Optical DiffServ in FWM Impaired Dynamic Optical Networks

Iguatemi E. Fonseca[1], Moisés R. N. Ribeiro[2], and Helio Waldman[1]

***Abstract*—Optical *Quality of Service* (QoS) for different classes of service in dynamic transparent optical networks is here addressed through three *Four Wave Mixing* (FWM)-aware algorithms. The traffic classes differ in quality attributes, namely, transmission *Bit Error Rate* (BER) and blocking probability. The algorithms are tested on two mesh topologies against offered traffic, different transmitted power and wavelength grid. Results suggest that in order to simultaneously maintain *Optical Service Level Agreement* (OSLA) and efficient utilization of the resources, there must be some form of *Connection Admission Control* (CAC) mechanisms to provide class isolation.**

***Index Terms*— Optical QoS, Routing and Wavelength Assignment, Physical Impairments, Dynamic Optical Networks.**

I. INTRODUCTION

The widespread use of applications based on *Internet Protocol* (IP) will demand from next-generation Internet several advanced services that will ultimately rely upon physical layer *Quality of Service* (QoS) guarantees. However, the problem of providing optical QoS in all-optical networks continues unsolved, especially in a scenario with clients with different QoS requirements [1]. Previous QoS methods proposed for IP network, namely, *Integrated Services* (IntServ) [2] and *Differentiated Services* (DiffServ) [3], are difficult to apply to all-optical networks mainly due to the fact that such methods are based on store-and-forward model [4]. There is no consolidated optical memory technology to date and the use of electronic memory in an optical switch needs *Optical-to-Electrical-to-Optical* (OEO) conversions. Moreover, employing OEO along a lightpath has disadvantages such as cost and the impossibility of providing end-to-end bit-rate transparency within the optical network [5].

Therefore, efforts to achieve optical QoS in all-optical networks have been mainly focused on the development of QoS-routing algorithms [6]-[10]. In such works, optical QoS can be classified into two categories. The first one concerns the limits imposed by *physical impairments*, such as *Polarization Mode Dispersion* (PMD), and *Amplified Spontaneous Emission* (ASE), while the other covers *functional requirements* such as ligthpath routing stability and survivability [9]. However, optical QoS guarantee for multiple classes of service in a dynamic transparent optical network is yet to be addressed in the literature. Previous works have neglected the influence the *Wavelength Assignment* (WA) algorithms may have on optical QoS. Indeed, WA becomes a key issue when non-linear effects - such as *Four Wave Mixing* (FWM) *and Cross-Phase Modulation* (XPM) - lead performance of lightpaths sharing common links to be tightly interwoven. Thus, *Connection Admission Control* (CAC) mechanisms integrated to RWA have to be put in place if optical QoS is to be preserved [11].

In this paper, we propose QoS-aware CAC/*Routing and Wavelength Assignment* (CAC/RWA) algorithms with optical QoS guarantees for two classes of service in dynamic transparent optical networks. In order to address the influence of WA algorithm in QoS-Aware dynamic networks, this paper focus on the impact of FWM. This is the most intricate non-linear effect from WA standpoint under requirements for either deterministic or statistical optical QoS. Although some may argue that the practical relevance of FWM is confined to networks solely based on *Dispersion Shifted Fibers* (DSF), the reduced channel spacing allowed in the new *International Telecommunication Union* (ITU) grid [12] may strongly favour FWM elsewhere. Experimental investigations in [13] present FWM impact in systems built with non-zero dispersion fibers as channel separation is reduced. Moreover, it was recently shown that dispersion compensated links may be mainly impaired by FWM induced distortion rather than XPM [14].

II. THRESHOLD VIOLATION PROBABILITY

Optical QoS in transparent networks, when related with physical impairments, is usually defined as a static value for *Bit Error Rate* (BER) allowed on lightpaths across the network [6]. Note, however, that the BER of a particular lightpath may fluctuate when connections are established or torn down elsewhere in the network. Thus, a threshold BER

---

[1] Iguatemi E. Fonseca and Helio Waldman are with *Optical Networking Laboratory* - DECOM/FEEC/UNICAMP, P.O. Box 6101, 13083-970, Campinas, SP, Brasil Tel. +55-19-37883793, Fax +55-19-32891395, Email: (iguatemi, waldman)@decom.fee.unicamp.br.
URL: http://www.optinet.fee.unicamp.br

[2] Moisés R. N. Ribeiro is with Department of Electrical Engineering, UFES, Vitória, Brazil. Tel. +55-27-3335-2662, Fax: +55-27-3335-2644, (moises@ele.ufes.br).

This work was supported by the Brazilian Agencies CAPES and CNPq, ERICSSON Telecomunicações do Brasil, and GIGA Project.

may be required as an element composing an *Optical Service Level Agreement* (OSLA) to set the minimum acceptable BER. This paper proposes a metric called *Threshold Violation Probability* (TVP) [11] standing for the probability for at least one active lightpath across the whole network having its BER below minimum requirement just after a change in lightpath status in the network. Actually, TVP proves useful as a means of representing global, i.e. for the whole network, statistical optical QoS provisioning and preserving. Global deterministic optical QoS is, therefore, only achieved when TVP reaches zero, i.e. the process of establishing or releasing lightpaths brings no harm to the whole set of ongoing connection (and even to the candidate itself in case of setting up a new connection in FWM impaired networks).

The FWM noise power at destination node over a given wavelength, denoted by P_{DN}, gathered along its H hops by either a candidate or an active lightpath out of W wavelengths per link is evaluated using (1)

$$P_{DN}(f_a)=\sum_{c=1}^{H}\sum_{f_k=f_i+f_j-f_a}\sum_{f_j}\sum_{f_i}P_{FWM}(f_i,f_j,f_k) \qquad (1)$$

P_{FWM} is the FWM crosstalk power and it is calculated as in [15]; f_a is the lightpath optical frequency being audited, f_i, f_j, and f_k (i, j, k =1, 2,…,W; $i\neq k$, $j\neq k$) are the optical frequency of interfering lightpaths, i.e. those with common links with the request. The connection Q factor is calculated using the Gaussian approximation model [15].

III. OPTICAL QOS MECHANISMS FOR DIFFERENT CLASSES OF SERVICE UNDER THE INFLUENCE OF NON-LINEAR EFFECTS

The choice of a wavelength for serving a particular network client request in a network under the influence of non-linear effects must take into account the impact that each available wavelength has over ongoing lightpaths that share common links. We propose three CAC/RWA algorithms, simply named A, B and C. Differentiated classes of service can then be supported. We suppose that optical network will provides clients two *Forward Equivalence Classes* (FECs). Class_1 or Cl_1, which has an OSLA demanding a threshold line with BER $<10^{-12}$, provides the *Premium Service*. This class does not accept violations performance, i.e. TVP=0 for Cl_1. While the Class_2 (Cl_2), has a less demanding OSLA for assessing optical QoS of lightpaths crossing the network, i.e. BER$<10^{-9}$ and violations of this performance may be accepted, i.e. Cl_2 may suit *best-effort* traffic. Figure 1 illustrates the three CAC/RWA's algorithms investigated in this paper.

Algorithm *"A"* states that violations of BER threshold line are not admitted, i.e., TVP=0, for both Cl_1 and Cl_2. In other words, if at least one active ligthpath in the network will have its BER below 10^{-12} in case of Cl_1 connections or 10^{-9} in case of Cl_2 connections, this request must be blocked. Algorithm B ensures that violations of BER threshold line are not accepted only for Cl_1 connection. In this case, TVP=0 for Cl_1 and TVP≥0 for Cl_2. Notice that Cl_1 network requests to be admitted into the network have more strict requirements. As a result, it is expected that the blocking probability for Cl_1 to be higher than the experienced for Cl_2 connections requests. Algorithm "C" uses the strategy of limiting the number of links taken by Cl_2 connections in the network, thus Cl_1 blocking probability is expected to decrease. Algorithm "C" preventively blocks Cl_2 requests that are longer than the average interference length (L_{int}) [16].

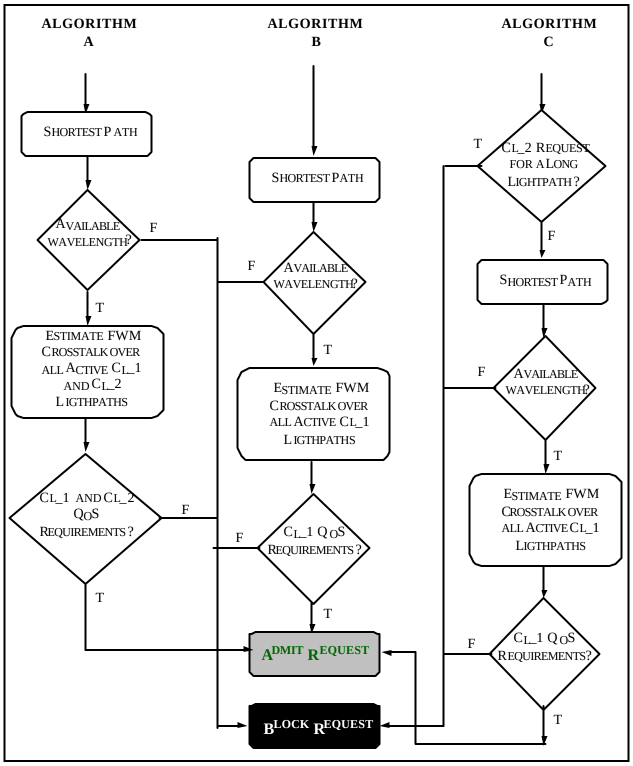

Figure 1: CAC/RWA Algorithms

In previous works [11], [16], we investigate the influence of long paths over the FWM crosstalk generation. It is observed that requests for long paths are more likely to be rejected due to their own FWM contamination, rather than by the degradation they cause on other pre-existing paths. Then, rejecting long Cl_2 request, we are also facilitating the ingress of long Cl_1 request as far as FWM crosstalk contamination is concerned.

IV. RESULTS

Different networks scenarios are presented for lightpath transmitted power set at 0 dBm and 4 dBm per channel over a 50 GHz and 100 GHz Grid, respectively. The topologies considered here are a semi-regular network with 9 nodes and an irregular topology with 19 nodes using W=10 wavelengths per link. Optical amplifiers to compensate the 100 km DSF link attenuation connecting two adjacent nodes with wavelengths under the ITU-T grid [12] are employed. The fiber attenuation, fiber nonlinear coefficient, zero-dispersion wavelength, and chromatic dispersion slope are, respectively, 0.22 dB/km, 2.3 $(W.km)^{-1}$, 1553 nm, and 0.067 ps/[$(nm)^2$km]. For the purpose of this paper, FWM is assumed to be the major degrading effect over OSNR, i.e. other noises sources are neglected. CW lightpaths is considered for worst case FWM crosstalk analysis [17]. The spatial traffic profile is uniformly distributed, bearing Poisson (mean used to set a given traffic load) arrivals and exponential distribution (mean=1s) for call generation and its duration, respectively. Performances of different network topologies are compared using total network traffic instead of either traffic per node or per wavelength. The routing algorithm is based on shortest paths. The proportion of Cl_1 connection requests in the total amount of demands for lightpaths is represented by *p*. Discussion on results takes client and throughput viewpoints separately.

A- Network client viewpoint

Blocking probability per class for a 19-node network under Algorithm "A" (100 GHz grid and lightpath transmitted power set at 4 dBm) is shown in Fig. 2. It is clear that performance achieved for Cl_1 is close to the one found for Cl_2, even under heavy traffic. Algorithm "A" proves to be insensitive to traffic composition since it provides similar OSLA for both classes. To better explain this result, Fig. 3 brings blocking probability for the proposed Algorithms under different traffic composition in two network scenarios at 80Er. When there is just one class of service with strict OSLA, i.e. the network blocking performance under Algorithm "B", the connection request blocking probability for Cl_2 is slightly improved, but the side effects are shown in Fig. 3a Fig. 3c and Fig. 4. An expressive increase in Cl_1 blocking probability is noticed when compared with the amount of requests turn down from this traffic class under Algorithm "A". In addition, TVP levels for CL_2 reach figures well above 10% in Fig. 4 for small percentage of *Premium* traffic (e.g. *p*=0.1). Interestingly, as *p* increases above 0.5 for networks under Algorithm "B", the blocking probability experienced by CL_1 decreases. For instance, Cl_1 blocking at p=0.9 is lower than it is at p=0.5 for both networks loaded at 80Er in Figs. 3a and 3c. The performance of Cl_1 will improve for $p \to 1$ due to the reduction in Cl_2 requests to the network. Eventually, this will favour the admission of Cl_1 connections requests. Note also that TVP for Cl_2 under Algorithm "B" in Fig. 4 follows this trend accordingly, once it is less likely to impair ongoing Cl_2 connections after establishing a Cl_1 lightpath when *p* increases towards 1.

By introducing *preventive blocking* for long connections belonging to Cl_2 clients, Algorithm "C" manages to reduce blocking probability for *premium* requests; provided they do not make the majority of the offered traffic. Realistic traffic scenarios may assume strict OSLA, such as Cl_1, composing less than 50% connection requests. In this context, Algorithm "C" presents attractive blocking performances in Fig. 3 as far as Cl_1 is concerned, particularly for $p \leq 0.3$. Notice that TVP for Cl_2 is also significantly reduced in Fig. 3 when compared to Algorithm "B". Nevertheless, this should be down to the massive blocking probability experienced by Cl_2 requests seen in Figs. 3b and 3d caused by the policy of deterministic rejection of connection requests beyond the average interference length.

B -Network throughput viewpoint

Total blocking probability imposed on connection requests is here defined as the ratio between the blocked requests (regardless of its class) and the total number of requests for lightpaths. Thus network throughput can be assessed against *p*. As seen in Fig. 5, the total blocking probability for Algorithms "B" and "C" is consistently higher than networks operating under Algorithm "A". Besides, the performance of algorithm "A" remains almost constant, as expected, with the increment of proportion of Cl_1 connection request. Recall

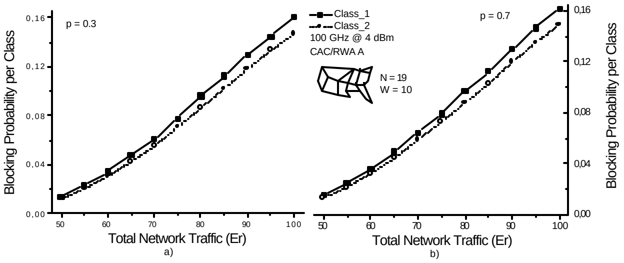

Figure 2: Blocking Probability per Class, algorithm A. 4 dBm @ 100GHz Grid @ 80Er

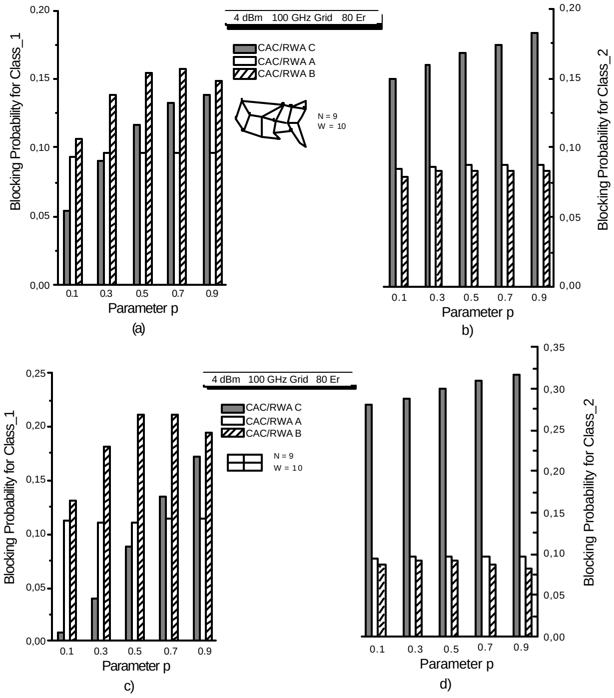

Figure 3: Blocking Probability for Cl_1 and Cl_2. 4 dBm @ 100GHz Grid @ 80Er

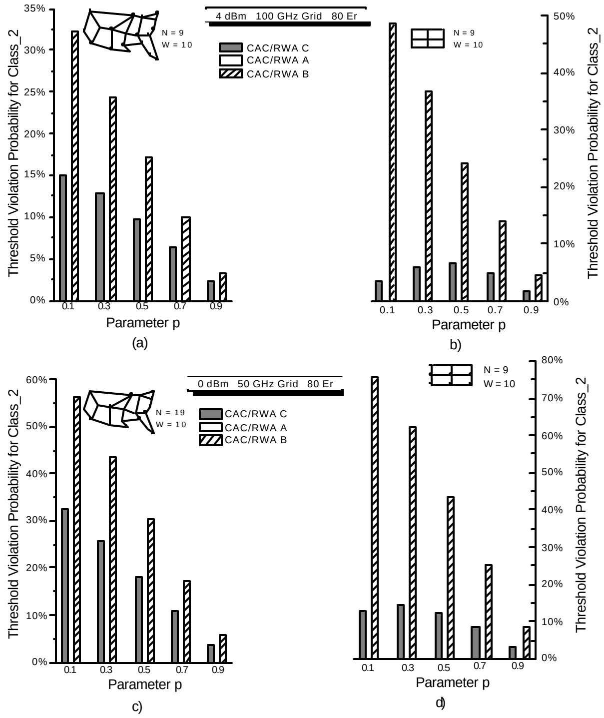

Figure 4: Threshold Violation Probability for Cl_2. 4 dBm @ 100GHz Grid @ 80Er, and 0 dBm @ 50GHz Grid @ 80Er

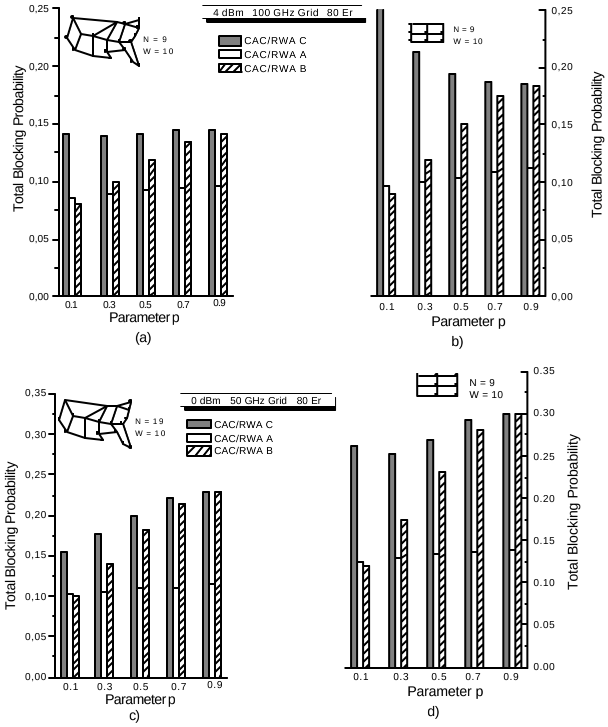

Figure 5: Total Blocking Probability. 4 dBm @ 100GHz Grid @ 80Er, and 0 dBm @ 50GHz Grid @ 80Er

that Algorithms "B" and "C" are aimed at providing privileges to *Premium* traffic, which has a stricter OSLA (lower BER and TVP=0). But it is clear from Fig. 5 that such policies jeopardizes network throughput except for Algorithm "B" when request for *Premium* lightpaths makes 10% of the total connection requests for networks loaded at 80Er. Notice, however, that *Best effort* traffic over Cl_1 lightpaths will frequently be disturbed by OSNR fluctuations leading BER below 10^{-9} as TVP at p=0.1 in Fig. 4 indicates. In order to maximize throughput, network serving different classes should use CAC/RWA algorithms that preserve class isolation, such as in Algorithm "A" where TVP=0 is kept for both classes. In case Algorithm "C" is used as a means of reaching extremely low blocking probability for Cl_1 (see Figs. 3a and 3c at *p*=0.1), network designer can make use of results in Fig. 5 to support pricing studies for *Premium* lightpaths. Lower throughput leads to less revenue (as fewer clients are served) unless the amount charged for provisioning *Premium* lightpaths compensates this reduction in profitability.

V. CONCLUSION

Algorithms with optical QoS guarantee for two classes of service in dynamic transparent optical networks impaired by FWM were proposed and analysed. Results showed a trade-off between amounts of traffic with high priority, the network utilization, and the policy for the accommodation of class with low priority. Class isolation mechanisms proved a key factor in CAC in dynamic networks under such intricate physical impairment to preserve throughput. Future work will address complexity reduction of such CAC/RWA algorithms along with techniques to take into account other physical layer limitation and investigation on pricing.

REFERENCES

[1] A. Kaheel, T. Khattab, A. Mohamed, and H. Alnuweiri, "Quality-of-Service Mechanisms in IP-over-WDM Networks", *Communications Magazine*, Vol. 40, pp. 38-43, Dec. 2002.

[2] R. Braden et al., "Integrated Services in the Internet Architecture: An Overview", *RFC 1633,* June 1994.

[3] S. Blake et al., "An Architecture for differentiated Services", *RFC 2475,* Dec. 1998.

[4] C. B. Ahmed, N. Boudriga, and M. S. Obaidat, "Supporting Adaptive QoS for Multiple Classes of Service in DWDM Networks", *Proc. IEEE Int. Conf. On Parallel Processing Workshops*, pp. 283-288, Sept. 2001.

[5] R. Ramaswami and K.N. Sivaraja, "Optical Networks: A Practical Perspective", 2nd Ed. San Francisco, CA: Morgan Kaufmann Publishers, 2002.

[6] D. Levandovsky, "Wavelength routing based on physical impairments", *Proc. IEEE OFC'01*, 2001.

[7] B. Ramamurthy, D. Datta, H. Feng, J. P. Heritage, and B. Mukherjee, "Impact of transmission impairments on the

teletraffic performance of wavelength-routed optical networks", J. Ligthwave Technology, Vol. 17, pp.1713-1723, Oct 1999.

[8] M. Ali, L. Tancevski, "Impact of Polarization-Mode Dispersion on the Design of Wavelength-Routed Networks", Photonics Technology Letters, Vol. 14, pp. 720–722, May 2002.

[9] N. Golmie, T. D. Ndousse, and D. H. Su, "A differentiated optical services model for WDM networks", *Communications Magazine*, Vol. 38, pp. 68-73, Feb. 2000.

[10] A. Jukan and H. R. Van As, "Service-specific Wavelength Allocation in QoS-Routed Optical Networks", *IEEE GLOBECOM'98*, Vol. 4, pp. 2270-2275, Nov. 1998.

[11] I. E. Fonseca, M. R. N. Ribeiro, R. C. Almeida Jr., and H. Waldman, "Preserving Global Optical *QoS* in FWM Impaired Dynamic Networks", *Electronics Letters*, vol. 40, pp. 191-192, Feb 2004.

[12] ITU-T Rec. G.694.1, "Spectral Grids for WDM Application: *DWDM* Frequency Grid", Jun 2002.

[13] S. Song, C. Allen, K. Demarest, L. Pelz, X. Fang, and Y. Pua, "Experimental study of four wave mixing in non-zero dispersion fiber", *Proc. IEEE LEOS '97*, Vol. 2, pp. 224–225, Nov 1997.

[14] B. Xu and M. Brandt-Pearce, "Comparison of FWM- and XPM-induced crosstalk using the Volterra series transfer function method", *J. Ligthwave Technology*, vol. 21, pp. 40-53, Jan 2003.

[15] K. Inoue, "A simple expression for optical FDM network scale considering fiber *FWM* and optical amplifier noise", *J. Ligthwave Technology*, Vol. 13, pp.856-861, May 1995.

[16] I. E. Fonseca, R. C. Almeida Jr., M. R. N. Ribeiro, and H. Waldman, "Algorithms for *FWM*-aware Routing and Wavelength Assignment", *Proc. IEEE/MTT SBMO IMOC'03*, Setp. 2003.

[17] G. P. Agrawal, "Nonlinear Fiber Optics", 3rd Ed San Diego, CA: Academic Press, 2001.