IMPLICATION OF FWM IN Q FACTOR AND BIT ERROR RATE (BER)

In WDM system with C frequency channels, at any particular channel frequency, there will be a number of FWM waves generated from various combinations of interacting signals whose frequencies satisfy: $f_{FWM} = f_i + f_j - f_k$, where f_i, f_j and f_k are the signal light frequencies and f_{FWM} is the four-wave mixing light wave frequency. The time-average optical power generated at frequency f_{FWM} is given by[9]:

Corresponding Author: Tan Saw Chin, Faculty of Information Technology, Multimedia Univeristy, 63100 Cyberjaya, Selangor, Malaysia Te1: +603-83125346 Fax: +603-83125264

$$P_{FWM}\left(f_i,f_j,f_k\right)=\eta\left[\frac{1024\pi^6}{n^4\lambda^2c^2}\right]\left(\frac{L_{eff}}{A_{eff}}\right)^2(dx)^2P_iP_jP_ke^{-\alpha L} \quad (1)$$

where: η: The four-wave mixing frequency, n: The fiber refractive index, λ: The wavelength, c: The speed of light, L_{eff}: The effective length of the fiber ($L_{eff} = (1-e^{-\alpha L}/\alpha)$), A_{eff}: The effective mode area of the fiber, d: The degeneracy factor(d = 3 for i = j, d = 6 for i $\neq$ j), x: The third-order nonlinear susceptibility, P_i: The input power of the frequency f_i, α: The fiber loss coefficient, L: The fiber length. The total power generated at frequency f_m may be expressed as a summation[9-10]:

$$P_{tot}\left(f_m\right)=\sum_{f_k=f_i+f_j-f_m}\sum_{f_i}\sum_{f_j}P_{FWM}\left(f_i,f_j,f_k\right) \quad (2)$$

The FWM interference noise power can be expressed as[9-10]:

$$N_{FWM}=2b^2P_s\frac{P_{FWM}}{8} \quad (3)$$

where b is the quantum efficiency and P_s is the signal light power at the receiver which can be expressed as $P_s = P_0e^{-\alpha L}$, with P_0 represents the input light power to the fiber. The signal to noise ratio (SNR) can be expressed as factor Q[9-10] where N_{th} and N_{sh} are the thermal and shot noise respectively, which are very small and could be neglected in front of N_{FWM} and So equation can be written as[9,10]:

$$Q=\frac{bP_s}{\sqrt{N_{FWM}}}=\frac{2\sqrt{P_0e^{-\alpha L}}}{\sqrt{P_{FWM}}} \quad (4)$$

In the Gaussian noise approximation, the Bit Error Rate (BER) for OOK (On-Off keying) signal with intensity modulation can be calculated through[10]:

$$BER=\frac{1}{\sqrt{2\pi}}\int_Q^\infty e^{-\frac{-t^2}{2}}dt \quad (5)$$

All the connections that are accepted in the network should obey two criteria, one for the network layer and another for the physical layer. The network layer criterion is about the wavelength continuity restriction (free-resources status) and the physical layer criterion is about the quality of the optical signal (signal-quality requirement). If a request has a Bit Error Rate (BER) above of the threshold BER (10^{-9}), it will be blocked. The total crosstalk power at the destination for the connection is found by adding the contributions of each link as follows:

$$P_{dest}=\sum_{C=1}^{H}P_{tot}\left(f_m\right)$$

where H is the number of hops of the route. i, j $\neq$ k, 1, 2,…,C. C is the number of active channels in each connection. With the total crosstalk power at the destination, the FWM interference noise power and the Q factor of the request are obtained by using Eq. 3 and 4. After that, the decision about blocking or not of the connection is made.

ASSIGN SHORTEST PATH FIRST (ASPF) ALGORITHM

In this section, we present a wavelength assignment algorithm by always assign the wavelength to the shortest path. The objective of the ASPF is to optimize the light path connection based on wavelength clash and wavelength continuity restrictions. The routing algorithm is based on shortest paths. The following notations are used and the proposed wavelength assignment algorithm:

- C is the number of wavelengths used in assignment
- l is the number of links in the network topology
- N is the number of nodes in the network topology
- λ_k is the type of wavelengths, k = 1,2,…, C
- $link_i$ is the type of link in the network, i = 1,2,…,l.
- R (s, d) records the length of each route s-d, s, d = 1, 2,…N
- Route (s, d, i) stores the links ($link_i$) in the route R (s,d), i = 1, 2,…l
- F (s, d) is to record the type of wavelengths that assign to each route s-d, s, d = 1, 2,…N
- Counter_link ($link_i$) is a counter to record the number of wavelengths in the $link_i$
- Link_stored (λ_k) stores the links ($link_i$, i = 1, 2,…l) that has been assigned the wavelength λ_k. It equals to 0 is none of the links been assigned to wavelength λ_k

Step 1: Initialize k to 1. k indicates the type of wavelength λ_k. and initialize link_stored [λ_k] = 0 to indicate that none of the link has been assigned to wavelength λ_k.

Sorting and finding shortest route

Step 2: Sort a set of routes that have never been assigned by wavelength λ_k (F (s, d) $\neq$ -1).

Step 3: Search for connection that has the shortest route path (R $(s,d)_{min}$) among them.

Wavelength Assignment

Step 4: Assign wavelength λ_k to that connection (F (s, d) = λ_k) that has shortest route if it has never been assigned to any wavelength before or none of the links for this shortest path has been assigned to this wavelength before. Else go to Step 2 to search for the next shortest route.

Step 5: Update the link_stored [k] by storing all the links of the chosen shortest paths (if R (s, d) = R $(s, d)_{min}$) that has been assigned to wavelength λ_k based on the links in Route(s, d,:).

If all the links ($link_{i,}$ i = 1,2,…,l) in the network already appear in link_stored [k], go to Step 6, else go to Step 2.

Next wavelength for assignment

Step6: k is replaced by k+1.

Capacity of optical channels

Step7: If $k \leq C$, then go to Step 2 and repeat, else stop.

The above Assign Shortest Path First algorithm (ASPF) always assign the wavelength to as many connections as possible without considering the FWM crosstalk that may indulge in each linkThis new algorithm will continue search for shortest route path and assign wavelength while there is any available wavelength (k< = C) or there is link in the connection that never be assigned before.

RESULTS AND DISCUSSION

The performance of the proposed algorithm is studied in the 14 node, 20 link National Science Foundation (NSF) network as shown in Fig. 1. Our goal is to demonstrate the impact of FWM using the ASPF algorithm in different input light power for different optical channels. The network performance was measured in terms of average of blocking probability. In all cases we measured this probability with no FWM Crosstalk (this case, blocking happens due to only the wavelength continuity restriction). The algorithm used in the routing is the shortest path algorithm. We assume that all requests arrive from node to node following the shortest route.

Figure 2 shows the average FWM power versus input light power P_{in} for two different optical channel for comparison: C = 16 versus C = 32 in NSF network. From the diagram shown in Fig. 2, for the same value of P_{in}, lower optical channel (C = 16) produces lesser FWM effect compared to optical channel C = 32. This is because lower optical channel, there is less intersection wavelength occurs at each link. It is clear from the results that FWM is one of the serious factor possibly limiting system performance in higher optical channels.

Figure 3 show the average blocking probability versus the traffic loads for two different cases: (i) With FWM effect and (ii) Without FWM effect using the ASPF algorithm for two optical channels (C = 16 versus C = 32). The blocking probability in the absence of FWM is always lower compare to the presence of FWM for all optical channels. It can be seen that blocking probability and hence the systems performance, depends on the input light power.

For the diagram shown in Fig. 3a, when the input light power at the input of optical fiber is less than or equal to 10mW (23dBm), the corresponding FWM effect is zero in both optical channels (C = 32 and C = 16) where the blocking probability approaching ideal case (without FWM effect).

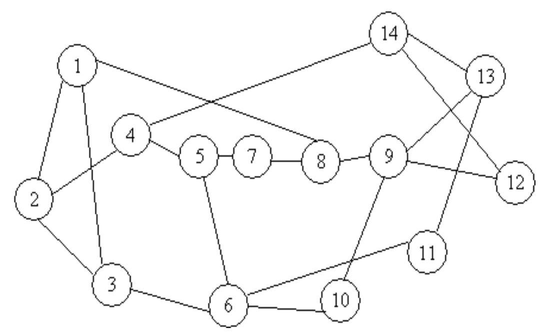


Fig. 1: NSF network

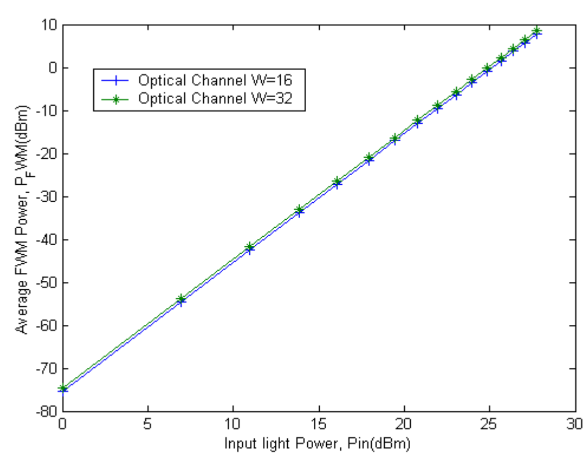
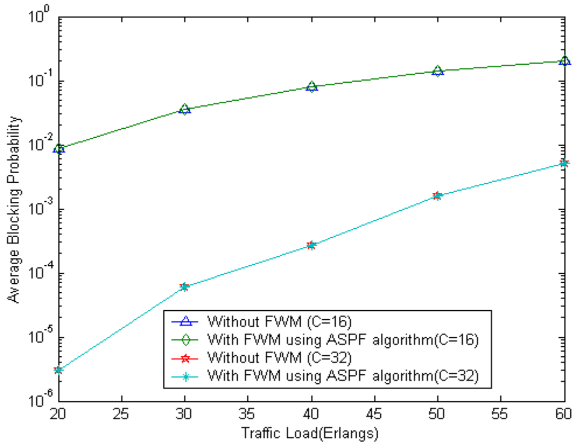
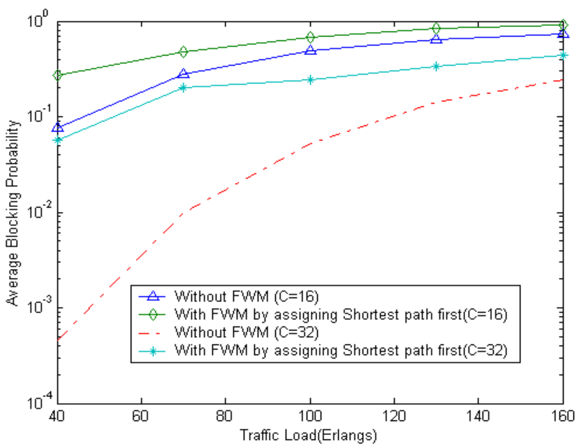


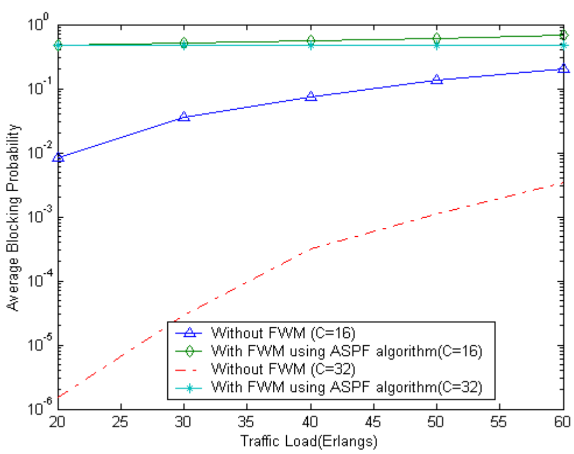
Fig. 2: FWM power versus Input light power for C = 16 and C = 32.



(a)



(b)



(c)

Fig. 3: Blocking probability versus traffic loads, a: Input light power≤10 m W, b: Input light power = 12 mW, c: Input light power = 15 mW

However, when the input power is 12mW(24dBm) as shown in Fig. 3b, the blocking probability due to FWM crosstalk is exist in both optical channels (C = 16 and C = 32) and the effect is more obvious in optical channel C = 32 compared to C = 16. From the diagram shown in Fig. 3c, when the input light power is 25mW, the effect of FWM crosstalk in both optical channels is very high leading to higher blocking probability and the FWM effect is still more obvious in higher optical channel (C = 32). From the diagram Fig. 3b and c, the blocking probability due to FWM effect using ASPF algorithm is always higher in optical channel C = 32 compared to C = 16 for all traffic loads. When the input light power is 15 mW (27 Bm) and optical channel C = 32, the FWM effect is extremely high as the blocking probability in C = 32 is even higher than the case without FWM effect in C = 16.

CONCLUSION

The results show that the impact of FWM can be ignored when input light power is less than or equal to 10 mW using the proposed ASPF algorithm for wavelength assignment. However, when the input light power is equal or more than 12mW, not all of the established light paths have the acceptable signal-quality requirements resulting in higher blocking probability. Furthermore, the results show that ASPF algorithm is indulges less FWM crosstalk in lower optical channel. It is because ASPF algorithm is not a FWM-aware wavelength assignment algorithm as it allow as many as possible of light path establish between the nodes. Thus, careful optical channel capacity, low FWM crosstalk, low input light power and a FWM-aware wavelength assignment algorithm are strongly desired for the accomplishment of efficient and high capacity WDM transparent optical network.

REFERENCES

1. Cerutti, I., A. Fumagalli and M.J. Potasek, 2002. Effect of chromatic dispersion and self-phase modulation in multihop multirate WDM rings. IEEE Photon. Technol. Lett., 14 (3): 411-413.
2. Ramamurthy, B., D. Datta, H. Feng, J.P. Heritage and B. Mukherjee, 1999. Impact of transmission impairments on the teletraffic performance of wavelength-routed optical networks. J. Lightwave Technol., 17: 1713-1723.
3. Ali M. and L. Tancevski, 2002. Impact of Polarization-Mode Dispersion on the Design of Wavelength-Routed Networks. Photonics Technol. Lett., 14: 720-722.

4. Yurong, H., J.P. Heritage and B. Mukherjee, 2005. Connection provisioning with transmission impairment consideration in optical WDM networks with high-speed channels. J. Lightwave Technol., 23 (3): 982-993.
5. Tomkos, I., D. Vogiatzis, C. Mas, I. Zacharopoulos, A. Tzanakako and E. Varvarigos, 2004. Performance engineering of metropolitan area optical networks through impairment constraint routing, IEEE Communications Magazine, 42 (8): 40-47.
6. Fonseca, I.E., R.C. Almeida, M.R.N. Ribeiro and H. Waldman, 2003. Algorithms for FWM-aware routing and wavelength assignment, Proceeding of the SBMO/IEEE MTT-S international microwave and Optoelectronics Conference, 2: 707-712, 20-23.
7. Fonseca, I.E., M.R.N. Ribeiro, R.C. Almeida Jr. and H. Waldman, 2004. Preserving global optical QoS in FWM impaired dynamic networks, IEE Electronics Lett., 40 (3): 191-192.
8. Fonseca, I.E., M.R.N. Ribeiro and H. Waldman, 2005. Differentiated optical QoS under a low complexity FWM-aware wavelength assignment algorithm, Conference on Optical Network Design and Modeling, pp: 431-438.
9. Inoue, K., K. Nakanishi, K. Oda and H. Toba, 1994. Crosstalk and power penalty due to fiber four-wave mixing in multichannel transmissions, J. Lightwave Technol., 12 (8): 1423-1439.
10. Inoue, K., 1995. A simple expression for optical FDM network scale considering fiber four-wave mixing and optical amplifier noise, J. Lightwave Technol., 13 (5): 856-861.