Priority-based Time Slot Assignment Algorithm for Hierarchical Time Sliced Optical Burst Switched Networks

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***Abstract*—Bandwidth-greedy applications are in continuous development. These applications are testing the bandwidth limit of current telecommunication and computer network infrastructures. Optical Burst Switching (OBS) is a promising optical switching technology to meet bandwidth requirements of such applications in the near-future. However, due to lack of matured and cost effective optical equipments, such as optical memories, this technology still suffers from high burst drops ratio as a result of contention in the core node. Many approaches have been proposed and evaluated to address this issue. In this paper, a priority-based time slot assignment algorithm, which we named as Priority-based segmented train algorithm (PSTA) is introduced and analyzed for Hierarchical Time Sliced OBS (HiTSOBS) a newly developed slotted OBS variant. The evaluation aims at comparing the performance of PSTA and that of HiTSOBS in terms of burst loss ratio and delay. Simulation results demonstrate that PSTA outperforms time slot assignment scheme used in HiTSOBS**

***Index Terms*—Optical Burst Switching (OBS); Hierarchical Time Sliced Optical Burst Switching (HiTSOBS); Burst Loss Probability (BLP); Time Slot; Contention.**

I. INTRODUCTION

Greedy-bandwidth applications are in continuous increase. Such applications require bandwidths that are not easily affordable by current telecommunication technology and infrastructures. Thus, alternative solutions are being searched to satisfy the needs of these applications. Optical networks are known for their high bandwidth support due to the nature of the fiber optic cable. Wavelength Division Multiplexing (WDM) technology and its derivatives such as Dense Wavelength Division Multiplexing (DWDM and Ultra-dense Wavelength Division Multiplexing (UDWDM) are emerging as a future evidence platform to transport advanced bandwidth demanding services, Currently, three optical switching paradigms have been proposed for that purpose. These technologies are: Optical packet Switching (OPS) [1] [2] [3] [4], Optical Circuit Switching (OCS) [5] and Optical Burst Switching. (OBS) [2] [6]. Among these three proposals, Optical Burst Switching technology is seen as the most feasible and viable solution to satisfy the needs of large bandwidth applications in the near future. Despite such favoritism for OBS, burst contention in the core network stands out as a major roadblock for its implementation. Burst contention occurs when flows from different input lines are sent to the same output port on the same fiber channel (wavelength) at the same time. In electronic networks, this problem is solved by using electronic memories (RAM) as buffers. Since there, are no mature and cost effective optical memories [7], OBS paradigm does not assume the use of buffer in the core network. Therefore, burst loss probability became a real hindrance to the deployment of OBS [8] and it is the focus of research in OBS. Before OBS can benefit the telecommunication service providers, contention must be solved so as to recue burst loss ratio. Various architectures of OBS have been proposed in the literature in an attempt to materialize the implementation of OBS. These attempts are based on two principles: non-slotted OBS and Slotted OBS. On one hand, non slotted OBS switch bursts in wavelength domain; on the other hand, slotted-OBS switch bursts in time domain [9]. The main advantage of slotted-OBS over non-slotted OBS is the optional use of non-cost effective wavelength converters and fiber delay lines (FDLs). In this paper, we focus on time slotted OBS variants where we propose and evaluate a priority-based segmented- train time slot allocation algorithm (PSTA) for the latest slotted OBS variant known as Hierarchical Time sliced Optical Burst Switching (HiTSOBS) [10]. To our best knowledge, this is the first time such algorithms are being proposed and evaluated for HiTSOBS. The rest of this paper is organized as follows: Section II goes through related works; Section III describes architecture of HiTSOBS. In Section IV, we discuss the PSTA algorithm. Simulation parameters, scenarios and results are discussed in Section V. Concluding remarks and future works are described in Section VI.

II. RELATED WORK

In this section, we review route, wavelength and time slot assignment schemes used in slotted WDM networks. RWA

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for non-slotted OBS were largely studied and reviewed. An early review of RWA can be found in [11]. From there on, new RWA schemes were proposed and analyzed as discussed in [12] [13], [14] [15] [16], [17] [18] [19] and others. For more details on these schemes, the reader is referred to listed references at the end of this paper. In [20], the authors studied routing and wavelength and time slot assignment problem for a circuit-switched time division multiplexed (TDM) wavelength-routed (WR) optical WDM network. So as to overcome the shortcomings of non-TDM based RWA. The algorithm was applied on a network where each individual wavelength is partitioned in the time-domain into fixed-length time-slots organized as a TDM frame. Moreover, multiple sessions are multiplexed on each wavelength by assigning a sub-set of the TDM slots to each session. A set of RWTA algorithms was proposed and evaluated in terms of blocking probability. Shortest path routing algorithm was used for the routine part of the algorithm. Least Load (LL) wavelength selection scheme was used for wavelength assignment, while a Least Loaded Time Slot (LLT) technique was proposed for time slot assignment. The researchers claimed that, their proposed RWTA algorithm performs better than random wavelength and timeslot assignment schemes. However, the use of SP as routing algorithm is performance hindrance in the algorithm. The work done by Wen et al. in [21] is similar to that proposed in [20] and suffers for the same performance problems. In [22], Rajalakshmi and Jhunjhunwala also proposed a RWTA solution for wavelength routed WDM networks to increase to increase the channel utilization when the carried traffic does not require the entire channel bandwidth. As in any TDM-WDM architecture, multiple sessions are multiplexed on each wavelength by assigning a sub-set of the TDM slots to each session. Different from the work in [20], the authors used fixed routing (FR) and alternate routing (AR) algorithms for route computation. First Fit (FF) channel assignment algorithm was used for both wavelength and time slot assignment. In this algorithm, when a call gets blocked, the already established calls in the network are rerouted; wavelength and timeslot reassigned so as to accommodate the blocked call. Based on the results obtained, it was reported that the proposed RWTA scheme can be used to maximize the time of first call blocking hence increasing the overall network performance. The use of FR, AR and FF algorithms make the algorithm less complex and easy to implement, but performance wise the algorithm lacks scalability and dynamism. The works done by the researchers in [23] and [22] are similar except that a dynamic routing algorithm was used in [23]to compute the routes in addition to FR and AR algorithms. In [24], Um et al. proposed a centralized control architecture and a time-slot assignment procedure for time-slotted optical burst switched (OBS) networks. In this centralized resource allocation technique, ingress nodes request time-slots necessary to transmit optical bursts, and a centralized control node makes a reply according to the slot-competition result. The aim is to improve burst contention resolution and optical channel utilization. Although the algorithm did achieve high resource utilization, it did so at the cost of high buffering delay at the ingress node. Additionally, the centralized nature of the algorithm makes it non-scalable. Thus it is not appropriate for large networks and expected implementation environment for OBS networks. The researchers in [25] considered dynamic traffic grooming issue in WDMTDM switched optical mesh networks without wavelength conversion capability and proposed an adaptive grooming algorithm to solve the problem. The goal was to efficiently route connection requests with fractional wavelength capacity requirements onto high- capacity wavelengths and to balance the load on the links in the network at the same time. A cost function that encourages traffic grooming and load balancing was used to achieve the aforementioned objective. The authors concluded that, their algorithm outperforms similar routing algorithms. However, nothing was mentioned about time slot assignment and its effect on network performance. In [26], Yang and Hall proposed and evaluated a distributed Dynamic RWTA algorithm based on dynamic programming approach. Their goal was to minimize blocking probability. The proposed consists of three distinct parts; each part solves a sub problem of the RWTA: Routing part; wavelength assignment section and finally, wavelength assignment section. The results were compared with SP algorithm and were reported to perform better than that algorithm. The drawback of this solution is the use of SP for route discovery. Noguchi and Kamakura [27] proposed a hybrid of one-way and two-way signalling algorithm for slotted optical burst switching (SOBS) [28]. Through numerical analysis with comparison two-way signalling algorithm, the researchers argued that their hybrid signalling algorithm performs better than its competitor in terms of end-to-end delay. In [29], the scientists observed that next generation metro network is most likely to be based on high-capacity agile all- optical networks and considered a star metro network architecture that consists of a number of buffers-less all-optical core switches. They developed three resource sharing techniques. The first scheme is reservation-based, in which decisions are made at each core switch to avoid collision and it is called Centralized TDM (CTDM). In the second scheme, distributed and independent decisions are made at edge switches, but dropped packets at the core nodes are retransmitted; this algorithm is called Distributed TDM (DTDM). Finally, a combination of the above two techniques named Hybrid TDM (HTDM) was developed to support different optical network architectures. According to the simulation results, the authors reported that, among the three schemes, HTDM performs better because. This high performance of HRDM is attributed to the fact that it can achieve a better performance under both low and high traffic loads most of the time. However, HTDM needs more evaluations under different classes of service to confirm such claims. The researchers in [30] proposed a new dynamic RWTA algorithm based on a principle known as: the maximum contiguous principle. The proposed algorithm is called: Most-Continuous-Same-Available (MCSA) resources. K shortest path routing algorithm was used to compute the routes in accordance with hops from small to large stored in the network nodes routing table.

Although the simulation results suggest that, the algorithm did reduce the blocking probability and achieved high resource utilization, the algorithm has a high network overhead due to the fact it needs the real-time information such as network wavelength utilization, time slots allocation. Finally, in [31], the researchers proposed and evaluated the optical time-slot switching (OTS) technology, in which the fixed size time-slot is adopted as the basic switching granularity, and switching is done in the time domain, rather than wavelength domain. They also studied the issue routing, wavelength and time-slot assignment (RWTA) problem. To this end, they introduced an adaptive weight function to the routing and wavelength selection algorithm, and proposed several approaches for time slot assignment such as the train approach, wagon approach and p-distribution approach. They have demonstrated that, OTS and the underlying dynamic RWTA scheme performs better than conventional non time-based OBS in terms of burst loss probability (BLP), quality of service (QoS) and class of service (CoS). In this OBS design, time slots are reserved in groups. Such constraint lead to high burst loss rate. The authors did not include loss investigation results in their paper. Thus, the architecture needs further studies and modifications. However, it is worth noting that, this is the only paper, at the time of this writing, which has studied RWTA issue in the context of WDM OBS.

III. FRAME ARCHITECTURE AND OPERATION OF HITSOBS

In the HiTSOBS understudy, time-slots are numbered serially, starting at 0. The frame size known as radix and denoted by N represents the number of slots in each frame in the HiTSOBS hierarchy. i represents the time slot at which current burst transmission starts (Equation 2). The frame structure of HiTSOBS is depicted in Fig. 1. As in [10], a slot in the level-1 frame may expand into an entire level-2 frame and so on. However, in this paper, the maximum number of frame is fixed at 3. Beyond three levels, network performance is expected to degrade especially for delay sensitive applications. Bandwidth occupation per slot in a given level is determined by Equation 1

$$S_c = (\frac{1}{kN})W_c \quad (1)$$

where S_c is the share of a slot out of the total bandwidth of a particular wavelength of a fibre link denoted by W_c and k is the order of level transporting the burst and N is the frame size in time slot. Similar to conventional OBS, in HiTSOBS, ingress edge node accumulates data from different client networks (IP, ATM, and SONET/SDH, etc) into bursts, and classifies them into three classes: Bandwidth-greedy applications (Class 0), delay sensitive applications (Class 1) and finally loss sensitive applications (Class 2). Class 0 data are transmitted at level-1; class 1 data are transported at level-2; level-3 frames are used to transport class 2 bursts.

A. Control Plane Operation

Prior to the transmission of a burst, a burst header packet (BHP) is sent to reserve necessary resources. The BHP contains four types of information as depicted in Figure 3.0: the QoS of a burst, the start slot, and the burst length. Moreover, the BHP carries the initial routing information. Such information is not available in the BHP of [10] because routing was not studied. When a core node receive the control packet, it first deduces the outgoing link for the bursts and its QoS requirements and then using the PSTA algorithm determines where the slot lies in its hierarchy corresponding to that output link. The details of the algorithm are described in Section IV.

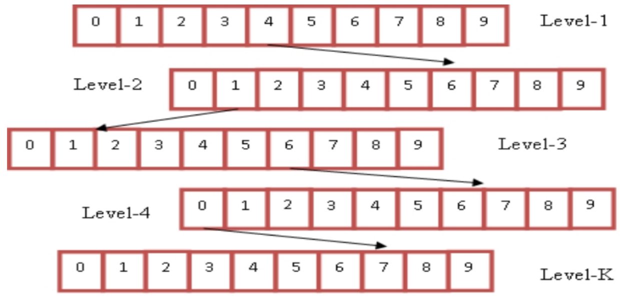


Fig. 1. Illustration of Frame Structure

Routing Information	QoS requirements	Start slot	Burst Length

Fig. 2. Burst Header Packet Contents

B. Data plane operation

Based on the routing information and the hierarchy constructed by the control plane, the data plane processes the incoming bursts and sends them to the reserved output link. A counter is maintained for each frame in the hierarchy, corresponding to the slot last served in that frame. Each time-slot, the counter for the level-1 frame is incremented by one, and the corresponding slot entry is checked. If it is a leaf entry containing a burst, the optical crossbar is configured so that the input line corresponding to that burst is switched to the output link under consideration. If on the other hand, the slot entry points to a lower level frame, the counter for the lower-level frame is incremented, and the process resources.

IV. PRIORITY-BASED SEGMENTED TIME SLOT ASSIGNMENT ALGORITHM

After a burst is assembled and sent to the network, a routing, wavelength and time slot assignment algorithm is responsible for choosing the appropriate route, wavelength and time slot to transport that burst. In this paper, shortest path routing and first fit wavelength assignment algorithms are assumed. For time slot assignment, a prioritized Segmented-Train time slot assignment algorithm (PSTA) is developed and implemented. See Fig 4. In this algorithm, time slots are allocated in a given level depending on the priority of the burst to be transported. Different form reservation technique used in [10], Equation 2 is used for time slot reservation.

$$S_R = i + (B - [\frac{(B-1)}{z}](z-1)z + [\frac{(B-1)}{z}]N \quad (2)$$

In the above equation, B represents burst size, N is the frame size, z represents the size of the train (number of coaches) and k is the initial position of time slot reservation. For instance, lets assume that, we have an optical time slot switch (OTS) that is capable of switching frames of 10 time slots (i.e., the frame size is 10 time slots). If a burst of high priority arrives at this core node, after being assigned the highest level in the hierarchy (i.e., level 1), High-PSTA(z), where the number of coaches of the train is fixed at 3, will be invoked. If the burst size is 10 time slots, time slot assignment is done as follows: The first 3 segments of the burst will be transmitted in slots No. 0, 3 and 6. And so on. Using the same OTS, if a burst of medium priority arrives at the core node, it is transmitted at the second highest level in the hierarchy (i.e., level 2) and Med-PSTA(z), where number of coaches is 2, is executed. The assignment procedures are similar to that of high priority burst except that time slots are reserved by pairs. When a low priority burst arrives at this core node, the lowest level in the hierarchy (i.e., level 3) is used to transport the burst and Norm-PSTA(z), where the train consists of only one coach will be called and the reservation of time slots is done one at a time as in the original HiTSOBS.

Algorithm 1 PSTA Algorithm

Notations:
t_a: Arrival time of a burst. $\mathbb{C}$: Class of the Burst. B_{qreq}: Burst QoS requirements. B: Burst to be transmitted. z: Number of coaches in a train. b : Minimum Bandwidth requirement. D: Maximum delay requirement.L: Maximum loss requirement.
for all B **do**
  initialize candidate time slots
  $T_n^m \leftarrow t$
  if $\mathbb{C} = 0$ **then**
    $B_{qreq} \leftarrow b$
    Execute High_PSTA(z)
  else if $\mathbb{C} = 1$ **then**
    $B_{req} \leftarrow D$
    Execute Med_PSTA(z)
  else
    $\mathbb{C} = 2$
    $B_{qreq} \leftarrow L$
    Execute Low_PSTA(z)
  end if
end for

V. Simulation Factors and Results

A. Simulation Factors and Scenarios

To test the efficiency of HiTSOBS in a mesh WDM OBS network environment and implement the newly developed time slot assignment algorithm, we have modified the discrete-event simulator developed by the researchers in [10] to integrate Shortest Path (SP) and first fit wavelength algorithms for routing and wavelength assignment purposes. The algorithm was evaluated using the 14 nodes NSFNET topology as shown in Fig refsec5:fig1. We assumed that, the nodes are interconnected with fiber links of 8 wavelengths each. Bursts for flow j arrive as a Poisson process at rate $\frac{\lambda_i}{B}$ bursts per timeslot where B represents the average burst size. The timeslot size was chosen to correspond to $1\mu s$, which is consistent with the switching speeds of solid-state optical switching technologies available in the industry [32] and [33]. Two wavelength capacities were analyzed: 1 Gbps and 10 Gbps. Burst size was fixed at 125 KB [10]. The number of levels was chosen to be 3. Three classes of burst were assumed: class 0 (High Definition Multimedia Video/audio), class 1 (High Definition Multimedia streaming) and class 2 (normal data: FTP, email, telnet, etc...). Each flow is assigned to a level depending on its class. Upon arrival of a flow's burst at the edge node, the following processing happens: if the arriving burst encounters a non-empty queue, the burst is queued in the buffer if it is not full and awaits service. If on the other hand the arriving burst encounters an empty queue, the edge node reserves a time slot according to PSTA using equation 2. Time slots are reserved over a number of frames equal to the burst length and the burst is transmitted on to the core node. As in [10], the slot positions for burst slices for any given flow vary each time the flow becomes newly backlogged; this is important because it helps prevent synchronization and phase locking which complicates the implementation of OPS. Simulation parameters are summarized in Table I.

TABLE I
SIMULATION FACTORS AND LEVELS

Factors	Levels
Wavelengths per link	8
Wavelength Capacity (Gbps)	1, 10
Frame Size (Time slot)	10
Burst Size (KB)	9
Time Slot size (μs)	1, 2
Buffer Size (Time slot)	10
Number of Flows	1000
Topology	NFSNET
Number of Simulation run	20

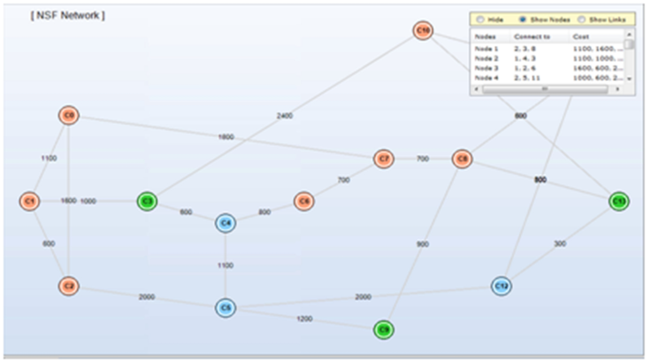
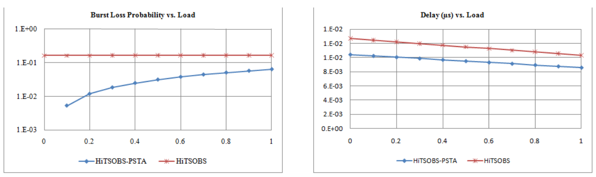


Fig. 3. Simulation Topology



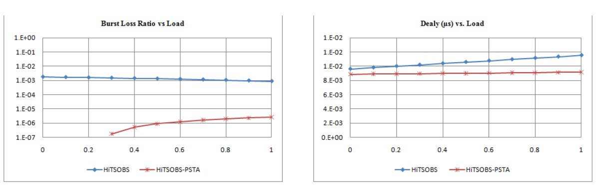
(a) Loss vs. Load for 1 Gbps (b) Delay vs. Load for 1 Gbps

Fig. 4. Investigating the effect of 1 Gbps Channel Capacity

B. Results Analysis

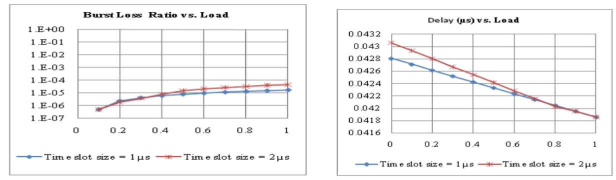
In this section, different simulation results are discussed. Fig 4 shows the burst loss ratio (BLR) and the delay performance for HiTSOBS and HiTSOBS-PSTA for wavelength capacity of 1 Gbps. In Fig 5, the same comparison is made for wavelength capacity increased to 10 Gbps. Fig 6 compares the performance of both algorithms for different time slot size in μs. Similar to the work in [10], the burst size and frame size were chosen to be 125 KB and 10 respectively. Shortest path algorithm was used for route selection and first-fit technique was used for wavelength assignment.

From the above figures, it can be observed that, the proposed time slot assignment algorithm (PSTA) performs better than the scheme used in [10] for time slot assignment. This is due to the fact that, in PSTA, when a burst is announced, we try to reserve more than one time slot in one frame based on the QoS requirements of the burst. Also, the way bandwidths are allocated to each time slot contributes to the superiority of our algorithm. Fig 5 demonstrates similar results as in Fig 4 and the arguments of the superiority are similar. However, in this case, wavelength capacity was increased to 10 Gbps which has,



(a) Loss vs. Load for 10 Gbps (b) Delay vs. Load for 10 Gbps

Fig. 5. Investigating the effect of 10 Gbps Channel Capacity



(a) Loss vs. Load (b) Delay vs. Load

Fig. 6. Investigating the effect of Time Slot size

remarkably, pulled the performance up. To study the effect of time slot size on both loss and delay for HiTSOBS, we run two cases of simulation; one with $1\mu s$ and the other with $2\mu s$ as time slot size for both algorithms. For space limitation, we only show the results of this investigation for HiTSOB-PSTA in Fig 6. These results suggest that longer time slots have negative impact on loss and delay of a burst inverse especially at low and medium load (0.5). This is not surprising, because longer time slot means more time to process, so at low load, burst will have to wait longer before they are assigned a time slot (more delay) and this lead to more loss as load increases and the delay starts to decrease at very high load and the size of time slot size becomes negligible.

VI. Conclusion

In this paper, we have proposed and evaluated a prioritized time slot assignment algorithm for HiTSOBS. Simulation results demonstrate that, the newly propose algorithm (PSTA) does help in improving HiTSOBS in terms of loss and delay as compared with the technique used in [10]. However, the authors believe that, HiTSOBS-PSTA should produce better results when better route and wavelength selection algorithms are used. Additionally, we think that HiTSOBS should perform better than traditional OBS. To prove these hypothesis, the authors have integrated PSTA with an adaptive and QoS based route and wavelength assignment algorithms that is integrated with PSTA and it is under evaluation.

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