Performance of Optical Burst Switched Networks for Grid Applications

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Abstract

This paper presents a performance assessment of optical burst switching (OBS) networks for grid applications, focusing on effective usable bandwidth and mean burst end-to-end delay for several burst loss ratios scenarios and network topologies. We show that for burst loss ratio scenarios that are not too punitive, OBS can still deliver fast and fair transmission of data between any two nodes. For irregular topologies, we also show the occluded node effect using a new set of OBS network evaluation statistics and assess the usable bandwidth for three studied topologies as a ratio of the overall network bandwidth and the effectively used resources.

1. Introduction

Optical Burst Switching (OBS) [1-3] is an emerging technology that promises important impact in near future Internet and also has been shown as a major supporting technology for Grid computing [4]. There have been identified several OBS characteristics that enable Grid computing over OBS, namely, native mapping between bursts and grid jobs, the separation of the control and data planes, and the electronic processing of the burst control packet at each node [5]. Also, OBS is viewed as a time broker for the network resources as the data bursts are sent in an all optical form between the ingress and egress nodes [6].

OBS networks have been extensively studied and simulated, although there is no paper presenting results on how real topologies make their resources available to users. The goal of this paper is to present an assessment on how much bandwidth is usable in several typical OBS networks, being, to the best of our knowledge, the first time this ratio is presented, and to calculate the mean burst delays on end-to-end transmission for real size 15 node European Optical Network (EON) and 14 node NSFnet, also to the best of our knowledge, the first time that this delay is estimated. This paper also shows similar metrics for a regular mesh-torus 4x4 network with 10km long links. We evaluate the problem of occluded nodes for these topologies and establish a relation between fairness of the node’s own bursts drop ratio and overall burst loss ratio at these nodes.

The remainder of this paper is organized as follows. Section two presents the studied networks and section three discusses the results of this research. Section four concludes the paper.

2. Resource Usability in OBS Networks

For the EON network we used the version with 15 nodes deployed across Europe. Figure 1 shows this topology, with the longest link is 1100 Km between Athens and Budapest and the shortest link is Budapest – Vienna with 200 Km. Figure 2 shows the studied 14 node NSFNet topology. Here the longest link is defined as 3000 Km long between Seattle and Champaign (nodes 0 and 7), and the shortest link is set to measure 600 Km between College Pk and Princeton (nodes 12 and 13). The third topology simulated was a mesh-torus network with 16 nodes, with all link lengths equal to 10 Km.

The simulation was performed using an adapted version of a simulator previously published in [7], validated as proposed by [8]. Strictly shortest path [9] routing was used, full wavelength conversion capability ate the nodes was assumed and the protocol simulated was JIT [3]. Destination for bursts was defined by a
homogenous random function, i.e., each node addresses bursts to any other node following a homogeneous distribution. Each simulation scenario consisted of bursts being generated at each node with a rate of 1 burst per millisecond, exponentially distributed, while the number of data channels was increased from 4 to 72 in a 4 channel addition step. The results show several performance thresholds for each scenario. For each scenario several simulations were run (usually 30 runs for each set of parameters), and the results presented follow the batch means method. Each run consisted of the simulation of the network for a fixed period of simulated time. For this set of experiments, the simulated time was set to 5.5 seconds. Results are presented per second, when appropriate.

Figure 1. The EON network.

Figure 2. The 14 node NSFnet network.

The relevant metrics obtained from simulation were: burst loss, burst mean size, burst mean transmission delay and also, for each node, maximum, minimum and mean successful burst transmissions between two consecutive burst losses, maximum, minimum and mean elapsed time between two consecutive burst losses. Although the usually relevant parameters are the burst loss ratio and the burst traffic statistics, we have found that for irregular networks such as the EON or the NSFnet, some nodes do not perform acceptably, despite of the apparent good performance of the overall network. Burst loss ratios are obtained by the ratio of the number of lost bursts over the total number of generated bursts. Burst mean size is the average size, in milliseconds, of the generated bursts, and burst mean transmission delay is the average time a burst takes since it enters the ingress node until it arrives fully to the destination node. If we consider that the burst entry at the ingress node may start the transmission of a Burst Control Packet (CP), then we can overlap the offset time between the CP and the burst with the burst assembly time. In fact, the creation of the CP can be performed as soon as the first packet of a burst enters the burst assembly queue, as by then, all the relevant burst properties are well defined, except perhaps the burst length, over which restrictions or assumptions can be made allowing for expedite CP creation and transmission. This proposal has been discussed in [10].

The new set of statistics help to assess the efficiency of a node, since it gives an additional insight on how long a node is kept in an unsuccessful burst transmission state. This may happen because the node is on a highly loaded traffic network area or because its neighbour nodes have a selfish behaviour and flood the network with its burst requests. Since in the simulation all the nodes behave similarly as to traffic generation patterns, we will show that the nodes that are prevented from transmitting its bursts are located in network areas more penalized by the static shortest-path load unaware routing algorithm implemented in the simulator. We then say these nodes are in an occlusion area, or are occluded.

The identification of the network usable bandwidth along with the statistics that show the fairness of accessing that bandwidth by each node, allows a more accurate evaluation of the network usability by a Grid computing structure, or by any other network structure for that matter.

Setting to measure how much of the network capacity we can use, we must first define how to measure the network capacity of an OBS network. As previously referred, an OBS acts as a time broker for its resources. If we bound the channel to a specific data rate, we can easily estimate the network offered load and the network capacity [11]. From another perspective, we will define the Network Offered Load as the number of burst it can carry per second, assuming an average burst length. The network global capacity is therefore defined as follows:

$$C = \bar{l} n w$$  \hspace{1cm} (1)

where \(\bar{l}\) is the average link length (in time units), \(n\) is the number of unidirectional links of the network and \(w\) is the number of wavelengths per channel, thus \(C\) is expressed in a time unit. To calculate the amount of
bursts that can populate the network at any given instant we will have

\[ W = \frac{C}{\bar{b}} \]  

(2)

where \( W \) is the working capacity of the network in terms of number of transmitted bursts, and \( \bar{b} \) is the average burst length. To be more realistic, we suggest that this value should include framing and signal synchronization space.

3. Simulation Results

The simulator provided statistics as to the amount of generated traffic each tested topology was able to carry. Since the traffic generation was defined on a per node basis, the average offered traffic per node was similar for each network (not equal because of the stochastic nature of the simulator). Figure 3 shows how the carried traffic for each network is different, and converges with the traffic offered by each node as the available resources increase. The change in the speed of convergence is not significant, although for 4 wavelengths there is a clear difference between the three tested topologies. This is a direct consequence of the connectivity of the networks: the Mesh Torus 4x4 network has a nodal degree of 4, the 15 node EON has a nodal degree of 3.46(6) and the 14 node NSFnet has a nodal degree of 3. The higher the nodal degree, the better the performance of the network, this being a well known result [12].

The network was simulated in a rate independent mode, i.e., the rate for the data channel was not set, instead, using the time-broking aspect of the OBS paradigm, bursts were considered to be chunks of data compressed in a segment of channel time. This allows us to extrapolate the results for any desired data rate.

The efficiency of each topology is shown in Figure 4. It was expected that EON would perform better than NSFnet because of its higher connectivity. Using the same line of reasoning, we would expect Mesh Torus 4x4 to perform better than any of the other two topologies, since its nodal degree is 4. Nevertheless, we see that this regular topology performs worse than EON. The crossing of the plots for Mesh Torus and EON is related to the regularity / irregularity of its topologies.

Figure 5 presents an explanation to this scenario – when we analyze the burst drop ratio per node, we can see that last nodes in the Mesh Torus network are heavily penalized compared to the rest of the network – its burst drop ratio is much higher than the average. This is a result of the static shortest path routing implemented in the simulator, and this shows how routing sensitive architectures and algorithms, e.g. [13, 14] can reap additional efficiencies from these underperforming nodes. Following the hypothesis that in the simulations we would find nodes that are “burst droppers”, we then analyzed the possibility of occurrence of such behavior in nodes for other networks. Figure 7 and Figure 6 show the burst drop ratio for the nodes in the EON and NSFnet networks. For EON, we see node 5 having a consistently higher burst drop than the remaining nodes (node 5 corresponding to Warsaw). For higher resource availability, we add nodes 6, 10 and 11 to this list, corresponding to London, Lyon and Milan. For NSFnet, the burst dropping nodes are nodes 7 and 9 (Champaign, IL, and Atlanta, Ga), being node 0, 8 and 12 (Seattle, Wa, Ann Arbor, Mi, and College Pk, Md) the best performing nodes. For these irregular full sized links topologies, we find that often the nodes with lowest performance are in the middle of the topology, e.g., Warsaw belongs to the paths that connect the northern nodes (Stockholm, Berlin) to the southern nodes (Vienna, Budapest, Rome, Milan, Athens). Obviously, real topologies take this scenario into account and thus nodes with heavier traffic receive higher capacity links. Further analysis falls in the scope of future work.
the bursts that are dropped and are issued by each node, a relation that was expected – if a node can not convey bursts that are being transmitted and thus must be dropped at that hop, then it will equally have resource shortage to transmit its own bursts. The not surprising conclusion that Figure 5 to Figure 10 allow is that this relation is not very strong, mainly because own burst drops relates not only to the bursts that are trying to ingress at that node, but also to the bursts which, having ingressed at a node, end up being dropped by another node, and still count as own burst dropped bursts.

![Figure 5. 16-node Mesh Torus network burst drop ratio per node for several number of available wavelengths scenarios.](image)

For instance, regarding NSFnet, while nodes 7 and 9 are “burst droppers”, its own bursts have a different successful transmission ratio (see Figure 7 and Figure 10). Also, it is clearly visible for the 4x4 Mesh Torus, that the nodes with higher id numbers are also the one which have more own burst drops. For EON, the graphs from Figure 6 and Figure 9 still show a relation between burst dropping nodes and own bursts dropped, particularly, the overload shown in Figure 6 for node 5 (Brussels) causes node 4 (London) to have higher ratio of own bursts dropped, because the routing algorithm chooses Brussels as part of the path between London and the nodes in the eastern part of the network. This conclusion is supported by the analysis of the routing tables generated by Dijkstra’s shortest path static routing implemented in the simulator.

We also measured the travel time for the bursts, counting from its ingress in the burst assembly queue until its arrival at the egress node. Figure 11 shows that for the scarce resource simulation scenarios (up to 32 wavelengths for NSFNet, 24 wavelengths for EON and 20 wavelengths for Mesh Torus 4x4), the mean transit time per burst stabilizes, independently of the burst drop ratio (see Figure 4), i.e., between the minimum and the maximum value in the 32 wavelength scenario and the 72 wavelength scenario range, the transit time changes about 0.79% while in terms of performance for that range, the burst drop ratio decreases over 3.5 orders of magnitude. The shorter transit times for bursts when the networks are heavily loaded are explained as we know that in these scenarios only bursts with very short paths are transmitted [6] and short paths imply short transit times.

![Figure 6. 15-node EON network burst drop ratio per node for several number of available wavelengths scenarios.](image)

![Figure 7. 14-node NSFNet network burst drop ratio per node for several number of available wavelengths scenarios.](image)

![Figure 8. 16-node Mesh Torus 4x4 network burst drop ratio for the bursts ingressed per node (own burst drop ratio) for several number of available wavelengths scenarios.](image)
From the data presented in Figure 11, we can see that although the mean link length in NSFnet is considerably larger than the mean link length for EON (approximately 12.45ms for NSFnet, 3.06ms for EON and only 0.05ms for Mesh Torus) the mean burst transmission times are very close, in value and in behaviour when the number of data channels increases. This is because of the burst assembly period and the offset time, that is considered here as part of this measurement.

To assess the usable portion of the network resources we used (2) for each of the topologies, considering the mean burst size as 10ms. Figure 12 shows the ratios for the three tested topologies. We can see that although the networks only operate at an acceptable burst loss ratio well after 52 wavelengths (64 wavelengths for NSFnet see Figure 4) it seems to carry much of the offered traffic after 24 wavelengths (see Figure 3). The ratio of transmitted bursts over overall network capacity shows a homogeneous behaviour. Fitting with exponential functions on the three plots returned values for $R^2$ of over 0.997 for both the EON and the NSFnet, and of 0.981 for the Mesh Torus. The fitting functions were, for the Mesh Torus, EON and NSFnet, respectively:

$$y = 0.0071e^{-0.0242x}$$

$$y = 0.0001e^{-0.0208x}$$

$$y = 3.10^{-5}e^{-0.0172x}$$

The network transport capacity ratio as a function of the overall network capacity shows how much traffic we can expect to be able to transport in an OBS network, given the number of nodes, the topology of the network, namely, its nodal degree, and the estimated average burst size. As future work, we need to assess these ratios for regular topologies with different nodal degrees, for different average burst sizes and average burst offered load per node.
4. Conclusions

We have studied three network topologies, two real network topologies at full scale, and one regular network topology with all link lengths equal to 10 km. For these topologies we simulated nodes with an exponentially distributed burst generation scenario, with an average of one burst per millisecond. Bursts were estimated to be 10ms in size, also exponentially distributed. Random homogeneous ingress and egress addresses were applied, with blind shortest path routing.

We have shown the existence of nodes which, despite the a satisfactory overall network performance, still show an unfair burst loss ratio, and named these nodes as occluded nodes, as bursts tend to drop there more than in other parts of the network. We explained this phenomenon as a consequence of routing algorithms, as these nodes are selected for paths more often than others.

We have also shown that occluded nodes have a lighter fairness problem than it could be expected, as although there is a relation between the bursts ingressed in these nodes and the bursts that are dropped at the occluded nodes, the relation is not very strong and is a function of the regularity of the network topology.

We assessed the average time a burst takes to travel between its ingress and egress node through simulation, shown to be between 31 and 37ms for the three topologies, despite of the fact that NSFNet is much larger than the other two (EON and NSFNET were taken with full link size). We explained the small variation of these values by the time consumed in the burst assembly process and the Control Packet transmission, both accounted in the simulator as burst transmission time. The average transmission time for a burst can thus be interpreted as the maximum average packet delay for a successful transmission of a burst.

Finally we assessed the usable ratio for an OBS network, as the quotient of the overall ideal OBS network capacity (in time units) and the usable OBS time, considering a 10ms average burst length. Following the time brokerage approach for the OBS paradigm, no data channel rate was considered. The results show a very similar behaviour for the three studied topologies, and fitting exponential equations were calculated, thus allowing a practical estimation of the network resources.

References


