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Benefits of static WDM add/drop multiplexers in optical burst switching networks of ring configuration

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Abstract: A new design principle of optical burst switching (OBS) networks of ring configuration cooperating with static wavelength-division multiplexed (WDM) optical add/drop multiplexers (OADMs) is described. The paper indicates that wavelength-bypassing provided by the OADMs improves burst transport in several ways. For example, the bypassing makes the size of OBS switch fabric and mean hop-counts small. The paper focuses on burst loss rate performance. An optimum design to minimize burst loss rate in an OBS ring network under a given WDM level and the number of nodes is formulated through theoretical analysis. Simulation results show good agreement with the theory.

Keywords: optical burst switching, wavelength-division multiplexing, optical add/drop multiplexer, ring network, burst loss rate

Classification: Photonics devices, circuits, and systems

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1 Introduction

Although optical burst switching (OBS) technology is still in its infancy [1], it is expected as a solution for IP-over-optical transport in the next-generation network [2]. In originally proposed OBS networks [3], burst transport in core nodes has been realized with photonic burst switches (PBSs) only, which provide multiprotocol label switching (MPLS) capability in the optical domain, where neither optical cross-connect (OXC) nor add/drop multiplexer (OADM) is needed. The original architecture allows complete bandwidth sharing like packet switching to make bandwidth efficiency maximize. Unlike packet switches, PBSs have little (or sometimes no) queueing space, so that providing PBSs in every node will lead to increased burst loss and latency. Recently, various design alternatives to OBS networks cooperating with OXCs of first circuit switching capability and OADMs of dynamic drop/insertion capability have emerged for decreasing burst loss rate and latency [4, 5]. For example, the optical burst add/drop multiplexing (OB-ADM) technique provides low latency as well as bandwidth efficiency [5]. However, the OB-ADM node is composed of a conventional PBS and a dynamic ADM, both with a full access to all the wavelengths multiplexed, and thus its complexity becomes formidable.

If one hopes to reduce burst latency, it is natural to think of using static (or quasi-static) OXCs and OADMs currently deployed, because their optical bypassing capability enables bursts to pass through nodes without experiencing burst switching. In this paper, we consider an OBS ring network of a unidirectional WDM fiber, where PBSs cooperate with static OADMs (or Static OADMs-Assisted OBS, SOA-OBS). Our motivation is two-fold. The first is to reduce burst latency as stated above. The second is to reduce the number of ingress (egress) ports of PBSs. SOA-OBS allows to bypass a portion of wavelengths multiplexed in a fiber, and thus the size (or the number of ingress/egress ports) of PBSs becomes less than WDM level, while PBS size in the OB-ADM node is identical to WDM level.

A critical design issue with OBS is to reduce burst loss rate under a given traffic load, while simultaneously minimizing the number of wavelengths [2]. We introduce an optimum design of SOA-OBS to minimize burst loss rate under a given WDM level and the number of nodes. Also we briefly discuss negative aspects of static OADMs in their applications to OBS networks.

2 Outline of SOA-OBS architecture

Consider the unidirectional WDM ring network of N core nodes shown in Fig. 1(a). An edge node terminates user IP packets, transforms them into optical bursts, and transmits bursts to its associated core node in the forwarding direction. Reverse function is provided in the receiving direction.

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There is a schematic block diagram of the core nodes in Fig. 1(b). We assumed a WDM level of w in a fiber. An OADM splits w waves into m waves for bypassing and n for burst switching in the OBS subsystem. Additionally, the OBS subsystem has n waves for up (down) links from (to) the edge node. Thus, the switch size (S) of the OBS node becomes $S = 2n$. We assumed that a portion of the n waves from the OBS subsystem (i.e. $w_{\rm bp}$) would directly be forwarded to the h-th next core node as shown in Fig. 1(c). We refer to $w_{\rm bp}$ and $(n - w_{\rm bp})$ as the number of bypassing and trunk waves.

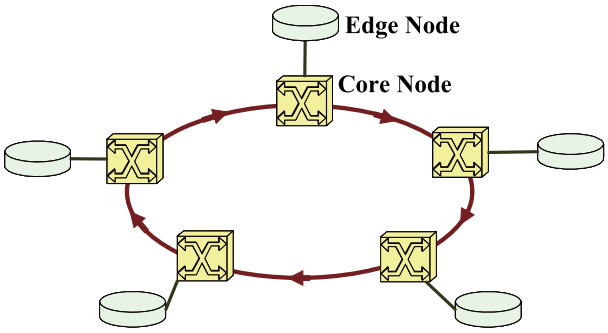
As a result, m and w are given by

$$m = (h - 1)w_{bp}, \tag{1}$$

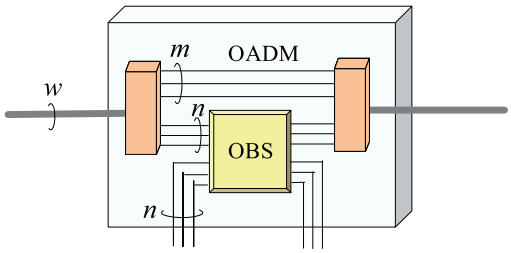
and

$$w = n + (h - 1)w_{bp}. \tag{2}$$

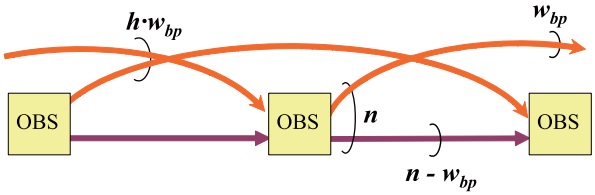
We also assumed that the edge node would generate optical bursts, whose durations and inter-arrival times would obey an exponential distribution, and the OBS subsystem has a wavelength-conversion capability. The destination of bursts is evenly distributed (or uniform traffic). The offered load from an edge node is set to A Erl.



(a) SOA-OBS in unidirectional ring network configuration



(b) Schematic block diagram of core nodes



(c) Definitions for bypassing and trunk wavelengths

Fig. 1. Outline of the SOA-OBS architecture

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3 Optimum design

We can define several design parameters from these assumptions and these are:

a: the traffic load between a pair of core nodes

T_0: the total traffic load on a trunk link when there is no bypassing wave

$T_{\rm bp}$: the traffic load transferred on $w_{\rm bp}$ waves

$T_{\rm ad}$: the traffic load transferred on $(S - w_{\rm bp})$ waves

These are given by

$$a = A/(N-1) \tag{3}$$

$$T_0 = N(N-1)a/2 \tag{4}$$

$$T_{bp} = aN(N/h-1)/2 \tag{5}$$

$$T_{ad} = T_0 - h \cdot T_{bp} = N(h-1)a/2 \tag{6}$$

It is obvious that bypassing decreases burst latency that is proportional to burst hop-counts. After this, we will focus on burst loss. The burst loss rate from load-balancing theory [6] becomes minimum when $T_{bp} = T_{ad}$ holds. Thus, we have the following equation.

$$aN(N/h-1)/2 = N(h-1)a/2 \tag{7}$$

As a consequence, we have optimum hop counts (h_{opt}) and the traffic load is carried on bypassing waves (T_{opt}) as:

$$h_{opt} = \sqrt{N} \tag{8}$$

$$T_{opt} = aN(\sqrt{N}-1)/2 \tag{9}$$

Then, the design issue is to deduce the number of bypassing waves ($w_{\rm bp}$) from the offered load and the given size of the OBS switch. It is evident that $w_{\rm bp}$ should be $n/2$ if no special routing policy is employed. However, we use deflection routing if blocking occurs in a bypassing route, i.e., we turn the blocked bursts to the trunk route destined for the next core node. Traffic intensity on the trunk waves in this routing scenario becomes slightly larger than that on the bypassing waves. Thus, the number of trunk waves should be increased. We evaluated an optimum number of bypassing waves so that it minimized the burst blocking rate at large. Figure 2 has the simulation results that show how burst blocking rate depends on $w_{\rm bp}$. There are two traces for $N = 8$ and 16 as examples. Their h_{opt} values are 3 and 4. Note that h_{opt} is given by $\sqrt{N}$ from (8), but it should be an integer closest to the theoretical value. We can see that the respective optimum values for $w_{\rm bp}$ are $w_{\rm bp-opt} = 12$ and 10 for $N = 8$ and 16.

Consequently, we have optimum design parameters of h_{opt} and $w_{\rm bp-opt}$ in an OBS unidirectional ring network with the bypassing offered by static OADMs. We compared the burst blocking rate in a conventional OBS ring to that in the proposed bypassing OBS ring, as shown in Fig. 3. We can see that the bypassing technique improves the blocking rate by about 100 times in this example. This is mainly due to the increased WDM level. We

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can see w becomes 56 in the proposed system, while it remains 32 in the conventional OBS system. However, it must be stressed that the size of the OBS subsystem remains unchanged, i.e., $n = 32$, for both systems. We can see another prominent feature achieved with the bypassing system in Fig. 3. The burst blocking rate dips around $h = 3$ and 6, which correspond to the core nodes accessed via bypassing waves in one and two hops (recall $h_{opt} = 3$). The burst blocking rate becomes insensitive to the increase in hop-counts in the SOA-OBS networks we propose, whereas it shows a sharp increase with h in conventional OBS networks.

In this paper, we assumed that traffic distribution among nodes is uniform and stationary. Non-uniform traffic distribution can be managed as well according to the load-balancing discipline if traffic requirements between each pair of core nodes are stationary and specified in a traffic matrix $\mathbf{T}=\{t_{\mathrm{sd}}\}$, where t_{sd} is the average of long-term traffic flowing from source node s to destination node d. Details of the computation are beyond the scope of the paper and will be discussed elsewhere..

It is obvious that the original OBS networks of full wavelength-accessibility can improve wavelength efficiency and are agile in nature to

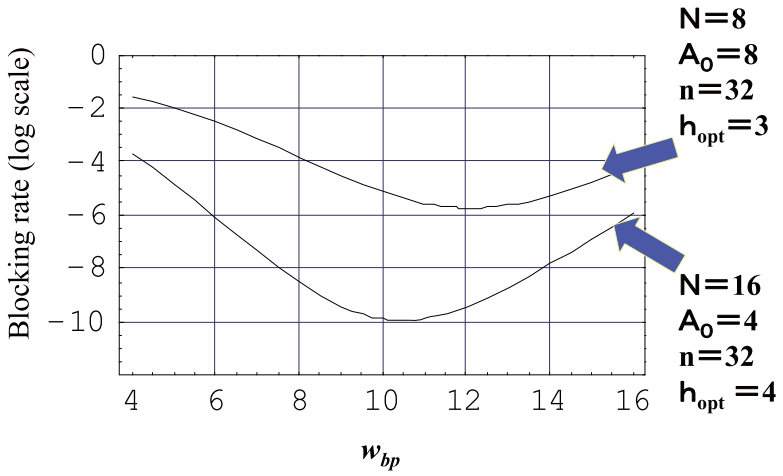


Fig. 2. Dependence of burst blocking rate on w_{bp}

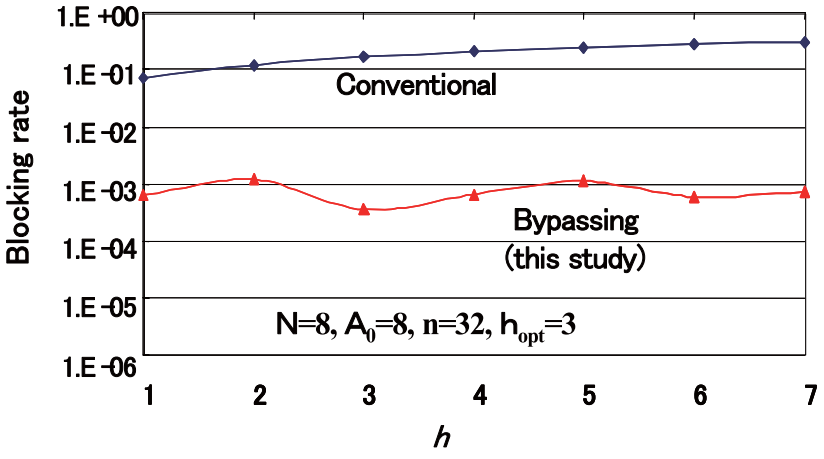


Fig. 3. Comparison of burst blocking rates

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adapt to a dynamic traffic environment at the cost of increased OBS switch size and latency. However, if the traffic patterns in the network are reasonably known in advance (e.g., daily and weekly cycles) and any traffic variations take place over long time scales, which is likely the case in core networks, the SOA-OBS can gracefully evolve in time by creating and tearing down wavelength paths in the same manner as current network operation with respect to static OADMs, or by using generalized multiprotocol label switching (GMPLS) techniques. Such an approach is a focus of recent study with OBS networks and needs future research.

4 Conclusion

We have shown that wavelength-bypassing provided by existing static (or quasi-static) OADMs improves burst transport in several ways. For example, the bypassing makes both the size of OBS switch fabric and mean hop-counts small compared to those of conventional OBS networks. An optimum design to minimize burst loss rate in a unidirectional OBS ring network under a given WDM level and the number of nodes in a case of uniform traffic pattern was formulated through theoretical analysis. Simulation results have shown good agreement with the theory. A brief discussion on negative aspects of static OADMs in their applications to dynamic traffic environments was given. Thus, the SOA-OBS is a potential solution for future optical transport, although it remains a rich area for future research.

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