Efficiency of OBS Networks

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ABSTRACT

In this paper, we evaluate, for certain scenarios, the achievable level of utilization of OBS networks while maintaining acceptable blocking probability. We consider bufferless optical burst switching (OBS) networks with deflection routing, in which channel reservation is used to avoid instability, and with realistically high number of channels per trunk. The blocking probability is evaluated based on the Erlang fixed-point approximation and the overflow priority classification approximation. We demonstrate that a fully meshed OBS network can achieve close to 90% utilization meeting 10^{-6} blocking probability and for a topology such as NSFNET, for an arbitrary set of source-destination pair, key bottleneck links can also achieve high utilization, while some unutilized links may lead to lower overall utilization. However, there is no evidence that the efficiency of OBS in case of large number of links per trunk is significantly lower than that of circuit switching equivalent alternatives, if the target blocking probability is low. We also demonstrate that for high number of links per trunk, with low target of blocking probability, deflection will not significantly improve efficiency.

Keywords: blocking probability, optical burst switching (OBS), utilization, efficiency, Erlang fixed point approximation (EFPA), overflow priority classification approximation (OPCA).

1. INTRODUCTION

Optical burst switching (OBS) [1] is an optical networking technology that facilitates one-way dynamic resource reservation of data flows suited to all-optical networks. In OBS networks, data that have the same destination are aggregated at ingress nodes and form bursts. A burst may include data from various sources in which case OBS operates at the core network, or from a single source in which case OBS operates end-to-end. Control packet of a burst is sent ahead to reserve the wavelength channels along the burst transmission path. Since the wavelength channels are reserved hop by hop, the resource reservation time before data transmission is generally shorter than in end-to-end channel reservation schemes like optical circuit switching (OCS).

There are several versions of OBS. In just-enough-time scheduling [2], the control packet reserves the output channel at each optical cross connects (OXC) for the duration when the burst will be occupying the channel. In just-in-time scheduling [3], a control packet reserves channels as soon as it arrives. Our analysis applies to both schemes if we do not consider the effects of the offset time between the control packet and the burst.

Due to the high cost of fiber delay lines and their space requirements, it is difficult to buffer bursts in all-optical networks. Accordingly, we consider bufferless OBS, where a burst is dumped if there is no output channel available at an intermediate OXC along its path. OBS is often compared to various circuit switching alternatives [4]-[7], including OCS or optical flow switching (OFS), where network resources are reserved in advance end-to-end, so that data sent always reach their destinations. In OBS, on the other hand, a burst of data, after using network resources, may be dropped never to reach its destination. This is a drawback of OBS versus OCS or OFS. Under certain blocking probability and hardware (e.g. the number of wavelength channels per trunk) constraints, OBS may carry less traffic compared with optical circuit switching (OCS) [4]. The authors of [4] considered cases of OBS without deflections and with a small number of channels per trunk. Here we consider OBS networks with deflection routing [8]-[11], and also cases where the number of channels per trunk ranges between 100 and 10000. As we look into the future, the large number of channels per trunk is justifiable by the advancement of manufacturing technologies of optical cables and fibers, as well as sub-wavelength technologies, like optical code division multiple access (OCDMA) [12], which enables bursts with different codes to transmit simultaneously in one wavelength channel. It is well known that efficiency of loss network is improved as the number of channels increases [13]. This has been demonstrated in [14] for a case of a single OBS node. In this paper, we extend the results of [14] from a single node to a network, and study the required number of channels per trunk to achieve high utilization in OBS networks while maintaining the end-to-end blocking probability below a given level.

Deflection routing may also reduce the blocking probability in OBS networks [8]-[11] by deflecting bursts to alternate routes when their primary routes are unavailable. However, deflection routing may destabilize OBS networks in high utilization conditions. We therefore consider reserving wavelength channels for non-deflected bursts in order to stabilize OBS networks [11]. We investigate how the maximal number of allowable deflections affects the utilization of OBS networks under given end-to-end blocking probability constraint, for a 6-node fully meshed and the National Science Foundation Network (NSFNET) OBS networks.

2. MODELLING AND PERFORMANCE EVALUATION

We consider the model of [15] of an OBS network consisting of a set of nodes and trunks. Each node represents an OXC or edge router. Each trunk connects two nodes, and contains a set of unidirectional wavelength channels called *links*. Although we consider links to represent wavelength channels, the model is also applicable to cases where links represent sub-wavelength channels (e.g. OCDMA). The set of directional source-destination (SD) pair is pre-assigned. For each SD pair, bursts arrive at the source as a Poisson process. We assume for tractability that burst lengths follow exponential distribution, which does not introduce significant errors [15][16]. It is likely that there are several routes that connect the source and destination. The route with the least number of hops is the primary path while a random choice is made in cases of routes with equal number of hops.

For a burst belonging to a SD pair, it is transmitted in the primary path if all the trunks along the path are available. If a trunk along the primary path is unavailable, the burst is deflected to an alternative route. If there are still trunks unavailable in a deflection route, the burst is deflected again. The burst is not allowed to use the same node or trunk twice. The maximal number of allowable deflections is denoted by D. If a burst finds all the output trunks at a node busy, or has been deflected D times and still sees an unavailable trunk along its path, it is blocked and cleared from the network. To stabilize the network, we reserve some links for non-deflected bursts. See [15] for complete information on the model.

There are several ways to evaluate the end-to-end blocking probability in OBS networks, such as Erlang fixed-point approximation (EFPA), overflow priority classification approximation (OPCA) and simulations [15]. EFPA is based on decoupling the network into independent trunks, each of which is modeled as an M/M/k/k queuing system [17]. OPCA calculates the blocking probability by using EFPA for a surrogate system that assigns higher preemptive priority to traffic with smaller number of deflections, to give more accurate evaluations by capturing the dependency among traffic on different trunks [18]. In this paper, we use the maximum of EFPA and OPCA (Max [EFPA, OPCA]) to evaluate the end-to-end blocking probability because of its superior performance demonstrated in [15].

3. NUMERICAL RESULTS

In this section we evaluate the utilization of OBS networks for a given value of required end-to-end blocking probability for a 6-node fully meshed network and 13-node NSFNET [15] and for various values of allowable number of deflections (D). In particular, we set the SD pairs, then, while maintaining the offered load equal on all SD pairs, we increase the offered load until overall blocking probability reaches the given value. The reservation threshold is 90%, i.e., the last 10% of links in each trunk are reserved for non-deflected traffic only.
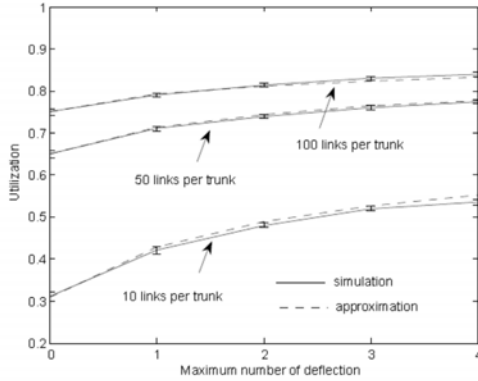

Figure 1. Simulation and approximation results of achievable utilization in 6-node fully meshed network when the blocking probability is 10^{-3}.
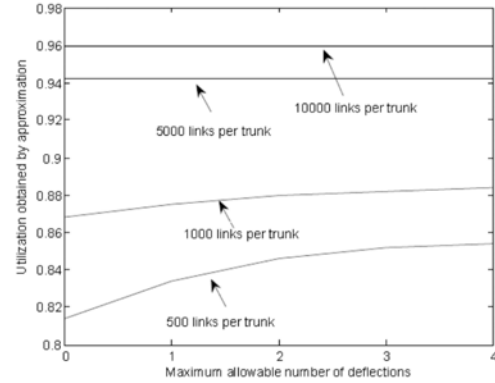
Figure 2. Achievable utilization in 6-node fully meshed network when the blocking probability is 10^{-6}.

Table 1. Ingress and egress SD pairs

Ingress	WA	CA1	CA1	CA2	TX	GA	MD	IL	MA	CD	NY	MA
Egress	MD	IL	MA	CD	NY	MA	WA	CA1	CA1	CA2	TX	GA

In Fig. 1, we provide results for achievable utilization for a 6-node fully meshed OBS network where the required blocking probability at 10^{-3} for the cases of 10, 50, and 100 links per trunk, and for $0 - 4$ maximal allowable deflections. The blocking probability approximation here is based on Max [EFPA, OPCA]. We also

provide here simulation results that were also presented in [15] with 95% confidence intervals to illustrate the accuracy of the Max [EFPA, OPCA] approximation. Having established the accuracy of the Max [EFPA, OPCA] approximation here and in [15], we present in Fig. 2 results for the achievable utilization base on Max [EFPA, OPCA] where the blocking probability is maintained at 10^{-6}, for cases where the number of links per trunk is in the range 500-10,000. For these cases, simulation is intractable. We observe that OBS can achieve very high utilization and that deflections are not necessary for cases where the number of link per trunk is large. These results are consistent with the results of [14] noticing that most traffic uses a single link.

Next, we consider the NSFNET with 13 nodes and 30 directional trunks. The topology is the same as in [15]. In Fig. 3, we provide additional evidence to support the accuracy of Max [EFPA, OPCA] where we compare achievable utilizations based on simulations (including 95% confidence intervals) and Max [EFPA, OPCA], where the required blocking probability is 10^{-3}. Then, in Fig. 4, we consider this NSFNET with required blocking probability of 10^{-6} and a range of 500-10,000 for the number of links per trunk.

In Table 1, we provide the 12 unidirectional SD pairs used for cases that led to the results presented in Figs. 3 and 4. These SD pairs are associated with the nodes in the NSFNET topology presented in [15]. We observe that the utilization in NSFNET is significantly lower than for the 6-node fully meshed network. This is because the NSFNET is asymmetric and the SD pairs are arbitrarily chosen. Recall also that we increase the load uniformly on all SD pairs as long as the required blocking probability is not violated. This can result in near zero utilization in some links and high utilization in other links. The resulted utilization is the average of all utilizations on all links. For example, in the case of 1000 links per trunk, $D = 3$ and 10^{-6} blocking probability, the highest utilization (achieved in 10 links) is 87%, while the lowest is zero (in 7 links), and the average utilization is 49%. Note that we can achieve near 100% utilization in NSFNET with large number of links per trunk, if all SD pairs are chosen to be in adjacent nodes. Note also that based on computation of blocking probabilities according to our study of OCS networks in [19] and [20], OBS results mainly for the cases of large numbers of links per trunk, are comparable to those of its circuit switching equivalents, while OCS may have some advantage for cases with low number of links per trunk as observed in [4].
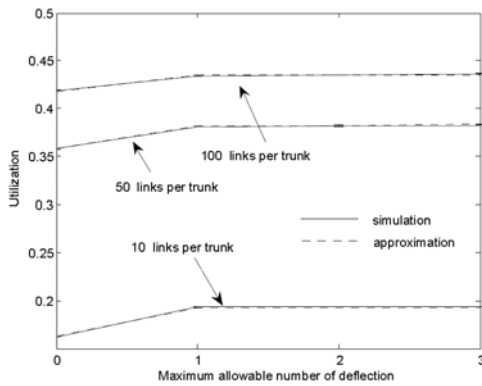

Figure 3. Simulation and approximation results of achievable utilization in NSFNET when the blocking probability is 10^{-3}.
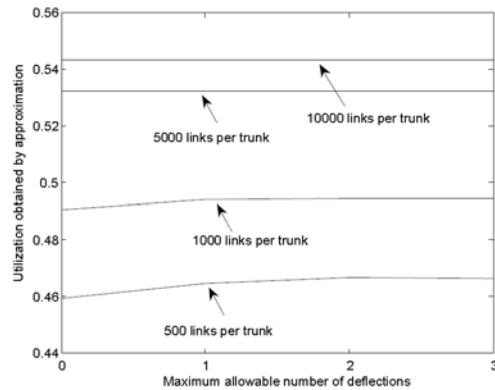
Figure 4. Achievable utilization in NSFNET when the blocking probability is 10^{-6}.

4. CONCLUSIONS

OBS has advantage over circuit switching alternatives in fast setup of burst transmission and it also has known energy saving benefit of switching whole flows or bursts rather than packets. We have demonstrated that generally OBS also achieves high efficiency in networks with large number of links per trunk if the target blocking probability is low. In realistic networks such as NSFNET, some links may be under-utilized due to lack of traffic. However, in general, OBS is not significantly less efficient than its circuit switching counterparts if the number of links per trunks is large, and if the target blocking probability is low. Although thorough comparison of OBS and OCS under various conditions it still under study, we may speculate that as networks grow in terms of number wavelength channels per cable, and with developments of sub-wavelength technologies such as OCDMA, OBS may have a role to play in transporting individual large flows whether they carry data from a single or multiple sources. A possible scenario includes packet, burst and circuit switching in hybrid architecture [21] where cost is optimized for the various flows [22], and such optimization is enabled by OpenFlow [23].

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