Limits of effective throughput of optical burst switches based on semiconductor optical amplifiers

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Abstract: *Both signal degradation and burst losses limit the effective throughput of optical burst switches. These limitations are analyzed for different burst switch architectures, bit rates, and numbers of fibers and wavelengths.*

Introduction

Optical Burst Switching (OBS) is a promising candidate for a more dynamic optical layer to support the next generation Internet [1]. It can be considered a compromise between Optical Packet Switching (OPS) and Optical Circuit Switching. In an OBS network, edge nodes assemble several IP-packets with the same egress node and QoS class electronically into variable length optical bursts, which stay in the optical domain until they reach the egress edge node. Typical burst lengths are between a few µs and several 100 µs. Therefore switching times should be below 1 µs. Semiconductor optical amplifier (SOA) based switches with switching times in the ns range are well suited for this application. The maximum throughput of a node is limited by signal degradation caused by power loss, noise and crosstalk.

A key characteristic of OBS is the one-pass reservation scheme of network resources for each individual burst [1]. Bursts are sent without an acknowledgement of successful path setup and burst loss can occur in case of contention. The burst loss probability B can be reduced by using many wavelengths per fiber in combination with λ conversion and additionally by fiber delay lines (FDL) as buffers. For a given acceptable burst loss probability (B), node architecture and burst reservation scheme determine maximum utilization of output fibers.

First we extend our scalability analysis of OBS nodes [2] by considering power loss, noise and crosstalk for nodes with FDLs and limited range λ converters. For nodes with 8 and 16 input/output fibers and for different line rates (2.5, 10, 40 Gbps) the maximum throughput is calculated, which is limited by the number of possible wavelength M . Second we determined the maximum utilization of output fibers for the nodes for a burst loss probability of $B \leq 10^{-6}$. This gives us the effective throughput, which is the product of maximum throughput and maximum utilization.

By considering both, physical constraints as well as results from performance evaluation of optical burst switches, a better understanding of the potential of future optical burst switching networks is achieved.

Node Architectures for Optical Burst Switching

To reduce cost and signal degradation we consider architectures with only one SOA in the signal path. For OPS, several similar one-stage architectures have been investigated [3, 4]. Fig. 1a shows a broadcast-and-select node architecture adapted for OBS which we call the tune-and-select (TAS) node [2]. This node has N input/output fibers and M wavelengths per fiber. It is strictly non-blocking and has multicast capability. The incoming burst will be converted into the desired output wavelength by a tunable λ converter and then switched to the desired output fiber by SOA gates. $M{*}N^2$ SOAs and M*N tunable λ converters with switching times less then 1 µs are needed.

A modification of the TAS node (Fig. 1b) with one WDM FDL per output fiber (TAS-FDL) can resolve contention and reduce burst losses. Drawbacks of this node are higher splitting losses and larger switching arrays with $2{*}M{*}N^2$ SOA gates.

Another variant of the TAS node applies λ converters of limited tuning range (TAS-LTR). The node architecture is very similar to Fig. 1a. Here, the wavelengths are divided in G groups and each λ converter can only convert signals within its group which leads to smaller output combiners and their partial replacement by WDM-MUX. Also, less noise contributions (from M/G SOAs instead from M SOAs for TAS) are disturbing the transmitted signals and a λ converter with a smaller tuning range may be easier to realize. In our analysis we set G = 4.

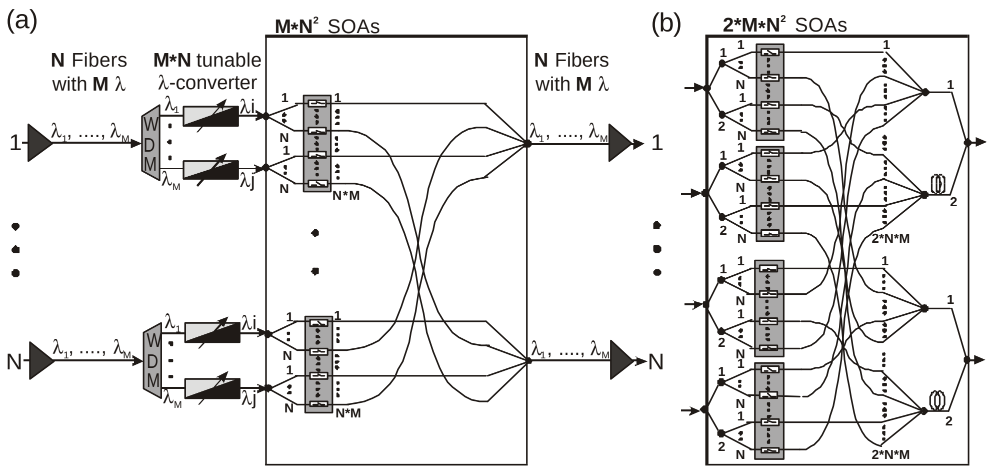

Fig. 1. OBS switching nodes. (a) tune-and-select (TAS); (b) TAS node with 1 fiber delay line (TAS-FDL)

Component parameters and system environment

In our calculations the following component parameters (Tab. 1) are used, which, to our best knowledge, represent the present state-of-the-art:

Node	input power	-16dBm
	output power	0dBm
EDFA	noise figure	6dB
	max. gain	30dB
	max. output power	19dBm
SOA	noise figure	11dB
	max. gain	17dB
	max. output power	11dBm
	extinction ratio	50dB
Splitter/ Combiner	excess loss	0.3 - 3dB
WDM MUX/ DeMUX	excess loss	5dB
	crosstalk	-30dB
λ converter	input power	-16dBm
	output power	5dBm
Delay Line	loss	0,2dB/km

Tab. 1. Parameters for the calculations.

The mean burst length is assumed to be 100 kbit which leads to a mean transmission time of 40/10/2.5 µs at 2.5/10/40 Gbps respectively. Delay lines have a delay of two mean burst transmission times which corresponds to 16/4/1 km of fiber for the different bit rates.

Calculation of maximum size and effective throughput

To determine the maximum number of wavelengths M of the considered node architectures at different bit rates, the bit error rate respectively Q-factor is calculated. To have enough margin for other impairments Q = 10 (BER = 10^{-22}) is taken as the limit of signal degradation. Due to the assumption of regenerative (3R) λ converters accumulation of signal degradation is terminated at each λ converter and only has to be considered between two neighboring nodes, i.e. consecutive λ converters.

In our calculations only noise generated by optical amplifiers (SOA, EDFA) is considered. The design criterion for low noise is to keep signal power as uniform as possible and not let it decrease too much. The most critical point is at the output of the large combiners behind the SOAs as the combiner is the component with the highest loss (TAS: 1/(N*M), TAS-LTR: 1/(N*M/4), TAS-FDL: 1/(2*N*M)).

We take two major crosstalk sources into account and perform a worst case calculation. The first source is the WDM demultiplexer with M-1 interfering signals, the second is the non ideal extinction ratio of the SOA gates. N-1 switched-off amplifiers have the same input wavelength (TAS-FDL: 2*N-1) as the considered channel with the consequence of coherent crosstalk. These calculations result in the maximum throughput of the nodes, given as the product of the number of fibers N, the number of wavelengths M and the bit rate.

Maximum utilization of an output fiber is calculated from the number of wavelengths per fiber M using models of burst loss probability which are based on a Poisson arrival process [1, 5, 6]. For TAS and TAS-LTR, results are analytically calculated and insensitive to burst length distribution. For TAS-FDL, exponential burst length distribution and PreRes buffer reservation scheme are assumed and results are obtained from simulations [6].

Results

Figure 2 shows the maximum and effective throughput for a node with 8 input/output fibers. The highest maximum throughput (10.24 Tbps) can be achieved with TAS-LTR because only the SOAs of one group contribute to the noise in one channel. With TAS-FDL, only rather small nodes (2.56 Tbps) can be built due to higher splitting losses and losses of the delay line. Maximum throughput of a specific architecture is independent of bit rate, except for a bit rate of 2.5 Gbps at which the maximum throughput is smaller by a factor of two for the TAS and the TAS-LTR nodes due to crosstalk.

Despite big differences in maximum throughput, effective throughput is almost balanced among all architectures: it is about 2 Tbps for 2.5 and 10 Gbps and about 1 Tbps for 40 Gbps. For 40 Gbps the maximum load is small because of the small possible number of wavelengths M. The architecture with the highest utilization is TAS-FDL at 2.5 Gbps.

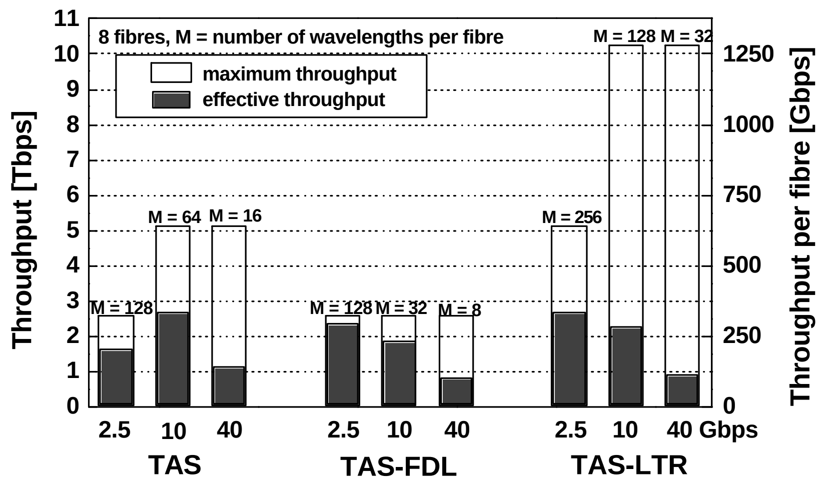

Fig. 2. Throughput for different node architectures with 8 input/output fibers.

The situation is different for the nodes with 16 input/output fibers (Fig. 3). Here, the maximum throughput of a specific architecture is the same for all bit rates. It is highest for

TAS-LTR (10.24 Tbps), followed by the original TAS structure (5.12 Tbps) and TAS-FDL with only 1.28 Tbps throughput. Also, the effective throughput is significantly decreasing with increasing bit rate from 2.5 Gbps to 40 Gbps due to the smaller number of possible wavelengths M. For example, the effective throughput goes down from 5.4 Tbps to only 0.5 Tbps for TAS-LTR. Again, due to the high splitting losses TAS-FDL allows only a very small number of wavelengths, so that not only the nodes are small but also the effective throughput is unacceptable. The highest effective throughput can be achieved with TAS-LTR at 2.5 Gbps and is 5.4 Tbps.

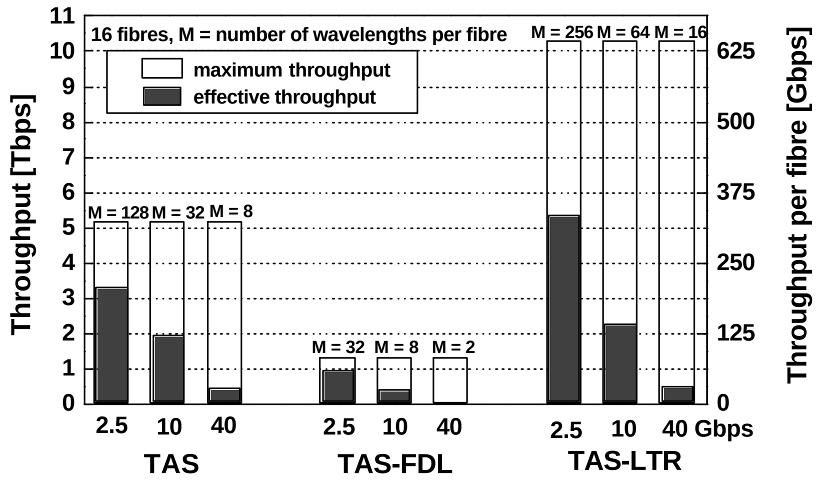

Fig. 3. Throughput for different node architectures with 16 input/output fibers.

Conclusion

Three different architectures of optical burst switches with 8 and 16 input/output fibers and bit rates of 2.5, 10 and 40 Gbps have been analyzed. Signal degradation caused by noise and crosstalk limits the number of possible wavelengths M for a given structure. The maximum size and throughput of these nodes is determined using a Q-factor of 10. The effective throughput is calculated for a burst loss probability $B \leq 10^{-6}$.

Among the studied architectures, an OBS node based on 4 groups of λ converters with limited tuning range (TAS-LTR) with 16 input/output fibers at 2.5 Gbps has been shown to achieve the highest effective throughput of 5.4 Tbps. A node with one FDL per output (TAS-FDL) with 8 input/output fibers at 2.5 Gbps achieved a maximum utilization of over 90% ($B \leq 10^{-6}$). In comparison with lower line rates, 40 Gbps is less efficient and results in an unacceptable effective throughput for all studied architectures.

References

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