A New Approach for Wavelength Assignment in Optical Burst Switching Networks

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***Abstract*—In this paper, we propose a new approach for wavelength assignment in Optical Burst Switching (OBS) networks. Unfortunately, existing priority based approaches do not efficiently use available information at the routers. Our approach employs learning-based wavelength assignments (LWA) in OBS networks. In order to strengthen LWA approach, we further propose two algorithms; LWA with preemption (LWA-WP) and Dynamic Burst Aggregation (DBA) algorithms. While the former aims at reduced burst drops for wavelength conversion incapable routers, the latter aims at speeding up the learning phase of LWA algorithm. We show that the proposed learning based approaches profoundly decrease the burst drop ratio and increase the system performance.**

***Index Terms*— wavelength assignment, wavelength conversion, burst aggregation, OBS, WDM**

I. INTRODUCTION

Optical Burst Switching (OBS) is a promising technique that combines the advantages of optical packet switching and circuit switching. A control packet is sent before the burst of data via a dedicated wavelength channel and the connection is set up by configuring the switches along the path. Therefore data bursts can traverse the network without the need for waiting in buffers or being extracted and processed at each node [1][2]. Recently, researchers are investigating various OBS parameters, and proposing different OBS architectures [7]. In this paper, we investigate the importance of integrating intelligence into wavelength assignment in OBS networks.

One of the most important issues in OBS, just as in any WDM network, is whether the OBS routers are wavelength conversion capable (WCC) or not. Most of the OBS architectures in the literature assume full wavelength conversion capability, which is desirable but not a practical assumption due to the immaturity and the expense of the conversion technology. In the wavelength conversion incapable (WCI) case, it is necessary to deal with the wavelength continuity constraint, which causes high burst loss ratios. Some wavelength assignment techniques are proposed in wavelength routed networks which can be applied in centralized architectures. Since most of the proposed OBS architectures are decentralized, some distributed methods need to be devised.

For the wavelength assignment problem, assigning more than one wavelength for each burst may be a solution but obviously it is very inefficient. To solve the problem of efficient wavelength assignment in decentralized OBS architectures with no wavelength conversion capability, *Wang et al.* [3] propose a priority based idea which minimizes blocking probability by favoring an appropriate wavelength for each source-destination pair. Each source keeps a wavelength priority database for every destination node where the priorities of wavelengths depend on statistical data of past transmission results. Successful transmissions increase the priority and unsuccessful ones decrease. This way senders tend to assign safest wavelengths to the burst, the network adapts to dynamic traffic, and burst loss probability due to contentions is decreased. Authors of PWA extend their algorithm to be applicable in sparse wavelength convertible OBS networks and they conclude that their approach is successful in decreasing the burst drops [4]. The idea behind PWA is nice but it may suffer especially in large scaled networks. Assume if there are high number of nodes between source and destination, the prioritization scheme will not properly use all available information. Similarly, past information for WCC nodes is not fully utilized. In addition, PWA may suffer when dynamic traffic is considered. The efficiency of PWA algorithm is also related with many OBS parameters that should be identified and investigated explicitly. Recently, some work is done to improve the performance of PWA. Teng *et al.* [8] combine PWA with traffic engineering and take the network topology into account for more efficient assignment of wavelengths. However, there are many OBS-specific features that should be adjusted for further improvement of the performance.

To meet the challenges above in wavelength assignment, we put together all the available information, and include intelligence into priority based approaches in OBS network. Specifically, we propose a new learning based distributed wavelength assignment algorithm for sparse wavelength conversion capable OBS networks. Besides the end nodes, we also carry the intelligence to core routers that are WCC. We describe this technique, namely learning-based wavelength assignment (LWA). Based on this technique, we propose two new techniques that increase the efficiency and the learning speed of the system. The first one is LWA with preemption (LWA-WP), which allows preemption in WCI nodes. In LWA-WP, various parameters could be chosen as a metric for preemption. The second one is Dynamic Burst Aggregation (DBA) aiming at increased learning speed. In DBA algorithm, we fine-tune the burst aggregation process to account for the different needs of learning phase and stable traffic delivery phase.

The rest of this paper is organized as follows. Section 2 presents the learning based wavelength assignment (LWA) algorithm. Section 3 presents LWA with preemption (LWA-WP) algorithm for WCI nodes. Section 4 presents Dynamic Burst Aggregation (DBA) algorithm. Section 5 presents the simulation environment and performance results for the proposed techniques under various system parameters. Section 6 concludes this work.

II. LEARNING-BASED WAVELENGTH ASSIGNMENT (LWA)

LWA depends on deciding the safest wavelength for a route from a source to a destination in an OBS network with sparse network conversion capability. Different from PWA, we differentiate between the edge nodes and core switching nodes. Core nodes are classified according to their wavelength conversion capability: Wavelength Conversion Capable (WCC) and Wavelength Conversion

Incapable (WCI) nodes. Each edge node and WCC node aims to pass the burst to the next WCC node or to the destination with the most appropriate wavelength. For this purpose, they store a database of past transmission info which includes the following values for each source-route pair:

$\boldsymbol{S(\lambda_i)}$: Success degree for each λ_i.
$\boldsymbol{U(\lambda_i)}$: Fault degree for each λ_i.
$\boldsymbol{D(\lambda_i)}$: Success ratio.

For each successful transmission, an ACK is received and $S(\lambda_i)$ is incremented by a value of constant F. Similarly, $U(\lambda_i)$ is incremented by a value of constant G when a NACK is received. F and G could be constant values or variables that are proportional with some parameters like burst sizes. To compensate for the effect of the absolute value of S in comparisons in the presence of a large value for U or vice versa, we define a new variable as the ratio of S to U to measure the success rate of a particular lambda, λ_i. We define $D(\lambda_i)$ as $S(\lambda_i) \ / \ U(\lambda_i)$ where $S(\lambda_i)$ and $U(\lambda_i)$ are initially 1. In an edge node or a WCC node, the bursts originated from a particular source and traversing a particular route are directed to the outgoing lambda with the highest D value (corresponding to their source-route pair) among all available wavelengths.

As we mentioned above, the aim is passing the burst to the next WCC node. Bursts that are safely passed to the next WCC node are treated to be successful; even if they are dropped before reaching the final destination. If a WCC node receives a NACK, it increments the fault degree and marks the NACK before passing it upstream (M-NACK). A WCC node or an edge node receiving the M-NACK increments its success degree instead of fault degree and the source node resends the burst. Figure 1 illustrates Marked NACK concept.

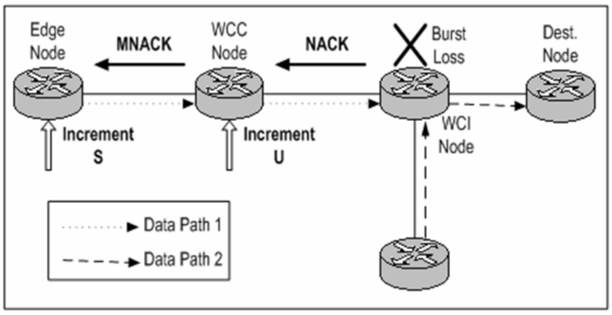

Figure 1 Marked NACK concept

While resending a burst, we argue that aggregating it with the newly arriving bursts would increase the learning performance, as well as decreasing the overhead due to control packets and guard bands. The effect on the learning performance is due to avoiding the concurrent transmissions to a destination, and hence avoiding transmitting the burst with a lambda that is not favored.

Time is also an important parameter in case of dynamic traffic. Most recent information about successful or unsuccessful transmissions is more important than old information. Therefore, we propose an aging mechanism that decreases all S and U values at a ratio of R_A with a given time period T_A. R_A and T_A values should be carefully selected for different network topologies and traffic patterns, and remain as design parameters.

III. LWA WITH PREEMPTION

WCI nodes are the most critical nodes in the context of burst drops. If the incoming lambda is not available for outgoing link, burst is dropped. If we allow preemption we can decide which one(s) of the contending bursts to drop, and we may define a number of different metrics that will enable us making a fair choice. Favored bursts force the drop of others even if they have already been registered. In the case of preemption, a cancellation message should be sent downstream in order to avoid resource waste.

In LWA-WP, deciding which bursts to favor is an important issue. We propose following metrics for this purpose:

A. *Previous Success Ratio (D value):* This is the D value for the (source, route) pair of the burst on last passed WCC node. This value should be stored in control packet. If this value is small for a burst, this means the burst is traversing with an unstable lambda. In order to favor more stable ones over the unstable ones, it is reasonable to pick this value as preemption metric. Moreover, employing this value could also achieve better fairness between the successful transmissions on long versus short data paths. Fairness problem arises from the fact that it is easier to find free wavelengths along links of a shorter path rather than a longer one [5]. Long routes could be prioritized by assigning larger D values for them. This can be done by setting the increment values of success and fault degrees (F and G values) proportional with the hop-count of the corresponding route.

B. *Hop-count:* Number of hops traversed before the contention. By picking this value as preemption metric, the bursts that have traversed more routers are favored over the bursts that have only recently.

C. *Burst size:* For long bursts, probability of being dropped is higher than short bursts and drop of long bursts cause more data loss. Therefore, to improve performance it is reasonable to favor long burst over short ones.

D. *Priority:* In order to satisfy QoS, high priority bursts should be favored over low priority bursts. Hence, if we allow high priority bursts to preempt others, relative QoS could be provided.

E. *Hybrid Scheme:* Each of the metrics listed above have some attractive features. Employing the first metric (previous D) seems to increase the learning speed and achieve fairness between short versus long paths. Second and third metrics (hop-count and burst size) seem to improve performance and lower data drops even they have some prevention on learning mechanism. Fourth metric (priority) is desirable to achieve QoS. Therefore it is a nice idea to employ a hybrid scheme. Various hybrid schemes and their effects are discussed in the next sections.

The preemption metric (say M_P) for each burst is stored in WCI nodes when the reservation is made. In the case of contention, burst_i will force burst_j to be dropped if $\boldsymbol{M_{Pi}} > \boldsymbol{M_{Pi}} \text{ x } \boldsymbol{D_S}$ where D_S is a determined degree that is greater than 1.

IV. DYNAMIC BURST AGGREGATION (DBA)

In OBS, packets coming from the electrical network with the same destination are aggregated at the edge of the optical network into bursts. Burst assembly strategy is implemented at edge nodes and has great impact on the overall network operation. It is possible to employ a traffic shaping at the edge nodes and adjust the burst injection process into the optical core by adjusting the assembly strategy. The key parameters for this adjustment are a pre-set timer and maximum and minimum burst sizes [6]. The timer is used to determine the burst assembly frequency. In order to avoid excessively large data bursts, burst sizes are constrained with a maximum threshold value and aggregation is completed before the time period ends. Burst aggregation is also limited by a minimum threshold in order to avoid very short bursts which can cause possible control packet congestion.

Adjusting these parameters, it is possible to improve the performance of the proposed learning mechanism. For this purpose we classify transmission from a source to a destination into two phases: learning phase and stable phase. When a source newly starts transmitting on a particular route, there would be no favored lambda and the transmission is said to be in the learning phase. When a lambda is favored or a pre-determined time expires, it switches to the stable phase. It stays in stable phase unless a long idle period comes. *S* and *U* values could be a measure for this phenomenon, since the aging mechanism in LWA would reduce those statistical values to almost their initial values (one) in long idle periods.

In order to speed up learning in the first phase, we propose to shorten burst aggregation period; hence, form large number of bursts with smaller sizes and update the database more frequently. When the learning phase ends, aggregation period is increased. Figure 2 illustrates the idea. **T_L** and **T_S** corresponds to the time periods for aggregation in learning phase and stable phase successively.

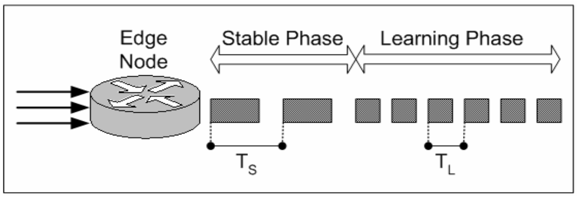

Figure 2 Dynamic Burst Aggregation

Setting T_L too small may increase the learning speed but it causes control packet congestion and decreases the utilization due to guard bands needed between bursts (to accommodate possible timing jitters at each intermediate node). Therefore T_L should be set appropriately depending on the network characteristics.

Problem arises when applying DBA to LWA-WP. Since the number of bursts increase in the learning phase, number of contentions is expected to increase. If we allow short bursts (that are in learning phase), to preempt longer bursts (that are in stable phase) throughput could decrease significantly. To avoid this scenario, it seems necessary to include burst size in the preemption metric.

V. SIMULATIONS

The simulation of proposed techniques is based on a 21-node network topology as shown in Figure 2. Twelve of them are edge routers and nine of them are core routers. Core routers are partitioned as WCC and WCI nodes as shown in the figure. The central routers are expected to carry more traffic and chosen to be WCC. All links are two way and have equal length of 150 km. This topology, rather than an arbitrary network layout, is chosen to show the effects of design parameters better.

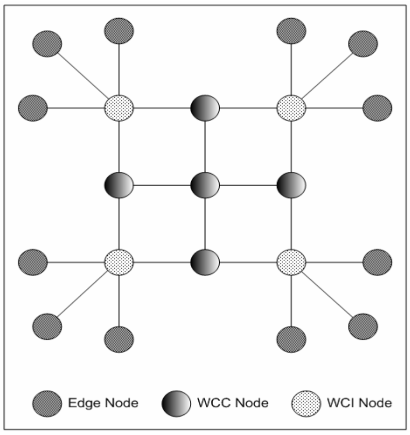

Figure 3 Simulation network topology

As shown in Figure 3, edge nodes can be classified into four groups. We assume that each source node sends burst to three destinations (each from different group) in a Round-Robin fashion as described in [9]. Aggregation period is 6 ms for all arrivals except in the learning phase for DBA. Each node collects data from four different links. From each link, data arrives with an exponential distribution with mean 5 Mbits. Some other assumptions and settings are as following:

- Transmission rate is 10 Gbps
- Dijsktra's shortest path algorithm is used as routing protocol. Routes are statically predetermined. Deflection routing is also not supported.
- Delayed reservation (JET) [1] is assumed as the resource reservation scheme. Exact burst sizes are assumed to be estimated perfectly. Guard bands are also disregarded.
- When two bursts simultaneously arrive to a core node, one that is randomly picked is assumed to have arrived first.
- Offset time is static and set to 0.5 ms.
- In WCC nodes, full wavelength conversion is assumed, i.e. a wavelength could be converted to any wavelength.
- WCC nodes include dedicated wavelength converter for each wavelength along each output link.
- *F* and *G* (increment values for success and fault degrees) are set to constant values of 1 and 4, successively.
- Aging period (T_A) is set to 20 ms and aging ratio (R_A) is 0.9.

Some definitions that we used while presenting our simulation results are listed below:

- M_P: Preemption metric
- N_W: Number of wavelengths per link
- N_D: Number of drops

The basic performance metric for our networks, as in any OBS network, is the burst drop ratio. We discuss drop ratio in two ways: First is the ratio of number of dropped bursts to the number of transmissions, and the second is the total size of the transmitted bursts to the total size of the transmitted bursts to the total size of the transmissions.

$$R_{N/A} = \frac{Number\,of\;\;NACKs}{Number\;of\;\;ACKs}$$

$$R_{D/T} = \frac{Total\;size\,of\;\;dropped\;bursts}{Total\;size\;of\;\;transmitted\;bursts}$$

Moreover, we define some other metrics in order to better observe the effect of various techniques.

$$R_{W/T} = \frac{Total\ unsuccessful\ link\ utilization\ time}{Total\ successful\ transmission\ time}$$

$$R_{Pi} = \frac{Dropped\ bursts\ with\ priority\ i}{Transmitted\ bursts\ with\ priority\ i}$$

$R_{W/T}$ is the ratio of total utilization time of network resources by the bursts that are exposed to drop, to the total utilization time of network resources by the bursts that are successfully transmitted (unsuccessful link utilization time is not included in total successful transmission time). This value of $R_{W/T}$ is expected to be small if most of the burst drops occur in the initial hops. It also gives an idea about average end-to-end delay.

First, we test the burst loss performance of learning strategy by comparing three strategies: Random wavelength assignment, LWA-EO (edge-nodes only) and LWA. LWA-EO is the same as LWA technique except that WCC nodes have no learning mechanism and randomly assign outgoing wavelength if continuity is not satisfied. Also marking NACK concept is taken out and databases in edge nodes are not updated if the burst is subjected to wavelength conversion in any WCC along its route. Note that LWA-EO is very similar to PWA proposed in [4]. We include this technique to our simulations in order to observe the effects of making core intelligent. Firstly we simulate the network for $N_W = 5$. We take the average of 30 runs and results of the simulations show that learning mechanism effectively works and as time passes number of new drops converges to zero in the case of static traffic. Figure 4(a) shows the number of burst drops in each 100 ms time interval and Figure 4(b) shows the overall data drop ratio until the corresponding time unit. It can be seen clearly that making WCC nodes intelligent significantly improves the performance.

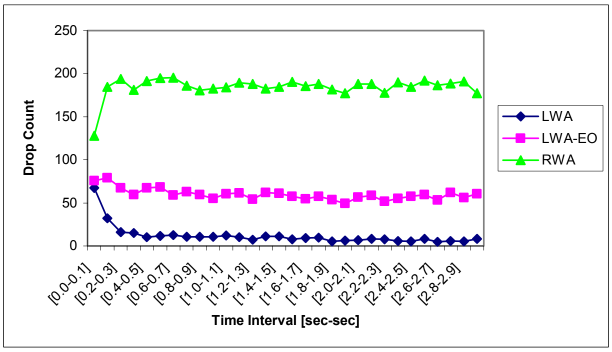

Figure 4(a) Number of drops (N_D) vs time interval

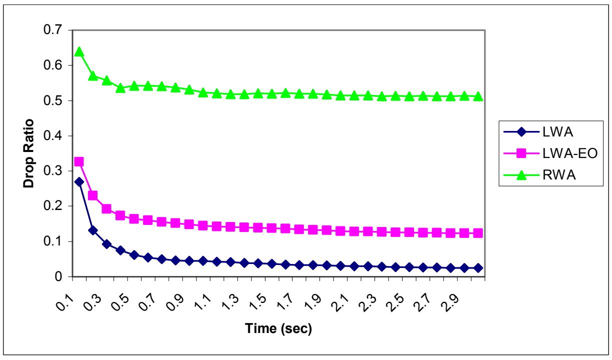

Figure 4(b) Data drop ratio ($R_{D/T}$) vs time

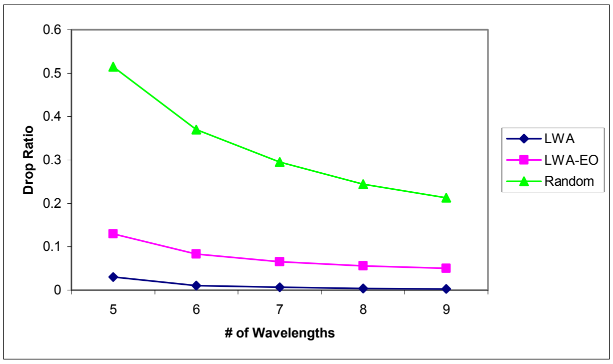

Figure 5 Data drop ratio ($R_{D/T}$) vs N_W

Obviously, N_W has a great impact on the performance. For $N_W < 5$, bursts would be dropped because of the wavelength shortage and this condition could not be avoided by any wavelength assignment strategy. Starting from $N_W = 5$, we test the effect of learning mechanism as N_W increases and results are shown in Figure 5. We observe that as N_W increases, the effect of learning mechanism is seen better and the relative difference between LWA and random case increases.

Next, we test the effect of adding preemption capability in WCI nodes. From this point on, we make changes in the simulated traffic to better observe the effect of proposed improvements. Half of the twelve edge nodes send data to three fixed destinations. Other half also sends data to three destinations, but their destination triple randomly changes in each 200 ms. We compare the performances of LWA and various LWA-WP schemes for $N_W = 8$. Comparison results are shown in Table 1.

We observe that when we do not employ burst size as preemption metric, $R_{D/T}$ increases. Long bursts are subjected to being dropped more than short bursts and allowing short bursts to preempt long ones causes unfair conditions. Moreover, since we aggregate retransmitted bursts with newly arriving bursts, burst size could continue to increase beyond our control, and it becomes even harder to transmit them in bursty traffic. In addition to all of these reasons, longer burst drops cause more data loss and it seems necessary to include burst size to the preemption metric for LWA-WP case. Another observation is that $R_{W/T}$ is best in hop-count case. This is expected because when employing hop-count as preemption metric, most of the burst drops occur in initial hops, therefore unsuccessful link utilization decreases. Some hybrid schemes including burst size metric are also tested and the results are listed in Table 1. In hybrid cases, all of the preemption metrics are normalized with mean 1 and the weight of each metric is chosen to be same (We assume that average burst size, average hop count and average priority value could be estimated or known). We normalize D value by modifying it as follows:

$$D(\lambda_i) = \begin{cases} 2 - \dfrac{U(\lambda_i)}{S(\lambda_i)}, & if\ \ S(\lambda_i) > U(\lambda_i) \\ \dfrac{S(\lambda_i)}{U(\lambda_i)}, & otherwise \end{cases}$$

Hence D value varies between 0 and 2.

Simulation results show that hybrid schemes are preferable, but they do not contribute much when compared to pure (BS) scheme. Minimum $R_{D/T}$ value is generally obtained by pure (BS) case, whereas minimum $R_{N/A}$ and $R_{W/T}$ values are usually obtained by hybrid schemes.

TABLE 1 Simulation Results for LWA and LWA-WP, N_W=8, D_S=1.25, Time=2sec

M_P	$R_{D/T}$	$R_{N/A}$	$R_{W/T}$
None	0.0210	0.0190	0.0075
Burst Size (BS)	0.0158	0.0177	0.0069
Hop count (HC)	0.0218	0.0184	0.0064
Previous D (PD)	0.0207	0.0178	0.0075
Hybrid (BS+HC)	0.0158	0.0174	0.0066
Hybrid (BS+PD)	0.0160	0.0172	0.0070
BS+HC+PD	0.0161	0.0171	0.0064

Next, we test the QoS support in LWA-WP. We define three priority classes at increasing order; 1, 2, and 3. The existence ratios of bursts with classes 1, 2 and 3 are assumed to be 3/6, 2/6 and 1/6, respectively. Results are given in Table 2. If M_P is chosen to be pure priority, relative QoS is satisfied. Surprisingly, burst drop ratio is also slightly better than the pure LWA case. This might occur because we aggregated the bursts that are to be resent with the newly arriving ones with the priority of new bursts. Since dropped ones generally have low-priorities, this way they are favored during retransmission. Including burst size to the preemption metric increases the performance, but there exists a trade-off between QoS and overall burst drop rate.

TABLE 2 Simulation Results for QoS supported LWA-WP, N_W=8, D_S=1.25, Time=2sec

M_P	$R_{D/T}$	R_{P1}	R_{P2}	R_{P3}
None	0.0210	0.0191	0.0189	0.0189
Priority (PR)	0.0213	0.0261	0.0125	0.0024
PR+BS	0.0168	0.0220	0.0157	0.0111

Finally, we changed the arrival process as described in Section 4 in order to observe the contribution of DBA to the learning mechanism. We set DBA parameters as following:

- T_L (aggregation period in learning phase):1.2 ms.
- Maximum expiration time for learning phase: 50 ms.
- A lambda is said to be favored when *S/U>10*. If a lambda is favored before the maximum time expires, learning phase ends.

For the same traffic we simulate some LWA and LWA-WP schemes employing DBA and the results are shown in Table 3.

$R_{N/A}$ and $R_{W/T}$ increases in DBA case. This is expected because drop count in learning phase is more than drop count in stable phase and most of the dropped data is small bursts. Average length of successfully transmitted bursts is much higher than the average length of dropped bursts.

Pure LWA (without preemption) results with somewhat poor performance because of the high drop rate of longer bursts. Long bursts are more likely to be dropped then short bursts. Since in DBA we feed traffic with a number of short bursts in learning phase, favoring long bursts over others will improve performance. As we mentioned in Section 4, including burst size in preemption metric gives better results. Even if the effect of guard bands (which we ignored) and congestion of control packets (which increased almost 1.3 times in our simulation) would degrade the performance, simulation results show that DBA has a significant contribution to the system utilization.

TABLE 3 Simulation Results for DBA, N_W=8, D_S=1.25, Time=2sec

M_P	$R_{D/T}$	$R_{N/A}$	$R_{W/T}$
None	0.0146	0.0242	0.0091
BS	0.0101	0.0235	0.0084
HC	0.0173	0.0270	0.0086
PD	0.0170	0.0268	0.0097
BS+HC	0.0104	0.0241	0.0082
BS+HC+PD	0.0128	0.0277	0.0097

VI. Conclusions

In this paper we proposed a new learning-based wavelength assignment (LWA) algorithm for use in Optical Burst Switching (OBS) networks. LWA algorithm reduces the blocking probability by using past transmission information for wavelength assignment. Based on LWA, we elaborated two techniques; LWA with preemption (LWA-WP) and Dynamic Burst Aggregation (DBA). LWA-WP increases performance by favoring important bursts via a preemption mechanism in Wavelength Conversion Incapable (WCI) routers. We showed that the best performance result in LWA-WP is achieved for burst size of preemption metric. Moreover, DBA technique is proposed to further increase the learning speed by adjusting burst aggregation period at the beginning of transmission. Simulation results show that DBA technique successfully decreases the burst drop ratio and improves performance. We are currently working on routing problem using the proposed LWA based algorithms.

Acknowledgements

This work is supported by the State Planning Organization of Turkey under grant number 03K120250, and by the Bogazici University Research Projects under grant number 04S105.

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