Intermediate Node Buffering-Based Contention Minimization Scheme

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Abstract—**Optical burst switching (OBS) is a candidate switching paradigm for future backbone all-optical networks. However, data burst contention can be a major problem especially as the number of lightpath connections as well as the overall network radius increases. Furthermore, the absence of or limited buffering provision in core nodes, coupled with the standard one-way resources signalling aggravate contention occurrences resulting in some of the contending bursts being discarded. In this paper we propose and analyze a restricted intermediate Node Buffering-based routing and wavelength assignment scheme (RI-RWA) scheme in which intermediate buffering provisioning is implemented for contending data bursts have already propagated more than half the network's diameter. The aim is not to discard such bursts as they would have already utilized a considerable amount of available network resources. We comparatively evaluate the scheme's performance in terms of performance indicators such as fairness, load balancing as well as throughput.**

***Keywords*— Optical Burst Switching (OBS), contention avoidance, contention resolution, Quality of Service (QoS), Intermediate Buffering**

I. Introduction

Current and future OBS networks are expected to provide connectionless transport through multiple end-to-end lightpath connections that are wavelength multiplexed. With such a scenario there is a possibility that data bursts may frequently contend with each other for the same output ports (resources) at intermediate nodes. The fact that the OBS switching paradigm relies on one-way signaling and reservation protocols in which data bursts are transmitted on a "best effort manner" basis i.e., before actually resources reservation confirmation means that by the time it arrives at the node, the anticipated resources may no longer be available. Furthermore, because of the frequent aggregations of various transit lightpath streams from other sections of the network, two or more bursts utilizing the same wavelength may compete for the same network resource and this will result in contention and consequently, burst losses. Frequent data burst losses will always seriously impact on overall network performance as well as the QoS of already running applications. As a main design objective in the deployment of OBS networks, it is necessary that contention avoidance and resolution measures be addressed. Primarily, contention resolution aims at moving all but one burst from the port where the contention is occurring. This can be done by employing a variety of mechanisms that are normally categorized as either space, time, wavelength or any hybrid combinations. Typical examples include deflection routing (space domain), wavelength conversion (wavelength domain) and optical buffering (time domain).

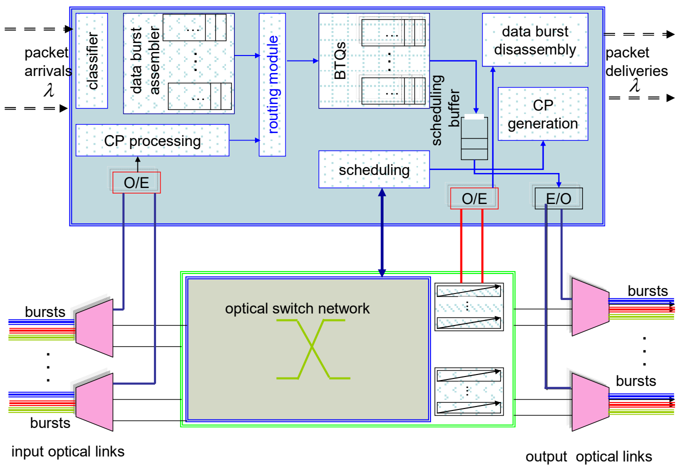

Figure 1: A Generalized OBS node

An example OBS node architecture is provided in Fig 1. Its primary functions include data burst assembling, disassembling as well as forwarding. e.g. in the burst assembling case, packets received from users are initially buffered according to destination and traffic classes before assembling into class-segmented bursts in the assembly queues [1]. [2]. Ultimately, the assembled data bursts are scheduled on available outgoing channels together with their associated header packets (HPs) that contains key routing associated information. It is crucial to note that during the scheduling routine, each associated HP is dispatched ahead at an offset time [2] that will allow for pre-configuring of required resources at intermediate nodes before the actual data burst arrival. In serving transit connections, an associated HP of a given connection is pre-processed by a routing module at each node. If the intended destination of the soon to arrive burst is local, the burst is forwarded to a burst disassembly module which disassembles it into packets. However, if the transit connection still needs to traverse further, routing information extracted from the associated HP is instead forwarded to the scheduling module, and eventually the data burst will be rescheduled as well to the next hop.

As previously noted, contention at OBS nodes may lead to server performance degradation as some of the contending data bursts may be discarded as part of the contention resolution measures. As a further contention resolution measure, the available limited buffering at each node may be used to buffer those data bursts that have already traversed many hops in the network core nodes. Overall, in order to guarantee good network performance as well as consistent QoS for the various applications and services, data burst assembly algorithms at ingress nodes as well as an effective routing and wavelength assignment (RWA) approach are necessary to alleviate, minimize or avoid contention occurrences.

II. Related Works

In order to achieve contention minimization in the design and deployment of an OBS switched backbone network, the available resources at various levels, e.g. link, path and wavelength have to be dimensioned appropriately so as to maximize on the aggregate number of simultaneous end-to-end lightpath constraints. The obvious constraint being that at any given time, a given wavelength can only serve a single lightpath connection (data burst) on any given link. Whereas the ingress node generally executes RWA such as to avoid any contention, however the inevitable merging of new lightpath connections with transit streams at various other intermediate nodes, raises the risk of contention further occurring. As mentioned before, contention will take place when multiple data bursts utilizing identical wavelengths contend for the same resources simultaneously. The contention can be addressed by changing and varying resource attributes such as wavelength, link or time, even though this will be at added resources constraint.

The contention resolution measures are mostly reactive in nature and various approaches have been studied. The authors in [3] propose a time-based contention resolution mechanism using fiber delay lines (FDLs) to delay one or more of the contending bursts for a while. However, implementing such a scheme would be prohibitively expensive as a very long fiber is required in order to achieve a 1 microsecond delay [4]. The authors in [5], suggest resolving contention by way of implementing deflection routing [5]. However, it is important to note that deflection routing can lead to endless network looping, network traffic load imbalances as well as elongated network latencies. The authors in [6] propose a burst segmentation approach in which only the segments of a given contending data burst are discarded instead of the entire burst. In the optical domain, wavelength converters (WCs) are utilized to shift the contending wavelength of a data burst to a non-contending one subject to availability. Note that WC implementation is quite expensive. In any case, several types of WCs exist including tunable wavelength converters (TWCs) and fixed wavelength converters (FWCs) [7].

Overall, the three reactive based contention avoidance measures discussed so far are only effective in cases were the network loads are very low to moderate. They however will not be as affective should the network become congested, hence the need to regulate congestion as an indirect approach towards preventing contention occurrence. Hence in [8], [9], the authors investigated the impact of traffic control as well as burst discarding on overall OBS network performance. They noted however, the possible occurrence of burst contentions even when the network was lightly loaded should multiple data bursts simultaneous demand the same wavelength of the same output fiber link. In such instances only one of the contending bursts would have to be sparred even though resources existed. In such cases, partial buffering in conjunction with congestion control would likely improve performance. Because of the obvious cost and capacity limitations with regards to buffering in optical domain, worth considering would to schedule the injection instants of data bursts at the ingress nodes in a manner such as to avoid any further contentions in the network interior. Hence in [10] the authors consider overall network utilization maximization when both burst length (congestion control variable) and offset time (burst contention resolution variable) are jointly controlled. They go on to develop a distributed algorithm that assumes explicit signaling among nodes comprising the network. Such a joint control was shown to decouple throughput performance from burst loss performance such that the network could still be loaded to almost 100% but to no significant burst losses. Studies in various literatures also show that when transit flows merge with other traffic at intermediate (core) nodes, contention will still occur, and that further scheduling of bursts will reduce contention occurrences at subsequent nodes. It would always be necessary that WCs be provisioned at all scheduling nodes so that, the scheduler will initially inspect the targeted wavelength at an outgoing link before scheduling any data burst. Should this wavelength be free and available for use at that moment in time, it will be assigned, otherwise the WC will be used to schedule the burst on any other available free wavelength. Several scheduling algorithms have been explored in various literatures [9], [10]. The work in [11] demonstrated that by utilizing voids that emerge during OBS normal operation, void filling algorithms can be implemented in order to achieve improved link utilization as well as lowered contention occurrences.

Overall by comparison, the deflection routing approach is a more attractive solution for reducing the blocking probability but to no considerable cost. Any idle links are candidate deflection paths. In the process the network traffic is redistributed evenly, and the utilization of the links is improved. However, the approach does not completely eradicate contention in that it may still occur in the deflection routes. Moreover, deflection routing may trigger traffic congestion in other sections of the network if deflection routes are not chosen carefully.

In this paper, we propose and analyze a restricted intermediate Node Buffering-based routing and wavelength assignment (RI-RWA) scheme to address contention occurrences as well as prevent deletion of contending bursts. The scheme primarily prioritizes the selection of primary as well as deflection paths for establishing lightpath connections as a function of individual wavelength contention performances. It further provides restricted intermediate buffering provisioning for contending data bursts that have already traversed a significant number of hops in the network (typically this should be half or more of the network's diameter).

The remainder of the paper is organized as follows. The proposed scheme is presented in section III. Section IV. compares the performance of the proposed algorithm with that of existing similar RWA algorithms, finally section V concludes the paper.

III. Proposed RI-RWA Scheme

The basis of our proposed RI-RWA scheme is as follows: For each data burst, a least cost lightpath connection has to be established from the ingress to the egress node. The wavelength to be assigned to the lightpath connection must satisfy the general RWA constraints, i.e. that the assigned wavelength should not be concurrently shared with any other connection requests on the same fiber (link) end-to-end, otherwise contention will take place. Since the lightpath connection is likely to merge with other streams at various nodes as it traverses the network, there is a likelihood of the RWA constraint being violated. Any proposed RWA scheme should focus on maximizing the number of lightpath connections in the network, but without violating the key constraint emphasized earlier. When contention occurs, its resolution must not result in the escalation of network costs, neither should there be degradation of overall network performance in this or other sections of the network. Fairness to all lightpath connection requests irrespective of hop count is also necessary. This is because it has been established in quite a number of literatures that long hop lightpath connections are likely to encounter contention as well as discarding. Furthermore, discarding data burst that have since traversed a distance exceeding half the network's diameter is wasteful of resources hence restricted intermediate buffering to resolve contention in such situations may be worth considering.

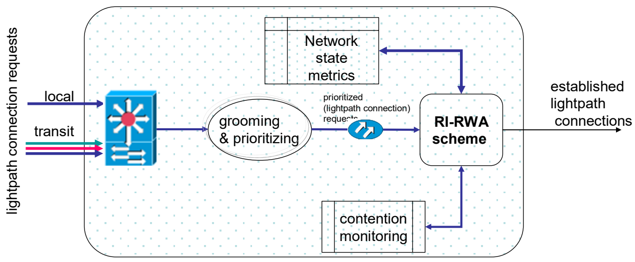

Figure 1: RI-RWA summary concept

Our proposed scheme initially grooms and prioritizes the lightpath connection requests at each node. This is followed by assigning the least cost route(s). The wavelengths and paths assigned are selected based on current resources states as well as according to general performance with regards to contention, e.g. wavelengths and routes that are currently experiencing contention will be least prioritized. Fig 2 summarizes the key steps of the proposed scheme. At each node, lightpath connection requests are groomed as well as prioritized. After the grooming, the RI-RWA scheme will assign routes taking into account current network (path and link) states as well as general individual wavelength performance with regards to contention. The key steps are summarized as follows:

A: Grooming and Prioritizing

In the grooming process, direct links as well as high QoS connection requests are assigned higher priority. The lightpath connection request grooming and prioritizing is summarized by the following algorithm [7].

Algorithm I: Grooming and prioritizing

initialize
Step1: lightpath connection requests destined for the same (s,d) groomed within link capacity
Step II: queue all lightpath connection requests.
Step III: categorize them into low and high priority.
end

B: Network States

If we define $\rho_{\max}^{s,d}$ as the maximum sustainable load by a given link, then for a given link's load link state (LS) is defines as follows:

$$\rho_{i,j} \geq \rho_{\max}^{i,j} = LS_{i,j} = \begin{cases} 1 \rightarrow congestion \\ 0 \rightarrow available \end{cases} \tag{1}$$

and the path congestion is:

$$\underset{LS \neq 1}{LS_{s,d}^{p}} = \sum_{e(i,j) \in r^{P(s,d)}} LS_{(i,j)} \tag{2}$$

The proposed RI-RWA scheme will always prefer both a path and link with minimum congestion likelihood, i.e. $\min(LS_{(s,d)}^{p})$.

The congestion likelihood levels at any given time is expressed as:

$$c_{(i,j)}(t) = \frac{N_{drop(i,j)}}{N_{total(i,j)}} \tag{3}$$

and the end-to-end lightpath connection burst blocking probability as:

$$P_{B(\pi_k,t)} = 1 - \prod_{1 \leq i \leq n_k} (1 - c_{(i,j0)}) \tag{4}$$

Because data bursts routed on a link whose wavelengths are underutilized are not likely to encounter any contention, we thus also define the wavelength utilization of a link at any given time as follows [11];

$$U(e,t) = \frac{\sum_{i=1}^{N_s} T_i^S}{W_l \times t} \tag{5}$$

where W_l is the number of available wavelengths on a link.

The proposed scheme also periodically tracks all contentions recorded on the various links and share the statistics with all nodes. This information is used to prioritize the various wavelengths at the nodes.
We further incorporate an intermediate buffering queue (IBQ) to temporarily store those data bursts that have since traversed half or more of the network's diameter. The network's diameter $(D_{s,d})$ as the maximum least cost distance in terms of hops between any source-destination pair. It is shown in [12] that data bursts traversing longer paths have a higher probability of being discarded as a result of contention and consequently this affects network throughput as well as efficient usage of resources.

Algorithm II: Summary RIB-RWA

initialize
input: acquire sets of new and transit connection requests from HP processing module.
output: groomed and prioritized sets of lightpath connection requests.
Step I: load network metrics:
 do search for K least cost path sets,
Step II: serve all requests according to priority.
Step III: from fail list:
 do transit connection request list;
 check hop distance $(if \geq {}^{D_{s,d}}\!/_{2})$,
send to IBQ. Re-set priority to highest, and repeat step II once
Step IV: drop any fails
end

IV. PEFORMANCE EVALUATION

We evaluate the RI-RWA's performance on a 16-node topology network shown in Fig 3. The hop distances are measured in kilometers. Each of the 16 nodes of the network incorporates edge-core nodes functionalities and is also provisioned with limited buffering. The traffic intensity on each link is varied up to a maximum of 100%, i.e. its maximum capacity and generally the link load is computed according to:

$$\rho = \left\lfloor \frac{S_{bursts}(t)}{B_{\lambda} \times W \times time} \right\rfloor \tag{6}$$

where $S_{bursts}(t)$ is the volume size of sent bursts, B_{λ} is the capacity of a single wavelength, W is the total number of usable wavelengths, and L is the aggregate number of links.

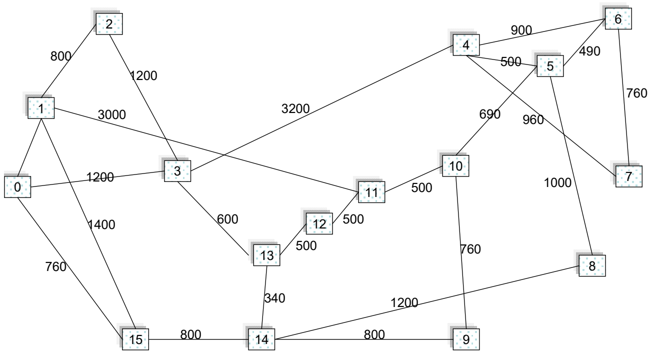

Figure 2: A 16 node network with 25 bidirectional links

Each link supports up to $10Gbps$ speed and the average burst length is $2.5MB$. The average processing time of each HP is $7\mu secs$. We assume best assembling discussed in [14].

The following are further assumptions as well as additional simulation parameters pertaining to the simulation as well as analysis of the proposed scheme:

- The offset time used in scheduling each burst is always large enough to avoid the associated data burst catching up or outpacing its corresponding HP.
- There is no provisioning for WCs throughout the network.
- The data burst length is regulated by the variable period of assembly as well as maximum burst length.
- A modified Dijkstra's shortest path routing algorithm is used for choosing candidate deflection routes.
- Switch network configuration time is $5\mu secs$.
- Link propagation delay is a function of actual hop length.
- All nodes are assumed to receive the same offered load in the network.

A: RI-RWA without Restricted Intermediate Buffering

Initially, we explore the proposed scheme's performance in terms of blocking. In so doing, we vary the link traffic load from 0 up to about 70% (0.7). This is carried out for varying number of wavelengths on the fiber link, i.e. $W = 8, 32$ and 64.

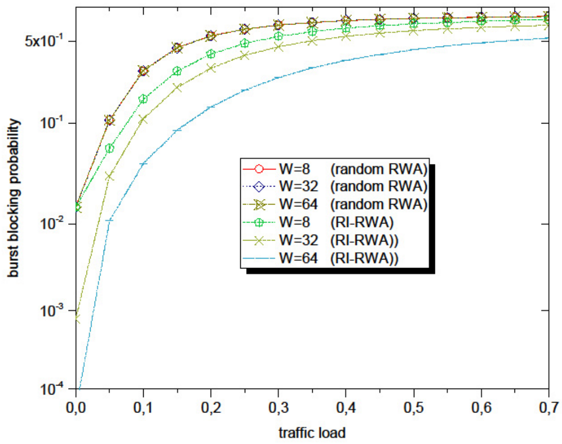

Figure 3: Blocking probabilities versus link c load

A plot of the throughput performance is shown in Fig 5. Once again, the proposed scheme improves on the overall throughput up to a maximum of 60% for $W = 64$ when the link load is almost 70%.

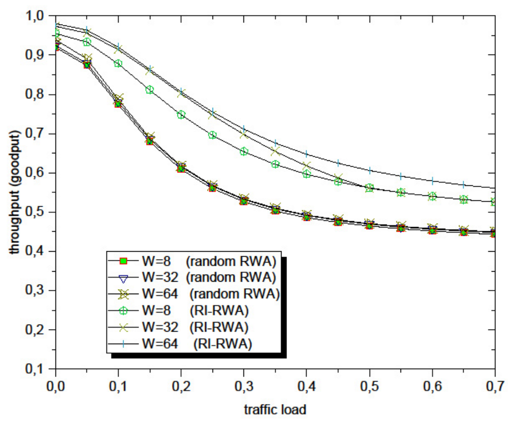

Figure 4: Network throughput

We compare the proposed scheme's performance with that of the traditional OBS routing approach, i.e. random RWA. The results are displayed in Fig 4, in which it is noted that the RI-RWA scheme reduces blocking probabilities. On the other hand, the traditional random RWA scheme does not seem to improve its performance at all even for high numbers of active wavelengths. It is also observed that at low W , the limited resources rather contribute to the blocking and not necessarily the wavelength assignment approach implemented.

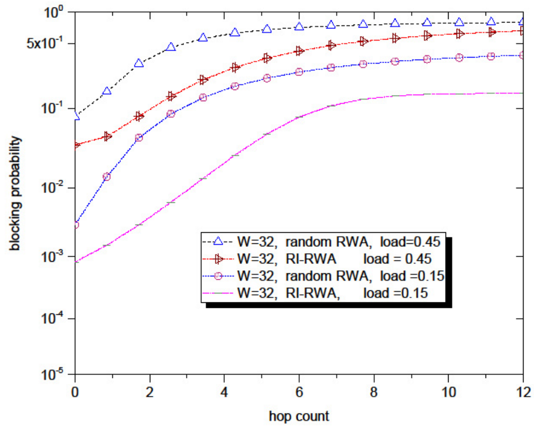

Figure 5.: Blocking performance versus hop count

The overall performance improvement of the RI-RWA with increasing W is explained by the degree of wave-length spatial reuse, this means that for large values of W available at the ingress node, more lightpath connections (bursts) can be scheduled on a given link.
Fig 6 plots the bursts blocking probability as a function of the hop count. For low link traffic loads the RI-RWA scheme relatively performs much better in terms of blocking probabilities in comparison to the random RWA scheme. At high traffic loads, the two schemes even off, and this indicates that no more wavelengths are available to serve new connection requests.

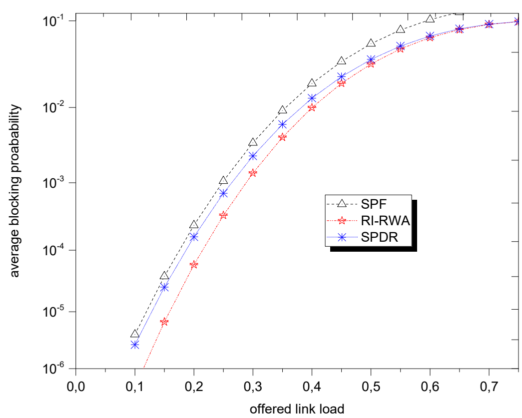

Figure 6: Average blocking probability

B: RI-RWA with Restricted Intermediate Buffering

We further allow limited or restricted intermediate buffering at core nodes as a contention resolution measure. It is noted that restricted intermediate buffering saves those data bursts that have already traversed multiple hops from being discarded whenever they encounter contention.
In the process it improves network performance in terms of blocking probabilities, as well as fairness to those data bursts that traverse the network through high hop counts. Fig 7 compares the proposed scheme with the traditional OBS routing's SPF (which uses random RWA), together with the shortest path deflection routing (SPDR) scheme.
The proposed scheme performs relatively better than the rest. Fig 8 plots the end-to-end throughput for selected routing strategies considering relatively uniform as well as distance-dependent traffic.

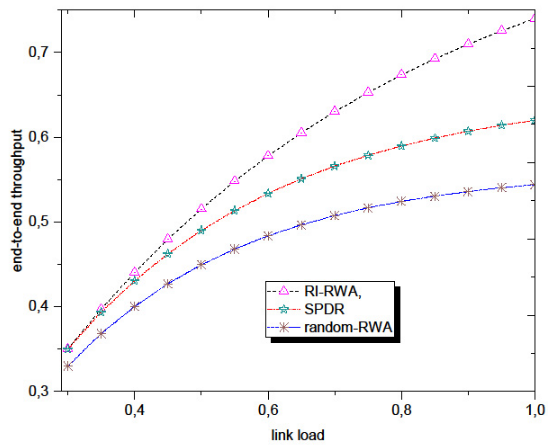

Figure 8: End to end throughput as a function of link load

Both SPDR and the proposed scheme outperform SPR. However, the proposed scheme utilizes the available network resources much more efficiently and shows the highest throughput overall.

CONCLUSIONS

In this paper, we proposed a priority based intermediate node buffering-based RI-RWA scheme to combat the problem of contention occurrences as well as minimize blocking of bursts already in the network. The RI-RWA scheme basically selects primary as well as deflection paths/links based on past contention frequency occurrences as well as current resources states in the candidate paths. Furthermore, the scheme also implements intermediate buffering for contending data bursts that have traversed several hops in the network. Obtained simulation results show that restricted intermediate buffering saves those data bursts that have already traversed multiple hops from being discarded whenever they encounter contentions further in the network. In the process it improves network performance in terms of blocking probabilities, as well as fairness to those data bursts that traverse the network through high hop counts. Overall simulation results obtained show that the scheme performs well in terms of key QoS metrics such as network throughput, data burst loss probabilities as well as load balancing. In future we will modify the scheme so that the overall network load can be increase to about 95% but subject to us still obtaining acceptable network performance.

ACKNOWLEDGMENT

The authors would like to acknowledge support from the Research Office.

REFERENCES

[1] Bakhe Nleya and M.Gomba, "Enhanced Congestion Management In OBS Networks", Proceedings of IEEE's Africon'17. CapeTown, 18-20 September, Cape town, 2017.

[2] N. Gomba, Bakhe Nleya and A. Mutsvangwa, "Class Segmented Burst Assembling Approach in OBS Networks", Proceedings of the 2015 Africon Conference , September 14-17, Addis Ababa, 2015

[3] J.Pedro, P.Monteiro and J.Pires, "Efficient Optical Burst-Switched networks using only Fiber Delay Line buffers for contention resolution",In Fourth International Conference on Broadband Communications, Networks and Systems, pages 2–11, Sep 2007.

[4] J. P. Jue and V.M. Vokkarane, "Optical Burst Switched Networks", Springer, 2005.

[5] Xi Wang, H. Morikawa and T. Aoyama, "Deflection routing protocol for burst switching WDM mesh networks. Terabit Optical Networking",Architecture, Control, and Management Issues, vol. 4213, pp. 242–252, 2000.

[6] V. Eramo, M. Listanti, and P. Pacifici, "A comparison study on the wavelength converters number needed in synchronous and asynchronous all-optical switching architectures", IEEE Journal of Lightwave Technology, vol. 21, no. 2, pp. 340–355, 200.

[7] B. C. Chatterjee, N. Sarma, and Partha Pritim Sahu, "Priority Based Routing and Wavelength Assignment with Traffic Grooming for Optical Networks", Journal of Optics Communications Networks, Vol. 4, June 2012.

[8] W. Park, M. Shin, and S. Chong, "Performance enhancement in OBS etwork with flow control and edge delay method," in Proc. IEEE GLOBECOMM, San Francisco, California, Nov. 2006.

[9] F. P. Kelly, A. K. Maulloo, and D. K. Tan, "Rate control in ommunication networks: shadow prices, proportional fairness and stability," J. of the Operational Research Society, vol. 49, pp. 237–252, Apr. 1998.

[10] S. H. Low, "A duality model of TCP and active queue management algorithms," IEEE/ACM Trans. on Networking, vol. 11, pp. 525–536, Aug. 2003.

[11] Gupta, Amit, R. S. Kaler, and Harbhajan Singh. "Investigation of OBS assembly technique based on various scheduling techniques for maximizing throughput."Optik-International Journal for Light and Electron Optics 124, no. 9 (2013): 840-844.

[12] Li Yang and George N. Rouskas, "Adaptive Path Selection in Networks. Journal of Lightwave Technology" Vol. 24, no. 8, pp. 3002-011, 2006.

[13] M. Ueda, T. Tachibana, and S. Kasahara,,"Last hop pre-emptive scheme based on the number of hops for optical burst switching networks". Journal of Optical Networking, Vol. 4, no. 10, pp. 648-660, 2005.

[14] H. Sibanda and Bakhe Nleya, "Model Analysis of Dynamic Priority Segmented Burstification and Deflection Routing", Proceedings of IEEE's Africon'17, Cape Town, 18-20 September, 2017.

[15] B. Nleya and A. Mutsvangwa, "Enhanced Congestion Management for Minimizing Network Performance Degradation in OBS Networks," in SAIEE Africa Research Journal, vol. 109, no. 1, pp. 48-57, March 2018, doi: 10.23919/SAIEE.2018.8531799.

[16] P. Khumalo and B. Nleya, "A Controllable Deflection Routing and Wavelength Assignment Algorithm in OBS Networks," 2018 International Conference on Intelligent and Innovative Computing Applications (ICONIC), Plaine Magnien, 2018, pp. 1-6, doi: 10.1109/ ICONIC.2018.8601303.

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