QoS Aware Wavelength Assignment in Wavelength Division Multiplexing Based Optical Networks

U. Mahmud, N.A. Malik, B. Rauf, K.A. Bhatti and H. Afzal

***Abstract*— Wavelength Division Multiplexing (WDM) is used in optical networks to implement data circuits. These circuits allow exchange of information as a measure of wavelength in optical domain. Quality of Service (QoS) provisioning is one of the issues in WDM optical networks. This paper discusses different QoS aware Routing and Wavelength Assignment (RWA) algorithms. Some unaddressed issues are identified that include the effects of degraded performance, traffic patterns and type of QoS service for users. A software module is proposed that calculates a 'D' factor facilitating in the wavelength assignment for QoS provisioning. This module is designed to work in conjunction with existing RWA algorithms.**

***Keywords*— QoS Aware Routing and Wavelength Assignment, Wavelength Division Multiplexing Networks, Wavelength Assignment and Optical Networks**

I. INTRODUCTION

With the advent of optical networks, long desired high speed data communication has finally become a reality. But this great feat is not easy to achieve [1], [2]. Optical networks though highly promising are still emerging and a number of trivial issues are still not addressed. QoS provisioning over large distances is among the latest concerns of the research community.

RWA is a technique in WDM based optical networks to partitions the optical bandwidth into a large number of channels (λx, λy, λz) for the simultaneous transmission of data [3]. This technique allows multiple data streams to be transferred along the same piece of fiber simultaneously as shown in Fig. 1. The issue is to allocate the same wavelength or λ for the complete light path. A light path is a link having one wavelength from ingress to egress node passing through intermediate nodes. Naturally same wavelength cannot be guaranteed for the complete light path in an ultra fast network where the number of data transfer requests at the ingress Optical Cross Connects (OXC) is very large. The optical transmission fiber in Fig. 1 is divided into three streams based on colour e.g., red, green and orange. The wavelength of different streams x, y and z is identified by the λx, λy and λz respectively.

An optical network is established by interconnecting optical nodes or OXC. These nodes typically span in scores of kilometers under ultra-high communication through Single Mode Fiber (SMF). These networks offer high bandwidth and speed. Optical networks employ different algorithms to establish routing and selecting light paths between the nodes, called RWA algorithms [3]. Fig. 2 illustrates a WDM Network with four OXC Routers interconnected by optical fiber link. Each router is configured with RWA algorithm for wavelength conversion [3]. In Fig. 2 each light path is given a separate wavelength (λ) for communication.

A myriad of online and offline versions of RWA have been designed. Offline algorithms are static in nature and establish paths on the basis of global information while online algorithms are dynamic in nature. Offline algorithms assign light paths prior to start of communication while online algorithms assign light paths at runtime [4], [5], [6], [7]. Optical networks are based on WDM that allows multiplexing a number of individual wavelengths or light colors over a single link. With the provision of triple play services (voice, data and video) over optical networks in Passive Optical Networks (PON), it is desired to provide a QoS module that supports the implemented RWA algorithm [8]. This module will provide differentiated services for each user. High priority is allocated to voice, medium for video and minimum for data services.

This paper offers discusses QoS aware RWA algorithms and also discusses different unaddressed issue in optical network. Section II introduces provides the related work, Section III identifies the diverse problems faced in optical network, Section IV provides proposed model which demonstrate better QoS in this subject and Section V discusses a conclusion of whole study.

U. Mahmud is with Department of Software Engineering, Foundation University Rawalpindi Campus (FURC), Foundation University Islamabad (FUI), Islamabad, Pakistan, (Email: umar.mahmud@fui.edu.pk).

N.A. Malik is with Management Information System, Pakistan Naval Engineering College (PNEC), Karachi, Pakistan, (Email: nazirmalik@pnec.edu.pk)

B. Rauf, K.A. Bhatti and H. Afzal are with Department of Computer Software Engineering, Military College of Signals (MCS), National University of Sciences and Technology (NUST), Islamabad, Pakistan, (Email: {bilalrauf, kabeer, hammad.afzal}@mcs.edu.pk)

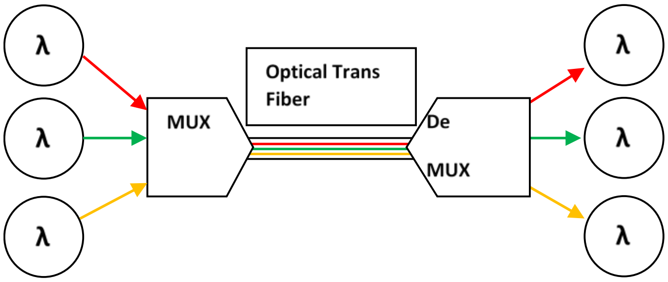

Fig. 1. Light paths in WDM Networks

II. BACKGROUND

QoS refers to the capability of network to provide some consistent services for data transmission, and measured in terms of qualitative characteristics, such as throughput, packet loss, delay and jitter1, which describe quality of data traffic over a network [9].

A. Factors Affecting QoS

There are a number of factors that affect the QoS of IP Networks. One major problem occurs while data communication over longer distance due to strict Wavelength Continuity Constraint (WCC) enforcement [10] . WCC demands that light paths be established prior to transfer of data over an optical link. This stresses that a light path occupied by a connection cannot be re-assigned to a competing connection unless it is released, resulting in unwanted delays and reduced performance.

The presence of predictable traffic in high speed backbones in terms of Static Light path Demands (SLD) allows us to develop offline RWA algorithms that provide an inexpensive mechanism to establish connections [11]. However, conflicts do occur resulting in loss of packets. Wavelength Converters offer an alternative to this problem at high cost and are hence impracticable for deployment. Moreover, the adaptability requirement is not supported by the offline algorithms. Online algorithms support adaptability but are complex in nature.

The aspiration is to provide an efficient, dynamic and fast algorithm that ensures QoS in the presence of both predictable and non-predictable traffic over longer distances, in optical domain, offering low Bit Error Rate (BER) and low blocking probability. At short distances, QoS is not an issue since the high speed of optical signals compensates for packet drops and the degraded performance is not noticeable.

Crosstalk[2] becomes an active component over large distances and degrades the performance. QoS cannot be guaranteed under high crosstalk. It is desirable to reduce the cross talk so as to have a better QoS provisioning link. One of the ways of reducing crosstalk is to introduce guard bands among the competing wavelength which is a hard solution.

B. QoS Provisioning Approaches

QoS aware RWA algorithms take into account the physical length of the link, size of the wavelength pool at each OXC and the number of established connections at each node [12]. It is believed that the identification of recurring traffic will considerably ease the load because the static traffic is highly predictable and can be considered as a contributing factor for prior decisions. A large portion of traffic on optical backbone is highly predictable as shown in Fig 3. The deployed algorithm should discriminate among both types of traffic wherein the anomalous traffic is handled dynamically [11].

One of the solutions models cross talk impaired signals and calculates a Q factor[3] [10]. This Q factor identifies a threshold beyond which QoS cannot be guaranteed due to increasing cross talk. Algorithmic support is provided in two alternates; Highest Q (HQ) and Minimizing the Maximum Q (MMQ). Simulations of both are carried out over an NFS topology and compared with standard Shortest Path (SP) algorithm. The comparison shows that the HQ algorithm provides low BER as compared to SP. The blocking probability is comparable to that of HQ and MMQ to that of SP. If the demand is low BER coupled with low blocking probability, HQ is better option.

An enhanced solution provides path protection in addition to dynamic QoS awareness [12]. It was discovered that HQ though being a better option has high computation time as compare to SP. This degrades the overall performance in terms of computation time and the solution becomes expensive. The task is now modified to provide advantages of HQ while maintaining a low computation time. Shortest Path Adaptive Link Weight (SPALW) algorithm provides low computation time and its blocking probability converges to HQ at large network load under dark lit path protection scheme while HQ has better performance in terms of blocking probability over large network load [12]. The SPALW calculates link weight as a linear function of path length, wavelength usage (which is the ratio of used wavelengths to the available wavelengths) and the connection state for each link. The link with the minimum weight is selected for high QoS provisioning. Both HQ and SPALW do not differentiate among predictable and non-predictable traffic. They are both adaptive algorithms and treat all traffic as unpredictable.

Another team of researchers considered jitter as the measure of QoS provisioning. The lower is the jitter, the high QoS can be guaranteed [13]. The jitter performance is studied in case of Ethernet Passive Optical Networks (EPON) and a Hybrid Granting Protocol (HGP) protocol is designed that provides an adaptive scheduler against the conventional Time Division Multiplexing (TDM) scheduler in the upstream direction. The HGP employs a Grant-Before-Report (GBR) mechanism to dynamically assign a wavelength to a user. In a regular EPON Grant-After-Report (GAR) in which grant always follows the reported information. This mechanism does not always provide minimum delay. Hence, in GBR delays can be

[1] Jitter: In IP networks, jitter is variation in time between packets arriving caused by route changes or network congestion.

[2] Cross Talk: Electromagnetic interference that comes from an adjacent wire

[3] Q Factor: Threshold beyond which QoS cannot be guaranteed.

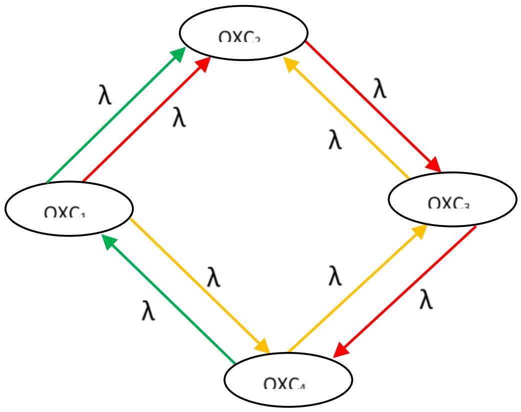

Fig. 2. RWA over OXC in WDM Networks

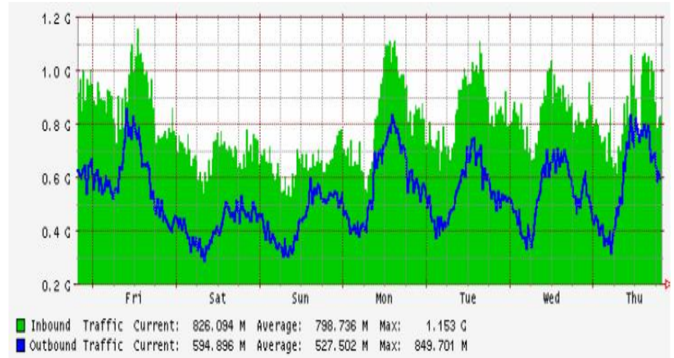

Fig. 3. Traffic on the New York – Washington link of Abilene backbone network from October 13- 20. 2005

reduced as nodes do not have to explicitly wait for the report before granting a connection. Three versions of HGP are developed as Expedite Forwarding (EF) that offers highest priority for voice services, A ssured Forwarding (AF) that offers medium priority for video and Best Effort (BE) that has lowest priority for data. The three HGP based versions are compared with their regular counterparts. The results show that the average packet delay in HG-EF is reduced by a factor of 2 as compared with the delay of the regular scheme under high load. On the other hand the throughput remains the same for both cases. Hence using a GBR mechanism provides an efficient mechanism that provides QoS based scheduling while maintaining the same throughput without the provision of a QoS scheduler.

III. UNADDRESSED ISSUES

As the research in QoS provisioning in optical networks is still in its infancy, there are some unaddressed issues under QoS. These are discussed in sub sections A, B and C.

A. Overcoming the Effect of Degraded Performance of an Established QoS Link

The QoS solutions presented in Section II-B establish light paths where the QoS can be guaranteed. These solutions are adaptive in nature. The degree of QoS is affected by the presence of crosstalk which is a direct result of more connections. Hence, once a QoS link is established, the incoming requests may decrease the degree of QoS provisioning. This would require rerouting the light paths. The frequent reestablishing and recalculation of a better path under hostile traffic will lead to annoying delays.

B. Predictable and Unpredictable Traffic

All the adaptive algorithms consider the traffic pattern as dynamic and unpredictable. With the presence of SLD the predictable patterns can be given pre-planned QoS links thus reducing the computational delays. This will make the algorithm complex as it would have to monitor the traffic on the basis of history and detect anomalous traffic at each node. If the traffic is anomalous then the link weights or the Q factors can be recalculated and a better path be provided. The notion of a threshold is still important under which a satisfactory level of QoS will not be guaranteed and should be negotiated with the peer nodes under a protocol.

C. Types of QoS Service for Users

QoS can come in different flavors. One user may prefer reliability over delay. This is an extremely complex task to establish the requirement of each user a priori. The presence of SLD does provide a limited mechanism to identify the future needs of predictable users. This would help in selecting the link under the schemes. The users can select the type as EF, AF or BE where each level is negotiated prior to start of communication through a supporting protocol.

IV. PROPOSED MODULE

Considering the unaddressed issues as mentioned in Section III, we propose a collaborating module that provides QoS awareness in optical networks. This module will be placed on the ingress router. The flow model of the proposed module is shown in Fig 4. The functions of the proposed module are divided into two phases; Calculating 'D' Factor and Wavelength Assignment. The wavelength assignment is dependent on the predictability of traffic as measured through history.

A. Calculating 'D' Factor

One of the ways to reduce crosstalk is to select non-adjacent wavelengths [10]. For this a 'D' factor is calculated which identifies the minimum distance beyond which a wavelength maybe selected within a pool of available wavelengths. This factor is dependent on the total number of wavelengths, the number of available wavelengths, the state of connections and the type of QoS demanded by the user. The 'D' factor essentially identifies a minimum distance beyond which a wavelength can safely be selected to provide high priority QoS to a user, provided the wavelength is supported by the node. If 'D' falls below a threshold, for instance, 1nm (all wavelengths will be adjacent), then the underlying protocol may negotiate with the user for low priority services or may drop the packets.

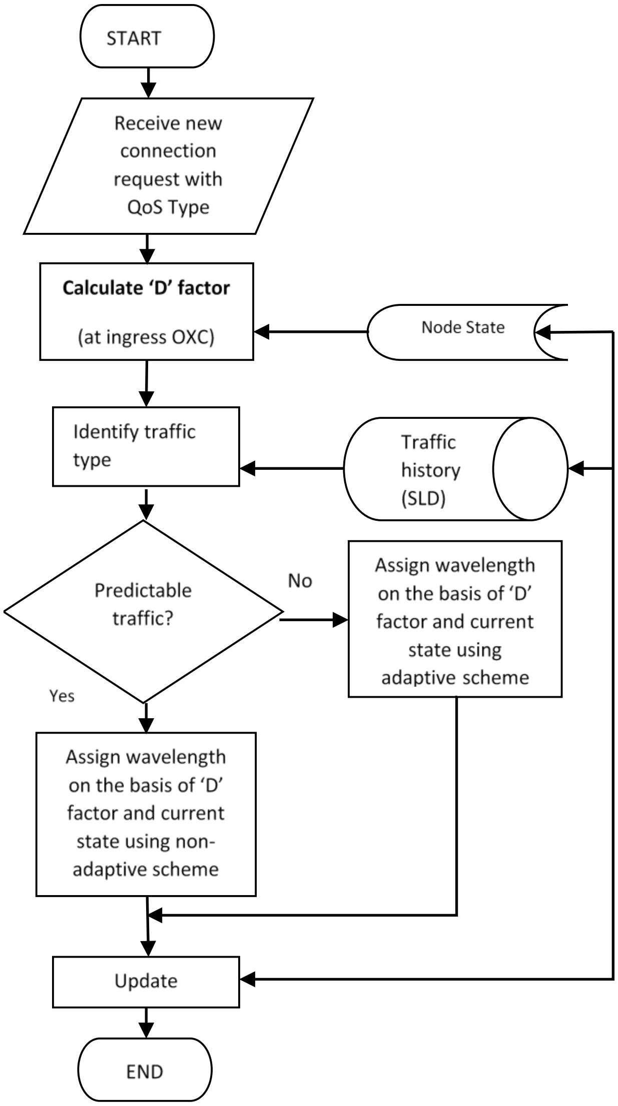

Fig. 4. Proposed Module

The node may not allow anymore connections beyond the set threshold as it would degrade the performance of existing connections due to crosstalk. The effect of crosstalk is optimistically reduced at the cost of underutilization of bandwidth. The larger is the 'D' factor lesser is the probability of crosstalk between two wavelengths where no intermediate wavelengths are allocated. The 'D' factor can be viewed as a dynamically allocated guard band size.

B. Wavelength Assignment

The second part of the module assigns the wavelength while following the constraint of the 'D' factor based on the predictability of the traffic. If the incoming request is identified under an entry in the SLD, then keeping in view the 'D' factor, a previously assigned wavelength can be assigned to the same connection. This previously assigned wavelength gives a limited guarantee that if this wavelength was previously assigned to the same connection under similar conditions, then the probability that this wavelength will be dropped or affected with cross talk is low. Optionally, each SLD can have a new entry for each session that shows whether the desired QoS was provisioned or not. If the traffic is unpredictable then an SLD becomes ineffective and the wavelength is assigned using any adaptive algorithm [14]. The advantage of this scheme is to reduce the computation time of complex QoS aware algorithms for each session where using SLD the previously proven wavelength could be assigned in a simpler way. The anomalous traffic patterns occurring in unpredictable traffic maybe given lower priority as compared to predictable traffic patterns.

V. CONCLUSION

The advent of optical networks has ensured fast communication and data transfer using photonics. The use of OXC in a photonic network has allowed the routing to be carried out in photonic domain. Previously the routing was performed in electrical domain at the cost of increased delays. As the optical network becomes dense and large number of OXC is used, the RWA becomes important due to WCC. The WCC enforces that the wavelength at the ingress OXC should remain constant over a light path. This hinders performance as the QoS parameters are included in RWA.

The aspiration of this paper is to provide a better, dynamic and fast algorithm that ensures QoS in the presence of both predictable and unpredictable traffic over long distance. Current methods are discussed and their shortcomings are also elaborated. Based on the results of the existing research works, a module is proposed that allows the provisioning of QoS over WDM optical links. This module suppresses crosstalk by calculating a 'D' factor and selects a light path by monitoring the history of a connection. This enhancement being modular can work in conjunction with existing RWA algorithms.

REFERENCES

[1] Ulyess Black, *Optical Networks: Third Generation Transport Systems*: Pearson Education, Inc, 2008.

[2] Rajiv Ramaswami, Kumar Sivarajan, and Galen H. Sasaki, *Optical Networks: A Practical Perspective*: Elsevier Inc, 2010.

[3] M. Al-Momin, J. Cosmas, and S. Amin, "Enhanced ACO based RWA on WDM optical networks Using Requests Accumulation and Re-Sorting Method," in *5th Computer Science and Electronic Engineering Conference (CEEC)*, Colchester, 2013, pp. 97-102.

[4] Rajneesh Randhawaa and J. S. Sohal, "Static and dynamic routing and wavelength assignment algorithms for future transport networks," *Optik - International Journal for Light and Electron Optics*, vol. 121, no. 8, pp. 702–710, April 2010.

[5] Hui Zang and Jason P. Jue, "A Review of Routing and Wavelength Assignment Approaches for Wavelength Routed Optical WDM Networks," *Optical Networks Magazine*, vol. 1, pp. 47-60, 2000.

[6] K. Christodoulopoulos, K. Manousakis, and E. Varvarigos, "Comparison of Routing and Wavelength Assignment Algorithms in WDM Networks," in *IEEE GLOBECOM Global Telecommunications Conference*, New Orleans, 2008, pp. 1-6.

[7] Rubio-Largo, M. A. Vega-Rodriguez, J. A. Gomez-Pulido, and J. M. Sanchez-Pérez, "A Comparative Study on Multiobjective Swarm Intelligence for the Routing and Wavelength Assignment Problem," IEEE Transactions on Systems, Man,

and Cybernetics, vol. 42, no. 6, pp. 1644 - 1655, November 2012.

[8] Cedric F. Lam, *Passive Optical Networks: Principles and Practice*: Academic Press, 2007.

[9] F. S.H. Souza, D. L. Guidoni, and G. R. Mateus, "Formulations for the RWA problem with Traffic Grooming, Protection and QoS in WDM Optical Networks," in *IEEE Symposium on Computers and Communications (ISCC)*, Cappadocia, 2012, pp. 265-270.

[10] Y. Pointurier, M. Brandt-Pearce, Tao Deng, and S. S. Subramaniam, "Fair QoS-Aware Adaptive Routing and Wavelength Assignment in All-Optical Networks," in *IEEE International Conference on Communications, ICC '06.*, Istanbul, 2006, pp. 2433-2438.

[11] Sooyeon Park, Jong S. Yang, and Young-Cheol Bang, "On RWA Algorithms for Scheduled Lightpath Demands in Wavelength Division Multiplexing Networks," *International Journal of Computer Science and Network Security*, vol. 7, no. 3, pp. 144-150, March 2007.

[12] Yuxiang Zhai, Y. Pointurier, S. S. Subramaniam, and M. Brandt-Pearce, "QoS-Aware RWA Algorithms For Path-Protected DWDM Networks," in *Conference on Optical Fiber Communication and the National Fiber Optic Engineers Conference OFC/NFOEC 2007.*, Anaheim, 2007, pp. 1-3.

[13] Shami, Bai Xiaofeng, C.M. Assi, and N. Ghani, "Jitter Performance in Ethernet Passive Optical Networks," Journal of Lightwave Technology, vol. 23, no. 4, pp. 1745-1753, 2005.

[14] A. Kretsis, K. Christodoulopoulos, P. Kokkinos, and E. Varvarigos, "Planning and Operating Flexible Optical Networks: Algorithmic Issues and Tools," IEEE Communications Magazine, vol. 52, no. 1, pp. 61-69, January 2014.

Umar Mahmud did his BE (Computer Software) and MS (Computer Software Engineering) from National University of Sciences and Technology (NUST), Islamabad, Pakistan in 2003 and 2006 respectively. He has published multiple papers in the areas of Context-Aware Computing, Distributed Computing, Machine Learning and Pervasive Computing. His h-index is 4 while his i-10 index is 10. He is presently serving as Assistant Professor of Computer Science in Department of Software Engineering (DSE), Foundation University Islamabad (FUI). He is a member of Pakistan Engineering Council (PEC), International Association of Engineers (IAENG) and IADIS.

Dr. Nazir Ahmad Malik did his BSc (Naval Sciences) form University of Karachi (KU), Pakistan in 1996 and MSc (Computer Science) from University of Agriculture Faisalabad (UAF), Faisalabad, Pakistan in 2000. He did his PhD (Information Security) from National University of Sciences and Technology (NUST), Islamabad, Pakistan in 2012. He is serving in the capacity of Assistant Professor in Pakistan Naval Engineering College (PEC), Karachi, Pakistan. His areas of interests include Information Security, Network Security, Cryptography, Research and Logic and Pervasive Computing. His h-index is 3 and i-10 index is 1.

Bilal Rauf did his MS in Computing Science with major in Wireless LAN from Umeå University, Sweden. He is also Cisco certified. His research interests are Wireless LAN, QoS in Wireless LAN and Computer Networks. Currently, he is involved in teaching undergraduate courses and supervising undergraduate final year degree Projects in the field of Computer Networks and Mobile Computing. He is currently serving as Assistant Professor in Department of Computer Software Engineering (DCSE), Military College of Signals (MCS), Rawalpindi, Pakistan.

Kabeer Ahmad Bhatti did MS (Telecom & Networks) from Iqra University, Islamabad, Pakistan in 2010 and Masters of Computer Science from University of Arid Agriculture Rawalpindi, Pakistan in 2001. His research interests are Computer Networks, Cognitive Radio Networks and Web Application. His research work has been published in international well reputed Journal and IEEE Conferences. Currently, he is serving as Lecturer and conducting variety of Lab in CSE and EE Departments, Military College of Signals (MCS), Rawalpindi, Pakistan.

Dr. Hammad Afzal completed his doctoral studies from School of Computer Science, University of Manchester, UK in Dec, 2009 under supervision of Dr. Goran Nenadic in Text Mining Group. Topic of his PhD dissertation is “Literature based framework for semantic descriptions of bioinformatics e-Services”. Before PhD, he completed MSc in Advanced Computing Sciences from University of Manchester, UK where he was awarded Program Prize of the year from Department of Computation for acquiring highest grades in MSc courses. He has also been affiliated with Digital Enterprise Research Institute (DERI), National University of Ireland, Galway as a Research Fellow from July, 2009 to Dec, 2009. He is working as an Assistant Professor at National University of Sciences and Technology (NUST), Pakistan. His h-index is 5 and i-10 index is 1.