A Novel Scheduling Algorithm for Optical Burst Switched Networks

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***Abstract*— Optical burst switching (OBS) is an emerging technology that allows variable size data bursts to be transported directly over DWDM links. In order to make OBS a viable solution, the wavelength scheduling algorithms need to be able to utilize the available wavelengths efficiently, while being able to operate fast enough to keep up with the burst incoming rate. When implemented in hardware, the running time of the well-known horizon scheduler is O(1) for practical numbers of wavelengths. Unfortunately, horizon scheduling cannot utilize the voids created by previously scheduled bursts, resulting in low bandwidth utilization. To date, Min-SV is the fastest scheduling algorithm that can schedule wavelengths efficiently. However, its complexity is O(log *m*) and it requires 10log *m* memory accesses to schedule a single burst. In this paper, a novel modified Horizon scheduling algorithm with minimum reordering effects (MHS-MOE) in OBS networks has been proposed. Simulation results have shown that the proposed algorithm runs much faster than Min-SV and is significantly simpler than Min-SV in terms of complexity. Thus, the proposed algorithm proves to be well-suited for high speed networks applications.**

***Index Terms*—** Optical Burst Switching (OBS), Wavelength Routing, Scheduling- Algorithms

I. INTRODUCTION

Recent advances in Dense Wavelength Division Multiplexing (DWDM) technology allow data rates as high as 10 Tb/s (terabits per second) to be carried over a single optical fiber. Therefore, new optical switching technologies need to be developed to take advantage of the enormous bandwidth made possible by DWDM technology. Optical circuit switching (wavelength routing) has been deployed and plays a major role in the current optical networks. However, wavelength-routed networks are not the most appropriate technology for the emerging optical internet. For example, it takes at least a round-trip time to establish a lightpath. The bursty nature of the data traffic leads to poor wavelength utilization. Optical packet switching [1] is an optimal way to provide statistical multiplexing. However, the technology is not mature enough to provide a viable solution. **A** major challenge is the requirement for synchronization. Optical packet switches usually work synchronously. For example, packets arriving at different input ports must be aligned before they enter the switch fabric. It is difficult and expensive to implement the synchronization components. Another serious issue is the lack of commercially viable optical buffers. Packet switched networks are store and forward networks, which store the packets in the switches before forwarding to the next switch due to output port contention. Unfortunately, there are no random access optical buffers.

The only alternative method to provide a limited time delay is to use optical fiber delay lines (FDLs). Therefore, optical packet switching is not a practical solution in foreseeable future.

Optical Burst Switching (OBS) [2-4] is an emerging technology that allows variable size data bursts to be transported directly over DWDM links. It makes effective use of statistical multiplexing by treating tens or hundreds of DWDM wavelengths as shared resources, rather than a collection of independent links. In OBS networks, control information is delivered out-of-band on a separate control channel. Shortly before the transmission of a data burst, a Burst Header Cell (BHC) is transmitted through the control channel and is processed by the OBS routers electronically. The OBS router uses electronics to provide control of WDM channel resources, setting up and tearing down lightpaths for data bursts on-the-fly. Data bursts can remain in the all-optical data plane and pass intermediate switching nodes transparently.

II. OPTICAL BURST SWITCHING (OBS)

Optical Burst Switching (OBS) has emerged as a promising transport technology for next-generation Internet. As a matter of fact, OBS networks (as shown in Table I.) become a combination of packet and circuit switched networks, where packets are firstly aggregated in edge routers and, then, are sent as bursts along bufferless optical networks. This provides the benefit from statistical multiplexing in the optical domain, which allows better adaptation than circuit-switched networks (OCS) to higher layer dynamics. Besides, it lessens technology requirements, in comparison with all-optical packet switching (OPS) networks [3].

TABLE I. COMPARISON OF OPTICAL SWITCHING SCHEMES

Optical switching (paradigm)	**Bandwidth Utilization**	**Latency(set-up)**	**Optical Buffer**	**Traffic Adaptively**
Circuit	Low	High	Not required	Low
Packet/Cell	High	Low	required	High
Burst	High	Low	Not required	High

One of the key issues in OBS networks is WDM channel scheduling. In order to make OBS a practical solution, we need to solve the following two problems at the same time: 1) how to design channel scheduling algorithms that can utilize the available wavelengths efficiently; 2) how to make the algorithm fast enough to keep up with the burst incoming rate. For the sake of efficiency, OBS relies on one-pass resource reservation. This means that, unlike in OCS networks, data transmission is not delayed until the reception of the reservation acknowledgement packet. Conversely, in OBS networks, a burst is subsequently transmitted after an offset time since the reservation request control packet was sent. Therefore, there is no sureness about the proper transmission of the bursts, which could be lost due to contention at intermediate nodes. Several contention resolution strategies [4] have been proposed to minimize burst loss probability, namely deflection routing, Fiber Delay Lines (FDLs) as optical buffers, wavelength conversion and even combinations of them. It has been extensively demonstrated that these strategies succeed in decreasing burst blocking probability. Nonetheless, an additional degree of reordering [5] can be introduced to the network.

III. RELATED WORK

Switching matrix scheduling algorithms have been extensively studied for electronic switches [6]. They are similar to the WDM channel scheduling algorithms in the OBS routers in a sense that

Brazilian Microwave and Optoelectronics Society-SBMO received 15 Sept, 2008; revised 11 Aug, 2009; accepted 28 Sept, 2009
Brazilian Society of Electromagnetism-SBMag ISSN 1516-7399

the goals of the both types of scheduling algorithms are to obtain the switching matrix configurations such that input traffic can be efficiently sent to the desired outputs. However, there are two fundamental differences between the switching algorithms designed for electronic switches and the ones needed for OBS routers. First, all scheduling algorithms designed for electronic switches rely on RAMs to buffer data waiting to be scheduled. One property of electronic RAMs is that once stored in the RAM, data can stay there until it is retrieved. Unfortunately, random access memory is not available in optical domain. Although Fiber Delay Lines (FDLs) can provide a limited time delay, the amount of delay is determined by the length of the FDL. In the OBS systems that do not have FDLs, data has to be discarded if it cannot be forwarded to the desired output at the time of arrival. Second, most of the switching matrix scheduling algorithms developed for electronic switches can only handle a small number of switching ports (32 for example). However, for an OBS router, each port can carry tens or hundreds of WDM channels, which exceeds the capability of almost all scheduling algorithms proposed for electronic switches. Therefore, existing scheduling algorithms designed for electronic switches cannot be applied to OBS routers. New scheduling algorithms have to be invented for OBS routers.

Several scheduling algorithms have been proposed for OBS routers [6-10]. The authors in [6] have proposed *Horizon time of a channel* as the time after which no reservation has been made on that channel. Horizon scheduling provides fast wavelength scheduling. However, it can cause excessive burst discard since it can not utilize the voids created by previously scheduled bursts [6]. First Fit Unscheduled Channel (FFUC) is an algorithm proposed in [7]. Using FFUC the data burst is sent to the first channel, according to a predefined order e.g. fixed or round robin, among the channels in which the horizon time is smaller than the arrival time of the new data burst. This algorithm is the simplest algorithm for burst scheduling and its main advantage is a very low complexity. Latest Available Unscheduled Channel (LAUC) is an alternative algorithm proposed in [8]. It searches among the channels in which the Horizon time is smaller than the arrival time of the new data burst and selects the channel with the longest horizon time in order to minimize the created void. It has a greater complexity than FFUC, yet it is still quite simple and fast. LAUC-VF (Latest Available Unused Channel with Void Filling) can produce efficient channel schedules but it takes O(m) time to schedule a burst, which is too slow to be practical [9]. The Min-SV (Minimum Starting Void) algorithm [10] can produce the same wavelength schedule as LAUC-VF and its complexity is O(log m) where m is the number of voids per channel. This is a significant improvement over LAUC-VF. However, Min-SV still requires 10log (m) memory accesses for each burst request. It is not unusual that a system will have to keep track of 100 K to a million voids. This means that Min-SV takes up to a few microseconds to schedule a single burst, which is still too slow to meet the stringent burst scheduling requirement.

In this paper, a novel modified Horizon scheduling algorithm with minimum reordering effects (MHS-MOE) in OBS networks has been proposed. The proposed algorithm runs much faster than Min-SV and is significantly simpler than Min-SV in terms of complexity.

IV. PROPOSED MODIFIED HORIZON SCHEDULING ALGORITHM WITH MINIMUM REORDERING EFFECTS (MHS-MOE)

Based on the above comparison, it is clear that horizon scheduling can schedule a burst in a timely fashion. However, since it only keeps track of a single state for each channel, it cannot utilize link bandwidth efficiently in a general case. Thus, it is required to have an algorithm that runs as fast as horizon scheduling while being able to utilize channel bandwidth efficiently. In this paper, a novel modified Horizon scheduling algorithm with minimum reordering effects (MHS-MOE) in OBS networks (as shown in Fig.1.) has been proposed. A complete characterization of reordering becomes noteworthy, especially when assessing a protocol's viability over a given network. The detection of reordering is done at the destination, looking at the sequence number $s[i]$ of each

  ISSN 1516-7399

packet, where i numbers the arriving packet order at destination. This sequence number is set at the source node, following a consecutive integer sequence. The reordering ratio quantifies, given a certain data stream, the ratio of reordered packets. This figure is easily obtained as the number of reordered packets divided by the number of received packets. As a main application, it provides information about the minimal storage (i.e., buffer size) at the receiver, which would be needed to restore packet order at destination. Simulation results have shown that the proposed algorithm runs much faster than Min-SV and is significantly simpler than Min-SV in terms of complexity.

1. *Let $b_{s1} \ldots b_{sn}$ be a sequence of bursts, where b_{si} is characterized by a triple $(BCR_{tsi}, BA_{tsi}, BD_{tsi})$: BCR_{tsi} is the time of BHC receive, BA_{tsi} is the arrival time of the burst and BD_{tsi} is the length (time duration) of the burst.*
2. *The value of BA_{tsi} in the triple can be computed by adding the offset field to the BHC arrival time. For convenience, assume that for $i < j : BCR_{tsi} < BCR_{tsj}$; that is, the bursts are listed in the order in which the BHCs arrive.*
3. *The width (W_{b_s}) of a burst sequence (b_s) has been considered to be the size of the largest subset of bursts which all overlap in time with one another (that is, the earliest burst ending time in the set is later than the latest burst starting time in the set).*
4. *A sequence of bursts can be scheduled without delaying or dropping if and only if the number of channels on the link is at least equal to (W_{b_s}) .*
5. *If the bursts arrive in the same order as the BHCs, a horizon scheduler can schedule a burst sequence using no more than (W_{b_s}) channels.*
6. *The horizon scheduler uses at most (W_{b_s}) channels to schedule a burst sequence, if for all $i < j : BA_{tsi} < BA_{tsj} + BD_{tsj}$.*
7. *Reordering action:*
    - *The detection of reordering is done at the destination, looking at the sequence number $s[i]$ of each packet, where i numbers the arriving packet order at destination. This sequence number is set at the source node, following a consecutive integer sequence. In turn, the destination node maintains a counter $s'[i]$, which identifies the sequence number of the following expected packet.*
    - *Under normal conditions, $s'[i]$ is equivalent to the sequence number of the last received in order packet plus 1.*
    - *When packet i arrives, the packet is considered as reordered whether $s[i] < s'[i]$. Conversely, whether $s'[i] > s[i]$, the packet is considered in order and $s'[i+1] = s[i] + 1$.*
    - *The reordering ratio quantifies, given a certain data stream, the ratio of reordered packets. This figure is easily obtained as the number of reordered packets divided by the number of received packets. As a main application, it provides information about the minimal storage (i.e., buffer size) at the receiver, which would be needed to restore packet order at destination. N -reordering ratio: A received packet with sequence number $s[i]$ is considered as N -reordered whether $i - j \leq N < i \wedge s[j] > s[i]$.*
8. *Let δ be target time for the reordering extent. If a set of bursts with $Burst_{span} > \delta$ can all be scheduled on a single channel, then the Horizon scheduler can schedule them using no more than one channel (The same is applicable for n-channels).*
9. *In this scheme, the traffic flows from different edge nodes with the same priority have an equal share of the congested link; $C_c \cdot C_\lambda / |N|$ such a property is quantified by a fairness index (F_I) defined as: F_I $[TF]$ = $\left(\sum TF_i\right)^2 / |N| \left(\sum TF_i^{\,2}\right)$,Where $|N|$ is the number of concurrent flows into the congested link and TF_i is the sending traffic-flow of the i^{th} flow at equilibrium, (C_C) : Capacity of channel , (C_λ) : Number of wavelength channels carried by a link. F_I is a value between 0 and 1 with F_I = 1 indicating perfect fairness.*

Fig.1. Modified Horizon scheduling algorithm with minimum reordering effects (MHS-MOE)

Brazilian Microwave and Optoelectronics Society-SBMO received 15 Sept, 2008; revised 11 Aug, 2009; accepted 28 Sept, 2009
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V. PERFORMANCE EVALUATION

A. Simulation model

The NS-2 simulation tool [11] is used in this study. The details of the simulation are as follows;

- The network structure used in this study is the structure of the NSF Network with 12-nodes All the nodes have the function of both edge and core node, depending on which pair of node is selected to be the source (ingress edge node) and the destination (egress edge node).
- The burst length is exponentially distributed with an average of 10 µsec.The offset has a lognormal distribution with an average of 100 µsec.
- An additional fixed 10 µsec offset is added to data bursts at inputs.
- There are no fiber delay lines and wavelength converters in the network. The reservation scheme is based on the Just-Enough-Time (JET) reservation protocol.
- The value of δ is 10 µsec.
- The source and destination of each traffic flow are uniformly selected among the nodes.
- Wavelengths= 3-12 per fiber, Control burst processing time= 2.5-4 µsec ,Switching time = 12 µsec & Propagation delay on a link = 0.2 to 1 millisecond
- The data bursts are not retransmitted
- Bit errors in transmission are ignored.
- The size of the electrical buffers in the edge nodes is infinite.
- 3-Reordering burst ratio (N=3)

B. Numerical results

Fig.2 shows that the change of offered load nearly has no effect on the scheduling times of proposed algorithm (MHS-MOE) and Min-SV, which are always very small (close to zero). As to LAUC-VF, the simulation seems to suggest that the scheduling time is closely related to the load. When the load increases, the scheduling time grows almost linearly. Min-SV has a slightly worse performance on the scheduling time than proposed algorithm (MHS-MOE) because Min-SV needs to perform more operations, increasing complexity. It is also noted that the scheduling time of Min-SV remains a very small number even if the number of channels increases to hundreds. The scheduling time of LAUCVF, however, can easily become unreasonably large, when the number of channels increases.

From Fig.3, it is observed that burst-loss probability for proposed algorithm is lower than conventional methods. Using conventional algorithm, a burst-loss probability of $1x10^{-3}$(approx.) is obtained for 33 and 60 wavelengths (with burst arrival rate = 3200 and 6400 Bps) whereas 30 and 53 wavelengths are required for proposed algorithm. This shows an improvement in wavelengths usage of OBS network, which in turn increases the network utilization gain (i.e, efficiency).

Brazilian Microwave and Optoelectronics Society-SBMO received 15 Sept, 2008; revised 11 Aug, 2009; accepted 28 Sept, 2009
Brazilian Society of Electromagnetism-SBMag ISSN 1516-7399

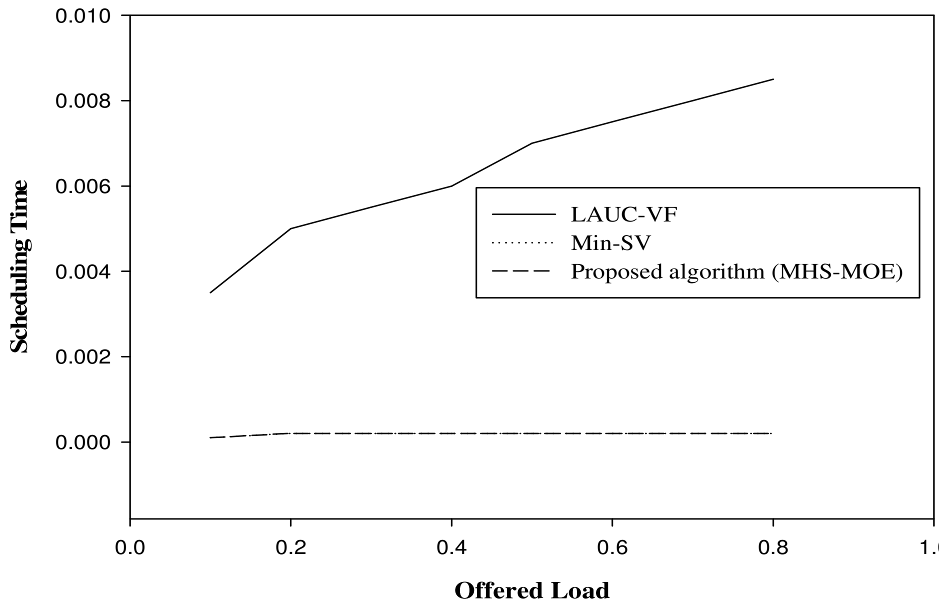

Fig. 2. Scheduling Time vs. Offered load

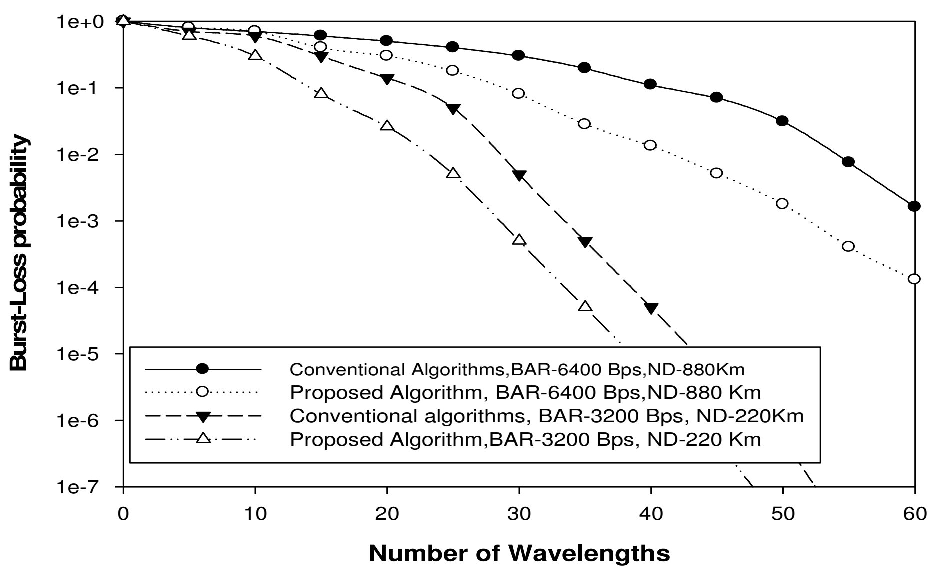

Fig. 3. Burst-loss probability V/s Number of wavelengths with burst-arrival rate (BAR) of 3200 Bps and 6400 Bps; Network-diameter (ND) 220 km & 880km

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Brazilian Society of Electromagnetism-SBMag ISSN 1516-7399

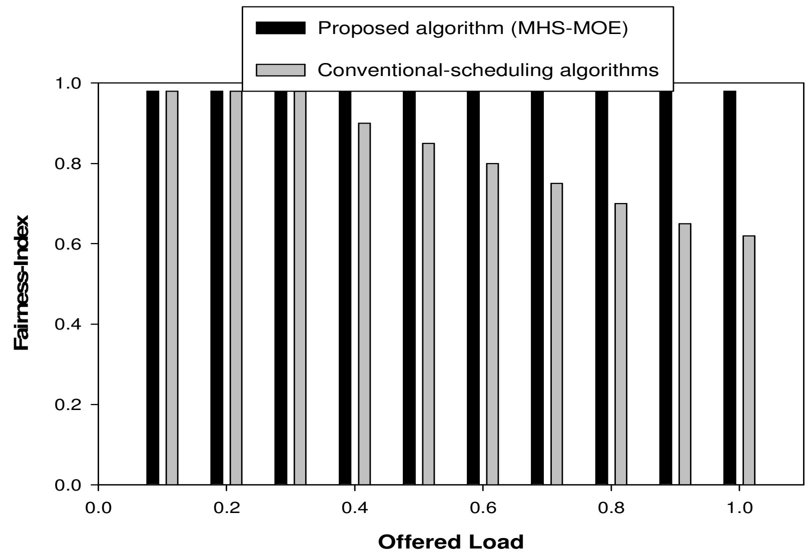

Fig.4. Fairness Index vs. Offered Load

Fig.4 shows that the proposed algorithm (MHS-MOE) can keep Fairness Index close to one. Fig. 5 shows the result of throughput of the network versus load. It has been observed that the throughput value of proposed algorithm is higher than conventional methods. Hence, this is attributed as throughput gains to the fact that proposed algorithm (MHS-MOE) can use bandwidth more efficiently.

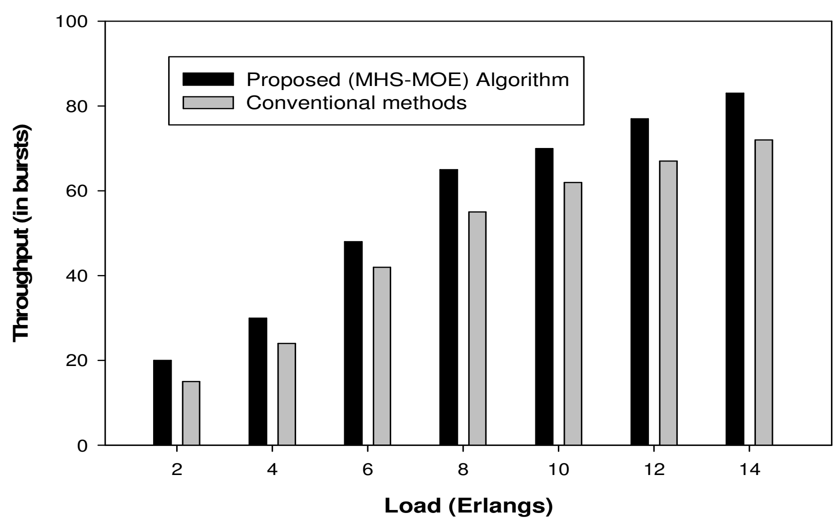

Fig. 5 Throughput V/s Load

VI. CONCLUSIONS

OBS is an emerging technology that allows variable size data bursts to be transported directly over DWDM links. In order to make OBS a viable solution, the scheduling algorithms need to be able to utilize the available wavelengths efficiently, while being able to operate fast enough to keep up with the burst incoming rate. Unfortunately, to date, scheduling algorithms that can utilize

Brazilian Microwave and Optoelectronics Society-SBMO received 15 Sept, 2008; revised 11 Aug, 2009; accepted 28 Sept, 2009
Brazilian Society of Electromagnetism-SBMag ISSN 1516-7399

wavelength efficiently take at least O(log *m*) time to schedule a single burst, which is too slow for practical OBS deployment. In this paper, a novel modified Horizon scheduling algorithm with minimum reordering effects (MHS-MOE) in OBS networks has been proposed. Simulation results have shown that the proposed algorithm runs much faster than Min-SV and is significantly simpler than Min-SV in terms of complexity. Thus, the proposed algorithm proves to be well-suited for high speed networks. Simulation results show that proposed algorithm (MHS-MOE) successfully prevents overloads while it is able to achieve fairness and optimized performance for future high speed networks applications.

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Brazilian Microwave and Optoelectronics Society-SBMO received 15 Sept, 2008; revised 11 Aug, 2009; accepted 28 Sept, 2009
Brazilian Society of Electromagnetism-SBMag ISSN 1516-7399