QoS Differentiated Adaptive Scheduled Optical Burst Switching for Grid Networks

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Abstract. This paper presents the QoS differentiated Adaptive Scheduled Optical Burst Switching (QAS-OBS) paradigm that efficiently supports dynamic grid applications. (QAS-OBS) paradigm enables differentiated-services optical burst switching via two-way reservation and adaptive QoS control in distribute wavelength-routed networks. Based on the network loading status, the edge nodes dynamically optimize per-class lightpath reservation control to provide proportional QoS differentiation, while maximizing the overall network throughput. Unlike existing QoS control schemes that require special core network to support burst switching and QoS control, QAS-OBS pushes all the complexity of burst switching and QoS control to the edge nodes, so that the core network design is maximally simplified. Simulation results evaluate the performance of QAS-OBS and verified the proposed control schemes could provide proportional QoS control while maximizing the overall network throughput.

1 Introduction

Optical network infrastructures have been increasingly deployed in grid systems to support data-intensive scientific and engineering applications with high bandwidth traffic. Wavelength-routed optical networks (WRONs) based on photonic all-optical switches and traffic control plane (e.g. GMPLS) had been used to support bandwidth intensive traffic of data-grid applications over multi-gigabit-rate lightpaths via end-to-end wavelength channel or lambda.

Interactive access-grid applications with time-varying participants require dynamic lambda grid systems, which connects grid resources (computation, storage, etc.) with on-demand provisioned lightpaths. For instance, a collaborative visualization requires connections among multiple remote computing clusters during a large period of time. However, only portion of these clusters are accessed at any given time. Thus, static provisioned lightpaths greatly reduce network resource utilization in this situation.

Discovery and reservation of optical networking resources and grid resources can be based on either the overlay or the integrated model. The overlay model [1] specifies the layer of grid resources to sit over the optical network, with separated resource control mechanisms. The integrated model [2] specifies a combined resource control mechanism (e.g. extended GMPLS) to support unified optical networking and Grid resources provisioning.

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Emerging collaborative grid applications have increasing demand for supports of diverse bandwidth granularities and multimedia traffic. This paper presents an optical burst switching (OBS) based grid network architecture to support such collaborative grid applications. An open issue for OBS based grid network architecture is provisioning for grid applications with multimedia traffic components requiring differentiated quality-of-service (QoS) performances.

Optical Burst Switching (OBS) schemes [3][4] have been proposed to enable wavelength statistical multiplexing for bursty traffic. The one-way reservation of OBS, however, incurs burst contention and data may be dropped at the core nodes due to wavelength reservation contention. The burst contention blocking recovery controls (including time, wavelength and link deflection) are employed to minimize contention blocking. These recovery controls, however, may incur extra end-to-end data delay. In addition, some burst contention recovery controls require special devices such as Fiber Delay Lines (FDLs) at the core network.

Wavelength routed OBS (WR-OBS) [5] guarantees data delivery through two-way wavelength reservation. WR-OBS is based on centralized control plane, and does not require special devices (e.g. FDLs) to be implemented at core nodes. However, the centralized control may not be practical for large-scale grid systems. Adaptive Reliable Optical Burst Switching (AR-OBS) [6] minimizes data loss in distribute-controlled WRONs based on wavelength-routed optical burst switching. AR-OBS minimizes the overall data loss via adapting the lightpath reservation robustness (maximal allowed time for blocking recovery) for each burst to the network loading status.

To optimize sharing of optical network resources, it is desirable to provide service differentiation in OBS based grid networks. Service differentiation via assigning different offset delay is proposed in [7][8]. In these schemes, higher priority bursts are assigned with extra offset to avoid burst contention with lower priority bursts. However, the higher priority bursts always suffer from longer end-to-end data delay and such control schemes are unfair to large size burst [9][10]. Look-ahead Window (LaW) based service differentiation schemes are proposed in [11][12]. Each core node buffers burst headers in a sliding window, and a dropping-based decision is made for the buffered bursts based on the QoS requirements. It shows that the collective view of multiple burst headers in LaW results in more efficient dropping decision than simple dropping-based schemes (e.g. the scheme proposed in [9]). The overall end-to-end delay of LAW is scarified due to the extra queuing delay in the window. By implementing Weighted Fair Queue for the burst reservation requests in central controller [12], WR-OBS could provide prioritized QoS. As mentioned above, the centralized control scheme may not be practical in large-scale network systems.

To facilitate easy pricing model for grid applications, it is better to provide proportional service differentiation. By intentional dropping lower-class bursts at the core network node, the QoS control scheme proposed in [9] provides proportional service-differentiation in terms of data loss ratio. Simple dropping-based schemes at each core node may cause unnecessary drop and deteriorate the wavelength utilization. Preemption-based QoS control scheme proposed in [14] provides proportional service differentiation by maintaining the number of wavelengths occupied by each class of bursts. To guarantee the preset differentiation ratio, bursts satisfying the corresponding QoS usage profiles will preempt the ones not satisfying its usage profiles. The preempted ones, however, will waste some wavelength resource and lower the wavelength utilization.

An absolute QoS model for OBS networks is proposed in [15] to ensure the data loss of each QoS class does not exceed a certain value. Loss guarantees are provided via two mechanisms: Early drop and wavelength group. The optimal wavelength sharing problem for OBS networks with QoS constraint is discussed in [16]. Optimized wavelength sharing policies are derived based on Markov decision process to maximize wavelength utilization while ensuring the data loss rate for QoS classes not exceeding the given thresholds.

All of the aforementioned QoS control schemes require implementing QoS control at every core network nodes, which increases the complexity of core network design. In addition, some of the schemes demand special optical switch architectures. For example, differentiated offset delay and LaW based QoS control schemes need the support of FDLs at every core network node to buffer the incoming optical bursts. The QoS control schemes proposed in [15] and [16] require every optical node to be wavelength convertible. These requirements may not be easily satisfied for existing WRONs, and will increase the investment cost for the core networks.

To simplify the core network design and push the complexity of burst switching and QoS control to the edge node in WRONs, QoS differentiated Adaptive Scheduled Optical Burst Switching (QAS-OBS) is proposed. QAS-OBS provides proportional service differentiation in terms of data loss rate while maximizing the overall network throughput. QAS-OBS employs two-way reservation to guarantee data delivery. The core network controllers are not involved into burst QoS control (e.g. dropping decision). The core network control could employs distributed reservation protocols with blocking recovery control mechanisms (e.g. S-RFORP [17] or RFORP [18] etc.). The QoS control in QAS-OBS is implemented at the edge nodes, which dynamically adjust the lightpath reservation robustness (i.e. maximal allowed signaling delay) for each burst to provide the service differentiation. To guarantee proportional differentiation under different network loading status, the edge controller dynamically adjusts lightpath reservation robustness for each burst based on network loading status. Round Trip Signaling Delay (RTSD) of the two-way reservation signaling is employed as an indicator to estimate the network loading status while not demanding explicit network loading status information distribution. A heuristic-based control algorithm is proposed in this paper. Simulation results show that QAS-OBS could achieve proportional QoS provisioning while maximizes the network throughput.

The reminder of the paper is organized as follows. Section II discusses the general architecture of QAS-OBS. The core signaling control is illustrated in Section III. Section IV presents multi-class QoS control. Section V presents the simulation results.

2 Architecture of QAS-OBS

QAS-OBS contains two functional planes: a distributed data plane consisting of the optical core network switches, and a distributed control plane taking care of the signaling control and switch configuration for each optical switch. The motivation of QAS-OBS is to push the complexity of QoS control from network core to edge. Edge nodes control the lightpath setup robustness (i.e. maximal allowed lightpath signaling time) and burst scheduling. Core network nodes are in charge of the lightpath reservation and do not need to participate in the burst QoS control, which simplifies the implementation of core network.

At the edge nodes, incoming data packets are aggregated in different buffers according to their QoS classes and destinations. QAS-OBS employs two-way reservation with lightpath setup acknowledgment to guarantee data delivery. To avoid long delay incurred by two-way reservation, lightpath signaling process is initiated during burst aggregation phase. Thus, the signaling delay is overlapped with burst aggregation delay and the data end-to-end delay is minimized.

To support service-differentiated control, robustness of lightpath reservation for each burst is set according to its QoS class. For higher-class bursts, less reservation blocking is achieved by assigning larger lightpath reservation robustness to the corresponding resource reservation process. Some optical resource reservation protocols could provide adjustable lightpath reservation robustness. For example, maximal allowed number of blocking recovery retries in S-RFORP [17] or RFORP [18] could be adjusted for each request. Larger number of blocking recovery retries will result in lower reservation blocking. In the following of this paper, we assume that QAS-OBS employs a resource reservation protocol that can support adjustable reservation robustness by assigning different upper bound of signaling delay (e.g. limitation of number of blocking recovery retries in S-RFORP).

To meet the QoS requirement in different network loading status, burst reservation robustness in QAS-OBS is adapted to the network loading status. The reservation robustness of each burst is selected to maximize the overall throughput while satisfying the QoS constraints. Delayed reservation is employed in QAS-OBS to maximize the wavelength utilization.

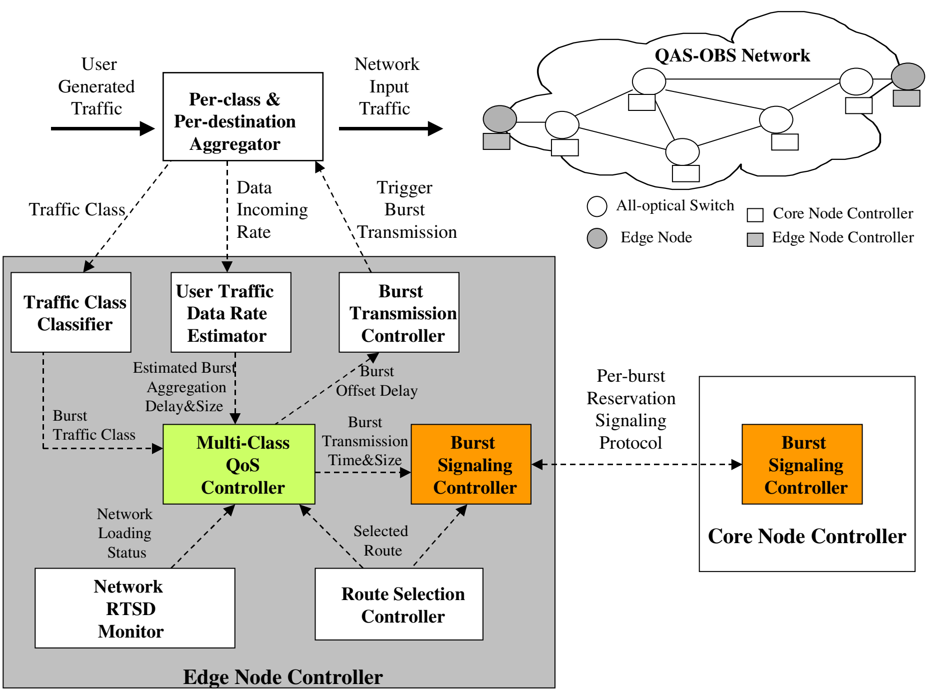

Fig. 1. Overall Architecture of QAS-OBS

Unlike the offset-delay-based QoS control in OBS systems that isolate different classes in time dimension, QAS-OBS provides service differentiation via controlling the blocking probability of lightpath reservation for each burst. The lower blocking does not trade off data end-to-end delay in QAS-OBS, since the lightpath signaling process is required to be completed by the end of burst aggregation process.

Fig. 1 shows the overall architecture of QAS-OBS with edge node function blocks. The incoming data is aggregated at the per-class per-destination aggregator. User Traffic Rate Estimator monitors the data incoming rate per-destination and per-QoS class, and predicts the burst sending time based on the criteria to avoid buffer overflow or data expiration at the edge node. Based on the estimated burst sending time and network loading status, The Multi-Class QoS controller dynamically selects the lightpath reservation robustness for each burst, and triggers the lightpath signaling procedure accordingly. We define offset delay to be the time interval between triggering lightpath reservation and sending out burst, which is also the time allowed for lightpath signaling (reservation robustness). To maintain proportional data loss rate among QoS classes and maximize the overall data throughput, Offset Delay is dynamically adjusted for each QoS class according to current network loading status. In QAS-OBS, the network loading status is estimated by the round-trip signaling delay (RTSD). Longer RTSD means there are more blocking recovery retries during lightpath reservation, and it is an indicator that the network is heavy loaded.

After getting lightpath setup request carrying burst sending time and burst size from Multi-Class QoS Controller, Burst Signaling Controller selects the route and sends out per-burst reservation request to the core network. The routing control in QAS-OBS is supposed to be based on shortest path selection. Wavelength selection algorithm depends on the employed signaling protocol (e.g. first fit or random fit). If the lightpath setup acknowledgement returns, Burst Transmission Controller triggers burst transmission and data is dumped from edge buffer into the optical network as an optical burst at the predicted burst sending time.

3 Burst Signaling Control

Burst signaling control is to reserve the wavelengths for each burst at specified burst transmission time. The signaling control is supported by both edge and core nodes. Based on the incoming rate of an aggregating burst, edge node determines the sending time of lightpath reservation signaling and wavelength channel holding time for corresponding burst. Core nodes interpret the signaling message and configure the corresponding optical switch to support the wavelength reservation. The objective of burst signaling control includes minimizing the data end-to-end delay and maximizing the wavelength utilization. In this section, we focus on the discussion of minimizing the end-to-end data delay. The wavelength utilization is maximized in QAS-OBS via delayed reservation [19].

In QAS-OBS networks, the burst is sent out after the lightpath setup acknowledgement returns, and data delivery is guaranteed. The offset delay is required to be larger than the signaling round-trip delay. To avoid larger end-to-end delay caused by the two-way reservation, QAS-OBS signals the lightpath before the burst is fully assembled. If

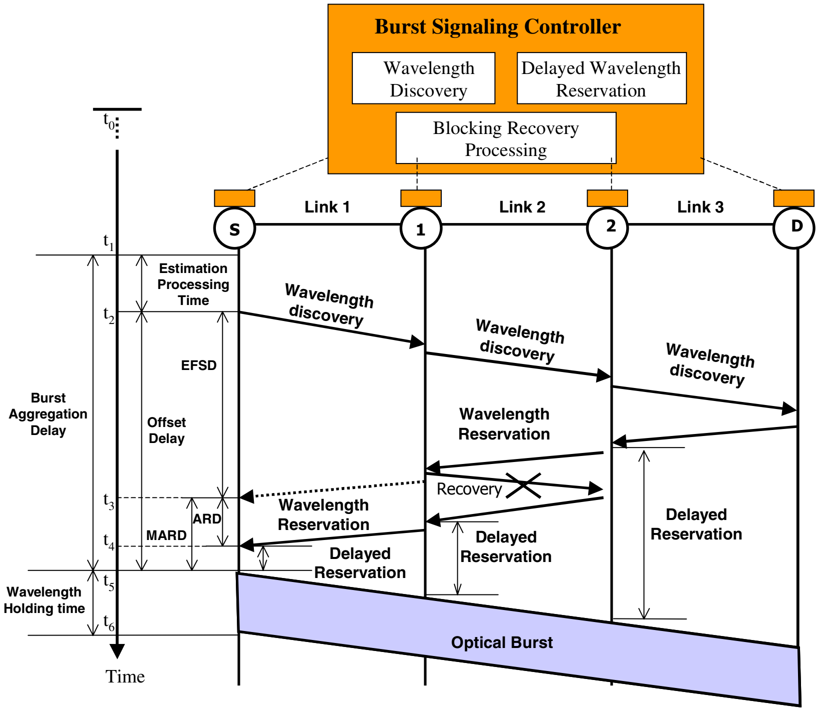

Fig. 2. Burst Signaling Control of QAS-OBS

the signaling is sent out early enough to ensure the lightpath acknowledgement returns before the burst is fully assembled, the total data end-to-end delay is minimized since the offset delay is not included.

Taking account of the extra delay incurred by the blocking recovery, offset delay in QAS-OBS consists of error free signaling delay (EFSD) and maximal allowed recovery delay (MARD). EFSD is the signaling delay for a given route if there is no blocking occurs. MARD is the maximal allowed time for blocking recovery control in the signaling process, which depends on the maximal allowed signaling delay. In the signaling procedure, the actual recovery delay (ARD) is limited by MARD to ensure the acknowledgement returns before the signaled burst transmission time. If the assigned MARD is not big enough to cover ARD, the lightpath request will be dropped. The actual round trip signaling delay (RTSD) is EFSD plus ARD, which is bounded by the given offset delay.

A signaling scenario is shown in Fig. 2 to illustrate the signaling control procedures. As shown in the figure, a new burst aggregation starts aggregation at t_1. After some processing time, the signaling request is sent out to core network at t_2 before the burst is fully assembled. The estimated wavelength channel holding time and burst sending time is carried by the signaling message. As shown in Fig. 2, the signaling message transverses three hops from source to destination during wavelength discovery phase. When the signaling message reaches the destination node, the wavelength reservation procedure will be triggered if there is common available wavelength along the route. Then the signaling message is sent back to source node from destination node. If there is no wavelength contention in the reservation phase, the signaling message returns the source node at t_3. The time between t_3 and t_2 is EFSD.

In Fig. 2, blocking recovery processing is triggered at blocked link (Link 2) due to wavelength reservation contention. The illustrated blocking recovery control is based on alternate wavelength selection proposed in [17]. After the contention blocking is recovered at Link 2, the signaling message will be passed to next link. The total allowed blocking recovery time along the route is bounded by MARD and the actually recovery delay may take less time than MARD. In the figure, the signaling message returns to the source node at t_4. The source node will send out the burst at t_5, which is the signaled burst sending time.

To maximize the wavelength utilization, delayed wavelength reservation is employed as marked in Fig. 2. The wavelength holding time ($t_5 - t_6$) of each burst is determined by the burst size and core bandwidth. Serialized signaling procedure shown in this scenario is for illustration only and may not be efficient to support burst switching. QAS-OBS employs a fast and robust signaling protocol, namely S-RFORP, proposed in [17]. Interested reader may refer to [17] for details of the signaling protocol.

4 Multi-class QoS Controller

In QAS-OBS, MARD is the time reserved for lightpath reservation blocking recovery. To provide differentiated QoS control in terms of data loss rate, MARD for each burst is adjusted according to the service class of that burst. Larger MARD allows the signaling protocol to have more chance for connection blocking recovery. For example, the signaling protocols proposed in [17] [18] will utilize the MARD to recover wavelength contention blocking via localized rerouting or alternative wavelength selection.

To guarantee the proportional differentiated-services in terms of data loss rate, the MARD should be adjusted according to the network loading status. In distributed networks, however, the real-time link status information is hard to collect either due to the excessive information exchange or due to security reasons. The actual additional signaling delay (i.e. ARD) is employed in QAS-OBS as an indicator of the network loading status. The wavelength contention and congestion occurs more often as the average link loading increases. If blocking recovery control is employed, the additional signaling delay caused by blocking recovery will depend on the probability of contention or congestion blocking, which is determined by the link loading.

The Multi-Class QoS Controller has the following functions: determine the Offset Delay, burst transmission starting time and burst size for a burst. Fig. 3 shows that the structure of Multi-Class QoS Controller. Based on the QoS Performance Requirement, Optimization Heuristic in the QoS Database Configuration module sets up the mapping between monitored ARD ($\hat{ARD}$) and Per-Class MARD, and stores the information in ARD to Per-Class Offset Delay Mapping Database. The mapping table in the database is the decision pool for the Per-Class MARD Adaptation module. Each QoS class will be assigned with MARD via the Per-Class MARD Adaptation module based on the monitored ARD. According to the QoS class, selected route and estimated burst

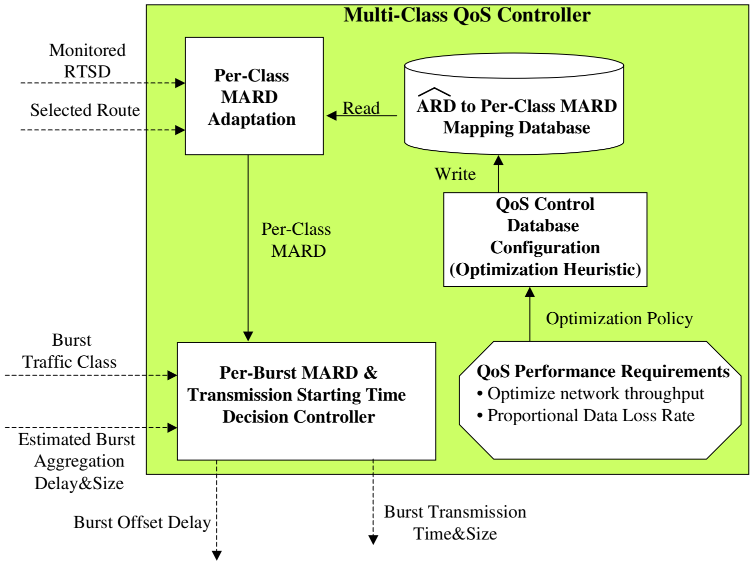

Fig. 3. Multi-Class QoS Controller

aggregation time of an aggregating burst, the Per-Burst Offset Delay&Transmission Starting Time Decision Controller will select the offset delay for the each aggregated burst. When it is time to sending out the signaling, Per-Burst Offset Delay & Transmission Starting Time Decision Controller triggers the lightpath reservation by passing the burst transmission time and size to the Burst Signaling Controller. Meanwhile, the burst transmission time is sent to Burst Transmission Controller.

Larger MARD will result in lower lightpath connection blocking; however, it will also increase the data loss due to edge buffer overflow. In section 2 and 3, we discussed that the burst size and sending time is based on estimation. The estimation processing time (shown in Fig. 2) is inversely proportional to the MARD, and the estimation error depends on the processing time. In QAS-OBS, the estimation error will be proportional to MARD. Taking account of the tradeoff between data loss due to connection blocking and edge buffer overflow, a mapping between MARD and data loss rate could be established.

Our control algorithm is to select the optimal MARD that minimizes the total data loss for the QoS class that requires minimal data loss rate. The MARD for other QoS classes will be selected based on the data loss rate ratio and the mapping between MARD and data loss rate. Such mapping could be setup by monitoring the history data. An example of the mapping between MARD and data loss rate is illustrated in the simulation part.

Within the function modules in Fig 3, the most important one is the ARD to MARD mapping database, which is the decision pool for MARD selection. Since MARD determines the reservation blocking for each burst, there is a mapping function between MARD and burst data loss rate for given network loading status. The one-to-one mapping between network loading and ARD is shown in the simulation. Based on this mapping, we can setup the ARD to MARD mapping database that satisfies the QoS requirement.

5 Simulation Results

The simulation results consist of two parts. The first part presents the simulated results needed for the proposed control algorithm. The second part shows the performance results of QAS-OBS such as the overall throughput and proportional data loss rate between two classes.

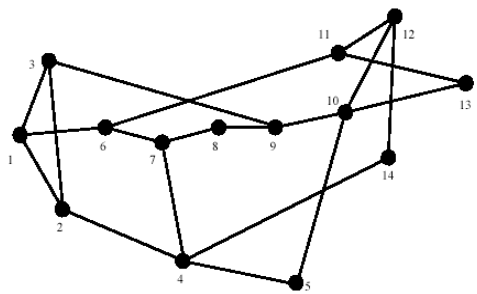

Fig. 4. 14-node NSF network topology

The network used for simulation is the NSF 14-node as shown in Fig.4. Without loss of generality, we assume that each link has identical propagation delay that is normalized to 1 time unit (TU). The wavelength discovery and reservation processing delay of each node is supposed to be 5 TU, and switching latency of each optical switch is normalized to be 3 TU. Shortest Path routing and first-fit wavelength assignment is assumed. The incoming traffic to each edge is VBR traffic, and packet size follows a Poisson distribution with average packet size to be 10kb and a maximal allowable edge delay 100 TU. Exponential weighted sliding window estimator is implemented. The simulation is running on a self-designed simulator written in C++.

The parameters of the topology model are: each node is supposed to have the full wavelength convertibility; number of links E=42 (bi-direction links assumed); default number of wavelength per link W=8. The average per-link wavelength loading is defined as:

$$Wavelength\ Loading = \sum_{(i)} \frac{\lambda^i \cdot H^i}{\mu^i \cdot |E| \cdot |W|}$$

where i is the index of a source destination pair, λ^i is the average connection arrival rate on the route of the source destination pair i, μ^i is the average wavelength holding time for the burst transmitted on the route of i, H^i is the number of hops on route of i.

A. Results needed by Control Algorithm

Fig. 5 shows the effects of MARD on burst data loss for given wavelength loading. As shown in Fig. 5 increasing the MARD will reduce the burst reservation blocking, but the efficiency of reducing burst connection blocking via increasing the MARD

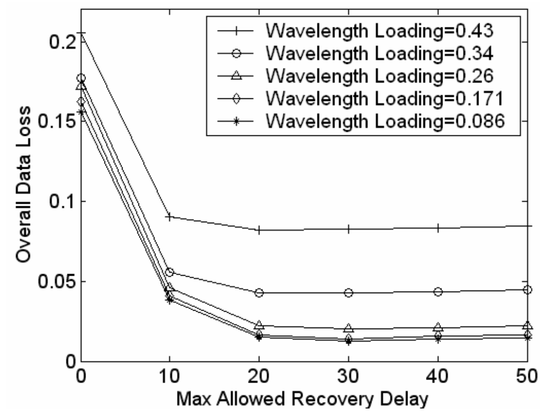

Fig. 5. Effects of Increment of Offset Delay on data loss rate

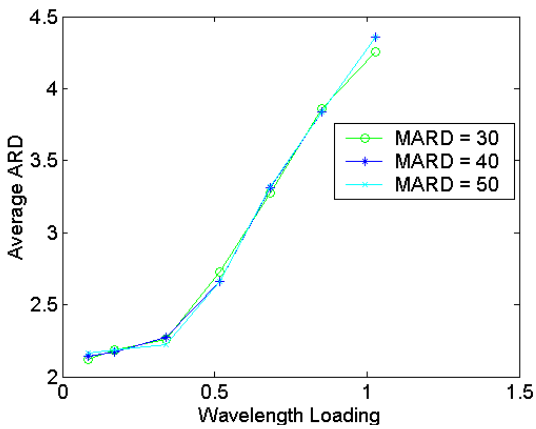

Fig. 6. Effect of Network Loading on ARD

reduces when the MARD is large enough. As the MARD increases, the increasing of edge overflow blocking will outperform the decreasing of burst connection blocking and the overall data loss rate will increase slightly when the MARD is large enough.

Fig. 6 shows the how ARD works as a network loading indicator. In QAS-OBS, sliding window average ARD ($A\hat{R}D$) is employed to indicate the network loading status. The figure shows that the $A\hat{R}D$ is proportional to the wavelength loading. In addition, $A\hat{R}D$ depends on the loading status only and is kind of independent to MARD. This characteristic qualifies $A\hat{R}D$ as a good loading status indicator.

After getting the results shown in Fig 5, and 6, the $A\hat{R}D$ to Per Class MARD mapping database can be derived following the steps presented in Section 4. The result of the database is shown in Fig. 7. The value of per-class MARD that satisfies the QoS requirement has one-to-one mapping with the monitored $A\hat{R}D$.

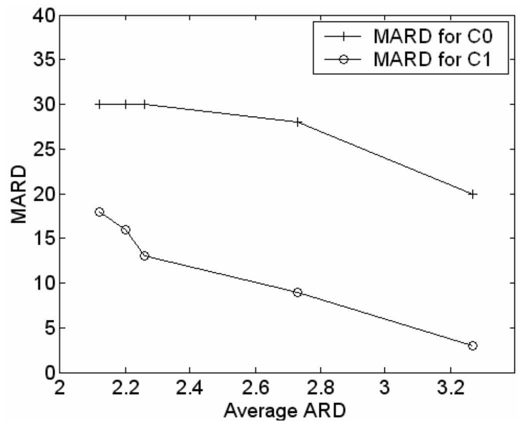

Fig. 7. $\hat{ARD}$ to Per Class MARD mapping database

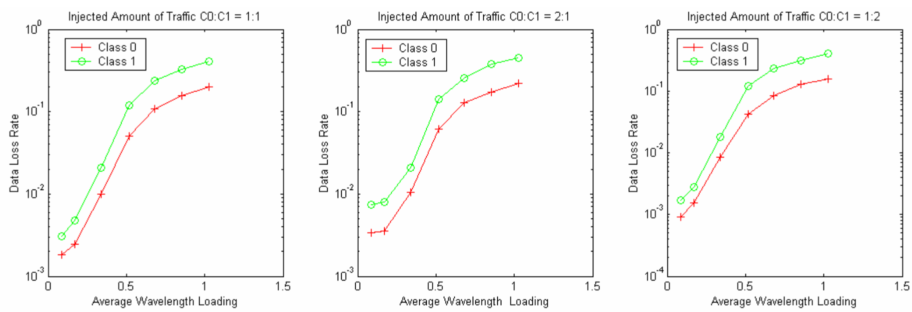

Fig. 8. Effects of Average Wavelength Loading on Data Loss Rate

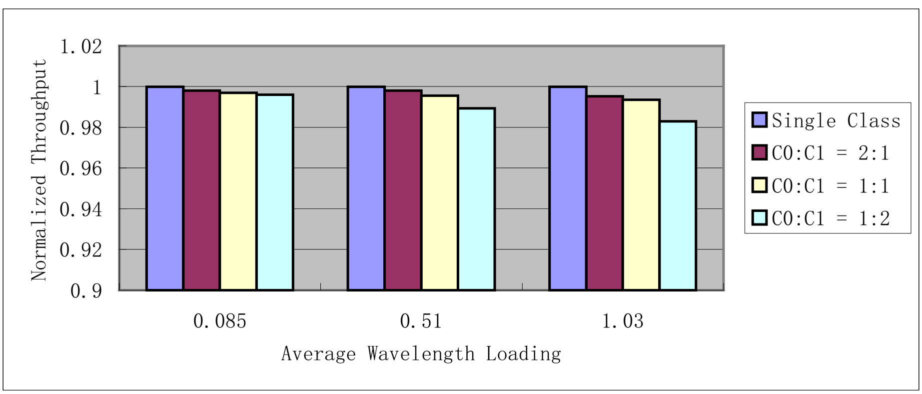

Fig. 9. Effects of Average Wavelength Loading on Overall Throughput

B. Performance Results

Fig. 8 shows one of the QoS constraint, proportional data loss ratio, is satisfied under different wavelength loading and traffic ratio. Three combinations with different traffic ratio of C_0 to C_1 are simulated for given total traffic amount. For example, C0:C1 = 2:1 means for given total traffic loading, 67% traffic belongs to class 0 and 33% belongs to class 1. It shows that the data loss rate of each class increases as the average wavelength loading increases. The data loss rate ratio between the two classes is largely fixed and independent of the wavelength loading. Thus, one of the QoS requirements (fixed data loss ratio between the two classes) is satisfied.

In Fig. 9, the performance of overall throughput of the multi-class case is compared with the classless (single class) case. The overall throughput of single class is assumed to be the sub-optimal because every burst is scheduled to minimize the blocking and maximize the overall throughput. In addition, the overall throughput in single class case can be considered as the upper bound of that for multi-class case. This is because the QoS constraint in multi-class case may results in lower overall throughput since some lower class burst is reserved with low reservation robustness even it could be transmitted to keep the fixed data loss rate. The simulation results show that the data loss rate and overall throughput in multi-class case are very closed to the performance in single class case. Thus, the other QoS performance requirement, maximize the overall throughput, is satisfied. In Fig. 8 and 9, different combination of class 1 and class 0 traffic will affect the overall data loss rate. This is because for given traffic loading, the blocking probability cannot be set to arbitrary low, and lower class traffic may be assigned low lightpath reservation robustness to keep the proportional data loss rate. When the lower class traffic becomes dominant, the overall data loss rate decreases. In such case, adjust the blocking ratio may be needed.

6 Conclusion

In this paper, we present QAS-OBS to provide proportional QoS differentiation for optical burst switching for grid applications in wavelength routed optical networks. Adaptive burst reservation robustness control is implemented to provide service differentiation while maximizing network throughput. QAS-OBS simplifies the core network design by pushing all the QoS control to the edge node, which makes it easy to implement QAS-OBS in existing WRONs. The control heuristic is presented and the performance is evaluated through simulation. It shows that QAS-OBS satisfies the QoS constraints while maximizing the overall network throughput.

References

1. Yu, O., et al.: Multi-domain lambda grid data portal for collaborative grid applications. Elsevier Journal Future Generation Computer Sys. 22(8) (October 2006)
2. Simeonidou, D., et al.: Dynamic Optical-Network Architectures and Technologies for Existing and Emerging Grid Services. J. Lightwave Technology 23(10), 3347–3357 (2005)
3. Qiao, C., Yoo, M.: Optical burst switching (OBS)-A new paradigm for an optical internet. J. High speed Networks 8(1), 69–84 (1999)

4. Xiong, Y., Vandenhoute, M., Cankaya, H.: Control Architecture in Optical Burst-Switched WDM Networks. IEEE J. Select. Areas Commun. 18(10), 1838–1851 (2000)
5. Duser, M., Bayvel, P.: Analysis of a dynamically wavelength-routed optical burst switched network architecture. J. Lightwave Technology 20(4), 574–585 (2002)
6. Yu, O., Xu, H., Yin, L.: Adaptive reliable optical burst switching. In: 2nd International Conference on Broadband Networks, 2005, October 3-7, 2005, vol. 2, pp. 1419–1427 (2005)
7. Yoo, M., Qiao, C., Dixit, S.: QoS Performance of Optical Burst Switching in IP-over-WDM Networks. IEEE J. Sel. Areas Commun. 18(10), 2062–2071 (2000)
8. Yoo, M., Qiao, C.: Supporting Multiple Classes of Services in IP over WDM Networks. In: Proc. IEEE Globecom 1999, pp. 1023–1027 (1999)
9. Chen, Y., Hamdi, M., Tsang, D.H.K.: Proportional QoS over OBS networks. In: Global Telecommunications Conference, 2001. GLOBECOM 2001, vol. 3, pp. 1510–1514 (2001)
10. Poppe, F., Laevens, K., Michiel, H., Molenaar, S.: Quality-of-service differentiation and fairness in optical burst-switched networks. In: Proc. SPIE OptiComm., Boston, MA, July 2002, vol. 4874, pp. 118–124 (2002)
11. Chen, Y., Turner, J.S., Zhai, Z.: Contour-Based Priority Scheduling in Optical Burst Switched Networks. Journal of Lightwave Technology 25(8), 1949–1960 (2007)
12. Farahmand, F., Jue, J.P.: Supporting QoS with look-ahead window contention resolution in optical burst switched networks. In: Global Telecommunications Conference, 2003. GLOBECOM 2003, December 1-5, 2003, vol. 5, pp. 2699–2703 (2003)
13. Kozlovski, E., Bayvel, P.: QoS performance of WR-OBS network architecture with request scheduling. In: IFIP 6th Working Conf. Optical Network Design Modeling Torino, Italy, February 4–6, 2002, pp. 101–116 (2002)
14. Loi, C.-H., Liao, W., Yang, D.-N.: Service differentiation in optical burst switched networks. In: IEEE GLOBECOM, November 2002, vol. 3, pp. 2313–2317 (2002)
15. Zhang, Q., et al.: Absolute QoS Differentiation in Optical Burst-Switched Networks. IEEE Journal of Selected Areas in Communications 22(9), 1781–1795 (2004)
16. Yang, L., Rouskas, G.N.: Optimal Wavelength Sharing Policies in OBS Networks Subject to QoS Constraints. IEEE Journal of Selected Areas in Communications 22(9), 40–50 (2007)
17. Xu, H., Yu, O., Yin, L., Liao, M.: Segment-Based Robust Fast Optical Reservation Protocol. In: High-Speed Networks Workshop, May 11, 2007, pp. 36–40 (2007)
18. Yu, O.: Intercarrier Interdomain Control Plane for Global Optical Networks. In: Proc. ICC 2004, IEEE International Communications Conference, June 20-24, 2004, vol. 3, pp. 1679–1683 (2004)
19. Yoo, M., Qiao, C.: Just-enough-time (JET): A high speed protocol for bursty traffic in optical networks. In: Proceeding of IEEE/LEOS Conf. on Technologies for a Global Information Infrastructure, August 26-27, 1997, pp. 26–27 (1997)