Resource Aware Routing and Intelligent Wavelength Assignment for Cooperative Clustered OBS Networks

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Abstract- Burst loss is a critical issue in Optical Burst Switching (OBS) networks which restrains its deployment. This article presents a novel routing and wavelength assignment strategy for the Cooperative Clustered OBS (C2OBS) network architecture, to proactively avoid contention. In C2OBS, the network topology is divided into several manageable overlapping zones/clusters, with a Zone Head (ZH) node keeping an information base of zone resources. The ZH pre-computes a list of alternate k-shortest disjoint paths for every ingress-egress node pair within the zone. The ZH utilizes both the inferred knowledge about wavelength usage at the zone intermediate nodes and a novel poles apart heuristic for assigning wavelengths to incoming bursts. A route is selected among the pre-computed paths where the selected wavelength is available. As a result, traffic is balanced among the set of pre-computed routes, thus proactively reducing probability of contention. This strategy is called Resource Aware Routing (RAR) and Intelligent Wavelength Assignment (IWA).

Keywords: Optical Burst Switching, Contention Avoidance, Routing and Wavelength Assignment

I. INTRODUCTION

Optical Burst Switching (OBS) is envisioned as an all-optical technology to fulfill the requirements of on demand high bandwidth bursty traffic applications running on the Internet. In this network architecture, the ingress node selects a route from ingress to egress node, a wavelength, and an offset time for the upcoming data burst. Then, it sends a Burst Header Packet (BHP) on the control channel, containing source and destination addresses, offset time, length, and the Class of Service (CoS) of the corresponding data burst, for reserving a wavelength channel at each intermediate core node along the route before transmitting the burst payload [1-6]. The ingress node lacks the global knowledge of resource availability in the network and often selects a sub-optimal wavelength and route causing resource contention and a relatively high burst loss probability. This issue has restrained both the development and deployment of OBS networks [7]. However, wavelength contention at the intermediate core nodes can be mitigated by effectively utilizing the wavelength paradigm and routing.

Wavelength contention can be reduced by providing wavelength convertors at intermediate core nodes. However, these devices are still immature and expensive and thus increase both the cost and complexity of implementing OBS networks. An alternative solution to mitigate contention is to intelligently assign wavelengths to incoming bursts [8, 9]. A number of heuristics have been proposed for assigning wavelengths like First-Fit, Random, Least Used/SPREAD, Most Used/PACK, Min-Product, Least Loaded, MAX-SUM, Relative Capacity Loss, Wavelength Reservation, Protection Threshold and Distributed Relative Capacity Loss [10], but are not appropriate for optimal performance in OBS networks [8]. Some priority based adaptive wavelength assignment algorithms [11, 12, 13] have also been proposed, but they are computationally expensive for on demand bursty traffic.

Routing techniques for OBS networks can be static, dynamic or fixed-alternate routing [14-16]. Static shortest path routing calculates the shortest path using the number of hops as the cost function. This approach is very simple, offers minimum delay, and optimizes resources utilization, but its performance is usually not sufficient under high load conditions. Furthermore, it often causes some links to become congested while others remain underutilized, resulting in poor network resource utilization. Such a situation is undesirable as a few highly congested links could lead to unacceptably high network burst loss probability [17].

In adaptive routing the path from a source node to a destination node is chosen dynamically depending on changes in the incoming traffic or in the topology, or both [18]. Adaptive algorithms can be centralized, isolated, or distributed. In the centralized approach, a single entity uses information collected from the entire network in an attempt to make optimal routing decisions. However, a single control node may become a performance bottleneck. In the adaptive isolated approach, a local algorithm runs separately at each node, using only local information, such as output link congestion. In this greedy approach, the routing decision may lead to a relatively high burst loss probability because it is taken without global knowledge of resource availability. The distributed algorithm uses a mixture of local and global information for making routing decisions. Nevertheless, computing paths dynamically for each incoming burst can be computationally very expensive.

In fixed alternate routing, each node in the network is required to maintain a routing table that contains an ordered list of a number of fixed paths to each destination node[19]. This approach reduces the blocking probability when the traffic distribution is static. However, due to lack of global knowledge, the performance is not adequate for bursty traffic. A Cooperative Clustered OBS (C2OBS) architecture [20, 21] has been proposed to reduce resource contention due to routing and wavelength limitations. In this network architecture each zone has a controlling node called Zone Head (ZH), containing complete zonal resource information

978-1-4673-2890-6/12/$31.00 ©2012 IEEE

called Zonal Information Base (ZIB) for effective resource reservation within the zone. The ZH also maintains a short resource usage history called Short History Base (SHB). A C2OBS network has multiple ZHs, one per zone, for controlling their corresponding zones. The neighboring overlapping zones have one or more common nodes serving as zone gateways, which cooperate for resource reservation between adjacent zones. Contrasting with the extant OBS architecture, and for facilitating optimal resource utilization, routing, wavelength assignment, and offset time estimation in C2OBS have been shifted from the ingress node to the ZH for taking advantage of its global knowledge of resource availability within the zone. The ZH computes the k-shortest disjoint paths for all source destination pairs within the zone, and has the ability to determine the wavelength channels available at the intermediate nodes between the ingress-egress node pair, in case of intra-zonal traffic, and between ingress node and zone gateway in case of inter-zonal traffic. The ZH also maintains a list of wavelengths and uses a poles apart heuristic to assign wavelengths to incoming bursts originating from neighboring source nodes by inspecting both the ZIB and the SHB for reducing the probability of contention.

Whenever there is a request for a burst transfer from an ingress node, the ZH selects a wavelength based on proposed poles apart heuristic and a route is selected where that wavelength is available on all intermediate core nodes within the zone. This centralized fixed alternate route selection strategy based on wavelength availability is called Resource Aware Routing and the wavelength assignment based on poles apart wavelength assignment heuristic (PAH) is called Intelligent Wavelength Assignment. In contrast with most approaches found in the literature for OBS networks, routing and wavelength assignment in C2OBS are jointly carried out, as the route selection depends on wavelength availability, from which traffic balancing and contention avoidance automatically result. This is possible because C2OBS consists of a cluster of relatively small manageable zones each having a centralized information repository which can be utilized to make optimal routing and wavelength assignment decisions.
Compared to WR-OBS [22], the C2OBS network architecture avoids the single controlling node performance bottleneck issue. Furthermore, it does not incur additional delay associated to the connection establishment while keeping all the inherent advantages of a centralized architecture.

The rest of the paper is structured as follows. Section II presents Routing and Wavelength Assignment Strategy for C2OBS architecture. This section explains novel Poles Apart Wavelength Assignment Heuristic (PAH) for wavelength assignment. This section also presents the Resource Aware Routing (RAR) and Intelligent Wavelength Assignment (IWA) strategy for proactively avoiding contention. Section III discusses the expected benefits of the RAR and IWA by comparing them with existing RWA techniques. Finally, Section IV concludes and highlights future work directions.

II. ROUTING AND WAVELENGTH ASSIGNMENT STRATEGY

Routing and Wavelength Assignment is a crucial task that can reduce the probability of contention and improve the overall network performance. However, combined routing and wavelength assignment is a hard problem to address in the existing OBS architecture [20]. Here, both are dealt with simultaneously.

A. *Poles Apart Wavelength Assignment Heuristic*

The aim of poles apart wavelength assignment heuristic (PAH) is to generate different order of wavelength assignment for payload bursts origination from neighboring source nodes. Consider a C2OBS network employing C2OBS-RR resource reservation strategy [18]. There are W wavelengths available per port and each port can transmit on any free wavelength, $\{\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_W\}$.

Let Z be the maximum number of source nodes in any zone and N be the integer part of the average number of nodes per zone. For the sake of clarity, consider only a single zone, where Z is necessarily equal to N.
The PAH divides the available wavelength space into N blocks of size X, where X is the integer part of W/N. These blocks of wavelengths are labeled as $A_1, A_2, \ldots, A_N$. The first block, A_1, comprises wavelengths $\lambda_1, \lambda_2, \ldots, \lambda_{W/N}$, the second block, A2, contains wavelengths $\lambda_{(W/N+1)}, \lambda_{(W/N+2)}, \ldots, \lambda_{(2W/N)}$ while the last block contains wavelengths $\lambda_{((N-1)W/N+1)}, \lambda_{((N-1)W/N+2)}, \ldots \lambda_W$. The number of arrangements of the N wavelength blocks is given by N! as shown in Table 1for N = 3 and W = 30. Each source node is assigned one distinct wavelength blocks permutation. The corresponding wavelength assignment table (Table 1) is kept in the ZH, where each record represents the order of poles apart wavelength assignment for a given source node. If two adjacent records have one identical block of wavelengths, the distinct order can be achieved by reversing the order of one of them. In the multi-zone scenario, a number of records from the wavelength assignment table equal to the number of source nodes in a given zone is selected and one distinct record is assigned to each source node. The PAH is applied to a single zone of C2OBS network, as shown in Figure 1, for illustration. The network consists of three source nodes labeled as 1, 2, and 3. The node 4 is an intermediate core node as well as the ZH while node 5 is the destination node. Let the wavelength space consists of thirty wavelengths and each source node can transmit on any free wavelength. The wavelength space is divided into a number equal to the number of source nodes. Thus each block of wavelength contains ten wavelengths, labeled as A_1, A_2, and A_3. The permutation of three wavelength blocks is stored in the ZH as shown in Table 1. Each source node is assigned one distinct wavelength blocks permutation.

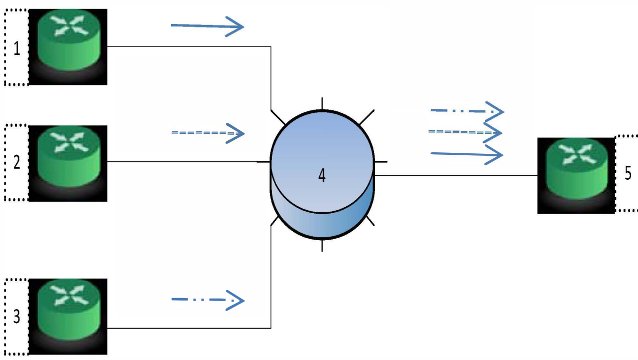

Figure 1: Example network showing three Bursts overlapping at an intermediate node

Table 1. Wavelength Assignment Table

Type	Wavelength Blocks		
1.	$A_1(\lambda_1$ to $\lambda_{10})$	$A_2(\lambda_{11}$ to $\lambda_{20})$	$A_3(\lambda_{21}$ to $\lambda_{30})$
2.	$A_3(\lambda_{21}$ to $\lambda_{30})$	$A_1(\lambda_1$ to $\lambda_{10})$	$A_2(\lambda_{11}$ to $\lambda_{20})$
3.	$A_2(\lambda_{11}$ to $\lambda_{20})$	$A_3(\lambda_{21}$ to $\lambda_{30})$	$A_1(\lambda_1$ to $\lambda_{10})$
4.	$A_1(\lambda_1$ to $\lambda_{10})$	$A_3(\lambda_{21}$ to $\lambda_{30})$	$A_2(\lambda_{11}$ to $\lambda_{20})$
5.	$A_2(\lambda_{11}$ to $\lambda_{20})$	$A_1(\lambda_1$ to $\lambda_{10})$	$A_3(\lambda_{21}$ to $\lambda_{30})$
6.	$A_3(\lambda_{21}$ to $\lambda_{30})$	$A_2(\lambda_{11}$ to $\lambda_{20})$	$A_1(\lambda_1$ to $\lambda_{10})$

Now consider that all the three source nodes request the ZH for resources for their upcoming bursts and the ZH selects $\lambda 1$ for node-1, λ_{21} for node-2, and λ_{11} for source node-3 from the first three rows of the wavelength assignment table. Similarly for subsequent requests, the three source nodes will be assigned λ_2, λ_{22}, and λ_{12} respectively. So the PAH provides poles apart wavelengths for assignment to the incoming bursts originating from neighboring source nodes.

B. *Resource Aware Routing and Intelligent Wavelength Assignment Strategy*

Resource Aware Routing assigns one of the k-shortest paths where resources are available while the Intelligent Wavelength Assignment scheme assigns a poles apart wavelength, computed by PAH, after verifying it's available at intermediate core node along the path. This strategy is proposed for C2OBS architecture employing C2OBS-RR scheme for resource reservation [20].

In RAR, k-shortest paths are computed using number of hops as a cost function. The highest priority is assigned to shortest path because it offers less delay and uses least network resources [18]. Moreover, the k-paths are preferred to be disjoint.

When a source node requests the ZH for resources, it selects the first wavelength from wavelength assignment table and checks its availability on all intermediate transit nodes along the high priority path by using its SHB. If the wavelength is free, the shortest path and the selected wavelength are assigned to the incoming burst. Otherwise, the same wavelength is checked for availability on other k-1 routes. If the selected wavelength is not free on all k-paths then the next wavelength from the list is checked along k-paths, in order of priority, for assignment to the incoming burst.

The advantage of the proposed strategy is that it tries to assign a shortest path where resources are available, thereby, optimizes the resource utilization. If resources are not available along the shortest path, it distribute the traffic along the alternate paths, where resources are available, to proactively reduce the probability of contention. Thus, traffic balancing within the zone is achieved based on the availability of wavelength along the path. For wavelength assignment, each neighboring source node within the zone is assigned a different wavelength computed by PAH after verifying its availability on intermediate core nodes.

The RAR and IWA are applied to a single zone of C2OBS network, as shown in Figure 2, for illustration. The network consists of three source nodes, labeled as 1, 2, and 3. Node 4, 5, 6, 7, and 8 are intermediate core nodes while node 9 is the destination node. Node 4 is also the ZH and it is assumed that the wavelength space consist of thirty wavelengths. The wavelength assignment table is computed by PAH and the first three rows of Table 1 are used by ZH to assign wavelengths to node-1, node-2 and node-3 respectively. For k = 2, Table 2 shows the routing table for the example network.

Now consider that all the three source nodes request the ZH for resource reservation for their upcoming bursts. Using Table 1, the ZH selects λ_1, λ_{21}, and λ_{11} for source node-1, node-2, and node-3 respectively. Then it searches λ_1, λ_{21}, and λ_{11} in the SHB to find whether the selected wavelengths are free on all intermediate core nodes along the shortest path. As in this case, the selected three wavelengths are free along the shortest paths; these wavelengths along with the corresponding paths are assigned to respective source nodes for their upcoming bursts.

If later on some of the wavelengths become occupied and the ZH finds that a wavelength is not free along the shortest path, it checks the alternate path with hop count 5 and assigns the longer path for burst transmission, if resources are available along that path. Thus it utilizes the unused network resources, optimizes the network resource utilization, to proactively reduce the burst loss probability.

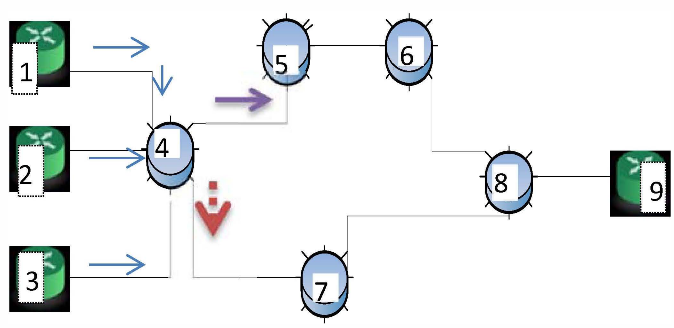

Figure 2: Example Network showing two alternate paths

Table 2: Routing Table

Source-Destination	Routes			
	Hop Count	Path-1	Hop Count	Path-2
1-9	4	1-4-7-8-9	5	1-4-5-6-8-9
2-9	4	2-4-7-8-9	5	2-4-5-6-8-9
3-9	4	3-4-7-8-9	5	3-4-5-6-8-9

III. EXPECTED BENEFITS OF RAR AND IWA STRATEGY

A discussion about the expected benefits of the C2OBS network architecture, its Resource Aware Routing and Intelligent Wavelength Assignment strategy is compared with the extant schemes. In C2OBS, the whole network has been divided into several manageable smaller units called zones, with a ZH that maintains Zone Information Base (ZIB) and Short History Base (SHB). This information is utilized by ZH for RAR and IWA to proactively avoid contention at intermediate core nodes and thus reduces the burst drop probability in the overall network. In comparison to single controlling node in WR-OBS architecture [23], the ZH does not become the performance bottleneck as there are several ZHs, one per zone, in C2OBS architecture. Moreover, it is difficult to optimize resource utilization in the extant architecture utilizing distributed resource reservation schemes like JET and JIT. In C2OBS architecture, the resource utilization can be optimized due to zonal architecture having central information repository. Another advantage of the proposed architecture is its scalability. If the number of nodes in the network is increased, the network can be redesigned by either adding the new node to an existing zone or creating a new zone to maintain the network performance. In the extant architecture, the network performance deteriorates with the increase in the network size in case of both centralized and distributed resource reservation schemes.

RAR selects one of the k-paths based upon the availability of a free wavelength. This routing strategy is less cumbersome than adaptive routing algorithms in terms of complexity and computational cost and more efficient than fixed shortest path routing in terms of utilization of resources and blocking probability. In shortest path routing, the bursts are dropped even though the resources are available in the network along other paths. In RAR, the traffic between same ingress-egress pair may follows different paths, optimally utilizing the available resource.

The IWA scheme utilizes the complete set of wavelengths on each source node. Still, it employs the wavelength dimension to isolate the traffic from different sources that uses the overlapping path within the zone, thereby reducing the probability of contention. It ensures that the ZH assign poles apart wavelengths to bursts originating from the nearby source nodes to avoid contention. The computation of poles apart wavelength is accomplished by employing the novel PAH heuristic. IWA is less computational expensive as compared to adaptive priority based wavelength assignment schemes where priorities in each switching node need to be updated based upon successful/unsuccessful burst transmission. Furthermore, the heuristic wavelength assignment schemes like First-Fit, Random being simple but not appropriate for OBS networks [8, 9]. Additionally, the intermediate nodes do not transmit the wavelength usage history to the ZH. In IWA, the ZH infers knowledge about the wavelength usage by using its SHB.

In the extant literature [6, 18] , routing and wavelength assignment problem is most times dealt with separately because it is difficult to find an optimal simultaneous solution to both problems. We proposed RAR and IWA where wavelength assignment and routing are dealt with simultaneously for optimal performance. This is made possible by the C2OBS zone based network architecture which is centralized within the zone but distributed when considering the whole network. The ZIB and SHB embedded in the central controlling node within the zone assists in selecting an optimal route and free wavelength along the path for reducing the probability of contention at intermediate nodes and are thus expected to enhance the overall network performance.

In the existing literature [24], the traffic engineering is accomplished by minimizing the maximum of link utilization which is used to move the traffic away from congested links. In RAR and IWA, the traffic is distributed along the k-paths where wavelength is available, thereby, balancing the traffic distribution based upon the availability of resources along the link.

Based on the above comparative analysis with existing architecture and RWA techniques, it seems that the proposed architecture is both more flexible and scalable. It is also expected that the RAR and IWA being less computational expensive, will be more efficient as compared to extant schemes. Moreover, the blocking probability is also expected to be lower because proactive contention avoidance has been proposed in this scheme.

IV. CONCLUSIONS AND FUTURE WORK

Intelligent wavelength selection at the ingress node can enhance the performance of the OBS networks in terms of burst drop probability. This article proposes IWA scheme for C2OBS architecture that employs novel poles apart wavelength assignment heuristic to assigns poles apart wavelengths to the bursts origination from nearby source nodes to proactively avoid contention at the intermediate core nodes. The availability of selected wavelength along a selected path is also verified before assignment. Furthermore, RAR has been proposed that uses fixed alternate routing and the knowledge of available resources to distribute the traffic in the network and thereby, reduce the burst loss probability. The IWA and RAR are inter-dependent as both the problems have been dealt with simultaneously.

As for as future work is concerned, the next objective is to implement a simulation model for analyzing the performance of the C2OBS network architecture, RAR and IWA strategy, and compare it with the extant RWA schemes for verification and validation.

ACKNOWLEDGEMENT

This work is funded by the ERDF – European Regional Development Fund through the COMPETE Programme (operational programme for competitiveness) and by National Funds through the FCT – Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) within project «FCOMP - 01-0124-FEDER-022701». Ihsan Ul Haq also acknowledges the Foundation for Science and Technology, FCT, Portugal for its research grant reference No. SFRH/BD/71311/2010.

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