Performance Assessment of Enhanced Just-in-Time Protocol in OBS Networks Taking into Account Control Packet Processing and Optical Switch Configuration Times

Joel J.P.C. Rodrigues and Mário M. Freire
IT – Networks and Multimedia Group
Department of Informatics, University of Beira Interior
Rua Marquês d'Ávila e Bolama, 6201-001 Covilhã, Portugal
Phone: +351 275 319 891; Fax: +351 275 319 899
{joel, mario}@di.ubi.pt

Abstract- **Enhanced Just-in-Time (E-JIT) is a new one-way resource reservation protocol for optical burst switching (OBS) networks. This paper investigates the effect of control packet (setup message) processing time and optical switch configuration time on the performance of OBS mesh networks for E-JIT protocol. A performance assessment of E-JIT is presented in comparison with Just-in-Time (JIT) protocol for the following mesh optical burst switching networks: degree-three and degree-four chordal rings, Mesh-torus, NSFNET, ARPANET, and the European Optical Network (EON). Among those topologies, for topologies with nodal degree around three D3T(1,19,7) leads to the best performance, while the worst performance is observed for ARPANET. For network topologies with nodal degree around four, D4T(1,19,3,9) leads to the best performance and the worst is presented by EON. It was shown that the network performance is almost independent of the optical switch configuration time for values smaller than 0.1ms. It was shown that the burst loss probability increases with the increase of the control packet processing time and it was observed that E-JIT may lead to a better performance than JIT.**

Index Terms—**Computer network performance, Optical burst switching, Resource reservation protocols**

I. INTRODUCTION

Optical burst switching (OBS) [1-5] appears as a feasible solution to overcome technical limitations of optical packet switching, namely the lack of optical random access memory and the problems with synchronization. OBS is a technical compromise between wavelength routing (optical circuit switching) and optical packet switching, since it does not require optical buffering or packet-level processing as in optical packet switching and it is more efficient than circuit switching if the traffic volume does not require a full wavelength channel.

In OBS networks, incoming IP (Internet Protocol) packets are assembled into basic units, referred to as data bursts. These bursts are transmitted over the optical core network after a burst header packet, with a delay of some offset time. Each burst header packet is transmitted in a specific channel, and 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.

In order to transmit a burst over the OBS network, a resource reservation protocol must be implemented to allocate resources and configure optical switches for that burst at each node [6]. This paper assumes that a resource reservation protocol implements signaling and scheduling tasks at each node. Several optical burst switching mechanisms were proposed in the literature, such as Just-in-Time (JIT) [3], JumpStart [4],[5], JIT^{+} [7],[8], Just-Enough-Time (JET) [1] and Horizon [2]. Therefore, after studied these protocols, a new resource reservation protocol, called Enhanced Just-in-Time (E-JIT), was proposed in [9].

The proposal of E-JIT is based on the relative performance evaluation of JIT, JumpStart, JIT^{+}, JET, and Horizon resource reservation protocols (presented in [10-14]) and its relative complexity (where JIT is the simplest to implement). E-JIT improves and optimizes the JIT protocol, keeping all the advantages of its simplicity in terms of implementation. Optimization is achieved by the improvement of data channel scheduling. The period of time in which data channel remains in "reserved" status is reduced, and it results in the optimization of the channel utilization and potentially reduce the burst loss probability.

E-JIT assumes an out-of-band signaling and the signaling channel is best-effort link by link. It implements the same resource reservation protocol functions that usually are used in one-way OBS reservation protocols such as it is described for JumpStart [4],[5],[15]. E-JIT protocol uses estimate (or implicit) release to set free the switch fabric resources. The setup message carries the information of burst length and burst offset length, allowing each node to predict the latest time the resources are no longer assigned to a burst transmission. Under E-JIT, an output data channel is reserved for a burst immediately after the arrival of the corresponding setup message, if (*i*) this data channel is free or (*ii*) if it is reserved, the *end time* of the last switched burst is smaller than the actual time to process the setup message ($\leq T_{Setup}$). If a channel cannot be reserved immediately, then the setup message is rejected and the corresponding burst is lost. In [9], a detailed description of E-JIT is provided.

As E-JIT is a JIT based protocol, this paper studies the influence of control packet (setup message) processing time and optical switch configuration time on the performance of OBS mesh networks with E-JIT protocol in comparison with JIT. The importance and the motivation for this study is that E-JIT accepts new bursts when a data channel is reserved and the *end time* of the last switched burst is smaller than the actual time to process the setup message ($\leq T_{Setup}$). Concerning the optical switch (cross-connect - OXC) configuration time (T_{OXC}), we aim to evaluate its influence on the performance of E-JIT because this protocol uses immediate resources reservation, where the OXC is configured immediately after the processing of the corresponding setup message.

JIT resource reservation protocol was proposed by Wei and McFarland [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 uses explicit releases to set free the switch resources. This message is sent either by the source node or the destination node, to tear down all switches 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.

The remainder of this paper is organized as follows. In section II, we present an overview of the main OBS parameters under study in this paper. In section III, we describe the model of the OBS network analyzed and the corresponding simulation parameters. Section IV discusses performance evaluation of E-JIT in comparison with JIT for OBS networks with mesh topologies, and main conclusions are presented in section V.

II. CONTROL PACKET PROCESSING TIME AND OPTICAL SWITCH CONFIGURATION TIME IN OBS NETWORKS

In this section, control packet (setup message) processing time (T_{Setup}) and optical switch (cross-connect - OXC) configuration time (T_{OXC}) are described.

The setup message processing time ($T_{Setup}(X)$) represents the amount of time that is needed to process the setup message in an OBS node according to a format defined by the resource reservation protocol *X*; *X* can be JIT or E-JIT. The time is not necessarily the same for both protocols, but it is assumed that it is equal in every node in the network because all of them use the same protocol. In this study, taking into account that E-JIT is a JIT based protocol, we assume the same value of T_{Setup} for both protocols.

The T_{OXC} is the time an OXC needs to configure its switch fabric to establish a connection between an input port and an output port. This may also be viewed as the time the OXC takes, after interpreting the command in the setup message, to position correctly the micro-mirrors (micro-electro-mechanical systems - MEMS - switch [16]) in the matrix to switch a burst.

This paper evaluates the changing of T_{Setup} in function of the variation of T_{OXC} according to a linear interpolation. Therefore, the value of T_{Setup} for JIT and E-JIT protocols, where *X* is the correspondent resource reservation protocol is given by:

$$T_{Setup}(X) = 1 + \frac{11.5}{10^4 - 20}(T_{OXC}(X) - 20)\ (\mu s) \qquad (1)$$

Another analysis considered in the paper assumes that the change of T_{OXC} is a function of the variation of T_{Setup}. It is obtained solving (1) regarding T_{OXC}. Therefore, the value of T_{OXC} for JIT and E-JIT protocols, where *X* is the correspondent resource reservation protocol is given by:

$$T_{OXC}(x) = 20 + \frac{(T_{Setup}(x) - 1)(10^4 - 20)}{11.5}\ (\mu s) \qquad (2)$$

III. NETWORK MODEL

This paper evaluates the performance of E-JIT in comparison with JIT, considering OBS networks with the following mesh topologies: degree-three and degree-four chordal rings, mesh-torus with 16 and 20 nodes, the NSFNET with 14-node and 21 links [17], the NSFNET with 16 nodes and 25 links [18], the ARPANET with 20 nodes and 32 links [17],[19], and the European Optical Network (EON) with 19 nodes and 37 links [20]. These topologies have the following nodal degree: degree-three chordal ring: 3.0 degree-four chordal ring: 4.0; 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: 3.89. We calculated the nodal degree for each topology because the network topologies with high nodal degree do not have better performance, as we will see later in the next section.

Chordal rings are a well-known family of regular degree three topologies proposed by Arden and Lee in the early eighties for interconnection of multi-computer systems [21]. 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 $(i+w) \bmod N$, where *w* is the chord length, which is assumed to be a positive odd, and *N* the number of nodes.

In [22], a general topology for a given nodal degree was introduced. It is assumed that a topology with a nodal degree of *n* (with *n* chords), where *n* is a positive integer. It is also assumed that each odd-numbered node *i* (*i*=1,3,…,*N*-1) is connected to the nodes $(i+w_1) \bmod N$, $(i+w_2) \bmod N$,

…, $(i+w_n) mod\ N$, where the chord lengths, w_1, w_2, … w_n are assumed to be positive odds, 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, a new notation is presented: a general degree n topology is represented by DnT(w_1, w_2,…,w_n). In this new notation, a chordal ring family with three connections per node (nodal degree-three) and a chord length of w_3 is represented by D3T(1,N-1,w_3), a bi-directional ring is represented by D2T(1,N-1), and a degree-four chordal ring with two chord lengths w is represented by D4T(1,N-1,w_3,w_4).

A major concern in OBS networks is resource contention resolution that leads to 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.

We assume that each OBS node supports F+1 channels per unidirectional link in each direction, considering one channel for signaling (that carries setup messages) and the other F channels carry data bursts. As above-mentioned, 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 and E-JIT. The offset value of a burst under protocol X is $T_{offset}(X)$.

In terms of setup message arrival process (and in consequence data bursts), a Poisson point process with rate λ is assumed (where $1/\lambda$ is the mean duration of the burst interarrival time) and the burst length follows an exponential distribution with an average burst length of $1/\mu$. Therefore, in the simulation tool, taking into account the average of burst length distribution ($1/\mu$) and the setup message arrival rate λ, the burst generation ratio is represented by λ/μ. It is also assumed that bursts are sent uniformly to every core node in the network, with the exception that a core node cannot send messages to itself and, one core node may generate, at the most, one message per time-slot or time period. Edge nodes are responsible for the burst generation process, i.e., neither the ingress core node nor any other core node creates or processes bursts.

Concerning the number of wavelength converters in each OBS node, it is assumed that each OBS node supports full-optical wavelength conversion. For simulation effects, the number of edge nodes connected to each core node is uniformly distributed, each core connecting 64 edge nodes. Between core nodes it is assumed that the geographical size is large so the typical link delays are in the order of 10ms [23] and the value of the edge to core node propagation delay is small, i.e., 0.5µs.

In the simulation, to select a free channel for an incoming burst (with equal probability), for the two resource reservation protocols, the *random* wavelength assignment policy is used [24].

For current available technology, using the existing Micro-Electro-Mechanical Systems (MEMS) switches [16], the time to configure the OXC is T_{OXC}=10ms, and the time to process the setup messages using JITPAC controllers [25] is $T_{Setup}(JIT)$= $T_{Setup}(E\text{-}JIT)$=12.5µs.

Details about the simulator used to produce results can be found in [26].

IV. PERFORMANCE EVALUATION

This section presents a study of the effect of the setup message processing time (T_{Setup}) and the optical cross-connect (OXC) configuration time (T_{OXC}) on the performance of OBS networks with degree-three and degree-four chordal rings, mesh-torus (with N=16 and N=25), the NSFNET (with N=14 and N=16), the ARPANET, and the EON for E-JIT and JIT protocols. The topologies with smallest diameter selected for degree-three chordal rings is D3T(1,19,7) and for degree-four chordal rings is D4T(1,19,3,9).

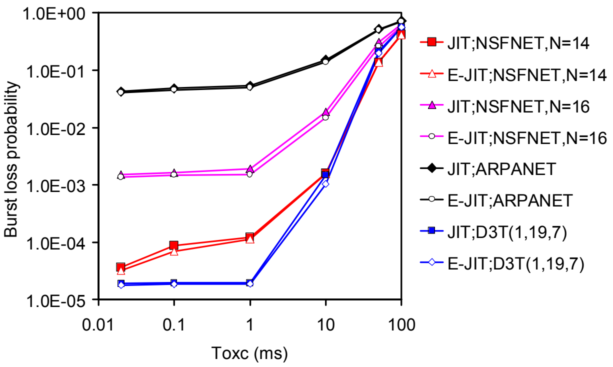

Fig. 1. Burst loss probability, as a function of OXC configuration time in the last hop of NSFNET (N=14), NSFNET (N=16), ARPANET (N=20), and D3T(1,19,7) (N=20) for JIT and E-JIT; F=64; λ/μ=32; T_{Setup}(JIT)=T_{Setup}(E-JIT)=12.5μs.

Figure 1 shows the burst loss probability as a function of OXC configuration time in the last hop of NSFNET (with N=14 and N=16), ARPANET, and D3T(1,19,7) for F=64 and λ/μ=32. In this figure, a fixed value of T_{Setup} time is defined for JIT and E-JIT taking into account the current available technology (JITPAC controllers [25]). T_{OXC} is assumed to range from the value estimated for a near future scenario (T_{OXC}=20µs) up to ten times the value defined for currently available technology, i.e. T_{OXC}=10*10ms=100ms. As may be seen, degree-three chordal ring topology has better performance than other networks, mainly, for $T_{OXC} \leq$10ms. It may also be observed that for $T_{OXC} \leq$1ms, the performance of the two protocols is more or less constant. However it is possible to conclude that despite the improvement and development of new technologies, the network performance does not present enhancement, and T_{OXC} (for values less than 1ms) does not influence the performance of those networks. Although

ARPANET have the great nodal degree (more connections per node), it presents the worst performance. It is a very important result because it expresses the importance of the way of connection between nodes in the design of network topologies. E-JIT performs slightly better than JIT in every network topologies.

Figure 2 confirms observations made for Figure 1 as it illustrates burst loss probability as a function of OXC configuration time in the last hop of NSFNET (with N=14 and N=16), ARPANET, and D3T(1,19,7) for JIT and E-JIT protocols, with F=64 and λ/μ=32. T_{Setup} is assumed to change with T_{OXC}, according to (1) for both protocols. This figure shows that the performance of NSFNET with N=14 is close to the performance of the chordal ring. For values of T_{OXC} less than 10ms, the best performance of E-JIT is more significant.

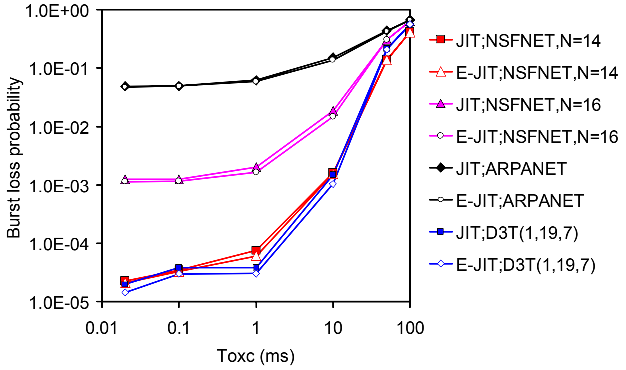

Fig. 2. Burst loss probability as a function of OXC configuration time in the last hop of NSFNET (N=14), NSFNET (N=16), ARPANET (N=20), and D3T(1,19,7) (N=20) for JIT and E-JIT; F=64; λ/μ=32; with changing T_{Setup} according to (1) for each protocol.

Figure 3 plots burst loss probability as a function of setup message processing time in the last hop of the same network topologies shown above in Figures 1 and 2 for JIT and E-JIT protocols, with F=64 and λ/μ=32. T_{Setup} assumes the value ranging between 1μs and 12.5μs, considering 5μs and 10μs as intermediate times. T_{OXC} is assumed to change with T_{Setup}, being computed according to (2). As may be seen, for values of T_{Setup} between the first and last value considered, the burst loss probability increases more than one order of magnitude for NSFNET with N=16 and chordal ring. When the value of T_{Setup} increases, the correspondent burst loss probability also increase.

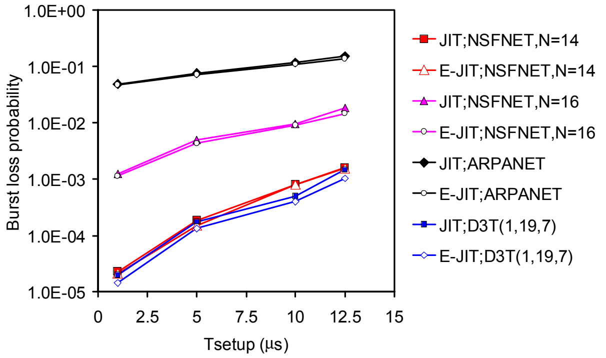

Fig. 3. Burst loss probability *versus* T_{Setup} in the last hop of NSFNET (N=14), NSFNET (N=16), ARPANET (N=20), and D3T(1,19,7) (N=20) for JIT and E-JIT; F=64; λ/μ=32, with changing T_{OXC} according to (2) for each protocol.

Next figures (Figures 4, 5, and 6) illustrate the same network conditions as previous Figures 1, 2, and 3 for network topologies with nodal degree around four, changing the value of λ/μ to 44.8. Network topologies under study are mesh-torus (with N=16 and N=25), EON, and the degree-four chordal ring D4T(1,19,3,9). As may be seen in Figures 4 and 5 the degree-four chordal ring has the best performance and the worst is presented by EON. Mesh-torus presents a similar performance for both number of nodes considered. This result is explained by the same nodal degree (four) and the same way of connections between their nodes. For values of T_{OXC} less than 1ms, the performance of each network does not improve. This observation confirms previous results where the performance of the networks is independent of the change of the T_{OXC}. Additionally, it may also be observed that the relative performance of the both resource reservation protocols is a little similar, being E-JIT better than JIT. However, the best performance of E-JIT is more evident for degree-four chordal ring when T_{OXC}≤10ms. These results are confirmed in Figure 6. As may be seen in Figure 6, when the performance of these protocols is better (for D4T(1,19,3,9)), the better performance of E-JIT in comparison with JIT is clearly evident.

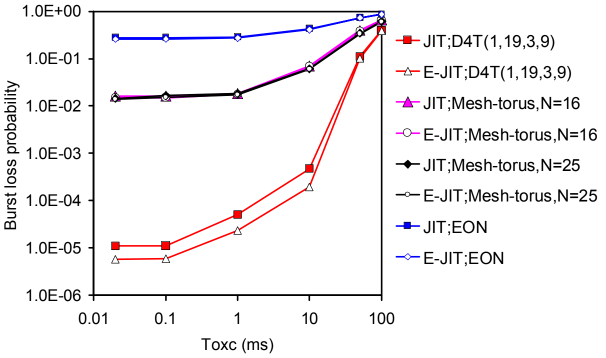

Fig. 4. Burst loss probability as a function of OXC configuration time in the last hop of D4T(1,19,3,9) (N=20), Mesh-torus (N=16), Mesh-Torus (N=25), and EON (N=20) for JIT and E-JIT; F=64; λ/μ=44.8; T_{Setup}(JIT)=T_{Setup}(E-JIT)= 12.5μs.

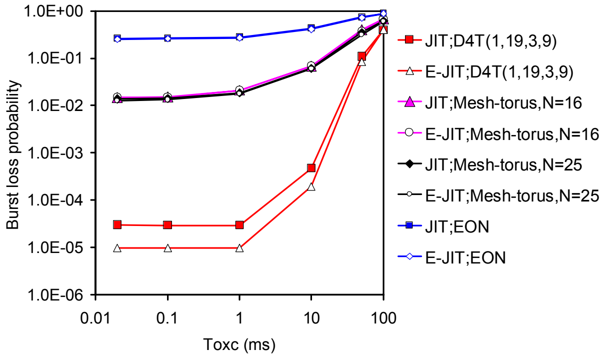

Fig. 5 Burst loss probability as a function of OXC configuration time in the last hop of D4T(1,19,3,9) (*N*=20), Mesh-torus (*N*=16), Mesh-Torus (*N*=25), and EON (*N*=19) for JIT and E-JIT; *F*=64; λ/μ=44.8; with changing T_{Setup} according to (1) for each protocol.

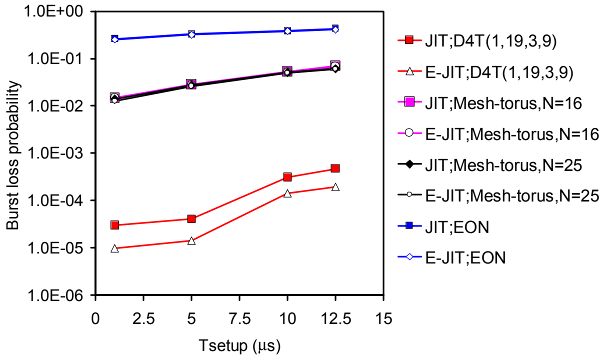

Fig. 6 Burst loss probability *versus* T_{Setup} in the last hop of D4T(1,19,3,9) (*N*=20), Mesh-torus (*N*=16), Mesh-Torus (*N*=25), and EON (*N*=19) for JIT and E-JIT; *F*=64; λ/μ=44.8, with changing T_{OXC} according to (2) for each protocol.

V. CONCLUSION

In this paper, we presented an analysis of the influence of setup message processing time and optical switch configuration time on the performance of OBS mesh networks for E-JIT protocol in comparison with JIT. In this study, the following mesh topologies were considered: chordal rings, Mesh-torus, NSFNET, ARPANET, EON. It was shown that the network performance is almost independent of the optical switch configuration time when this time is smaller than 0.1ms. It was also shown that setup message processing time does not have a significant impact on the network performance. It was shown that when the value of T_{Setup} increases, the correspondent burst loss probability also increase, being the performance of E-JIT better than JIT, mainly when burst loss probability is smaller.

ACKNOWLEDGMENT

Part of this work has been supported by the Group of Networks and Multimedia of the Institute of Telecommunications – Covilhã Lab, Portugal, by Fundação para a Ciência e a Tecnologia, Portugal, through CONDENSA Project contract POSC/EEA-CPS/60247/2004, and by the Euro-FGI 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", Journal of High Speed Networks, Vol. 8, no. 1, January 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] J. P. Jue and V. M. Vokkarane, Optical Burst Switched Networks, Springer, New York, USA, 2005.

[7] J. Teng and G. N. Rouskas, "A Comparison of the JIT, JET, and Horizon Wavelength Reservation Schemes on A Single OBS Node", Proceedings of The First International Workshop on Optical Burst Switching (WOBS), Dallas, Texas, USA, October 13-18, 2003.

[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] J. J. P. C. Rodrigues, M. M. Freire, N. M. Garcia, and P. P. Monteiro, "Enhanced Just-in-Time: A New Resource Reservation Protocol for Optical Burst Switching Networks", Proceedings of International Symposium on Computers and Communications (ISCC'07), Aveiro, Portugal, IEEE, July, 1-4, 2007.

[10] J. J. P. C. Rodrigues and M. M. Freire, "Performance Assessment of Signaling Protocols in Optical Burst Switching Mesh Networks," in Information Networking. Netwosrking Technologies for Broadband and Mobile Networks, H.-K. Kahng (Ed.), Lecture Notes in Computer Science (LNCS), Vol. 3090, Revised Selected Papers of ICOIN 2004, Springer-Verlag, Berlin Heidelberg, 2004, pp. 750-759.

[11] J. J. P. C. Rodrigues, M. M. Freire, and P. Lorenz, "Performance Assessment of Optical Burst Switching Ring and Chordal Ring Networks", Telecommunications Systems, Vol. 27, no. 2-4, October - December 2004, pp. 133-149.

[12] J. J. P. C. Rodrigues, M. M. Freire, and P. Lorenz, "Performance Implications of Nodal Degree for Optical Burst Switching Mesh Networks Using Signaling Protocols with One-way Reservation Schemes", Proceedings of The International Conference on Information Networking (ICOIN 2005), C. Kim (Ed.) Lecture Notes in Computer Science (LNCS), LNCS 3391/2005, Jeju, Korea, Springer, ISBN: 3-540-24467-0, pp. 352-361, January 31 - February 2, 2005.

[13] J. J. P. C. Rodrigues, M. M. Freire, and P. Lorenz, "The Role of Meshing Degree in Optical Burst Switching Networks Using Signaling Protocols with One-way Reservation Schemes", Proceedings of 4th International Conference on Networking (ICN'2005), P. Lorenz and P. Dini (Eds.), Lecture Notes in Computer Science (LNCS), Vol. 3420, Reunion Island, Springer, ISBN: 3-540-25339-3, pp. 44-51, April 17 - 23, 2005.

[14] J. J. P. C. Rodrigues, M. M. Freire, and P. Lorenz, "Performance Implications of Meshing Degree for Optical Burst Switched Networks Using One-way Resource Reservation Protocols", Telecommunications Systems, Vol. 30, no. 1-3, November 2005, pp. 35-47.

[15] A. H. Zaim, I. Baldine, M. Cassada, G. N. Rouskas, H. G. Perros, and D. Stevenson, "Formal description of jumpstart (Just-In-Time) signaling protocol using EFSM", Proceedings of Opticomm 2002: Optical Networking and Communications, 4874, Boston, MA, SPIE, pp. 160-173, July 29-31, 2002.

[16] P. B. Chu, S.-S. Lee, and S. Park, "MEMS: The Path to Large Optical Crossconnects", IEEE Communications Magazine, Vol. 40, no. 3, March 2002, pp. 80-87.

[17] 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, January 2002, pp. 34-46.

[18] 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.

[19] 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.

[20] 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.

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

[22] M. M. Freire, J. J. P. C. Rodrigues, and R. M. F. Coelho, "The Role of Network Topologies in the Optical Core of IP-over-WDM Networks with Static Wavelength Routing", Telecommunications Systems, Vol. 24, no. 2/4, 2003, pp. 111-122.

[23] C. G. Boncelet and D. L. Mills, "A labeling algorithm for Just-In-Time scheduling in TDMA networks", Proceedings of Conference on Communications Architecture & Protocols - ACM SIGCOMM, Baltimore, Maryland, USA, ACM Press, pp. 170-175, August 17-20, 1992.

[24] Y. Zhu, G. N. Rouskas, and H. G. Perros, "A Comparison of Allocation Policies in Wavelength Routing Networks", Photonic Networks Communication Journal, Vol. 2, no. 3, August 2000, pp. 265-293.

[25] I. Baldine, M. Cassada, A. Bragg, G. Karmous-Edwards, and D. Stevenson, "Just-in-Time Optical Burst Switching Implementation in the ATDnet All-Optical Networking Testbed", Proceedings of IEEE GLOBECOM 2003, IEEE (Ed.), Vol. 5, San Francisco, USA, IEEE, pp. 2777-2781, December 1-5, 2003.

[26] 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 IEEE Global Telecommunications Conference (GLOBECOM'2004) - Conference Workshops, 10th IEEE Workshop on Computer-Aided Modeling, Analysis and Design of Communication Links and Networks (CAMAD'2004), Dallas, TX, USA, IEEE Press, ISBN: 0-7803-8798-8, pp. 288-292, November 29 - December 03, 2004.