

Performance comparison of optical burst and circuit switched networks

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Abstract: This paper presents quantitative performance comparisons between the OBS and OCS networks. The simulation results indicate that, under the identical traffic demand and network capacity, OBS networks achieve a higher throughput than OCS networks.

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1. Introduction

Over the past decade, the phenomenal growth of the Internet traffic and the rapid advances of optical technologies have continuously driven the evolution of the optical Internet. To move towards IP-over-WDM (wavelength division multiplexing) architectures, various optical switching techniques [1-5] have been investigated by the optical communications community. Among them, the optical-circuit switching (OCS) [1,2] paradigm explores the wavelength functionality for routing by establishing end-to-end lightpaths between node pairs, and pursues a wavelength-routed networking architecture with a whole wavelength as its finest switching granularity. Several sub-wavelength switching schemes, notably optical packet switching (OPS) [3] and optical burst switching (OBS) [4,5], have also been proposed for the future optical Internet. In order to provide a fair benchmark in assessing these candidate techniques, it is important to consistently conduct quantitative performance comparisons under equivalent operating conditions. This paper adopts the OBS and OCS architectures for a performance comparison, each representing sub-wavelength and wavelength switching paradigms. The comparisons are performed under the identical network topology, traffic matrix, and network capacity. We conduct simulations in a representative NSFnet topology to evaluate their performance in terms of the burst loss rate, request blocking rate, and throughput.

2. Optical circuit switching and optical burst switching

Wavelength-routed OCS networks consist of wavelength routers interconnected by WDM fiber links. The basic communication mechanism in a wavelength-routed network is a lightpath, which may span multiple fiber links to provide a circuit-switched interconnection between two nodes. A sequence of lightpath requests arrives over time, and each successful request has a connection holding time. Due to the limitations in the network capacity or the connection states of the network, some lightpath requests may not be accepted, resulting in blocking. One of the primary design objectives in wavelength-routed networks is to minimize this blocking probability. The potentially beneficial schemes to improve the blocking performance include wavelength conversion [6] and alternate routing [7]. In the absence of wavelength converters, a lightpath would occupy the same wavelength on all fiber links that it transverses. The wavelength conversion can eliminate this wavelength continuity constraint and thus significantly improve the blocking performance [6]. Alternate routing [7], providing multiple alternative paths between node pairs, can also enhance the blocking performance. At the arrival of a connection request, the source node first attempts the preferred path. If the request is blocked, it will attempt alternative paths. This paper focuses on the OCS networks capable of wavelength conversion and alternate routing.

The OBS refers to a broad class of sub-wavelength switching architectures [4,5], which assembles optical bursts at the network edge and transparently forwards the bursts through the core network. In an OBS network, the ingress edge routers aggregate client data (e.g., IP packets) into large bursts. Each burst is associated with a control packet containing the related control information such as burst length and routing information. A control packet goes through an O/E/O conversion at each intermediate node for resource reservation while a burst is forwarded transparently in an optical domain. In the OBS networks, the bandwidth reservation is a one-way process—namely, a burst starts its transmission without waiting for a reservation acknowledgement. This requires OBS nodes to resolve possible contention, which arises if two or more burst simultaneously compete for the same output fiber on the same wavelength. The commonly-used contention resolution schemes [8] include wavelength conversion, deflection routing, and fiber delay line (FDL) buffering. Due to the impracticality of building massive FDL buffers, this paper focuses on the wavelength conversion and deflection routing for contention resolution. When contention occurs at one specific output fiber port, the OBS router will first seek an alternative free wavelength at that output

port. If none is available, the router will deflect the contending burst to a deflection port—an output port other than the preferred port—and anticipate for the next-hop routers to route the contented bursts to their destinations.

3. Performance simulation and results

Fig. 1 depicts a 14-node NSFnet topology for simulations, where each WDM link carries W wavelengths transmitting at 10 Gb/s. The simulation adopts a uniform traffic matrix to equally divide the total offered load among all node pairs. Further, both the OBS and OCS networks resort to wavelength- and space- domain for performance improvements; the OBS network uses wavelength conversion and deflection routing for contention resolution, while the OCS network adopts wavelength conversion and alternate routing for blocking reduction. All these considerations lead to unbiased operation conditions.

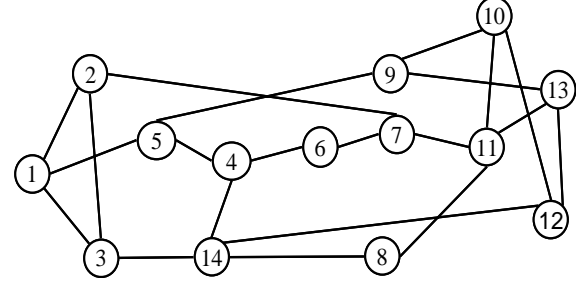


Fig. 1. NSFnet topology for simulations.

For the OBS networks, each node has W local add ports to ingress client traffic into the core network. For each local add port, there is a dedicated self-similar traffic source to generate IP packets following a realistic IP packet-length distribution [9] with peaks at 40, 552, 576, and 1500 bytes. This work adopts a self-similar traffic model called “Sup_FRP” [10] to generate packet traces with Hurst parameter $H=0.8$ and fractal onset time scale $FOTS = 100 \mu\text{sec}$. We define the normalized load ρ to each node as the ratio between the local ingress traffic and the node access capacity ($W \times 10$ Gb/s). The maximum timeout period for burstification is set at 100 μsec . We compute the least-hop path (called the shortest-path) for each node pair to establish the preferred routing table. When a burst arrives at an OBS router, the router will first determine its preferred output fiber port based on the preferred routing table. Then, it will use the wavelength converter to choose an available wavelength on that preferred port whenever one exists. If none is available, the router will deflect the burst to its secondary output port predefined in the simulation. When all options fail, it will discard the burst. To prevent repeated deflection of a burst in a network, the maximum hop count for bursts from node i to j is set at $3 \times \text{hop}[i][j]$, where $\text{hop}[i][j]$ is the hop count of the shortest path from node i to j . For the OCS network, the lightpath requests to each source node arrive as a Poisson process with rate λ . If a request is routed and served, the lightpath holding time follows a Pareto distributed with mean value of $1/\mu = 1$ second and the shape parameter of $\alpha = 1.4$. In the OCS networks, the normalized load to each node is defined as $\rho = \lambda/(W \times \mu)$. To support alternative routing in the OCS networks, we compute two *link-disjoint* paths for each node pair; one is the shortest-path between two nodes, and the other is the secondary path. When a request is issued, it will first traverse the shortest path and check if each link along this path has a free wavelength. If not, it will immediately retry the secondary path. If both paths fail, it blocks the request.

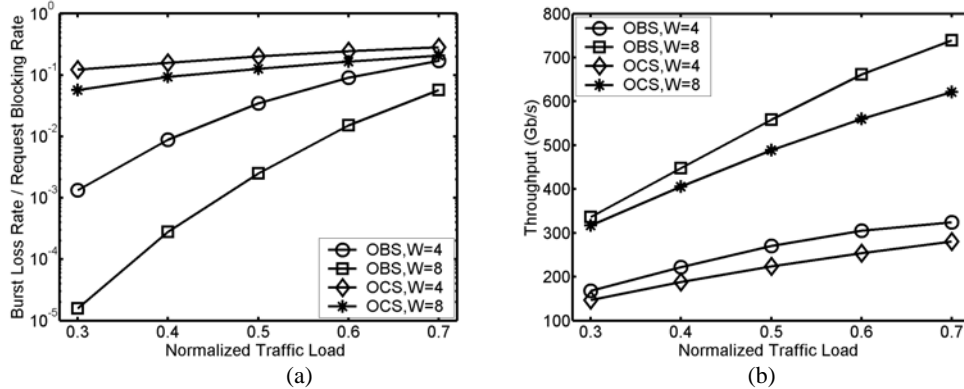


Fig. 2. Performance comparison between OBS and OCS networks: (a) burst loss rates and request blocking rates; (b) throughput.

Fig.2(a) shows the simulation results on burst loss rates and request blocking rates. With an identical traffic load and equivalent number of wavelengths, the burst loss rate is always smaller than the request blocking rate. For instance, in the case of $\rho = 0.5$ and $W = 4$, the burst-loss rate is about 0.034, while the request-blocking rate is near 0.21. Fig. 2(b) shows the results on the network throughput (in Gb/s), defined as the amount of traffic successful transported through a network during a unit time interval. Fig.2 (b) evidently demonstrates that the OBS networks achieve higher throughput than the OCS networks. With the aforementioned network configurations, the OBS network can achieve about 20% higher throughput than OCS networks. For instance, with $\rho = 0.5$ and $W = 4$, the throughput of the OBS and OCS networks are about 270 and 224 Gb/s, respectively. These results indicate the

higher efficiency of the OBS networks in utilizing the huge bandwidth of the WDM links, compared to the OCS networks. We also observe that the increased wavelengths could improve the network performance. When $\rho = 0.5$ and $W = 8$, the burst-loss rate and the request blocking rate decrease to about 0.0025 and 0.12, respectively.

To improve the blocking-performance of the OCS networks, service providers may allow the blocked requests to repeat their attempts, especially in the context of real-time dynamic optical service provisioning. In each attempt cycle, a request will first check the wavelength availability of the shortest path and immediately retry the secondary-path if necessary. The request will repeat this cycle until the number of cycles reaches a limit (denoted by C) or the lightpath is established. A backoff timer T_B exists between the consecutive cycles; this work assumes that T_B follows an exponential distribution with mean value of 1 second. Fig. 3 (a) shows the request loss rates at $W=4$, which measures the probability of a request that have never been served after C attempt cycles. Compared to the baseline case of “ $C=1$ ”, the network with repeated attempts achieves smaller request loss rates. Despite the tendency of the OCS networks with a larger C to achieve lower request loss rates, increasing C from 10 to 20 only produces marginal benefit. Fig.3 (b) shows fresh request blocking rates at $W=4$, which measures the probability of a fresh request blocked after its first attempt cycle. We observe that the blocking rates of fresh requests increase with increasing C . Since the lowering of the fresh request blocking rates can consequently lead to satisfaction of impatient clients, service providers should take this impact into account when designing their service policies. Furthermore, previous studies [11,12] have shown that alternate routing can produce network instability for heavily-loaded circuit-switched networks. Thus, designing of new service policies require detailed analyses to account for both alternate routing and request retrials, which are important topics for further studies.

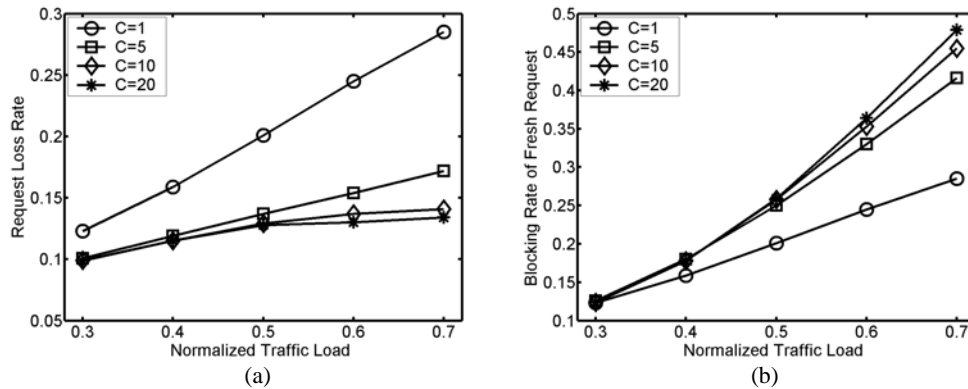


Fig.3. Performance of OCS networks ($W=4$) with repeated attempts: (a) request loss rates; (b) blocking rates of fresh requests.

4. Conclusion

This paper conducted quantitative performance comparisons between the OBS and OCS networks through simulations. The experimental results indicate that the OBS networks lead to a higher efficiency than the OCS networks in utilizing the WDM bandwidth; under the identical network capacity and traffic demand, the OBS networks can achieve about 20% higher throughput than the OCS networks. Further, this paper discussed the effects of request retrials on the OCS network performance. We observe that, while repeated attempts potentially lower overall request loss rates, these retrials can increase the blocking rates of fresh requests. One key topic that deserved further investigation is the optimization of the OCS network performance based on the interplay between alternate routing and request retrials.

5. References

- [1] B. Mukherjee, *Optical Communication Networks*, New York: McGraw-Hill Publisher, 1997.
- [2] R. Ramaswami and K.N. Sivarajan, "Routing and wavelength assignment in all-optical networks," *IEEE/ACM Trans. Networking*, vol.3, pp.858-867, Oct.1996.
- [3] S. Yao, B. Mukherjee, and S. Dixit, "Advances in photonic packet switching: an overview," *IEEE Commu. Mag.*, vol.38, pp.84-90, Feb. 2000.
- [4] C. Qiao and M. Yoo, "Optical burst switching (OBS)-a new paradigm for an optical network," *J. High Speed Networks*, vol.8, pp.69-84, 1999.
- [5] Y. Chen, C. Qiao and X. Yu, "Optical burst switching: a new area in optical networking research," *IEEE Network*, vol.18, pp.16-23, May 2004.
- [6] M. Kovacevic and A. Acampora, "Benefits of wavelength translation in all-optical clear-channel networks," *IEEE J. Select. Areas Commun.*, vol.14, 868-880 (1996).
- [7] R. Ramamurthy and B. Mukherjee, "Fixed-alternate routing and wavelength conversion in wavelength-routed optical networks," *IEEE/ACM Trans. Networking*, vol.10, pp.351-367, Jun. 2002.
- [8] S. Yao *et al.*, "A unified study of contention resolution schemes in optical packet-switched networks," *J. Lightwave Technol.*, vol.21, pp.672-683, Mar. 2003.
- [9] Agilent Technologies, Insight: For testing IP/optical networks. [On-line]. Available: http://advanced.comms.agilent.com/insight/2001-08/Questions/traffic_gen.htm
- [10] B. Ryu and S. Lowen, "Point-process approaches to the modeling and analysis of self- similar traffic: Part I - model construction". in *Proc. IEEE INFOCOM '96*, vol.3, pp. 1468-1475, Mar. 1996.
- [11] R.S. Krupp, "Stabilization of alternate routing networks," in *Proc. IEEE ICC'82*, pp.31.2.1-31.2.5, Jun. 1982.
- [12] M. Schwartz, *Telecommunication Networks: Protocols, Modeling and Analysis*. Reading, MA: Addison Wesley, 1988.