

A Limited Intermediate Node Buffering Based RWA Scheme in OBS Backbone Networks

Bakhe Nleya¹, Andrew Mutsvangwa²

Department of Electronic Engineering
Faculty of Engineering and Built Environment, DUT
Durban, South Africa

¹bakhen@dut.ac.za, ²massygomba@gmail.com

Abstract— An all optical backbone Optical Burst Switched (OBS) network comprises of a multitude of optical transport sub-systems erected in commercial, residential as well as industrial areas. The heterogeneous nature of the large volumes of traffic generated by various applications and services ideally requires an optical backbone network infrastructure to accommodate it. Such a network must be continuously adaptable to the changing nature of the traffic as well as its spontaneous growth with time. In so doing, it has to ensure high end-to-end quality of service (QoS), availability as well as provision adaptable controllability in cooperation with peripheral (service) layer networks. To successfully design and deploy a cost-effective backbone network, consideration must be taken with regards to system configuration, as well as in applied devices manufacturing. This is to ensure that any component failure does not add any noticeable performance degradation as the network will quickly reconfigure itself accordingly. At operational level, effective routing approaches are necessary to ensure minimized congestion as well as contention occurrences. The aggregation of both transit and local traffic at a node influences each other such as to aggravate congestion and to a certain extent reduce contention occurrences (due to the streamline effect). In this paper, we propose a priority based intermediate Node Buffering based PIB-RWA scheme to combat the problem of contention occurrences and to prevent bursts discarding. It 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 augments intermediate buffering provisioning for contending data bursts that are almost reaching the destination. Simulation results 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.

Keywords— *Optical Burst switching; streamline effect, congestion, contention, Routing and wavelength assignment.*

I. INTRODUCTION

The emergency of Internet of Things (IoT) enabled networks has resulted in a surge of various applications and services and generating massive amounts of traffic globally. This is necessitating the design and deployment of an all optical transport network infrastructure to serve as the core backbone network for the resultant diverse communications services. Such an infrastructure provides connectivity to millions of administrative, commercial industrial as well as residential centers. The

heterogeneous nature of the large volumes of traffic generated by various applications and services ideally requires an all optical backbone network infrastructure to accommodate it. Such a network must be continuously adaptable to the changing nature of the traffic as well as its spontaneous growth with time. In so doing, it has to ensure high end-to-end QoS, availability as well as provision adaptable controllability in cooperation with peripheral (service) layer networks. Utilization of Dense Wavelength Division Multiplexing (DWDM) in optical fibers has resulted in transmission bearers achieving speeds in the order of Terabits per second. However, current router switches have not been able to solve the speed mismatches between the high DWDM transmission speeds versus their low switching capabilities. Optical burst switching (OBS) is being rolled out to narrow the switching versus transmission speed gaps in current and future generation Optical backbone networks. The OBS approach is based on aggregating and assembling data packets at ingress nodes into optical data bursts. A control packet (CP) is separately generated to carry control data for each assembled burst on a separate wavelength channel. It is transmitted ahead of the actual burst and will thus reach the next intermediate node within some preset offset-time [1].

The magnitude of this timing is carefully set so that it is sufficient to allow for the CP's processing by a CP controller at all intermediate nodes. This also allows for the node's switch fabric pre-configuring as well as channel reservation on its output link prior to actual arrival of the optical data burst. This prior reservation of resources eradicates the need for optical burst buffering during the switching process, otherwise this would escalate network design and operational costs. The optical burst is then switched through and its reserved resources freed and made available for other lightpath connection requests. The OBS switching paradigm is prone to both congestion and contentions. Both reactive and proactive measures may be employed in the network to try to avoid contention. Such measures include backpressure routing, network segmentation, as well as prioritizing the network traffic. However, the existence of any congested links may drastically aggravate network throughput and consequently its overall performance. Notable QoS metrics that degrade as a consequence of congestion occurrences are burst blocking rate and end-to-end latency.

Burst contentions occurring in the core nodes may lead to some data bursts being deleted as a resolution measure. Overall, given the limited buffering at the core nodes, it is necessary that contention and congestion avoidance be jointly implemented in order to improve network throughput, thus in the process guaranteeing consistent acceptable QoS for the various applications and services. Burst assembling approaches at ingress nodes, RWA, contention/congestion resolution are key to minimizing both contention as well as congestion.

II. RELATED WORK

The task of contention minimization in OBS switched backbone networks is accomplished by addressing the available resources at various levels, e.g. wavelength assignment, link and path. The key constraint being that more than one data burst cannot be assigned the same wavelength at the same time on the same link. At wavelength assignment level, various schemes such as random wavelength assignment, first-fit (FF), minimum product, maximum sum, best-fit least loaded, least utilized, most frequently used and relative capacity loss have been explored [2]. The FF scheme generally performs relatively better in terms of burst loss probability, fairness. Furthermore, it has low computational overhead and complexity. To maximize on the number of simultaneous end-to-end lightpath connections, wavelength reassignment algorithms using minimum overlap and reconfiguration techniques have been suggested [3]. However, the suggested techniques only slightly reduce the blocking probabilities. The priority-based FF offline wavelength assignment scheme proposed in [4], [5] is geared towards maximizing both the number of simultaneous connections as well as low burst losses. With the scheme the wavelengths to be utilized for the connection requests are prioritized according to their estimated burst loss probabilities. It is seen in the priority-based FF approach that the average setup time is more than that of the FF approach due to the extra processing time required for estimation of end-to-end burst loss probabilities on each wavelength. At link and path levels, it is desirable that the shortest light path(s) from ingress to egress node be utilized, subject to constraints such as traffic load, congestion as well as wavelength assignment. As suggested in [6], optimized path computation techniques for efficient routing are quite important. Examples include the Dijkstra algorithm-based routing protocols such as the Intermediate System to Intermediate System (ISIS) and open shortest path first (OSPF). Whereas they always thrive to find the shortest path for every ingress to egress destination pair, they however cause the same shortest links to become congested as well as be prone to contentions. With respect to the ingress-node destination pair, the longer paths remain underutilized and overall there is traffic imbalance in the network. In order to counter this, a proposal in [7] is a distributed Path Computation Element (PCE) that enables routing protocols to efficiently utilize all available network links. PCE also applies software-defined networking (SDN) paradigms to separate path computing and path signaling functions, thus giving operators more control over their network and thus reduce contentions overall. An algorithm called the Self-Tuned Adaptive Routing

(STAR) was further incorporated to enhance traffic balancing as well prevent links from being overwhelmed [8].

A dynamic contention as well as congestion aware scheme that seeks to reduce blocking probabilities as well as boosting utilization by symmetrically distributing network traffic over all active links was proposed in [9]. Finally, in [10], the researchers proposed and investigated a per-link congestion control-based scheme that seeks to balance available network resources allocation by utilizing present and forecast demands of lightpath requests statistics. In essence, practical networks have a regularized topology and lightpath connection requests are generally random in nature. Given a fixed amount of resources (link, wavelengths, paths, as well as constraints) an increase in the traffic load results in the reduction of the number of idle resources per link and hence this will lead to both contention as well as blockings [11].

We propose a priority-based intermediate buffering and routing and wavelength assignment (RWA) scheme (PIB-RWA) to combat the problem of contention occurrences. The scheme initially grooms and prioritizes the local and transit lightpath connection requests. This is followed by prioritizing wavelengths according to their past performances in terms of contention occurrences on each. Finally, it assigns the wavelength to the various connection requests by further taking into consideration other resources states (such as congestion, and current traffic loads) in primary paths. Summarily, the paper's contributions are as follows:

- a) We introduce a burst grooming algorithm for mixing of transit and local data bursts at core nodes. As discussed later, the grooming helps in minimizing contentions.
- b) We propose and discuss a priority-based intermediate buffering and RWA (PIB-RWA) scheme in which contending bursts may be buffered at a core node depending on their residual hop count. As such it will be shown that this helps to improve the fairness in terms of drop rate of different hop-count bursts.

The remainder of the paper is organized as follows: A short discussion on RWA as well as constraints is provided in section III. Priority based RWA as well as Traffic Grooming and scheduling approach is introduced in section IV. Section V presents the proposed PIB-RWA scheme. Section VI compares the performance of the proposed algorithm with that of existing similar RWA algorithms. Section VII concludes the paper.

III. PROBLEM FORMULATION

In this section, we discuss the maximum RWA problem by separately defining the wavelengths, traffic, flow, bandwidth, link as well as path constraints. It is assumed that the physical topology of an OBS backbone network comprising both egress and ingress nodes can be modeled as a multigraph $G(V, E, W)$, where $V = \{v_1, v_2, \dots, v_n\}$ is the set of nodes each associated with a bidirectional optical link set, $E = \{e_1, e_2, \dots, e_n\}$ each supporting W active wavelengths. The set of active wavelengths is $\Lambda = \{\lambda_1, \lambda_2, \dots, \lambda_W\}$. In the topology graph, the link cost is $C(e)$

between any two nodes, otherwise it is ∞ [12]. The traffic corresponds to a set of K connections. The following assumptions and definitions are used in the model:

- No wavelength conversion capability in the network and each data burst train is assigned a single wavelength on a single lightpath connection.
- Each node can be an edge or core, and each has a finite number of tunable transceivers and can also add/drop light path connections.
- Lightpath connection requests to the various source-destination (s, d) pairs arrive randomly (Poisson process).
- Symmetrical traffic is assumed and therefore T is a traffic matrix, whose individual elements $T_{i,j}$ denotes the number of requested lightpath connection requests from node v_i to v_j .

Further notations used in the paper are as follows:

- $K_{s,d}$ is the set of lightpath connections between the ingress (source) and egress (destination) nodes (v_s, v_d) .
- A is the aggregate number of separate lightpath connection requests.
- N^{lp} is the aggregated sum of lightpath connection requests in the entire network.
- $N_{s,d}^L$ set of available links between a source-destination (s, d) node pair.
- Y is the number of groomed lightpath connection requests.
- $\rho^{s,d}$ is the traffic load between source-node (s, d) pair.
- $\rho_{i,j}^{s,d}$ is the fractional component of traffic intensity (i to j).
- $\rho_{i,j}$ is the aggregate traffic from i to j .
- $B_c^{s,d}$ lightpath capacity request (s, d) .
- B_C is channel capacity.
- $B(r_i^{s,d})$ lightpath connection capacity request.
- $gr^{s,d}$ groomed lightpath connection request.
- K is the number of available deflection paths.
- k lightpath connection from ingress node.
- $x_{k,e}^\lambda = \begin{cases} 1, & \text{if connection } k \text{ is accepted by node } v_i \\ 0 & \text{otherwise} \end{cases}$

- $x_{k,e}^\lambda = \begin{cases} 1, & \text{if wavelength } \lambda \text{ supports } k \\ 0 & \text{otherwise.} \end{cases}$
- $x_{k,i}^\lambda = \begin{cases} 1, & \text{if connection } k \text{ supported by } \lambda \text{ goes through } v_i \\ 0, & \text{otherwise} \end{cases}$
- $P_{s,d}$ is the set of candidate paths between v_s and v_d .

The following constraints will be assumed in our proposed scheme;

Link constraints [13]

The max-RWA for symmetrical traffic on a link will be as follows:

This is subject to:

$$F_{link} \equiv f_{link}(x) = \sum_{k=K} x_k \quad (1)$$

$$\sum_{\lambda \in \Lambda} \sum_{e \in \omega(v_i)} x_{k,e}^\lambda = 2x_{k,i} \quad k \in K, v_i \in V \setminus \{s_k, d_k\} \quad (2)$$

$$\sum_{\lambda \in \Lambda} \sum_{e \in \omega(v_i)} x_{k,e}^\lambda = 2x_{k,i} \quad k \in K, v_i = s_k, d_k \quad (3)$$

$$\sum_{k \in K} x_{k,e}^\lambda \leq 1 \quad e \in E, \lambda \in \Lambda \quad (4)$$

$$\sum x_k^\lambda = x_k \quad k \in K \quad (5)$$

$$x_{k,e}^\lambda \leq x_k^\lambda \quad k \in K, e \in E, \lambda \in \Lambda \quad (6)$$

$$2x_k = x_{k,s_k} + x_{k,d_k} \quad k \in K \quad (7)$$

$$2x_{k,e}^\lambda \leq x_{k,i} + x_{k,j} \quad k \in K, e = \{v_i, v_j\} \in E, \lambda \in \Lambda \quad (8)$$

$$x_k, x_k^\lambda, x_{k,e}^\lambda \in \{0,1\} \quad k \in K, e \in E, \lambda \in \Lambda \quad (9)$$

$$x_{k,i} \in \{0,1\} \quad k \in K, v_i \in V \quad (10)$$

Equations (5) and (6) define the required wavelength continuity.

Path constraints

Before we can define the paths constraints we further define the following variables with respect to routes (paths) on which links are established:

$$\bullet \quad x_{k,p}^\lambda = \begin{cases} 1, & \text{if } \lambda \text{ is used to support } k \text{ on path } p \\ 0, & \text{otherwise} \end{cases}$$

$$\bullet \quad a_{e,p} = \begin{cases} 1, & \text{if edge node lies on path } p \\ 0, & \text{otherwise} \end{cases}$$

$$F_{path} = f_{path}(x) = \sum_{\lambda \in \Lambda} \sum_{k \in K} \sum_{p \in P_{s_k, d_k}} x_{k,p}^\lambda \quad (11)$$

Subject to:

$$\sum_{k \in K} \sum_{p \in P_{s_k, d_k}} x_{k,p}^{\lambda} \leq 1, \quad e \in E, \kappa \in \Lambda \quad (12)$$

$$\sum_{k \in K} \sum_{p \in P_{s_k, d_k}} x_{k,p}^{\lambda} \leq 1, \quad k \in K \quad (13)$$

$$x_{k,p}^{\lambda} \in \{0,1\} \quad p \in P_{s_k, d_k}, k \in K, \lambda \in \Lambda \quad (14)$$

Equation (11) defines the wavelength exclusivity, i.e. that a lightpath connection can be routed through a node with a given wavelength, whereas equations (13) and (14) indicate that for each lightpath at most one path and wavelength may be selected.

Traffic flow constraints

For the traffic flow routed on the lightpath connections will face the following constraints;

$$\rho_{i,j} = \sum_{s,d} \rho_{i,j}^{s,d} \quad \forall (i,j) \quad (15)$$

$$\rho_{i,j} \leq \rho_{\max} \quad \forall (i,j) \quad (16)$$

Equation (15) states that the traffic ferried by a lightpath is aggregated from all path node pairs, while (16) defines conditions for congestion not to take place.

Bandwidth constraints

With relation to the bandwidth of a lightpath connection and the maximum capacity of a link (channel), the bandwidth constraint can be defined as follows:

$$B_c^{s,d} \leq B_C(s,d) \quad (17)$$

$$\rho_{i,j} \leq B_C * P_{i,j} \quad (18)$$

i.e. lightpath connection capacity cannot exceed that on the link (17) and that traffic offered from node i to j cannot exceed that of the lightpath.

Delay constraints

$$\text{minimize: } \sum_{s,d} t_{s,d}^{hop(s,d)} / \sum_{s,d} t_{s,d} \quad (19)$$

$$\text{maximize } \sum_{s,d} t_{s,d} \beta_{s,d} \quad (20)$$

IV. OBS NODE ARCHITECTURE

In order to transmit data bursts in an OBS network, lightpath connections are setup between desired source and destination pairs. A typical lightpath connection request is established through a series of lightpath connections from source to destination. These will now accommodate both control data as well as the data bursts. At each optical node, functionalities such as multiplexing and demultiplexing of channels as well as wavelength routing should be supported.

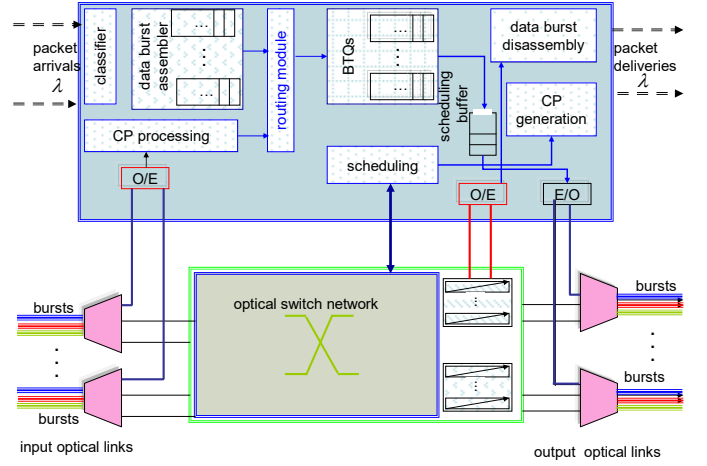


Figure 1. Example edge-core joint OBS node

As the data bursts are switched to intended output ports at network node, contentions may occur. It is therefore necessary to provision contention resolution mechanisms that will ensure burst loss minimization. We therefore assume that the architecture of each node should be designed in conformity with the operations of the priority-based intermediate buffering and routing and wavelength assignment (RWA) scheme (PIB-RWA) which we shall describe in due course.

The logical architecture of such a node is shown in Figure 1. Typically, the edge-core joint node example is a composite edge and core nodes. Such an architecture can perform bursts assembly utilizing edge node functionalities and also forward transit bursts to intermediate nodes using core node functionalities. Arriving packets from periphery user edge networks are classified according to their destination address as well as traffic class before being forwarded to assembly queues. The node uses the segmented burst assembly algorithm as well as adjustable offset timing [11], [12]. The segmented data bursts are ultimately forwarded to burst transmission queues (BTQs), where they are later on passed on to a scheduler for scheduling on available outgoing channels. Prior to scheduling, a CP is sent ahead at an offset time [12.]

The same node can also handle transit data burst connections. The associated CP of a transit data burst connection is processed by a routing module at each node. If the intended destination of the soon to arrive bursts is local, the bursts are forwarded to the burst disassembly module which disassembles them into packets. If transit bursts need to be forwarded to the next nodes, information is sent to the scheduling module, which looks for the availability to reserve output wavelength channel. If a channel is found after wavelength conversion (if required), the wavelength is reserved for incoming bursts, otherwise the burst is dropped. In this network, node architecture buffer provisions are necessary at assembly queues, burst transmission queues as well as at schedulers.

V. PROPOSED PRIORITY-BASED INTERMEDIATE BUFFERING SCHEME

Before a data burst is dispatched, resources have to be provisioned for it. This involves determining the least cost path to destination node on which the lighpath connection will be established, and assigning a wavelength to it. It is possible to avoid contention occurrences at the next and subsequent nodes by either assigning different links or different wavelength to concurrent bursts originating from the same node. However, at the next and subsequent nodes, each light path connection (data burst) is likely to merge with other transit connections. In so doing on any link, different wavelengths must be assigned to each of the bursts to avoid possible contentions should they partially or wholly overlap in time. The goal of RWA is to maximise the number of lightpath connections subject to these constraints. The contention resolution mechanisms at nodes must not escalate network costs, degrade performance (due to losses), or worsen contentions and other network performance metrics in certain section of the network. In certain instances, a data burst finds itself being discarded when it is only a few hops from the destination node, and this would be quite wasteful of resources. The proposed scheme involves enforcing a few measures such as traffic grooming at nodes, selection of both shortest possible paths to destination followed by the evaluation of their current resources states. Lastly, the selected routes will be prioritized according to the frequency of contention occurrences as well as current network resources metrics.

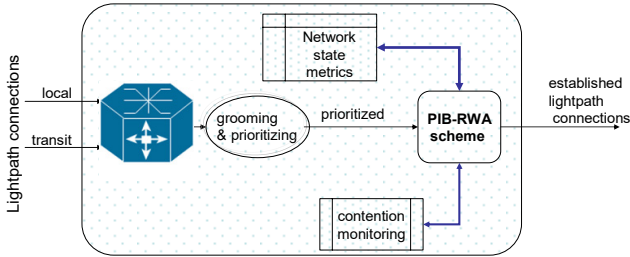


Figure 2. Proposed scheme's concept

As illustrated in Figure 2, lightpath connection requests are groomed according to priority (low or high priority). After grooming, the PIB-RWA scheme will choose routes (including deflection routes) based on current network state as well as frequency of contention occurrences. The various steps are discussed next:

A. Grooming

Primarily the purpose of grooming the connection request is to improve on network utilization. The groomed connection requests are further prioritized so that preference is given to higher priority class groomed connection requests first. In that way, more connection requests are likely to be successfully established in the process. Contentions as well as blocking probabilities are drastically reduced as a result of the grooming and wavelength prioritization facilitated by the

proposed PIB- RWA scheme. In the prioritization process, direct link as well as high QoS connection requests are assigned higher priority. The lightpath connection request grooming and prioritizing is summarized by the following algorithm [13]

Algorithm I: grooming and prioritizing

initialize

Step I: lightpath connection requests destined for the same (s, d) groomed within link capacity

$$R = \left\{ r_1^{s,d}, r_2^{s,d}, \dots, r_n^{s,d} \right\} / \sum_i^n B(r_i^{s,d}) = gr^{s,d}$$

Step II: queue all lightpath connection requests.

Step III: categorize them into low and high priority.

end

B. Network States

a) **Link/Path Congestion:** We commence with link as well path congestion. To this end, we utilize the maximum link threshold value $\rho_{\max}^{s,d}$ and if the link threshold value exceeds the set threshold value the link state (LS) is set to 1.

$$\rho_{i,j} \geq \rho_{\max}^{i,j} = LS_{i,j} = \begin{cases} 1 \rightarrow \text{congestion} \\ 0 \rightarrow \text{available} \end{cases} \quad (21)$$

The path congestion state on the primary path is determined from:

$$LS_{s,d}^P = \sum_{LS \neq 1} \sum_{e(i,j) \in P(s,d)} LS_{(i,j)} \quad (22)$$

Our scheme will always opt for a path with minimum congestion likelihood, i.e. $\min(LS_{(s,d)}^P)$. The same applies to links. In weighted terms, congestion levels at any given time t can be computed from;

$$c_{(i,j)}(t) = \frac{N_{\text{drop}(i,j)}}{N_{\text{total}(i,j)}} \quad (23)$$

Assuming link blocking probabilities to be independent, then at any time, the end-to-end lightpath connection burst blocking probability is:

$$P_{B(\pi_k,t)} = 1 - \prod_{1 \leq i \leq n_k} (1 - c_{(i,j_0)}) \quad (24)$$

b) **Wavelength utilization:** With regards to wavelength utilization, it is generally noted that data bursts routed on paths and links that are least used are not likely to encounter any contention. Furthermore, in the unlikely event that contention occurs along the path, the limited available contention resolution mechanisms will suffice to prevent any burst discarding.

At any given time, the utilization of a link is determined from [15],

$$U(e,t) = \frac{\sum_{i=1}^{N_s} T_i^S}{W_l \times t} \quad (25)$$

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

c) **contention frequency:** This is a tracking of all contentions recorded at output ports of all nodes within the core network. This value is acquired at fixed time intervals Δ for each output link($f_c^{i,j}$) and shared with all other nodes.

d) **Intermediate Buffering:** If a channel scheduler is unable to find an available wavelength on the desired output port link, the data burst is discarded. In the proposed scheme, we assume that each core node incorporates an intermediate buffering queue (IBQ) that will buffer those data bursts that have since traversed half or more of the network's radius. We define the network's radius ($\mathfrak{R}_{s,d}$) as half the maximum hop count between the longest of the shortest paths possible in a given network. As argued in various literatures e.g. in [14], bursts traversing longer paths have a higher probability of being discarded as they are likely to encounter contentions along the multiple hops and this may adversely affect the overall network throughput. Note that the discarded bursts would have already utilized significant amounts of network resources.

Algorithm II: PIB-RWA

initialize

input: acquire sets of new and transit connection requests from CP processing module.

output: sets of lightpath connection requests; These are classified as low or high priority.

Step I: acquire network metrics: congestion level, contention frequency, utilization and search for K shortest paths search for set of shortest paths,

Step II: Serve all requests according to priority.

Step III: From fail list: transit connection request check hop distance (if $\geq \mathfrak{R}_{s,d}$), **send to IBQ**. Re-set

priority to highest, and repeat step II once

Step IV: drop any fails

end

VI. PERFORMANCE EVALUATION

In this section we evaluate the performance of the proposed scheme. A 16-node topology interconnected by 25 bi-directional optical fiber DWDM links shown in figure 3 is used. The indicated hop distances are in kms. All nodes of the network are combined edge-core nodes as was previously described. Each node is also provisioned with limited buffering but no wavelength converters (WCs). The traffic load in the simulated network will be varied from zero to 100% and calculated as;

$$\rho = \left\lfloor \frac{S_{bursts}(t)}{B_\lambda \times W \times L \times time} \right\rfloor \quad (26)$$

where $S_{bursts}(t)$ is the aggregate size of bursts sent throughout the network, B_λ single wavelength's capacity, W is the number of wavelengths in a single link, and L is the number of links in the network.

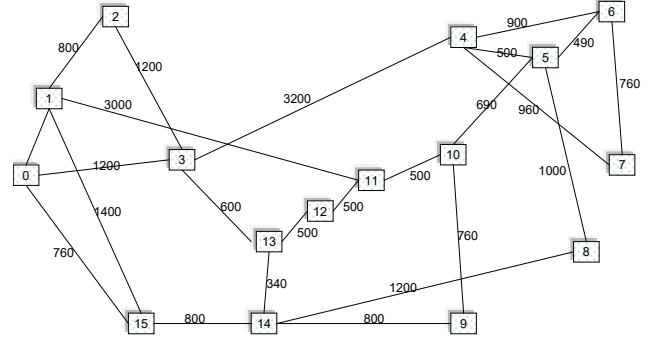


Figure 3. The Network with 16 node and 25 bidirectional links

Table 1. Simulation parameters

parameter	value
Number of node	16, edge-core
Link distance	Variable
Link bandwidth	10Gbps
Ave. burst length	3MB
CP processing time	10 μ s
Link status update	Every, 2 ms
Offset time	Variable =f(h)

A. PIB-RWA without Intermediate Buffering

We carry out a performance comparison of our proposed scheme versus the already existing routing ones: Initially, we will assume no intermediate buffering

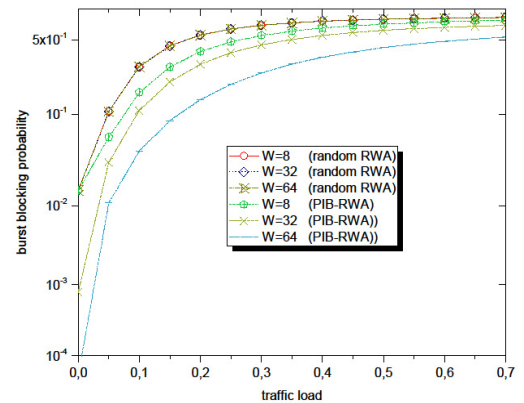


Figure 4. Blocking probabilities as a function of traffic load

We compare the performance of the proposed scheme versus random RWA (representing the traditional OBS approach). Initially we fix the number of wavelengths in a link to $W = 8, 32$ and 64

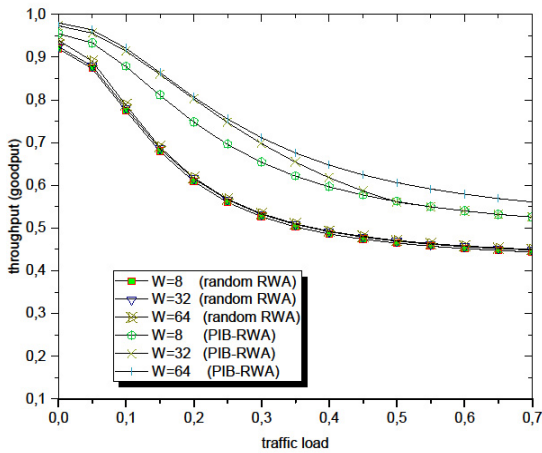


Figure 5. Network throughput

Figure 4, shows the burst blocking probabilities whilst Figure 5, shows the overall network throughput.

In general, the proposed PIB-RWA approach enhances network performance by reducing blocking and at the same time increasing the throughput. As expected, random RWA algorithms' performances for varying wavelength capacities are identical. On the other hand, the PIB-RWA algorithm outperforms the random RWA quite distinctively. It is also noted that for low values of W the limited resources rather dictate blocking probability and not the wavelength assignment approaches implemented.

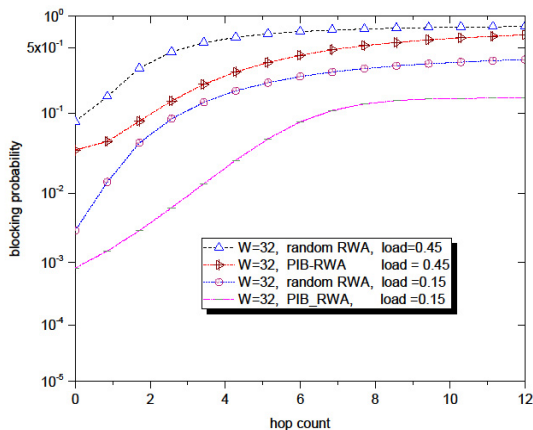


Figure 6. blocking as a function of hop count

The overall performance improvement of the PIB-RWA with increases in W can be attributed to the degree of wave-

length spatial reuse, i.e. for large values of W an ingress node can schedule more lightpath connections (bursts) on a given link. Consequently, more lightpath connections traversing different links can be concurrently assigned the same wavelength values. Furthermore, by comparing the two schemes at low traffic levels, the PIB-RWA has relatively better performance. This is because wavelength contentions prominently contribute to the blockings at low traffic loads, whereas as the network traffic load increases, most of the burst blockings are also caused by insufficient bandwidth. With regards to the number of nodes traversed, we note that for low traffic loads the PIB-RWA algorithm improves the network performance in terms of the blocking. However, the two approaches more or less perform identically at high loads, indicating that no more wavelengths are available for newly generated bursts and senders have to block them immediately.

B. PIB-RWA with Intermediate Buffering

In this subsection we compare the performance of the proposed scheme when it enforces intermediate buffering. We set the network diameter to 8. Figure 7 plots the average burst blocking probability as the link load is gradually increased. As anticipated, the PIB-RWA performs better than the other two. Overall, it is noted that intermediate buffering is effective in contention resolution and consequently improving network performance in terms of blocking probabilities as well as improving fairness to those data bursts that traverse the network through high hop counts.

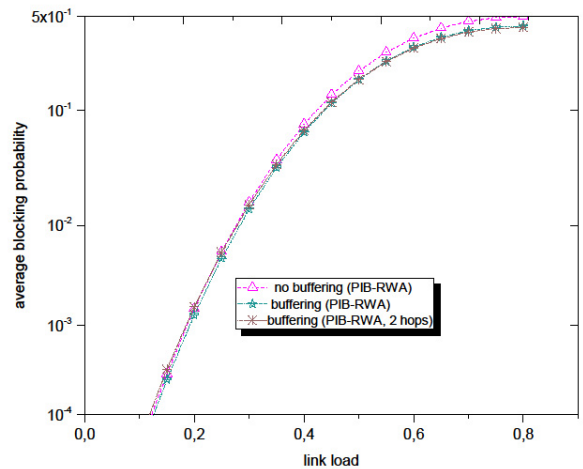


Figure 7. average blocking capacity when link traffic is increased

Figure 8 compares, the proposed scheme with the traditional OBS routing's SPF (which uses random RWA), together with

SPDR.

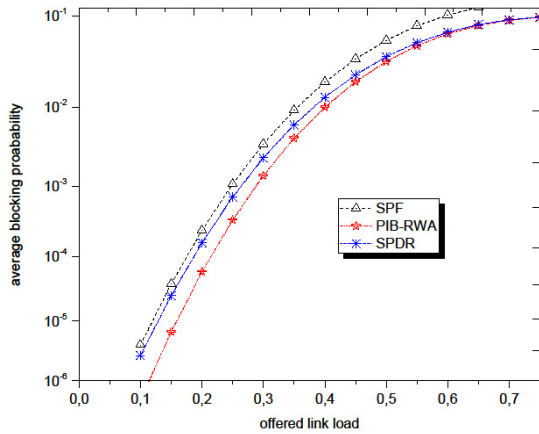


Figure 8. Average blocking probability SPF, PIB-RWA, and SPDR

The proposed scheme performs relatively better than the rest. Figure 9 plots the end-to-end throughput for selected routing strategies considering relatively uniform as well as distance-dependent traffic.

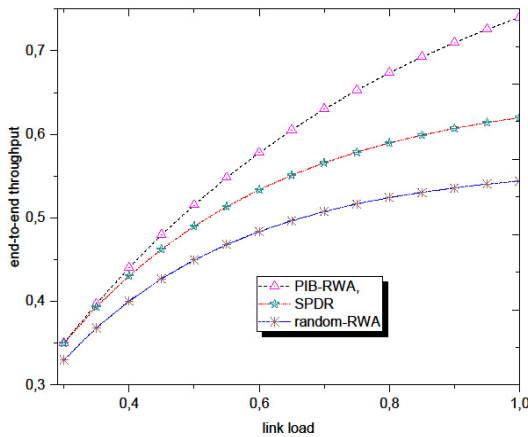


Figure 9. End to end throughput as a function of link load

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.

VII. CONCLUSIONS

In this paper, we proposed a priority based intermediate node buffering based PIB-RWA scheme to combat the problem of

contention occurrences as well as minimize blocking of bursts already in the network. The PIB-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. Simulation results 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

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