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Impact of Four Wave Mixing in Ring and Mesh Topologies for Routing and Wavelength Assignment

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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) in two different topologies. The results show that the ASPF algorithm indulges more FWM crosstalk in a 8 node Ring topology compared with a 8 node Mesh topology for optical channels of 16 and 32. Careful optical channel capacity, low FWM crosstalk power in different network topology are strongly desired for the accomplishment of efficient, cost-effective, high capacity WDM transparent optical network.

Key words: Four wave mixing, shortest path algorithm, routing and wavelength assignment, bit error rate, optical channel, network topology

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 (Cerutti *et al*., 2002; Ramamurthy *et al*., 1999). 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 problems that have been studied are: PMD (Ali and Tancevski, 2002; Yurong *et al*., 2005), ASE (Ali and Tancevski, 2002; Tomkos *et al*., 2004), FWM (Fonseca *et al*., 2003, 2004, 2005). All the FWM-aware RWA approaches in (Fonseca *et al*., 2003, 2004, 2005) optical network are analyses based on the effect of frequency grid, wavelength set position and connection length. None of them address the issue of correlation of topologies, optical channel and FWM crosstalk power. As careful optical channel capacity, low FWM crosstalk power are strongly desired for the accomplishment of efficient, cost-effective, high capacity WDM transparent optical network. Thus, the goal in this paper is to assess how network performance could be affected by FWM crosstalk in different topology.

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 Inoue *et al*. (1994):

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

Where:

- η = Four-wave mixing frequency
- n = Fiber refractive index
- λ = Wavelength
- c = Speed of light
- L_{eff} = Effective length of the fiber ($L_{eff} = (1-e^{-\alpha L}/\alpha)$
- A_{eff} = Effective mode area of the fiber
- d = Degeneracy factor(d = 3 for I = j, d = 6 for I≠j)
- χ = Third-order nonlinear susceptibility
- P_i = Input power of the frequency f_i
- α = Fiber loss coefficient
- L = Fiber length

Total power generated at frequency f_m may be expressed as a summation (Inoue *et al*., 1994; Inoue, 1995) as follows:

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

The FWM interference noise power can be expressed as (Inoue *et al*., 1994; Inoue, 1995):

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

Where:

- b = Quantum efficiency
- P_s = Signal light power at the receiver which can be expressed as $P_s = P_0e^{-\alpha L}$, with P_0 representing the input light power to the fiber

The Signal to Noise Ratio (SNR) can be expressed as factor Q (Inoue *et al*., 1994) 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 (Inoue *et al*., 1994; Inoue, 1995):

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

In the Gaussian noise approximation, the Bit Error Rate (BER) for OOK (On-Off keying) signal with intensity modulation can be calculated through (Inoue, 1995):

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

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 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:

$$P_{dest} = \sum_{C=1}^{H} P_{tot}(f_m) \quad (6)$$

Where, H is the number of hops of the route. i, j ≠ 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 for the connection is made.

ASSIGN SHORTEST PATH FIRST (ASPF) ALGORITHM

Here, we present a wavelength assignment algorithm by always assigning 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 the 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)≠ -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

Step 6: k is replaced by k+1.

Capacity of optical channels

Step 7: If k = 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 link.

EXPERIMENT RESULTS

The performance of the proposed ASPF algorithm is studied in the two different topologies: Mesh and ring topologies (Fig. 1a, b). Present goal is to demonstrate the impact of FWM using ASPF in different topologies for different optical channels. In all cases, we measure this probability with no FWM Crosstalk (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.

From the results in Fig. 2 and 3, the blocking probability for both cases (mesh and ring topologies) using ASPF algorithm for the consideration of FWM crosstalk is always higher than those without FWM crosstalk (ideal case) for optical channel of 16 and 32. The blocking probability for the case without consideration of FWM crosstalk is lower in ring topology compared to mesh topology. The blocking probability without

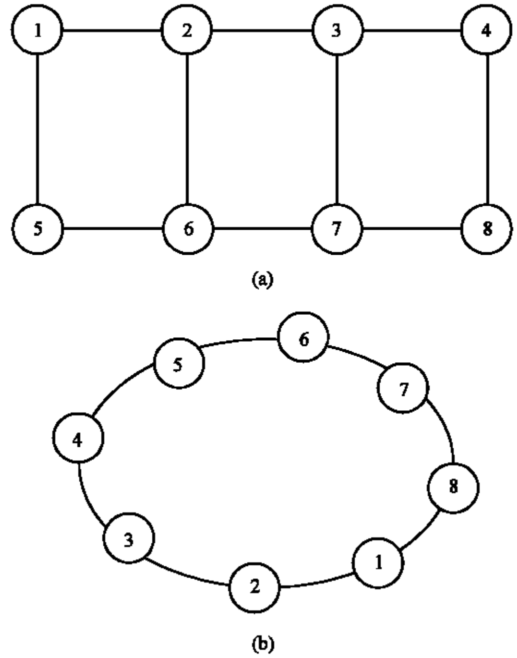

Fig. 1: Mesh and Ring topologies

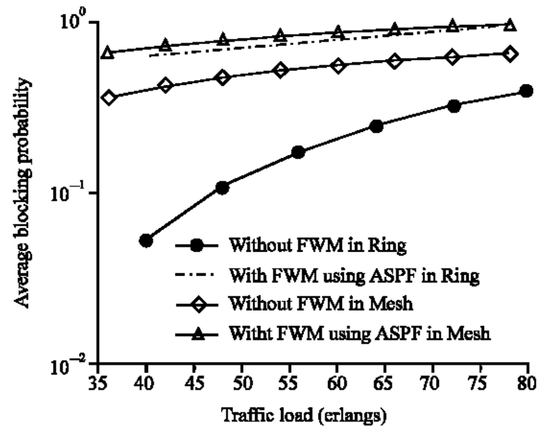

Fig. 2: Optical channel C = 16

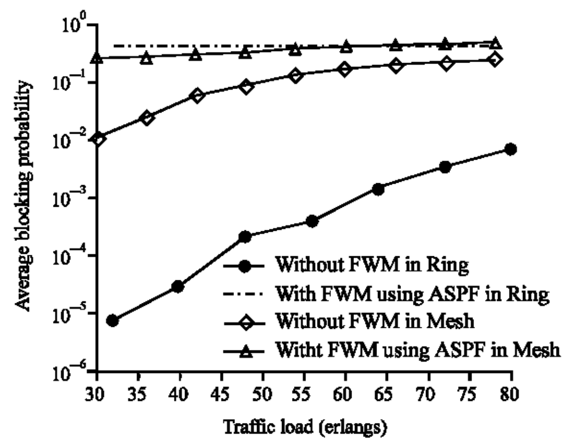

Fig. 3: Optical channel C = 32

consideration of FWM crosstalk for the optical channel of 32 is lower than the optical channel of 16 as higher optical channels able to support more connection request. This blocking probability (ideal case) acts as references point for analysis the impact of FWM in mesh and ring topologies.

From the results of Fig. 2 and 3, it is clear that the impact of FWM crosstalk in ring topology is more apparent compared to that of the mesh topology using the proposed ASPF algorithm for both optical channels. The results shows that the incensement of blocking probability due to FWM impact from the ideal case in ring topology is more obvious if compared with the mesh topology for optical channel of 16 and 32. These impacts become even more apparent in ring topology when the number of optical channel increases to 32. It is due to the fact that less alternative routes exist in ring topology and this causes higher rate of wavelength intersection in each link that further indulges FWM crosstalk.

However, the impact of FWM crosstalk is more stable (less variation) for optical channels of 16 and 32 in mesh topology. This can be seen from the Fig. 2 and 3 that the incensement amount of blocking probability from the ideal case is almost the same for optical channels of 16 and 32.

CONCLUSION

The results show that the impact of FWM using the proposed ASPF algorithm for wavelength assignment indulges less FWM crosstalk in mesh topology compared to ring topology for optical channels of 16 and 32. Thus, careful optical channel capacity, low FWM crosstalk power in different network topology are strongly desired for the accomplishment of efficient, cost-effective, high capacity WDM transparent optical network.

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