One-way Resource Reservation Protocols for IP Over Optical Burst Switched Mesh Networks

Joel J. P. C. Rodrigues, Mário M. Freire
Dep. of Informatics, Univ. of Beira Interior
Rua Marquês d'Ávila e Bolama,
6201-001 Covilhã, Portugal
{mario, joel}@di.ubi.pt

Pascal Lorenz
IUT, University of Haute Alsace
34, rue du Grillenbreit,
68008 Colmar, France
lorenz@ieee.org

Abstract

In this paper, we present a performance assessment of one-way resource reservation protocols in optical burst switched (OBS) mesh networks. The performance analysis considers five resource reservation protocols, Just-In-Time (JIT), JumpStart, JIT^{+}, Just-Enough-Time (JET) and Horizon, and focuses on the following topologies: rings, degree-three chordal rings, degree-four chordal rings, degree-five chordal rings, degree-six chordal rings, mesh-torus, NSFNET, ARPANET and the European Optical Network (EON). It is shown that when the nodal degree increases from 2 to around 3, the largest gain is observed for degree-three chordal rings (slightly less than three orders of magnitude) and the smallest gain is observed for the ARPANET (less than one order of magnitude). On the other hand, when the nodal degree increases from 2 to around 4, the largest gain is observed for degree-four chordal rings (with a gain between four and five orders of magnitude) and the smallest gain is observed for the EON (with a gain less than one order of magnitude). When the nodal degree increases from 2 to around 5 or 6, the gain is between four and six orders of magnitude. These results clearly show the importance of the way links are connected in OBS networks, since, in this kind of networks, burst loss probability is a key issue. Moreover, the performance of the five protocols is very close for those topologies.

1. Introduction

Optical burst switching (OBS) [1-6] has been proposed to overcome the technical limitations of optical packet switching, namely the lack of optical random access memory and to the problems with synchronization. OBS is a technical compromise between wavelength routing and optical packet switching, since it does not require optical buffering or packet-level processing and is more efficient than circuit switching if the traffic volume does not require a full wavelength channel. In OBS networks, IP (Internet Protocol) packets are assembled into very large size packets called data bursts. These bursts are transmitted after a burst header packet, with a delay of some offset time. Each burst header packet contains routing and scheduling information and is processed at the electronic level, before the arrival of the corresponding data burst. The burst offset is the interval of time, at the source node, between the transmission of the first bit of the setup message and the transmission of the first bit of the data burst.

According to the way of reservation, resource reservation protocols may be classified into two classes: one-way reservation and two-way reservation. In the first class, a burst is sent shortly after the setup message, and the source node does not wait for the acknowledgement sent by the destination node. Therefore, the size of the offset is between transmission time of the setup message and the round-trip delay of the setup message. Different optical burst switching mechanisms may choose different offset values in this range. Tell And Go (TAG) [7], Just-In-Time (JIT) [3], JumpStart [4-6], JIT+ [8], Just-Enough-Time (JET) [1] and Horizon [2] are examples of one-way resource reservation protocols.

In the TAG protocol, a source node sends a control packet and immediately after sends a burst. At each intermediate node, the data burst has to go through with an input delay equal to the setup message (control packet) processing time. If a channel cannot be reserved on a link, along the ingress-egress path, the node preceding the blocked channel discards the burst. To release the connection, a “tear-down” control signal or packet is sent [7, 9]. In this protocol a burst may need to be delayed (buffered) at each node, while waits for the processing of setup message and the configuration of the OXC switch fabric. TAG is practical only if the switch processing time of the setup

0-7695-2422-2/05 $20.00 © 2005 **IEEE**

message and the optical switch configuration time are very short [10].

The offset in two-way reservation class is the time required to receive an acknowledgement from the destination. The major drawback of this class is the long offset time, which causes the long data delay. Examples of resource reservation protocols using this class include the Tell And Wait (TAW) protocol [7] and the Wavelength Routed OBS network (WR-OBS) proposed in [11]. Due to the impairments of two-way reservation class and the critical limitation of TAG, the study is focused on one-way reservation schemes, being considered the following resource reservation protocols: JIT, JumpStart, JIT$^+$, JET, and Horizon.

A major concern in OBS networks is the contention and burst loss. The two main sources of burst loss are related with the contention on the outgoing data burst channels and on the outgoing control channel. In this paper, we consider bufferless networks and we concentrate on the loss of data bursts in OBS networks.

The remainder of this paper is organised as follows. In section 2, we present an overview of one-way resource reservation protocols studied. In section 3, we describe the model of the OBS network under study, and in section 4 we discuss performance implications of the nodal degree for OBS networks with mesh topologies. Main conclusions are presented in section 5.

2. One-Way Resource Reservation Protocols

This section provides an overview of one-way resource reservation protocols for OBS networks. One-way resource reservation protocols may be classified, regarding the way in which output wavelengths are reserved for bursts, as immediate and delayed reservation. JIT and JIT$^+$ are examples of immediate wavelength reservation, while JET and Horizon are examples of delayed reservation schemes. The JumpStart signaling protocol may be implemented using either immediate or delayed reservation.

Just-in-Time (JIT) resource reservation protocol was proposed by Wei and McFarland in December 2000 [3]. Under JIT, an output channel is reserved for a burst immediately after the arrival of the corresponding setup message. If a channel cannot be reserved immediately, then the setup message is rejected and the corresponding burst is lost. JIT protocol is an example of one-way resource reservation protocols with immediate resources reservation. JIT protocol uses explicit releases to set free the switch fabric resources. This message is sent either by the source node or the destination node, to tear down all OXCs along the path on an existing connection trail. Whenever any network element detects a "setup" failure, it sends a "release message" to all network elements along the path to the source node.

JumpStart [4-6] is a joint project supported by Advanced Research and Development Agency (ARDA) developed by the North Carolina State University (NCSU) and MCNC Research and Development Institute. The goal of JumpStart project is the definition of a signaling protocol and associated architecture for a WDM burst-switching network. Under JumpStart [4], a source edge OBS node first sends a setup message to its ingress OBS core node with information related to the burst transmission, including the source and destination addresses. If the ingress core node can switch the burst, it returns a setup ACK message to the edge node. Moreover, it forwards the setup message to the next node. Otherwise, the ingress core node refuses the setup message and returns a reject message to the edge node and the corresponding burst is dropped. In this case, the edge node enters in an idle period waiting for another burst. When a new burst arrives, the edge node repeats the process.

Horizon protocol was proposed by Turner in Terabit Burst Switching [2]. Horizon is considered a resource reservation protocol in the sense that it performs a delayed reservation, as mentioned in [4, 5, 8]. This resource reservation protocol introduces the concept of "Time Horizon" for a given channel and it is called Horizon because every data channel has a time horizon during which it is reserved. Time horizon is defined as "the earliest time to which there is no prevision to use the channel (wavelength)". This concept is used in other protocols with one-way resource reservation schemes such as JET and JIT$^+$ that are considered in this section. In Horizon, an output channel is reserved for a burst only if the arrival of the burst happens after the time horizon for that channel; if upon the arrival of the setup message, the time horizon for that channel is later than the predicted arrival time of the first bit of the burst, then, the setup message is rejected and the corresponding burst is lost.

Just-Enough-Time (JET) resource reservation protocol was proposed in [1, 12, 13]. Under JET, an output channel is reserved for a burst only if the arrival of the burst (1) happens after the time horizon defined for that channel, or (2) coincides with an idle state (Void) for that channel, and the end of the burst (plus the T_{OXC}) is sooner than the end of the idle interval; if, when the Setup message arrives, it is determined that none of these conditions are met for any channel, then the setup message is rejected and the corresponding burst is lost. JET is the best-known resource reservation protocol having a delayed reservation scheme with void filling (idle state), which uses information (from the setup message) to predict the start and the end of the burst. The authors of JET made analytical and simulation studies which confirmed the good effects of delayed reservation on burst loss probability in an OBS network.

The most recent resource reservation protocol is JIT$^+$ proposed by Teng and Rouskas in [8]. JIT$^+$ was defined as an improvement of JIT and it combines JIT simplicity with the utilization of the time horizon used by delayed resource reservation protocols, such as Horizon or JET. JIT$^+$ is a modified version of JIT protocol, which adds limited burst scheduling (for a maximum of two bursts per channel). Under JIT$^+$, an output channel is reserved for a burst only if (*i*) the arrival time of the burst is later than the time horizon of that data channel and (*ii*) the data channel has at most one other reservation.

3. Network Model

We consider OBS networks with the following mesh topologies: chordal rings with nodal degrees between 3 and 5, mesh-torus with 16 and 20 nodes, the NSFNET with 14-node and 21 links [14], the NSFNET with 16 nodes and 25 links [15], the ARPANET with 20 nodes and 32 links [14, 16], and the European Optical Network (EON) with 19 nodes and 37 links [17, 18]. For comparison purposes bi-directional ring topologies are also considered. These topologies have the following nodal degree: ring: 2.0; degree-three chordal ring: 3.0; degree-four chordal ring: 4.0; degree-five chordal ring: 5.0; mesh-torus: 4.0; NSFNET with 14-node and 21 links: 3.0; the NSFNET with 16 nodes and 25 links: 3.125; the ARPANET with 20 nodes and 32 links: 3.2; and the EON: 3.895.

Chordal rings are a well-known family of regular degree three topologies proposed by Arden and Lee in early 1980s for interconnection of multi-computer systems [19]. A chordal ring is basically a bi-directional ring network, in which each node has an additional bi-directional link, called a chord. The number of nodes in a chordal ring is assumed to be even, and nodes are indexed as 0, 1, 2, …, N-1 around the N-node ring. It is also assumed that each odd-numbered node i (i=1, 3, …, N-1) is connected to a node $(i+w) mod\ N$, where w is the chord length, which is assumed to be positive odd. For a given number of nodes there is an optimal chord length that leads to the smallest network diameter. The network diameter is the largest among all of the shortest path lengths between all pairs of nodes, being the length of a path determined by the number of hops. In each node of a chordal ring, we have a link to the previous node, a link to the next node and a chord. Here, we assume that the links to the previous and to the next nodes are replaced by chords. Thus, each node has three chords, instead of one. Let w_1, w_2, and w_3 be the corresponding chord lengths, and N the number of nodes. We represented a general degree three topology by D3T(w_1, w_2, w_3). We assumed that each odd-numbered node i (i=1, 3, …, N-1) is connected to the nodes $(i+w_1) mod\ N$, $(i+w_2) mod\ N$, and $(i+w_3) mod\ N$, where the chord lengths, w_1, w_2, and w_3 are assumed to be positive odd, with $w_1 \leq N$-1, $w_2 \leq N$-1, and $w_3 \leq N$-1, and $w_i \neq w_j$, $\forall_{i \neq j} \wedge 1 \leq i,j \leq 3$. In this notation, a chordal ring with chord length w is simply represented by D3T(1,N-1,w_3).

Now, we introduce a general topology for a given nodal degree. We assume that instead of a topology with nodal degree of 3, we have a topology with a nodal degree of n, where n is a positive integer, and instead of having 3 chords we have n chords. We also assume that each odd-numbered node i (i=1,3,…,N-1) is connected to the nodes $(i+w_1) modN$, $(i+w_2) mod\ N$, …, $(i+w_n) mod\ N$, where the chord lengths, w_1, w_2, … w_n are assumed to be positive odd, with $w_1 \leq N$-1, $w_2 \leq N$-1, …, $w_n \leq N$-1, and $w_i \neq w_j$, $\forall_{i \neq j} \wedge 1 \leq i,j \leq n$. Now, we introduce a new notation: a general degree n topology is represented by DnT(w_1, w_2,…,w_n). In this new notation, a chordal ring family with a chord length of w_3 is represented by D3T(1,N-1,w_3) and a bi-directional ring is represented by D2T(1,N-1).

We assume that each node of the OBS network supports F+1 channels per unidirectional link in each direction. One channel is used for signaling (carries setup messages) and the other F channels carry data bursts. Each OBS node consists of two main components [8]: i) a signaling engine (or switch control unit), which implements the OBS resource reservation protocol and related forwarding and control functions; and ii) an optical cross-connect (OXC), which performs the switching of bursts from input to output. It is assumed that each OXC consists of non-blocking space-division switch fabric, with full conversion capability, but without optical buffers. It is assumed that each OBS node requires [8]: i) an amount of time, T_{OXC}, to configure the switch fabric of the OXC in order to set up a connection from an input port to an output port, and requires ii) an amount of time, $T_{Setup}(X)$ to process the setup message for the resource reservation protocol X, where X can be JIT, JumpStart, JIT$^+$, JET, and horizon. It is also considered the offset value of a burst under reservation scheme X, $T_{offset}(X)$, which depends, among other factors, on the resource reservation protocol, the number of nodes the burst has already traversed, and if the offset value is used for service differentiation. In this study, it is assumed that [8]: $T_{Setup}(JIT)=T_{Setup}(JumpStart)={}_{Setup}(JIT^{+})=12.5\mu s$, $T_{Setup}(JET)=50\mu s$, $T_{Setup}(Horizon)=25\mu s$, $T_{OXC}=10ms$, the mean burst size, $1/\mu$, was set to 50ms (equal to $5T_{OXC}$), and the burst arrival rate λ of *setup messages*, is such that $\lambda/\mu=32$.

4. Performance Assessment of Resource Reservation Protocols

In this section, we present a performance assessment of OBS mesh networks for JIT, JumpStart, JIT^{+}, JET, and Horizon resource reservation protocols. Details about the simulator used to produce simulation results can be found in [20].

In chordal ring topologies, different chord lengths can lead to different network diameters, and, therefore, to a different number of hops. One interesting result that we found is concerned with the diameters of the D3T(w_1, w_2, w_3) families, for which $w_2=(w_1+2) mod\ N$ or $w_2=(w_1-2) mod\ N$. Each family of this kind, i.e. D3T(w_1,$(w_1+2) mod\ N$, w_3) or D3T(w_1, $(w_1-2) mod\ N$, w_3), with $1 \leq w_1 \leq 19$ and $w_1 \neq w_2 \neq w_3$, has a diameter which is a shifted version (with respect to w_3) of the diameter of the chordal ring family (D3T(1, N-1, w_3)). For this reason, we concentrate the analysis on chordal ring networks, i.e., DnT(1,19,w_3,…,w_n).

In order to quantify the benefits due to the increase of nodal degree, we introduce the nodal degree gain, $G_{n,k}(i,j)$, is defined as:

$$G_{n,k}(i,j)=\frac{P_i(n)}{P_j(k)} \qquad (1)$$

where $P_i(n)$ is the burst loss probability in the i-th hop of a degree n topology ($P_i(n)=P_i(\mathrm{DnT}(w_1,w_2,...,w_n))$) and $P_j(k)$ is the burst loss probability in the j-th hop of a degree k topology, for the same network conditions (same number of data channels per link, same number of nodes, etc), and for the same resource reservation protocol. It is used $G_{n,k}$ where n represents the nodal-degree of the $P_i(n)$ topology and k represents the nodal-degree of the $P_j(k)$ topology.

Figure 1 shows the burst loss probability in the last hop of ring, degree-three (D3T(w_1,w_2,w_3)) chordal ring and NSFNET, both with 16 nodes. As may be seen, when enough network resources are available (F=64), the degree-three chordal ring network with chord length of w_3=5 clearly have better performance. It was also observed that the performance of the NSFNET is very close to the performance of chordal rings with chord length of w_3=3 or w_3=7. These results reveal the importance of the way links are connected in the network, since chordal rings and NSFNET have similar nodal degrees and therefore a similar number of network links. Also interesting is the fact that chordal rings with w_3=5 have better performance than mesh-torus networks, which have a nodal degree of 4, i.e., more 25% of network links (shown in Figure 2). We have also observed that the best performance of chordal ring network is obtained for the smallest network diameter. As may be seen in Figure 1, the performance of the five resource reservation protocols is very close.

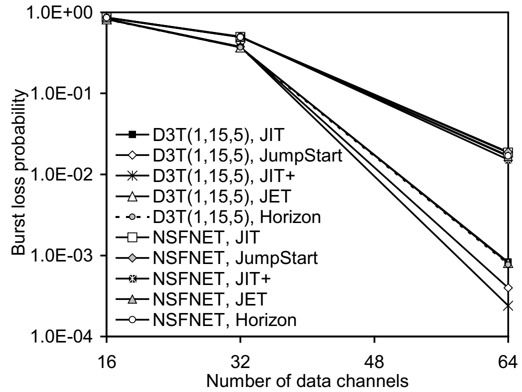

Figure 1. Burst loss probability, as a function of the number of data channels per link (F), in the last hop of D3T(1,15,5) and NSFNET for JIT, JumpStart, JIT^{+}, JET, and Horizon resource reservation protocols; N=16.

Figure 2 shows for JIT, the nodal degree gain in the last hop of each topology, as a function of the nodal degree, due to the increase of the nodal degree from 2 (D2T(1,14)) to 3 (NSFNET (N=14)), from 2 (D2T(1,15)) to: 3 (D3T(1, 15, 5)), 3.125 (NSFNET (N=16)), 4 (D4T(1,15,5,13) and Mesh-Torus (N=16)), 5 (D5T(1,15,7,3,9), and 6 (D6T(1,15,3,5,7,11)), from 2 (D2T(1,18)) to 3.89 (EON (N=19)), from 2 (D2T(1,19)) to: 3 (D3T(1,19,7)), 3.2 (ARPANET (N=20)), 4 (D4T(1,19,3,9)), 5 (D5T(1,19,3,7,11)), 6 (D6T(1,19,3,5,11,15)), from 2 (D2T(1,24)) to 4 (Mesh-Torus (N=25)), and from 2 (D2T(1,29)) to 6 (D6T(1,29,3,7,11,13)) (F=64). As may be seen, when the nodal degree increases from 2 to around 3, the largest gain is observed for degree-three chordal rings (slightly less than three orders of magnitude) and the smallest gain is observed for the ARPANET (less than one order of magnitude). When the nodal degree increases from 2 to around 4, the largest gain is observed for degree-four chordal rings (with a gain between four and five orders of magnitude) and the smallest gain is observed for the European Optical Network (with a gain less than one order of magnitude). When the nodal degree increases from 2 to around 5 or 6, the gain is between four and six orders of magnitude depending on the number of nodes. These results clearly show the importance of the way links are connected in OBS networks, since, in this kind of networks, burst loss probability is a key issue. Similar results were obtained for JumpStart, JIT^{+}, JET, and Horizon, not shown in this paper.

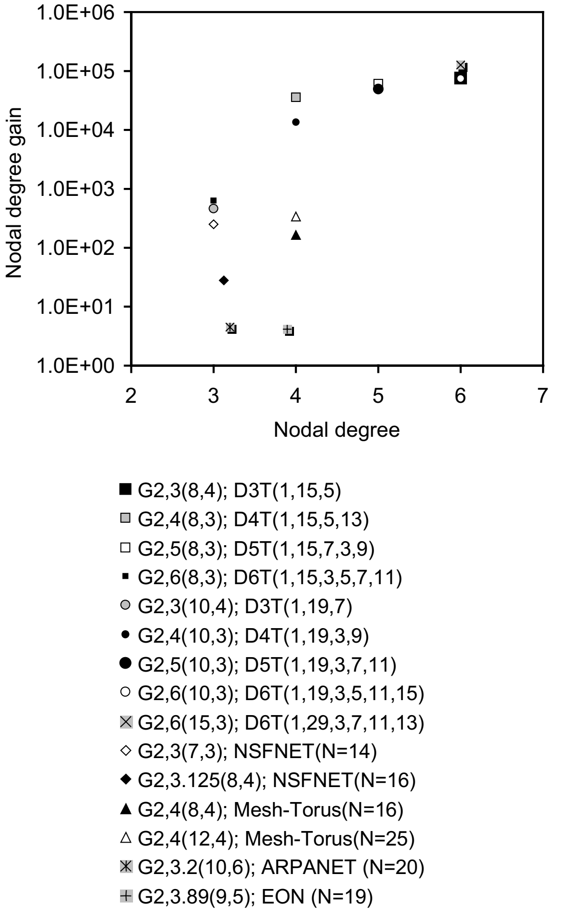

Figure 2. Nodal degree gain in the last hop of each topology, as a function of the nodal degree, for JIT resource reservation protocol; *F*=64.

In Figure 3, we compare the nodal degree gain in the last hop of each topology, as a function of the nodal degree, due to the increase of the nodal degree from 2 (D2T(1,15)) to 3 (D3T(1,15,5)) and 4 (D4T(1,15,5,13)), and from 2 (D2T(1,19)) to 5 (D5T(1,19,3,7,11)), for JIT, JumpStart, JIT^{+}, JET, and Horizon resource reservation protocols (*F*=64). Topologies leading to the best performances for nodal degree of 3, 4, and 5 have been considered for this figure. This confirms previous results where the performance of the resource reservation protocols considered is very close.

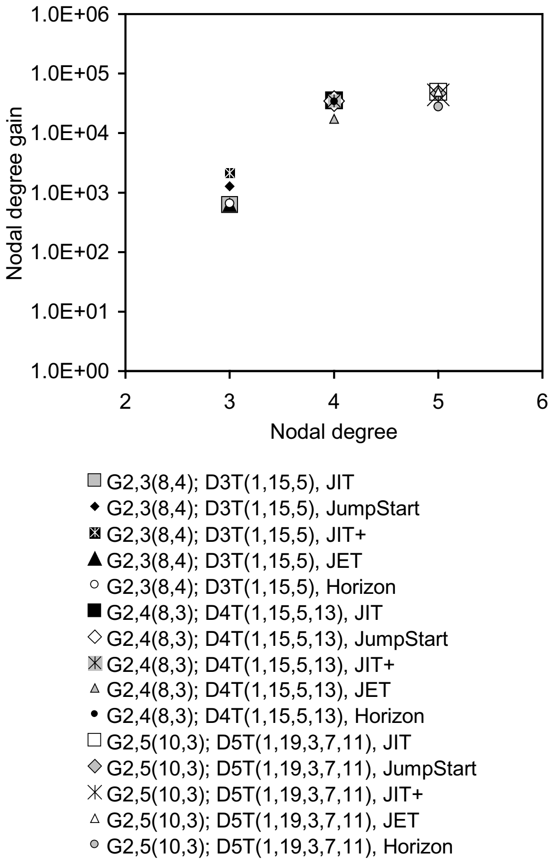

Figure 3. Nodal degree gain in the last hop of each topology, as a function of the nodal degree, due to the increase of the nodal degree from 2 (D2T(1,15)) to 3 (D3T(1,15,5)) and 4 (D4T(1,15,5,13)), and from 2 (D2T(1,19)) to 5 (D5T(1,19,3,7,11)), for JIT, JumpStart, JIT^{+}, JET, and Horizon resource reservation protocols; *F*=64.

5. Conclusions

A performance assessment of optical burst switched (OBS) mesh networks using one-way resource reservation protocols was presented. The following five resource reservation protocols have been considered: Just-In-Time (JIT), JumpStart, JIT+, Just-Enough-Time (JET) and Horizon. The analysis was focused on the following topologies: rings, degree-three chordal rings, degree-four chordal rings, degree-five chordal rings, degree-six chordal rings, mesh-torus, NSFNET, ARPANET and the European Optical Network. Best and worst topologies where identified when the nodal degree increases from 2 to around 3, when the nodal degree increases from 2 to around 4, and when the nodal degree increases from 2 to around 5 or 6. The results obtained clearly show the importance of the way links are connected in OBS networks, since large performance differences were observed for the same nodal degree. It was also observed that the performance of the five resource reservation protocols is very close for those topologies.

Acknowledgements

Part of this work has been supported by the Group of Networks and Multimedia of the Institute of Telecommunications – Covilhã Lab, Portugal, and by the Euro-NGI Network of Excellence of Sixth Framework Programme of EU.

References

[1] C. Qiao and M. Yoo, "Optical burst switching (OBS) - A new paradigm for an optical Internet", *Journal of High Speed Networks*, Vol. 8, no. 1, January 1999, pp. 69-84.

[2] J. S. Turner, "Terabit burst switching", *J. of High Speed Networks*, Vol. 8, no. 1, Jan. 1999, pp. 3-16.

[3] J. Y. Wei and R. I. McFarland, "Just-in-Time signaling for WDM optical burst switching networks", *Journal of Lightwave Technology*, Vol. 18, no. 12, December 2000, pp. 2019-2037.

[4] I. Baldine, G. Rouskas, H. Perros, and D. Stevenson, "JumpStart - A Just-In-Time Signaling Architecture for WDM Burst-Switched Networks", *IEEE Communications Magazine*, Vol. 40, no. 2, February 2002, pp. 82-89.

[5] A. H. Zaim, I. Baldine, M. Cassada, G. N. Rouskas, H. G. Perros, and D. Stevenson, "The JumpStart Just-In-Time Signaling Protocol: A Formal Description Using EFSM", *Optical Engineering*, Vol. 42, no. 2, February 2003, pp. 568-585.

[6] I. Baldine, G. N. Rouskas, H. G. Perros, and D. Stevenson, "Signaling Support for Multicast and QoS within the JumpStart WDM Burst Switching Architecture", *Optical Networks Magazine*, Vol. 4, no. 6, November/December 2003, pp. 68-80.

[7] I. Widjaja, "Performance Analysis of Burst Admission Control Protocols", *IEE Proceeding - Communications*, Vol. 142, no. 1, Feb. 1995, pp. 7-14.

[8] J. Teng and G. N. Rouskas, "A Detailed Analisys and Performance Comparison of Wavelength Reservation Schemes for Optical Burst Switched Networks", *Photonic Network Communications*, Vol. 9, no. 3, May 2005, pp. 311-335.

[9] A. Detti and M. Listanti, "Application of Tell & Go and Tell & Wait Reservation Strategies in a Optical Burst Switching Network: a Performance Comparison", Proceedings of IEEE International Conference on Telecommunication (ICT), 2, Bucharest, Romania, pp. 540-548, June 4-7, 2001.

[10] L. Xu, H. G. Perros, and G. N. Rouskas, "Access Protocols for Optical Burst-Switched Ring Networks", *Information Sciences*, Vol. 149, no. 1-3, January 2003, pp. 75-81.

[11] M. Düser and P. Bayvel, "Analysis of a dynamically wavelength-routed optical burst switched network architecture", *IEEE Journal of Lightwave Technology*, Vol. 20, no. 4, April 2002, pp. 574-585.

[12] C. Qiao, "Optical Burst Switching - A Novel Paradigm", Proceedings of Optical Internet Workshop '97, (http://www.isi.edu/~workshop/oi97/), Oct., 1997.

[13] M. Yoo and C. Qiao, "Just-Enough-Time (JET): A High Speed Protocol for Bursty Traffic in Optical Networks", Proceedings of IEEE/LEOS Conf. on Technologies For a Global Information Infrastructure, pp. 26-27, August, 1997.

[14] M. Sridharan, M. V. Salapaka, and A. K. Somani, "A Practical Approach to Operating Survivable WDM Networks", *IEEE Journal on Selected Areas in Communications*, Vol. 20, no. 1, Jan. 2002, pp. 34-46.

[15] S. Ramesh, G. N. Rouskas, and H. G. Perros, "Computing blocking probabilities in multiclass wavelength-routing networks with multicast calls", *IEEE Journal on Selected Areas in Communications*, Vol. 20, no. 1, January 2002, pp. 89-96.

[16] T. K. Nayak and K. N. Sivarajan, "A New Approach to Dimensioning Optical Networks", *IEEE Journal on Selected Areas in Communications*, Vol. 20, no. 1, January 2002 2002, pp. 134-148.

[17] M. J. O'Mahony, "Results from the COST 239 Project: Ultra-high Capacity Optical Transmission Networks", Proceedings of 22nd European Conference on Optical Communication (ECOC'96), Vol. 2, Oslo, Norway, pp. 2.11-2.18, September 15-19, 1996.

[18] M. J. O'Mahony, D. Simeonidou, A. Yu, and J. Zhou, "The Design of a European Optical Network", *IEEE Journal of Lightwave Technology*, Vol. 13, no. 5, May 1995, pp. 817-828.

[19] B. W. Arden and H. Lee, "Analysis of Chordal Ring Networks", *IEEE Transactions on Computers*, Vol. C-30, no. 4, 1981, pp. 291-295.

[20] J. J. P. C. Rodrigues, N. M. Garcia, M. M. Freire, and P. Lorenz, "Object-Oriented Modeling and Simulation of Optical Burst Switching Networks", Proceedings of 2004 IEEE Global Communications Conference Workshops (GLOBECOM 2004), IEEE, Dallas, TX, USA, pp. 288-292, Nov. 29-Dec. 03, 2004.