Enhanced Just-in-Time: A New Resource Reservation Protocol for Optical Burst Switching Networks

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Abstract

This paper proposes a new resource reservation protocol for optical burst switching networks, called Enhanced Just-in-Time (E-JIT). E-JIT intends to improve and optimize the traditional JIT protocol, keeping all the advantages of its simplicity in terms of implementation. E-JIT aims to improve data channel scheduling, reducing the period of time in which the data channel remains in reserved status, optimizing channel utilization and reducing the burst loss probability. A performance assessment of E-JIT is presented for mesh optical burst switching networks with 16 nodes. It is shown that E-JIT may lead to a better performance than JIT for small burst loss probabilities.

1. Introduction

Optical burst switching (OBS) [1-5] aims 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, 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 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. According to the reservation scheme, 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 time 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. Just-in-time (JIT) [3], JumpStart [4],[7], JIT^{+} [8], just-enough-time (JET) [1] and Horizon [2] are examples of one-way resource reservation protocols. Therefore, after studying these protocols, this paper proposes a new resource reservation protocol for OBS networks, named Enhanced Just-in-Time (E-JIT).

The proposal of E-JIT is based on the relative performance evaluation of JIT, JumpStart, JIT^{+}, JET, and Horizon resource reservation protocols (presented in [9-13]) and its relative complexity (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 improved data channel scheduling, as the the period of time in which the data channel remains in "reserved" status is reduced, resulting in optimizing channel utilization and potentially reducing burst loss probability.

The remainder of this paper is organized as follows. In section 2, we present an overview of the main OBS parameters under study in this paper. Section 3 discusses performance assessment of E-JIT in comparison with JIT for OBS networks with mesh topologies, and main conclusions are presented in section 4.

2. A New Resource Reservation Protocol: Enhanced JIT (E-JIT)

In this section, a new resource reservation protocol for OBS networks, called *Enhanced Just-in-Time* (E-JIT) is proposed. 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 JumpStart [4], namely path setup, data transmission, state maintenance, and path release.

E-JIT supports both short and long bursts. The setup message has the responsibility of Session Declaration, Path Setup and Data Transmission informing intermediate nodes of a burst arrival. Especially for long bursts, to maintain the connection (State Maintenance), the source edge node may also send KEEPALIVE messages to the intermediate nodes along the path to prevent the switch state from timing out.

E-JIT protocol uses estimate (or implicit) release to set free the switch fabric resources, as the setup message also 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. When a burst leaves an optical cross-connect (OXC), the OXC automatically frees its resources using an estimate release, like JET. Thus, this OXC can immediately accept and switch a new burst. When a burst arrives to its destination edge node, all OXCs along the path from source to destination were successively ready (in a “free” state) to switch a new burst. Otherwise, when a network element is unable to perform a successful “setup” (setup failure), it sends a “release message” to all previous network elements along the path back to the source node. Here, it is assumed that, as mentioned above, the status of data channel is updated to “free” when the last bit of the burst arrives at the switch and it is intended to present the operation of resources allocation using this protocol. An explicit release message is only sent if an event of detection of setup failure occurs during an end-to-end transmission along the path. The value of offset time depends on the resource reservation protocol and the number of nodes that the burst has already passed through (this value decreases as the burst crosses a node, because each node processes electronically the control message, delaying it). The main concern is to make this value such that the first bit of the burst arrives at the egress node shortly after the node is configured and ready to receive it. If k is the number of OBS nodes in the path of a burst from source to destination and X represents the protocol, then the minimum value to $T_{Offset}(X)$ is [8]:

$$T_{offset}^{(\min.)}(X) = k.T_{Setup}(X) + T_{OXC} \quad (1)$$

The message flow for E-JIT is illustrated in Figure 1.

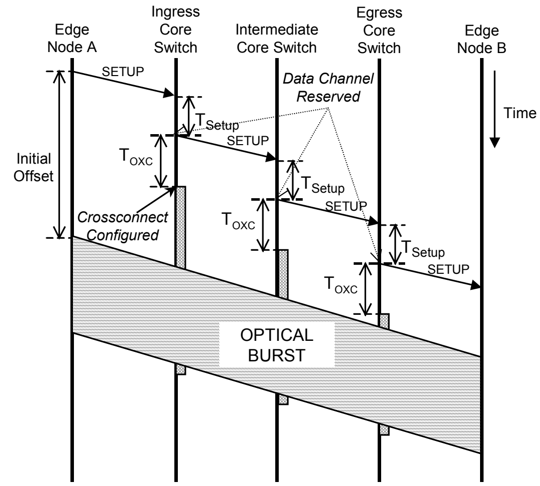

Fig. 1. Schematic representation of E-JIT signaling messages for a successful burst transmission.

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. The operation of E-JIT resource reservation protocol is illustrated in Figure 2.

Each data channel has one of two states: “free” or “reserved”. If the wanted data channel is “free”, the setup message and the corresponding data burst are accepted. If the wanted data channel is “reserved” and the *end time* of the last switched burst is smaller than the *end processing time* of the incoming setup message, the new setup message and the corresponding data burst are accepted. Otherwise, the setup message is rejected and the correspondent data burst is lost.

Both JIT and E-JIT are resource reservation protocols with immediate resources reservation. This proposal aims to optimize JIT protocol, reducing free time periods of data channels (until zero, if possible – as it may be seen in Figure 2) and increasing the data channel utilization. Consequently, data burst loss probability is reduced and OBS network performance is increased.

Figures 2, 3, and 4 show, in detail, the operation of E-JIT resource reservation protocol. In these figures, the following parameters are used:

- T_{Setup} represents the amount of time that is needed to process the setup message in an OBS node. It is assumed that this time is equal in every node in the network, since all of them are configured under the same protocol.
- T_{OXC} is the time 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 OXC takes, after interpreting the command in the control message, to configure the switching elements in the switching matrix, e.g. to position micro-mirrors

correctly (MEMS switch [14],[15]) to allow the burst to transparently cross the node.
– T_{idle} is the idle time in an output channel in an OBS node. During this period of time, OXC is already configured and it continues waiting to switch a burst.

In Figures 2-4, a single data channel of an OBS node is considered, to present the operation of resource reservation protocol. A temporal line is used to illustrate the sequence of events. On this time line, this sequence of events leading to the reservation of a data channel to switch a burst can be best observed. The time line does not show each time in terms of the same scale, due to space limitations (e.g. T_{OXC} is currently around 10 times larger than T_{setup} [16]).

At instant t_0, it is considered that OXC receives the setup message (*Setup A*) and, between t_0 and t_1 converts it from an optical to an electronic signal to be processed. Instant t_1 is the earliest time after which the data channel of OXC is said to be "reserved".

Figure 2 shows two successive bursts (*Burst A* and *Burst B*) and its corresponding setup messages (*Setup A* and *Setup B*). For *Burst A*, the OXC operates like JIT, because the channel was previously "free". At instant t_5 arrives a new setup message (*Setup B*) and at instant t_7 it is assumed that OXC has processed it. At this time it is possible to accept and switch *Burst B* because $t_7 > t_6$ (t_6 is the end of the *Burst A*). In case of JIT protocol, *Burst B* would be rejected because the arrival time of the message *Setup B* happens after the return of the data channel to a "free" condition (at time t_5, the channel is still labelled as "reserved").

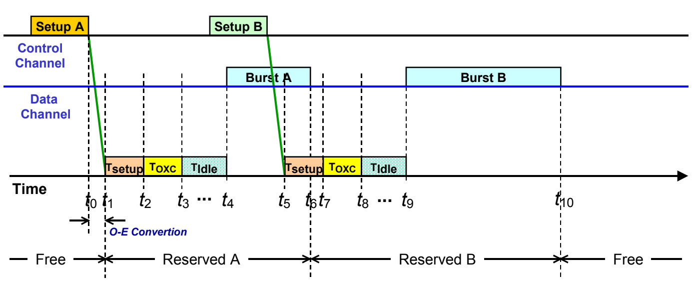

Fig. 2. Operation of E-JIT resource reservation protocol.

After t_6, data channel continues reserved (*Reserved B*) because it will switch *Burst B*. Immediately, after processing the setup message (*Setup B*) at time t_7, between instants t_7 and t_8 OXC is configured to switch *Burst B* (immediate resources reservation). The burst is switched between t_9 and t_{10}. After t_{10} (end of the *Burst B*) the state of the data channel changes to "free" again waiting for a new burst.

The change of state to "reserved" takes place upon receipt of the setup message, whereas the change to state "free" occurs when the last bit of the burst arrives at the switch at time t_5. The length of state "reserved" is equal to the burst length plus the correspondent remaining offset time (T_{Offset}). The length of a state "free" is equal to the time until the arrival of next setup message. If OXC receives a setup message and the *end processing time* of this setup message is greater than the *end switch time* of the last burst, the state remains "reserved" for the new burst (see Figure 2).

Figure 3 addresses the same sequence of two incoming bursts (*Burst A* and *Burst B*) mentioned above and the intention to receive a third (*Burst C*). In this case, OXC cannot accept the setup message of the third burst (*Setup C*) because the *end processing time* (t_{10}) of the new setup message (*Setup C*) is less than the *end time* of *Burst B* (t_{11}).

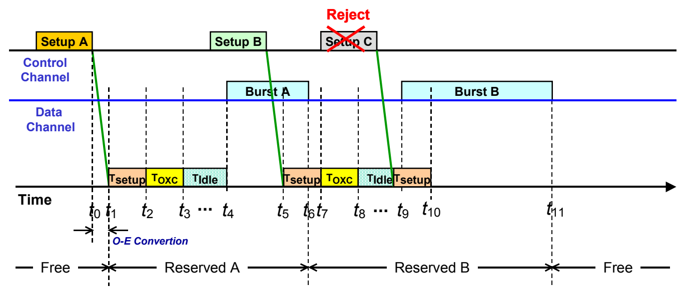

Fig. 3. Operation of E-JIT resource reservation protocol (rejecting a burst).

Figure 4 shows the arrival of a new burst and the correspondent setup message (*Setup D*), in the sequence of Figures 2 and 3. When a new setup message arrives to OXC, at time t_{9b}, this setup message is accepted because its *end setup time* (t_{10}) is greater than the *end switch time* (t_{9c}) of the last switched burst (*Burst B*). This situation is similar to the case of switching *Burst B* (at time t_6), the state remains "reserved" changing for *Burst D* at time t_{9c}.

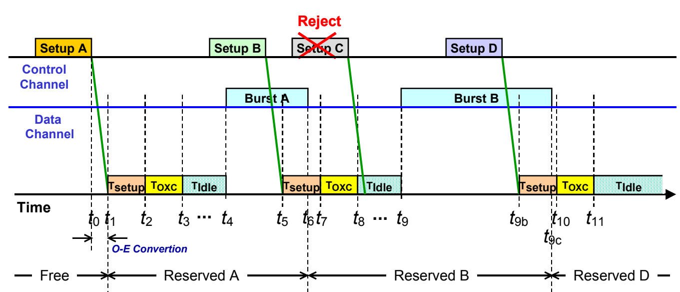

Fig. 4. Operation of E-JIT resource reservation protocol (accepting a new burst).

Both JIT and E-JIT resource reservation protocols use first-come, first-serve (FCFS) service. Bursts are switched in the order in which their corresponding *setup messages* arrive at the node. Similar to JIT^{+}, E-JIT schedules the first available data channel to accommodate a burst [8].

3. Performance Assessment of E-JIT Protocol

E-JIT is an OBS one-way resource reservation protocol proposed in this paper and described in Section 2. Therefore, it is necessary to evaluate the performance of this new protocol in comparison with others. In this study is used the network model described in [17] and details about the simulator used to produce results can be found in [18]

As above-mentioned, it was observed that the performance of the five one-way resource reservation protocols is very similar (JIT, JumpStart, JIT^{+}, JET, and Horizon). As E-JIT is a JIT based protocol, this section studies the performance of the E-JIT protocol in OBS networks, in comparison with JIT. The performance evaluation is studied for rings, degree-three and degree-four chordal rings, NSFNET (with N=14 and N=16), Mesh-torus (with N=16 and N=25), ARPANET and EON network topologies.

Figure 5 plots burst loss probability as a function of number of data channels per link for JIT and E-JIT protocols, in the last hop of ring (D2T(1,15)), chordal ring (D3T(1,15,5) and D4T(1,15,5,13)), NSFNET, and Mesh-Torus networks with N=16 and λ/μ=32. As it may be seen, when enough network resources are available (F=64), chordal rings with high nodal degree have the best performance and ring networks present the worst performance. Network topologies can be sorted from the best to the worst performance as: D4T(1,15,5,13), D3T(1,15,5), Mesh-Torus, NSFNET, and D2T(1,15). These results confirm previous observations in terms of relative performance of network topologies. However, the most important result of this and the next figures is the relative best performance of E-JIT in comparison with JIT. Expectedly, when the burst loss probability is smaller, i.e., more network resources are available, the performance improvement of E-JIT over JIT is more significant.

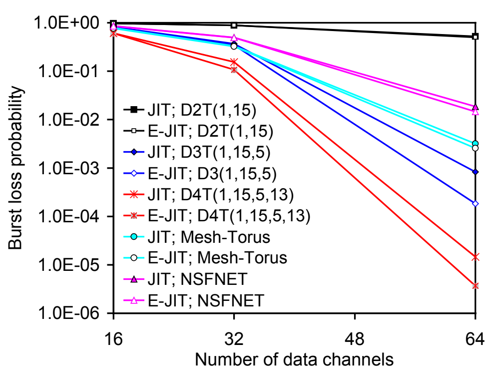

Fig. 5. Burst loss probability, as a function of number of number of data channels per link (F), in the last hop of ring (D2T(1,15)), chordal ring (D3T(1,15,5) and D4T(1,15,5,13)), NSFNET, and Mesh-Torus networks for JIT and E-JIT protocols; λ/μ=32; N=16; T_{Setup}(JIT)=T_{Setup}(E-JIT) =12.5μs.

Figure 6 confirms observations made for Figure 5 as it illustrates the burst loss probability as a function of number of hops for the same network topologies and conditions considered previously. In the first hop of D4T(1,15,5,13), the value of the burst loss probability tends to zero. This topology has better performance than others and it has the smallest network diameter (three). For network topologies with same network diameter, equal to four, degree-three chordal ring performs better, followed by Mesh-torus and NSFNET. The ring, with the largest network diameter equal to eight, performs worst than the other topologies.

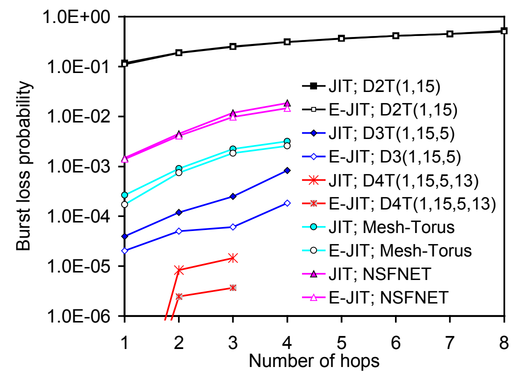

Fig. 6. Burst loss probability, as a function of number of number of hops, for ring (D2T(1,15)), chordal ring (D3T(1,15,5) and D4T(1,15,5,13)), NSFNET, and Mesh-Torus networks using JIT and E-JIT protocols; λ/μ=32; F=64; N=16; T_{Setup}(JIT)=T_{Setup}(E-JIT) =12.5μs.

Figure 7 shows burst loss probability as a function of λ/μ for the studied network topologies, in the last hop of D2T(1,15), D3T(1,15,5), D4T(1,15,5,13), Mesh-torus (N=16) and NSFNET (N=16), for JIT and E-JIT, with F=64 data channels per link. As it may be seen, the probability of burst loss increases with the increase of λ/μ. The behavior of both topologies is similar for each resource reservation protocols; however, the performance of E-JIT is again better than JIT. When λ/μ increases, the difference between the performance JIT and E-JIT decreases. For values of λ/μ less than 32 for chordal rings and Mesh-torus, less than 25.6 for NSFNET, and less than 19.2 for ring, the result of burst loss probability is zero.

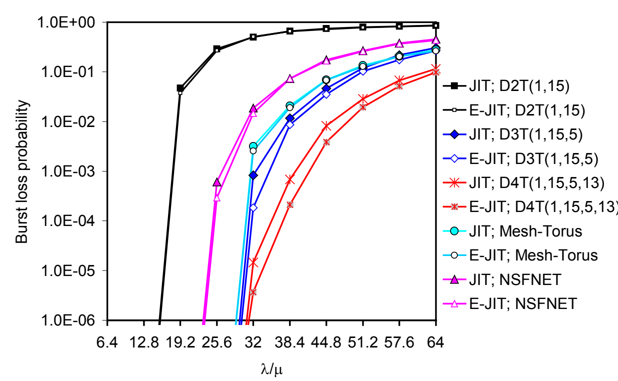

Fig. 7. Burst loss probability, as a function of λ/μ, in the last hop ring (D2T(1,15)), chordal ring (D3T(1,15,5) and D4T(1,15,5,13)), NSFNET, and Mesh-Torus networks for JIT and E-JIT protocols; F=64; N=16; T_{Setup}(JIT)=T_{Setup}(E-JIT) =12.5μs.

Figure 8 studies the impact of number of nodes in the performance of JIT and E-JIT resource reservation protocols considering mesh topologies with nodal degree around two and three between 10 and 30 nodes. NSFNET with N=14 nodes has nodal degree equal to 3, NSFNET with N=16 nodes has nodal degree equal to 3.125, and ARPANET with nodal degree equal to 3.2 are examples of nodal degree around three. As shown in Figure 8, for networks with number of nodes less between 18 and 22 (inclusive), D3T(1,N-1,5) performs better than others topologies and D3T(1,N-1,7) performs better for networks with number of nodes equal to 20 and more than 22 nodes. For networks with nodal degree around three, E-JIT performs better than JIT, but its gain is not significant, except for D3T(1,15,5). Network topologies with nodal degree equal to two (i.e. rings) present the worst performance. In terms of irregular mesh topologies, NSFNET with 14 nodes performs better than NSFNET with 16 nodes and ARPANET.

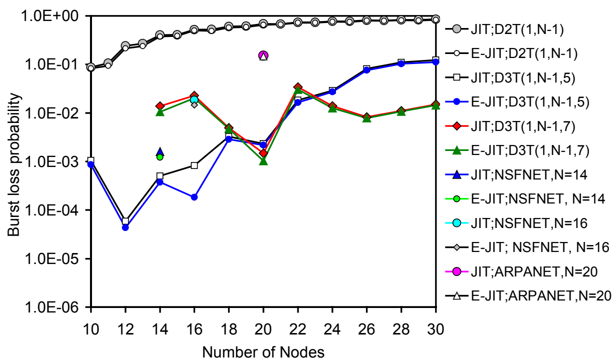

Fig. 8. Burst loss probability, as a function of the number of nodes (N), in the last hop of rings, degree-three chordal rings, FCCN-NET, NSFNET, and ARPANET, for JIT and E-JIT protocols; λ/μ=32; *F*=64; T_{Setup}(JIT)=T_{Setup}(E-JIT) =12.5μs.

Figure 9 presents the study of the performance of OBS networks, based on the nodal degree gain for mesh topologies with nodal degree between three and five for *N*≤16. This figure shows for JIT and E-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)), and 5 (D5T(1,15,7,3,9) with *F*=64 and λ/μ=32. As may be seen in the figure, when the nodal degree increases from 2 to around 3, the largest gain is observed for degree-three chordal rings with *N*=16 (between slightly less than three and four orders of magnitude) and the smallest gain is observed for the NSFNET with N=16 (between one and two orders of magnitude). When the nodal degree increases from 2 to around 4, the largest gain is observed for degree-four chordal rings with *N*=16 (with a gain between four and five orders of magnitude) and the smallest gain is observed for the Mesh-torus (with a gain between two and three orders of magnitude). When the nodal degree increases from 2 to 5, the gain is slightly less than five orders of magnitude for the degree-five chordal rings. The largest gain is observed when the nodal degree increases from 2 to 5. In terms of performance comparison of JIT and E-JIT resource reservation protocols, the nodal degree gain of E-JIT is greater than JIT, and the largest gain is observed for degree-five chordal ring. 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. Examples of this finding are the similar performance of the NSFNET (with *N*=14 and nodal degree of 3) in comparison with mesh-torus (with *N*=16 and nodal degree of 4), and the similar performance of the ARPANET (with nodal degree of 3.2) in comparison with EON (with nodal degree of 3.89). These observations show that more connections between nodes (larger nodal degree) do not mean better performance of those networks.

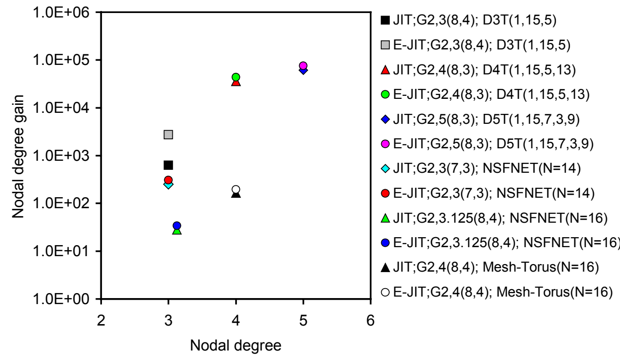

Fig. 9. Burst loss probability, as a function of the number of nodes (*N*), in the last hop of rings, degree-three chordal rings, FCCN-NET, NSFNET, and ARPANET, for JIT and E-JIT protocols; λ/μ=32; *F*=64; T_{Setup}(JIT)=T_{Setup}(E-JIT) =12.5μs.

4. Conclusions

In this paper we proposed, described, and evaluated the performance of a new OBS one-way resource reservation protocol, named Enhanced Just-in-Time (E-JIT). Performance assessment of E-JIT was made in comparison with JIT, taking into account mesh topologies with 16 nodes. The impact of number of nodes and the influence of nodal degree on nodal degree gain were also considered. E-JIT is a JIT based protocol, maintaining its simplicity in terms of implementation. It was shown that E-JIT performs better than JIT. For network topologies with 16 nodes, when the burst loss probability is lower, the relative better performance of E-JIT over JIT is more significant. Concerning the influence of nodal degree on the nodal degree gain, it was observed that when the nodal degree increases from 2 to around 3, the largest gain is observed for degree-three chordal rings with *N*=16 (between slightly less than three and four orders of magnitude) and the smallest gain is observed for the NSFNET with *N*=16 (between one and two orders of magnitude). When the nodal degree increases from 2 to around 4, the largest gain is observed for degree-four chordal rings with *N*=16 (with a gain between four and five orders of magnitude) and the smallest gain is observed for the mesh-torus with *N*=16 (with a gain more than two orders of magnitude). When the nodal degree increases from 2 to 5, the gain is slightly less than five orders of magnitude for chordal rings with *N*=16. The largest gain is observed when the nodal degree increases from 2 to 5. In terms of performance comparison of JIT and E-JIT protocols, the nodal degree gain of E-JIT is larger than JIT, and the largest gain is observed for degree-three chordal rings with *N*=16.

Acknowledgments

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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] 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.

[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 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.

[10] 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.

[11] 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.

[12] 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.

[13] 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.

[14] 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.

[15] J. I. Dadap, P. B. Chu, I. Brener, C. Pu, C. D. Lee, K. Bergman, N. Bonadeo, T. Chau, M. Chou, R. Doran, R. Gibson, R. Harel, J. J. Johnson, S. S. Lee, S. Park, D. R. Peale, R. Rodriguez, D. Tong, M. Tsai, C. Wu, W. Zhong, E. L. Goldstein, L. Y. Lin, and J. A. Walker, "Modular MEMS-Based Optical Cross-Connect With Large Port-Count", *IEEE Photonics Technology Letters*, Vol. 15, no. 12, December 2003, pp. 1773-1775.

[16] J. Teng, "A Study of Optical Burst Switched Networks with theJumpstart Just In Time Signaling Protocl," *A dissertation submitted to University of North Carolina State University in partial satisfaction of the requirements for the Degree of Doctor of Philosophy*, Department of Computer Science, Raleigh, 2004.

[17] J. J. P. C. Rodrigues, M. M. Freire, and P. Lorenz, "Performance Implications of Control Packet Processing and Optical Switch Configuration Times in Optical Burst Switched Mesh Networks with Degree-Four Topologies", Proceedings of The 7th IEEE International Symposium on Computer Networks (ISCN'06), F. Alagoz and M. U. Çaglayan (Eds.), Istambul, Turkey, IEEE, pp. 167-172, June 16 - 18, 2006.

[18] 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.