OBS vs. OpMiGua -
A Comparative Performance Evaluation

Joachim Scharf[1], Andreas Kimsas[2], Martin Köhn[1], Guoqiang Hu[1]
[1] University of Stuttgart, Institute of Communication Networks and Computer Engineering (IKR)
Pfaffenwaldring 47, 70569 Stuttgart, Germany
Tel: +49 711 685 67979, Fax: +49 711 685 57979, e-mail: joachim.scharf@ikr.uni-stuttgart.de
[2] Norwegian University of Science and Technology (NTNU)
O. S. Bragstads plass 2B, 7491 Trondheim, Norway

ABSTRACT

Optical Burst Switching (OBS) and Optical Migration Capable Networks with Service Guarantees (OpMiGua) are two all-optical network architectures. In this paper we compare both by means of a quantitative performance evaluation based on simulations. In order to achieve a maximum of comparability both models are chosen as similar as possible and especially are fed with identical traffic. Results show differences regarding loss probabilities at which OpMiGua has a better performance.

Keywords: optical networks, OBS, OpMiGua, performance evaluation

1. INTRODUCTION

In the last years, several all-optical network architectures have been proposed in literature. The first proposed architectures rely on packet and circuit switching, i.e., *Optical Packet Switching* (OPS) and *Optical Circuit Switching* (OCS), respectively, and the newly introduced paradigm burst switching, i.e., *Optical Burst Switching* (OBS) [1]. Later, also hybrid approaches have been proposed employing more than one switching paradigm like *Optical Burst Transport Network* (OBTN) [2], *Overspill Routing in Optical Networks* (ORION) [3] or *Optical Migration Capable Networks with Service Guarantees* (OpMiGua) [4].

In common, in each node at least one switching matrix is implemented, that establishes transparent optical lightpaths between input and output fibers. Depending on the switching paradigm, this switching matrix must be able to operate on different time scales ranging from nanoseconds up to minutes or even hours.

During the last years, many aspects of these network architectures have been discussed ranging from algorithms for certain functions like routing and scheduling to concrete node architectures. Experimental setups realized nodes and networks in test beds to show their technological feasibility. Also, the performance of each of the different architectures has been extensively investigated with respect to characteristical parameters in different scenarios and for different traffic conditions.

Nevertheless, most publications investigate only one architecture and do not compare different architectures – neither qualitatively nor quantitatively. Also, it is usually impossible to directly compare different performance studies as system parameters are very different – for OPS, traffic is described on packet level whereas for OCS, connection arrivals and departures are modelled – as well as different parameter settings/scenarios are used.

In this paper, we compare two all-optical network architectures, namely *Optical Burst Switching* (OBS) and *Optical Migration Capable Networks with Service Guarantees* (OpMiGua) in order to determine which architecture is better suited for a given scenario. We describe our modelling approach that allows us to directly compare the architectures and present results of a quantitative performance evaluation. Furthermore we discuss the impact of basic traffic characteristics.

The remainder of this paper is structured as follows: section 2 introduces both architectures and discusses important differences of them. Then we introduce our modelling approach and the simulation scenario together with the achieved quantitative results in section 3. Finally, section 4 concludes the paper and provides an outlook.

2. SELECTED ARCHITECTURES FOR DYNAMIC ALL-OPTICAL NETWORKS

2.1 Optical Burst Switching

While today in literature many variants of *Optical Burst Switching* (OBS) exist, we will consider in the following the OBS approach introduced in [1]. At the edge of such an OBS network, packets of the same forwarding equiv-

---

This work is based on results of a Short Term Scientific Mission funded within COST Action 291
“Towards Digital Optical Networks”.

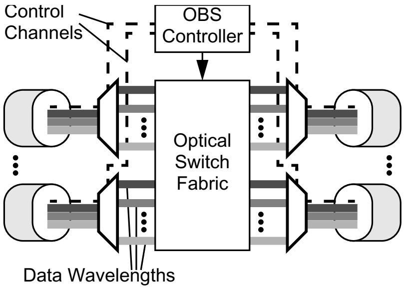

Fig. 1 OBS node architecture

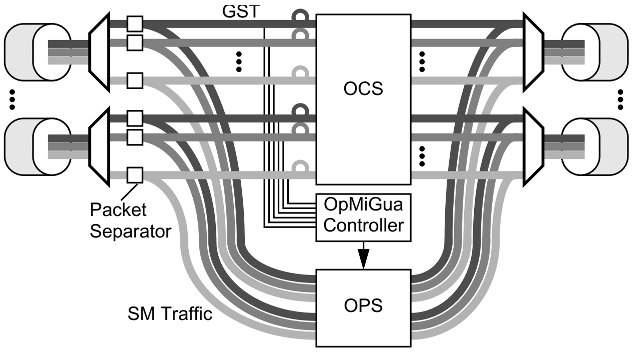

Fig. 2 OpMiGua node architecture

alence class are assembled into so called bursts. After transmission through the network towards their destination the bursts are disassembled at the egress and the packets are forwarded to the client network.

Within the core of the network a control header packet precedes every burst with a certain offset time and includes relevant control information like length and offset time of the corresponding burst, i.e. data and control information are separated. Electronic processing of burst control information allows timely selection of a path through the node as well as reservation of required resources for the necessary time period. Hereby, consideration of all node resources like wavelength converters or fiber delay lines is necessary. Furthermore, the control header packet has to be updated and sent to the next node. However this one-pass reservation is no guarantee for successful delivery of a burst. If all available contention resolution mechanisms fail, the burst must be discarded.

One feature of this OBS flavour is the support of different priorities. As resources for switching are reserved when processing the control header packet, assigning a larger offset time to high priority traffic increases the likelihood of finding necessary resources available compared to bursts with lower priority. By this even an absolute prioritization can be achieved if the offset time is larger than the maximum burst duration plus offset time of lower priority bursts. Without this criterion in place, absolute prioritization can only be achieved via use of preemptive techniques [5].

Figure 1 shows the architecture of a basic OBS node. Based on control header information an optical switch fabric switches bursts to the desired output fiber. In general the wavelength continuity constraint has to be met, i.e., incoming and outgoing wavelength must be identical. However, usage of wavelength converters can ease or even completely remove this constraint, as they enable adaptation of the wavelength for transmission to the next node.

Besides the depicted architecture others also exist. They may have wavelength converters organized, e.g., as a shared converter pool [6], or fiber delay lines. Depending on the available contention resolution mechanisms the resulting blocking probability varies [7]. Nevertheless, focus of this article is to compare basic characteristics of the two architectures. Therefore, only full wavelength conversion is henceforth assumed.

In summary the switching paradigm OBS supports highly dynamic traffic in future networks. By switching on a burst level in the optical data plane it provides on the one hand a much greater flexibility than a network based on circuit switching. With processing of information in the electrical domain, OBS avoids on the other hand severe technological challenges of an optical packet switched network, as for example, optical signal processing and optical switching on a tiny time scale.

2.2 Optical Migration Capable Networks with Service Guarantees

An inherent separation of different traffic classes is given in *Optical Migration Capable Networks with Service Guarantees* (OpMiGua) [4]. High requirements concerning packet loss and jitter are granted by the so called Guaranteed Service class Traffic (GST). Traffic of this class is transported in a connection oriented manner along preestablished end-to-end lightpaths and is given absolute priority. This ensures that there are no losses due to contention and delay jitter is minimized.

The other class with looser requirements is Statistically Multiplexed (SM) traffic. This is handled without reservations via packet switching. Losses due to contention and delay jitter due to buffering or deflection routing are allowed. Despite this inherent separation both traffic classes use sequentially the capacity of the same wavelength.

The architecture of a basic OpMiGua node is shown in **Fig. 2**. After entering the node on a wavelength SM and GST packets are separated in the optical domain according to a specific label, e.g., polarization. While GST packets are forwarded to a circuit switch, SM packets are directed to a packet switch. After traversing the respective switches GST and SM packets directed to the same output wavelength have to be multiplexed. Thus, by inserting SM packets in-between the gaps created by subsequent GST packets, the resource utilization is increased.

In order to maintain the absolute prioritization of GST packets, the switching decision for SM packets in the depicted scenario is aware of interfering GST packets on the output wavelengths within a sufficiently large time window. This is commonly realized by monitoring the occupancy of each wavelength before the traffic is delayed in an FDL as indicated in Fig. 2. Preemption of SM packets would be another method to realize the prioritization [8], however we do not consider this any further in this paper.

With the applied scheme an SM packet cannot be scheduled to a certain wavelength if there is currently a GST packet being transmitted or if a GST packet will be transmitted before complete transmission of the SM packet. Hence, reducing the number of GST arrivals decreases the blocking probability of SM packets as observed in [9]. As consequence we also use aggregation of GST packets into bursts. However the aggregation time may not be arbitrarily long as the GST class is mainly considered for traffic with stringent timing requirements. In contrast, there is no need to aggregate SM packets.

Furthermore it has to be mentioned that in OpMiGua there is a unique relationship between incoming and outgoing wavelength of the circuit switch and vice versa. That means, it is not possible to statistically multiplex GST packets from different wavelengths to a common one, as this would make contention as well as loss possible.

In the following we assume the packet switch as well as the circuit switch to be all-optical with full wavelength conversion but without any buffering. Also, we assume that the GST class is used for high priority (HP) and the SM class for low priority (LP) traffic.

2.3 Differences between OBS and OpMiGua

A comparison of OBS and OpMiGua on architectural level reveals two conceptual differences, that are expected to have significant impact on the system performance. First, while in both architectures HP traffic is aggregated, LP traffic is only aggregated in case of OBS. As LP traffic has to get along with voids left over by HP traffic the probability of finding a void of sufficient length should decrease in general with increasing required length.

The second difference is the fixed assignment of incoming and outgoing wavelengths for HP traffic in OpMiGua. As consequence not only losses of HP traffic are impossible but also HP traffic on a wavelength is less bursty.

3. QUANTITATIVE COMPARISON OF OBS AND OPMIGUA

Our approach for a quantitative comparison of the two architectures OBS and OpMiGua is to use simulation scenarios as similar as possible, which especially includes the traffic offered to both models. However the traffic offered to the OBS and OpMiGua node itself is different as LP traffic is aggregated in one case and unaggregated in the other. Therefore, statistically identical traffic is generated on packet level and fed afterwards to an architecture specific aggregation unit, which aggregates HP and LP packets if needed.

One commonly used metric for evaluation of an architecture like OBS and OpMiGua is the packet or burst loss probability, which has the disadvantage of not considering differences in the length of lost units. We choose instead the bit loss probability (BLP) as metric, which specifies the lost traffic volume in comparison to total traffic. We consider for this metric both traffic classes in OBS and OpMiGua. However, in OpMiGua, HP traffic does not contribute to this metric as it is by definition lossless.

3.1 Scenario

For the simulations we select a basic scenario, where one single node is examined. This node has n incoming and n outgoing fibers, each with w wavelengths.

As both models do not distinguish between through and add/drop traffic on incoming or outgoing fibers, HP as well as LP traffic is equally distributed on all wavelengths. Thereby S gives the share of HP traffic with respect to the total traffic. Also, the traffic offered to the n output fibers is uniformly distributed. In case of OpMiGua there are $n \cdot w$ dedicated connections for HP traffic, which means each wavelength carries one HP connection.

Within each traffic class packets are generated with exponentially distrubuted interarrival times and trimodal distributed length of 40, 576 and 1500 bytes [10]. The probabilities for different packet sizes are 0.58, 0.26 and 0.16.

Traffic aggregation is done on a per wavelength basis with a maximum burst duration of 150 µs equivalent to a maximum burst length of 187500 byte at a line rate of 10 Gbps. For the maximum aggregation timeout we chose 5 ms [11]. After aggregation the bursts, and in case of OpMiGua also LP packets, are forwarded to an unbounded FIFO queue, which avoids overlapping of bursts and packets on one wavelength.

The additional QoS offset of HP bursts in OBS we chose such that it is bigger than the maximum LP burst duration. This results in an absolute prioritization, but HP bursts may still be lost due to contention among themselves.

Finally for both OBS and OpMiGua we use *Just-Enough-Time* (JET) as scheduling algorithm, which is able to use voids between already scheduled units [12].

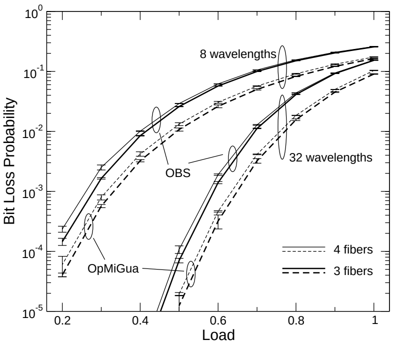

Fig. 3 BLP vs. load for $S = 0.3$

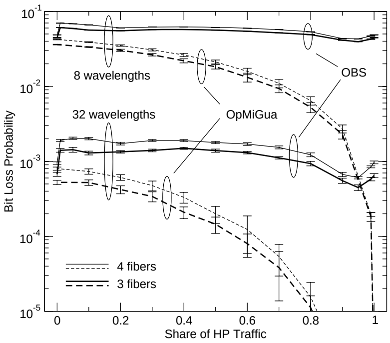

Fig. 4 BLP vs. S at load 0.6

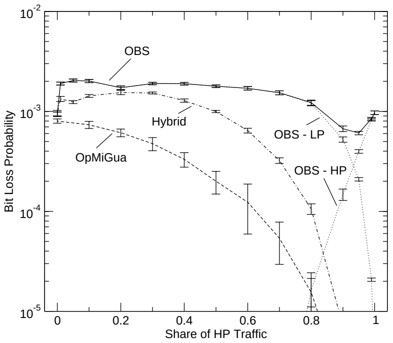

Fig. 5 BLP vs. S for $n = 4$ and $w = 32$ at load 0.6

3.2 Impact of number of wavelengths and fibers

Figure 3 shows BLP versus load for OBS and OpMiGua in scenarios with 3 and 4 fibers for an HP traffic share of 30%. In each case, we also inspect the influence of the number of wavelengths per fiber (8 and 32 respectively). At load 1 the mean generated traffic amount per time is equivalent to the maximum transmission capacity of the system.

The diagram reveals several phenomena. First the BLP increases as expected with increasing load independent of other parameters. Second the BLP drops with increasing number of wavelengths and as can be seen, the difference in BLP for 8 and 32 wavelengths is in the order of several magnitudes for reasonable loads. Third the number of fibers has only a very small influence, with a smaller BLP for 3 than for 4 fibers. And last but not least the BLP for OpMiGua is lower than that for OBS. Nevertheless the developing of BLP values is very similar.

While the decrease in BLP with more wavelengths can be reasoned by predominant effect of multiplexing gain, this is more difficult for the third phenomenon. In principle size changes of aggregated bursts could have an influence. However, in the chosen scenarios the end of aggregation is more or less always triggered by the maximum size criterion. Therefore aggregation can be excluded as reason. Looking at the cause for losses helps to clarify the behavior. Losses occur if there is temporarily too much incoming traffic from the $n \cdot w$ incoming wavelengths for the same destination. The more bursty the arrivals are, the more losses occur. Reducing the number of sources, which is the effect of less fibers, helps to smooth the traffic due to the strictly sequential transmission on a wavelength and in consequence the BLP decreases. The difference between OBS and OpMiGua will be explained later in detail.

3.3 Impact of high priority traffic share

The dependency of BLP and S is shown in **Fig. 4** for a fixed load of 0.6. The patterns observed in the previous section with respect to the number of fibers and wavelengths are still valid. However, now there are obvious differences in the behavior of OBS and OpMiGua. The BLP of OpMiGua is monotonically decreasing with increasing S. This seems reasonable as the share of lossless HP traffic increases. Fragmentation of the available phases of output wavelengths due to HP traffic is not a real problem for the small LP packets.

All OBS curves show the same basic behavior, but this is totally different to OpMiGua. Therefore it is exemplarily explained for the scenario $n = 4$ and $w = 32$, which is also depicted in **Fig. 5**. Furthermore, BLP is broken down into the parts caused by losses of LP and HP traffic (“OBS-LP” and “OBS-HP”).

BLP for $S = 0$ and $S = 1$ should be nearly identical in case of OBS as the offset does not matter anymore if all bursts belong to the same traffic service class. The simulations clearly confirm this expectation.

For very small values of S the completion of HP bursts is mainly triggered by the timeout criterion, which results in small bursts. These small bursts fragment the phases during which a maximum size LP burst can be scheduled. This scheduling is not always possible and in comparison to $S = 0$, where this fragmentation does not occur, the BLP is higher.

In the range from $S = 0.2 \ldots 0.8$ the BLP stays rather constant and originates only of LP losses. Although the LP share decreases it becomes more and more difficult to schedule the maximum size LP bursts due to increasing occupation by HP bursts.

For $S > 0.8$ the LP part of the BLP traffic drops very fast. Besides the obvious reason of decreasing share of LP traffic, the LP bursts also get smaller and by this better to be scheduled into the voids. On the other hand an increasing amount of HP traffic is lost. As result of this two trends in opposite directions a minimum of the BLP at $S \approx 0.95$ occurs.

3.4 Impact of differences in traffic

Until now only the accumulated impact of the differences between OBS and OpMiGua has been observed and it is unclear to which extend the smoother HP traffic of OpMiGua influences the BLP. Therefore the OBS node is fed with HP traffic having the same characteristics like in case of OpMiGua. Nevertheless this hybrid scenario is rather theoretical, as it is impossible to guarantee this lossless HP traffic within a OBS network scenario.

The resulting BLP ("Hybrid") can also be seen in **Fig. 5**. While this BLP shows at small S more similarities to OBS, it finally behaves like OpMiGua and goes to zero. The sharp increase for $S > 0$ is not as big as for OBS. The reason is, that in this scenario less HP bursts are produced. However these bursts are longer as the HP traffic amount is still the same. Remaining differences to OpMiGua, which are in the order of one magnitude, are due to the aggregation of LP traffic.

4. CONCLUSIONS

With OBS and OpMiGua two transport network architectures with QoS support for two traffic classes are compared in this paper. The result is, that for the investigated scenario OpMiGua is better suited. Although traffic generated for both models is statistically identical, traffic fed to the nodes itself shows differences due to absence of LP traffic aggregation and one single destination per wavelength for HP traffic in case of OpMiGua. Observed performance advantages of OpMiGua are caused by these two factors and the difference generally increases with higher HP traffic share.

For future studies concerning the comparison of OBS and OpMiGua two interesting areas are identified. This is on the one hand a quantitative evaluation of delays including the edge nodes. On the other hand we consider in this paper only basic node architectures with sole full wavelength conversion as enhancement. Therefore, a performance evaluation of more complex but also more powerful architectures as it could be achieved with the introduction of buffers for instance would be interesting.

ACKNOWLEDGEMENT

The authors would like to thank Steinar Bjørnstad and Christoph Gauger for their support.

REFERENCES

[1] C. Qiao, M. Yoo: "Optical burst switching (OBS) – a new paradigm for an Optical Internet." *Journal of High Speed Networks, Vol. 8, No. 1, 1999, pp. 69-84*

[2] C. Gauger, B. Mukherjee: "Optical Burst Transport Network (OBTN) – A Novel Architecture for Efficient Transport of Optical Burst Data over Lambda Grids." *In Proceedings of IEEE High Performance Switching and Routing (HPSR), Hong Kong, 2005, pp. 58-62*

[3] E. Van Breusegem, J. Cheyns, D. Colle, M. Pickavet, P. Demeester: "Overspill routing in optical networks: a new architecture for future-proof IP over WDM networks." *In Proceedings of Optical Networking and Communications (OptiComm), 2003, pp. 226-236*

[4] S. Bjørnstad, D. R. Hjelme, N. Stol: "A highly efficient optical packet switching node design supporting guaranteed service." *Proc. of Europ. Conf. on Optical Communication (ECOC), 2003, Mo4.4.5, pp.110-111*

[5] C. Gauger, K. Dolzer, J. Späth, S. Bodamer: "Service Differentiation in Optical Burst Switching Networks." *In Proceedings of ITG-Fachtagung Photonische Netze, 2001, pp. 124-132*

[6] C. Gauger: "Performance of Converter Pools for Contention Resolution in optical burst switching." *In Proceedings of Optical Networking and Communications (OptiComm), 2002, pp. 109-117*

[7] C. Gauger, M. Köhn, J. Scharf: "Comparison of Contention Resolution Strategies in OBS Network Scenarios." *In Proceedings of International Conference on Transparent Optical Networks (ICTON), 2004, Vol. 1, pp. 18-21*

[8] A. Kimsas, S. Bjørnstad, H. Overby, N. Stol: "Reservation Techniques in an OpMiGua Node." *Accepted for pub. in Proc. Conference on Optical Network Design and Modelling (ONDM), 2007, Greece*

[9] S. Bjørnstad, D. R. Hjelme, N. Stol: "A Packet-Switched Hybrid Optical Network with Service Guarantees." *IEEE Journal on Selected Areas in Communications, Supplement on Optical Communications and Networking, Vol. 24, Issue 8, 2006, pp. 97-107*

[10] K. Claffy, G. Miller, K. Thompson: "the nature of the beast: recent traffic measurements from an Internet backbone." *In Proceedings of the International Networking Conference (INET), 1998*

[11] S. Junghans: "Pre-Estimate Burst Scheduling (PEBS): An efficient architecture with low realization complexity for burst scheduling disciplines." *Proc. of International Conference on Broadband Networks, 2005, Vol. 2, pp. 1124-1128*

[12] M. Yoo, C. Qiao: "Just-enough-time (JET): A high speed protocol for bursty traffic in optical networks." *In Proceedings of IEEE/LEOS Summer Topical Meetings, 1997, pp. 26-27*