Impact of Setup Message Processing and Optical Switch Configuration Times on the Performance of IP over Optical Burst Switching Networks

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Abstract. This paper discusses the influence of setup message processing time and optical switch configuration time on the performance of IP over optical burst switched mesh networks using one-way resource reservation protocols. It is shown that the network performance is almost independent of the optical switch configuration time for values smaller than 0.1ms. It is shown that setup message processing time does not have a significant impact on the network performance and it is shown that the five resource reservation protocols under study have a similar performance in both ring and mesh networks.

1 Introduction

In order to provide optical switching for next-generation Internet in a flexible and feasible way, a new switching paradigm called optical burst switching (OBS) [1]-[6] was proposed, which is an alternative to optical packet switching (OPS) and wavelength routing (WR). OBS combines the best of OPS and WR, and it is a technical compromise between both OPS and WR, since it does not require optical buffering or packet-level processing and is more efficient than wavelength routing 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],

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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 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 optical cross-connect (OXC) switch fabric. TAG is practical only if the switch processing time of the setup 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 reminder of this paper is organized as follows. In section 2, we present an overview of one-way resource reservation protocols considered along this study. In section 3, we briefly describe the model of the OBS network under study, and in section 4 we discuss performance implications of the setup message processing time and optical switch configuration time on the performance of optical burst switched mesh networks. Main conclusions are presented in section 5.

2 One-Way Resource Reservation Protocol

This section provides an overview of one-way resource reservation protocols for OBS networks. This kind of protocols may be classified, regarding the way in which output channels (wavelengths) are reserved for bursts, as immediate and delayed reservation. JIT and JIT^+ are examples of immediate channel 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 [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]. 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 recently proposed resource reservation protocol is JIT^{+} [8]. It 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

In this study, we consider OBS networks with the following mesh topologies: chordal rings with nodal degrees of 3 and 4, mesh-torus with 16 and 20 nodes, the NSFNET with 14-node and 21 links [12], the NSFNET with 16 nodes and 25 links [13], the ARPANET with 20 nodes and 32 links [12], [14], and the European Optical Network (EON) with 19 nodes and 37 links [15]. 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; degree-six chordal ring: 6.0; 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.

Chordal rings are a well-known family of regular degree three topologies proposed by Arden and Lee in early eighties for interconnection of multi-computer systems [16]. 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, $w_1, w_2, \ldots w_n$ 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 wavelength channels per unidirectional link in each direction. One wavelength is used for signaling (carries setup messages) and the other F wavelengths carry data bursts. Each OBS node consists of two main components [8]: i) a signaling engine, 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, 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. As in [8], in this study it is assumed the mean burst size, $1/\mu$, is equal to 50 ms (equal to $5T_{OXC}$), and the burst arrival rate λ is such that $\lambda/\mu=32$ or $\lambda/\mu=44.8$.

4 Performance Assessment

This section presents a study of the effect of the setup message processing time and the optical cross-connect (OXC) configuration time on the performance of OBS networks with ring, degree-three and degree-four chordal ring topologies for JIT, JumpStart, JIT$^+$, JET, and Horizon protocols. The topology with smallest diameter selected for degree-four chordal rings is D4T(1,19,3,9). Details about the simulator used to produce simulation results can be found in [17].

Figure 1 plots the burst loss probability as function of OXC configuration time in the last hop of D2T(1,19) and D3T(1,19,7) for the five protocols under study, with F=64 and λ/μ=32. In this figure a fixed value for T_{Setup} time is assumed, which is the value defined for JIT, JumpStart, and JIT$^+$ and estimated for JET and Horizon for currently available technology [8]. 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 in this figure, chordal rings clearly have better performance than rings for $T_{OXC}\leq$50ms. It may also be observed that for $T_{OXC}\leq$1ms, the performance of the chordal ring is independent of the change of the T_{OXC} , which means that a reduction of the values of T_{OXC} to ones smaller than 1ms does not improve the network performance. Moreover, it may also be observed that the relative performance of the five resource reservation protocols is similar, being JIT and JIT$^+$ slightly better than the other ones.

Figure 2 confirms results found in Figure 1. Figure 2 illustrates the burst loss probability as function of the setup message processing time (T_{Setup}) in the last hop of D2T(1,19) and D3T(1,19,7) for the five protocols under study, with F=64 and λ/μ=32. Two scenarios are considered regarding T_{OXC}: it assumes the value for the

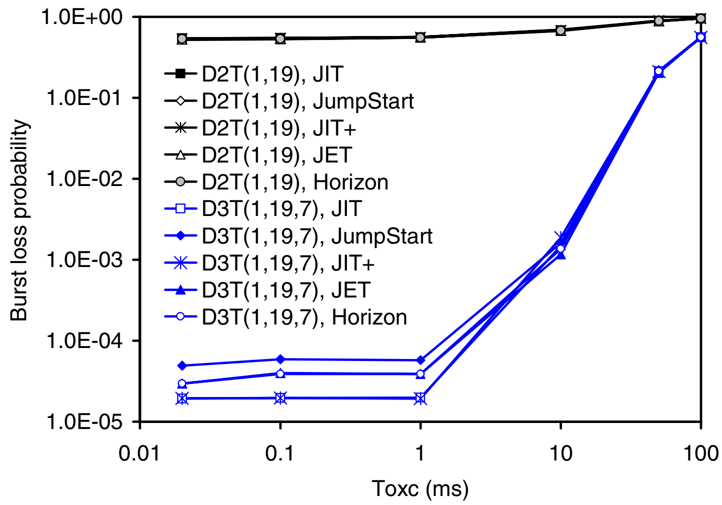

Fig. 1. Burst loss probability as function of OXC configuration time in the last hop of D2T(1,19) and D3T(1,19,7) for JIT, JumpStart, JIT$^+$, JET, and Horizon; F=64; λ/μ=32; T_{Setup}(JIT)=T_{Setup}(JumpStart)=T_{Setup}(JIT$^+$)=12.5μs; T_{Setup}(JET)=50μs; T_{Setup}(Horizon)=25μs.

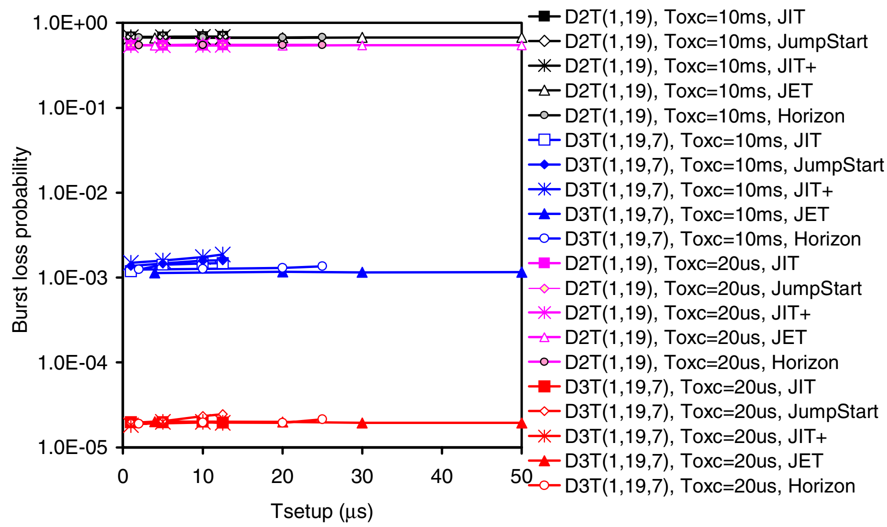

Fig. 2. Burst loss probability as function of Setup processing time in the last hop of D2T(1,19) and D3T(1,19,7) for JIT, JumpStart, JIT$^+$, JET, and Horizon; F=64; λ/μ=32

currently available technology (T_{OXC}=10ms) or an estimated value for a near future scenario (T_{OXC}=20µs). For each curve of figure 2, T_{OXC} is assumed to have a fix value while T_{Setup} ranges between the values considered for the current available

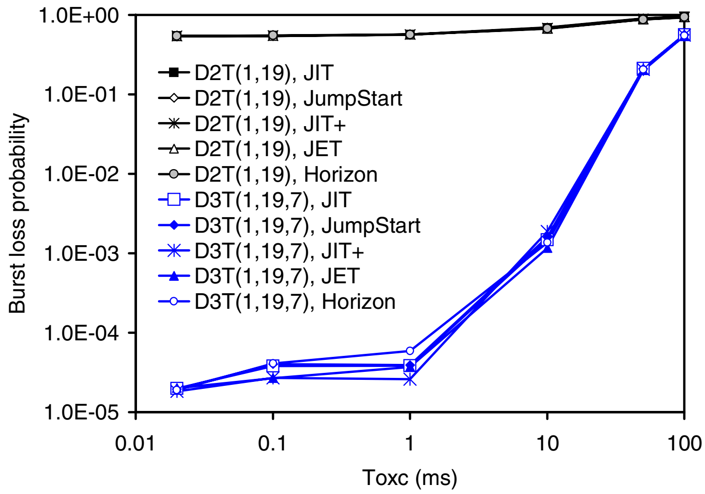

Fig. 3. Burst loss probability as function of OXC configuration time in the last hop of D2T(1,19) and D3T(1,19,7) for JIT, JumpStart, JIT$^+$, JET, and Horizon; F=64; λ/μ=32; with varied T_{Setup} according to (1), (2), and (3) for each resource reservation protocol

technology and the estimated values for the near future technology. Thus, T_{Setup} ranges between 12.5µs and 1µs, for JIT, JumpStart, and JIT$^+$, ranges between 25µs and 2µs for JET, and between 50µs and 4µs for Horizon. As may be seen in this figure, the performance of chordal rings is clearly better than rings and the behavior of the five protocols is very close. This figure confirms that the reduction of T_{Setup} does not lead to a better network performance. It may also be observed that for chordal rings a reduction of the T_{OXC} from 10 ms down to 20 µs leads to a performance improvement about two orders of magnitude. For rings, the burst loss is so high that the reduction of T_{OXC} does not have impact on the network performance.

In figure 3 it is assumed that the change of T_{Setup} is a function of the variation of T_{OXC} according to a linear interpolation. Therefore, the value of T_{Setup} for JIT, JumpStart, and JIT$^+$ protocols, where X is the correspondent resource reservation protocol is given by:

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

T_{Setup} for JET protocol is given by:

$$T_{Setup}(JET) = 4 + \frac{46}{10^4 - 20}(T_{OXC}(JET) - 20) \quad (\mu s) \tag{2}$$

For Horizon signaling protocol, T_{Setup} is given by:

$$T_{Setup}(Horizon) = 2 + \frac{23}{10^4 - 20}(T_{OXC}(Horizon) - 20) \quad (\mu s) \tag{3}$$

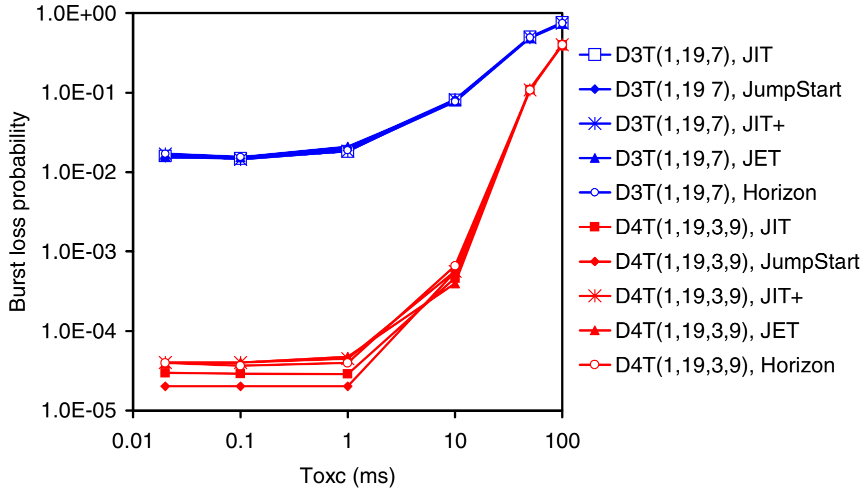

Fig. 4. Burst loss probability as function of OXC configuration time in the last hop of D3T(1,19,7) and D4T(1,19,3,9) for JIT, JumpStart, JIT$^+$, JET, and Horizon; F=64; λ/μ=44.8; with varied T_{Setup} according to (1), (2), and (3) for each resource reservation protocol

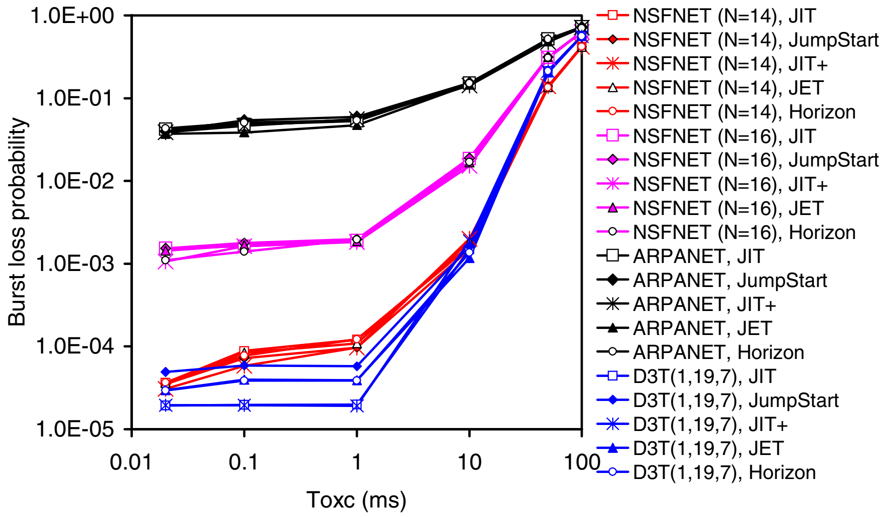

Fig. 5. Burst loss probability as function of OXC configuration time in the last hop of NSFNET (N=14), NSFNET (N=16), ARPANET, and D3T(1,19,7) for JIT, JumpStart, JIT$^+$, JET, and Horizon; F=64; λ/μ=32; T_{Setup}(JIT) = T_{Setup}(JumpStart) = T_{Setup}(JIT$^+$) = 12.5μs; T_{Setup}(JET)=50μs; T_{Setup}(Horizon)=25μs

Figure 3 shows the burst loss probability as function of OXC configuration time in the last hop of D2T(1,19) and D3T(1,19,7) for JIT, JumpStart, JIT^{+}, JET, and Horizon, being T_{Setup} computed according to (1), (2), and (3) for each protocol. As may be seen, for T_{OXC}<0.1ms, a small change in the burst loss can be observed regarding figure 1. However, this small change is not significant in terms of network performance and therefore, this figure also confirms the previous observations about the influence of T_{setup} and T_{OXC} in the network performance.

Figure 4 plots the burst loss probability as function of OXC configuration time in the last hop of D3T(1,19,7) and D4T(1,19,3,9) for the five protocols under study, with F=64, λ/μ=44.8. T_{Setup} is assumed to change with T_{OXC}, according to (1), (2), and (3). Again, values of T_{OXC} smaller than 1ms do not have a significant impact. It may also be observed that the relative performance of the five protocols is similar. Fig. 5 confirms the results of Fig. 1 for the following topologies: NSFNET (N=14), NSFNET (N=16), and ARPANET. We have also investigated other mesh topologies such as mesh-torus and the European Optical Network and similar results have been obtained regarding the independent network behaviour for T_{OXC}<0.1ms and the similar performance of the five resource reservation protocols under study.

5 Conclusions

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 with the following topologies: rings, chordal rings, NSFNET, ARPANET. The performance assessment was carried out for the following five one-way resource reservation protocols: JIT, JumpStart, JIT^{+}, JET, and Horizon. 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 also observed that the five resource reservation protocols under study have a similar performance.

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