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OBS vs. OpMiGua – Comparing two Transport Network Architectures*

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Abstract

In this paper we compare with Optical Burst Switching (OBS) and Optical Migration Capable Networks with Service Guarantees (OpMiGua) two all-optical network architectures. While delay is analyzed qualitatively, a quantitative performance evaluation based on simulations shows differences regarding loss probabilities. In order to achieve a maximum of comparability both models are fed with identical traffic on the packet level. Results show that OpMiGua has a better performance.

1 Introduction

In the last years, several all-optical network architectures have been proposed in literature. The first proposed architectures rely on the principle switching paradigms 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 tried to realize nodes and networks in test beds and showed their technological feasibility. Also, the performance of each of the different architectures has been investigated with respect to almost all 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 where as 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), which both support several classes of service. We describe our modelling approach that allows us to directly compare the architectures. Also, we show results of a qualitative and quantitative performance evaluation and discuss the impact of basic traffic characteristics.

The remainder of this paper is structured as follows: in section 2, both architectures are introduced and important aspects discussed. Then we compare both architectures with respect to the performance qualitatively in section 3. In section 4, we show our modelling approach and give quantitative results of the comparison. Finally, section 5 concludes the paper and provides an outlook.

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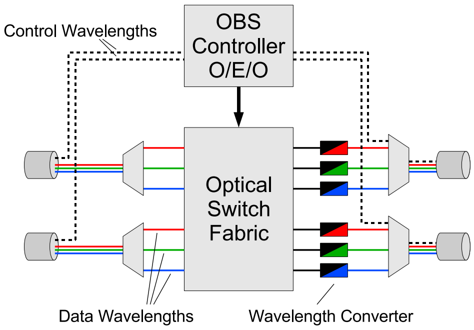

Fig. 1 OBS node architecture

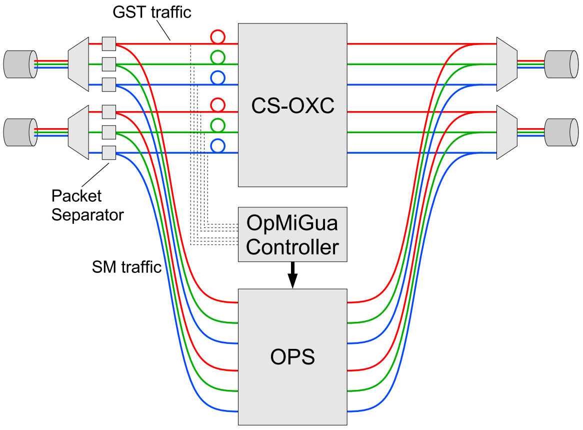

Fig. 2 OpMiGua node architecture

2 Architectures for dynamic all-optical networks

2.1 Optical Burst Switching

In the commonly considered approach of *Optical Burst Switching* (OBS) [1], packets from client networks are assembled at the edge of the network into so called bursts. Hereby, each burst only consists of packets for the same forwarding equivalence class. These bursts are transmitted through the network towards their destination. At the egress, bursts are disassembled and packets are forwarded to the client network.

To allow sophisticated processing of the burst's control information while keeping the complexity low, control information is separated and processed electronically while data remains in the optical domain. Thus, a control header packet precedes with a certain offset time the actual burst. The content of the control header packet, which is amongst others burst length and offset time, allows to select a path through a node and to reserve the required resources for the necessary time period. Hereby, all node resources like wavelength converters or fiber delay lines (FDLs) must be considered.

This one-pass reservation does not guarantee the successful delivery of a burst. Contention may occur and as final consequence bursts have to be discarded, if all available contention resolution mechanisms fail.

Fig. 1 shows the architecture of a basic OBS node. It consists of an optical switch fabric which switches bursts to the desired output fiber based on the control header packet information. Further, wavelength converters are placed at each output of the switch fabric to convert the burst to the appropriate wavelength for transmission to the next node. However full wavelength conversion, i.e., a converter on each output wavelength, is not mandatory for OBS as also a shared pool with a limited number of wavelength converters leads to substantial performance improvements in comparison to the total absence of converters [5].

Though further decreases of the blocking probability by contention resolution mechanisms like buffering via fiber delay lines are possible in OBS [6], they are not considered in the following.

As already stated resources are reserved for a burst at the instance of arrival of the control header packet. This offset time can be efficiently used to introduce different priorities. The greater the offset time, the greater is the likelihood to find the necessary resources available. If the offset time is larger than the maximum burst duration plus offset time of bursts with lower priority even an absolute prioritization is achieved. Without this criterion in place, absolute prioritization can only be achieved via use of preemptive techniques [7].

In summary OBS is a switching paradigm supporting 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. As information about bursts is processed 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

Optical Migration Capable Networks with Service Guarantees (OpMiGua [4]) have an inherent separation of different traffic classes. The so called Guaranteed Service class Traffic (GST) has high requirements concerning packet loss and jitter. Therefore, 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 blocking and delay jitter is minimized.

The other class is Statistically Multiplexed (SM) traffic, which has looser requirements and can be handled without reservations. For this class losses due to blocking and delay jitter due to buffering or deflection routing are allowed. Despite this inherent separation both traffic classes can share the capacity of the same wavelength.

In **Fig. 2** the architecture of a basic OpMiGua node is shown. On each wavelength, SM and GST packets enter multiplexed the node. The traffic classes are separated by a packet separator according to a specific label[a]. GST packets are forwarded to a circuit switch whereas SM packets are directed to a packet switch. After traversing the circuit and packet switch, SM and GST packets for the same direction are multiplexed on each wavelength.

In this node architecture GST packets are circuit switched after separation. So, a wavelength can be used only by GST packets with the same source and destination node. Statistical multiplexing of GST packets from different sources is unfeasible.

The treatment of SM packets is completely different. After separation they are forwarded to a packet switch. This can be realized all-optically or electronically with O/E/O conversion. Packets are switched towards their destination and scheduled onto a currently available wavelength on the correspondent output fiber. Hereby, the occupancy of the wavelengths by GST packets must be considered. As absolute priority is given to GST traffic, two options arise: first, preemption of SM packets is necessary in case of GST arrivals. Second, scheduling of SM packets has to be already aware of future GST arrivals within a sufficiently large time window. This is commonly realized by monitoring the occupancy of each wavelength before the traffic is delayed in a FDL as indicated in Fig. 2. Combinations of those schemes are also possible, i.e., the time window of known future GST arrivals is not as big as that in the case of total collision avoidance [8].

In consequence of this resource utilization, successful transmission of SM packets is only possible during gaps between GST packets. Blocking may occur on an output wavelength either if the output port is occupied by packets of any service class, or if the control unit computes that a collision will occur between the SM packet to be scheduled and an incoming GST packet.

As explained in the previous paragraph, every arrival of a GST packet/burst may cause an SM packet to be lost. Hence, reducing the number of arrivals should decrease the blocking probability of SM packets. Indeed, this is observed in [9] and aggregation of GST packets into bursts is used here too. 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.

In the following we assume that the occupation of the wavelength by GST packets is known in advance for the maximum duration of a SM packet transmission. By this it is possible to achieve minimum losses of SM packets. Furthermore, we assume the packet 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.

3 Qualitative comparison of OBS and OpMiGua

Comparing the two architectures, two main differences can be seen, that have an impact on the system performance. First, while in OBS all traffic is aggregated into bursts at the network ingress, in OpMiGua only the HP traffic is aggregated. Second, while in OBS all traffic shares all wavelengths, in OpMiGua each HP packet is transported on an end-to-end wavelength and only LP traffic can use all wavelengths – in the ingress as well as each core node.

In the following, we discuss the impact of these two differences on delay and capacity requirements while the impact on loss will be discussed in section 4.

3.1 Delay and delay jitter

In OpMiGua high priority packets are aggregated based on limitation of time-out and size in order to defragment the free slots for low priority traffic. Therefore, those packets experience a non-constant aggregation delay. This is limited by the assembly time-out, i.e., the maximum time between the arrival of the first packet for a burst and the departure of the burst.

Furthermore, high priority bursts destined for the same node have to be transmitted consecutively if there is only one appropriate high priority wavelength. That means if a HP bursts is presently transmitted and further aggregation units finish bursts, those have to wait.

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[a] As distinguishing label it is one possibility to use the polarization of the light. However the actual realization is not of importance for the considerations in this paper and not considered any further.

In the core nodes, for certain schemes of multiplexing HP and LP traffic after switching it is necessary to know in advance if a certain wavelength will be free within the time necessary for transmission of the LP packet. This is realized by delaying in each node high priority bursts after detection, e.g., by a fiber delay line, leading to an additional constant delay.

Low priority traffic is not aggregated in OpMiGua. Thus, it is only marginally delayed at the network ingress other bursts. In core nodes, the delay depends only on the realization of the packet switches in the core nodes. Here, several impacting factors have to be considered ranging from FDLs in all-optical solutions to electronic input and output buffers in electronic switches.

Compared to OpMiGua, in OBS both traffic classes are aggregated and thus the packets delayed. Beyond that, the traffic is delayed in the edge node for two reasons. First, in an electronic buffer the bursts are delayed before scheduled onto a outgoing wavelength due to limited fiber resources. But in contrast to OpMiGua, in OBS it does not matter on which wavelength a HP burst is transmitted. Thus – due to the economy of scale – the waiting time is much smaller than for OpMiGua. Second, as between header packet and burst the offset time must be ensured, a burst may be further delayed. But this delay is small in comparison to the assembly delay (equal or less than the offset time) and can be neglected.

Accordingly, for reasonable load in the edge node the delay of HP traffic is comparable in OBS and OpMiGua whereas the delay of LP traffic is higher in OBS.

Within a OBS network, the delay depends on the node architecture – e.g., whether processing delay is compensated by delay lines or by offset times – as well as on contention resolution strategies – whether FDLs and deflection routing is applied or not. Both aspects have impact on HP traffic as well as on LP traffic. Accordingly, in the network the delay and especially the delay jitter of HP traffic is usually higher in OBS than in OpMiGua whereas the delay of LP traffic is almost comparable.

3.2 Capacity requirements

As in OpMiGua high priority traffic is only circuit switched, direct end-to-end wavelengths are necessary for each node pair exchanging HP traffic. Thus, a full mesh of wavelength channels is needed under the assumption that every node exchanges HP traffic with each other. It can be easily seen, that if the share of HP traffic is small, i.e., only a small fraction of a wavelength, and LP traffic cannot fill the remaining capacity, the provisioned capacity is very high compared to an OBS network.

For example, in a mesh torus network with 9 nodes and uniform traffic demands, in OpMiGua on each link at least 3 wavelengths per direction are needed assuming that each pair of nodes exchanges HP traffic. In contrast, in an OBS network the lower bound is a single wavelength.

4 Quantitative comparison of OBS and OpMiGua

4.1 Modelling approach

While qualitative statements about an architecture can be done often very easily, it is much more difficult to achieve comparable quantitative results. In simple scenarios analytic methods may lead to such results. In more complex scenarios this approach is usually unavailing and results have to be achieved by simulation. Often a comparison of simulation results for different models is not feasible as different scenarios are used. Our approach is therefore to use for both architectures scenarios as similar as possible. This includes especially the traffic which is offered to both models.

Commonly OBS is investigated in two separated steps. First, the impact of burst assembly and its specific options on traffic characteristics is investigated. For this, input traffic is described on packet level. Second, the performance of a burst switched network is evaluated for traffic which is described on burst level. Similar, the performance of OpMiGua networks is evaluated based on traffic described on the according level neglecting the details of the assembly process for HP traffic. But to compare the two architectures with respect to absolute values, this approach is not sufficient. Here, for both scenarios identical traffic models describing the traffic on the same level must be used.

Thus, our approach is to apply a model specific aggregation to adopt identical input traffic. So we compare OBS and OpMiGua including their basic edge functionalities alike assembly and scheduling. With this, we can describe all input traffic on the packet level.

For evaluation of OBS and OpMiGua we chose instead of the commonly used packet or burst loss probability the bit loss probability (BLP) as metric. This metric gives the probability that an arbitrary bit is lost due to blocking. Another interpretation of this metric is, that it is the packet/burst loss probability weighted by the packet/burst length. We consider for this metric both traffic classes in OBS and OpMiGua. However, in

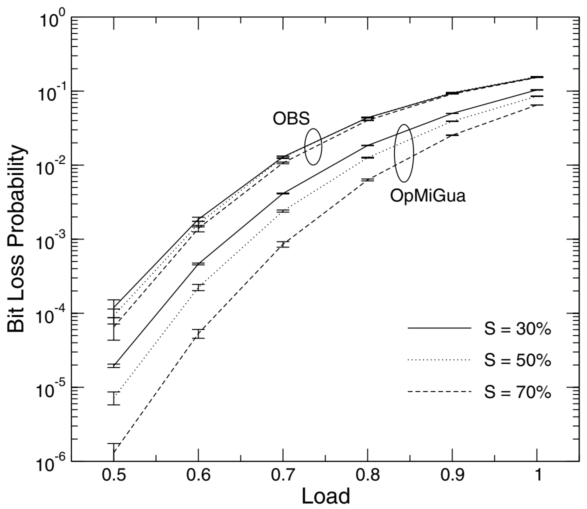

Fig. 3 Bit loss probability of OBS and OpMiGua in dependency of load and share of HP traffic

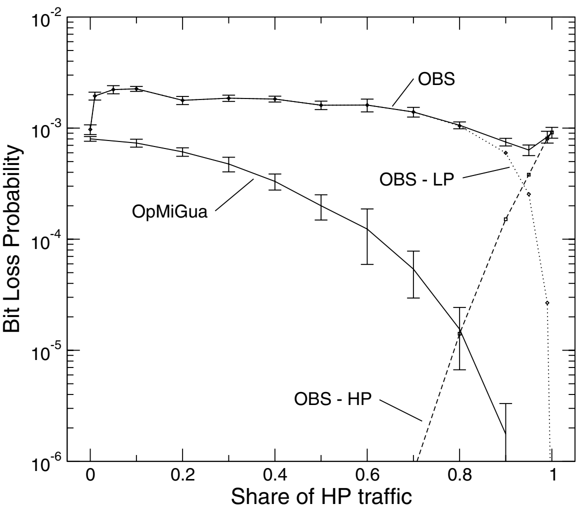

Fig. 4 Bit loss probability of OBS and OpMiGua in dependency of S at load 0.6

OpMiGua, HP traffic, which is per definition lossless, does not contribute to this metric.

The drawback of this approach is the increased number of events (packet arrivals instead of burst arrivals) that must be processed leading to a higher computational complexity.

4.2 Parameters

For the simulations we select a basic scenario in order to minimize the parameter space. Therefore only a single node is examined. The node has $n = 4$ incoming and outgoing fibers, each with $w = 32$ 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 four output fibers is uniformly distributed. In case of OpMiGua there are $n \cdot w$ dedicated connections for HP traffic, which means, that every wavelength carries such traffic.

Within each traffic class packets are generated with a negative exponential interarrival time and a trimodal distributed length [10]:

- 58% packets with length of 40 bytes
- 26% packets with length of 576 bytes
- 16% packets with length of 1500 bytes

Traffic aggregation is done on a per wavelength basis with a maximum burst duration of 150 µs leading at a line rate of 10 Gbps to a maximum burst length of 187500 Byte. For the maximum aggregation delay we chose 5 ms [11]. After aggregation the bursts are forwarded to an unbounded FIFO queue which sends only one burst/packet at the same time on one wavelength.

The additional QoS offset of high priority bursts in OBS we chose such that it is bigger than the maximum LP burst duration, which results in an absolute prioritisation.

Finally for both OBS and OpMiGua we use a scheduling algorithm, which is able to use voids between already scheduled units [12]. This algorithm leads to a near optimal resource utilization.

4.3 Simulation results

Fig. 3 shows the BLP versus the load for three shares of HP traffic, 30%, 50%, and 70%, respectively. A load equal to 1 implies that there are no idle phases on the incoming wavelengths. It can be seen that the BLP decreases with smaller loads. This effect is intuitive as with smaller loads the probability increases to find free resources. Furthermore it is noteworthy that the BLP seems to decrease with higher S.

Fig. 3 also shows performance differences of OBS and OpMiGua. For $S = 30\%$ and $S = 50\%$ OpMiGua is approximately half an order of magnitude better than OBS. For $S = 70\%$ it is about one order of magnitude or even more. The reason for this behaviour will be examined in more detail in the following.

Fig. 4 shows the BLP for varying S at a fixed load of 0.6. In case of OBS the BLP for $S = 0$ and $S = 1$ should be nearly identical as the offset does not matter anymore if all bursts have the same offset. The simulations clearly confirm this expectation. The shape of the curve between those two points is more difficult to understand.

At $S = 0.01$ small HP bursts fragment the phases during which a LP burst can be scheduled into short periodes. LP bursts with maximum or close to maximum length have to be fit in. This is not always possible and in comparison to $S = 0$ where this fragmentation does not occur the BLP is higher.

In the range from $S = 0.2 \ldots 0.8$ all bursts have very similar sizes as here the process of sending a burst is mainly triggered by the burst size limitation. Within this range fragmentation still occurs but HP traffic uses the resources more efficiently. As consequence there are only minor differences regarding the BLP. However the tendency is a small decrease with increasing S.

The smallest BLP is achieved around $S = 0.95$ and increases afterwards again. The decomposition of the BLP for OBS into shares resulting from HP and LP traffic, which are also drawn in Fig. 4, explain this behaviour. Almost the whole BLP is caused by losses of LP traffic until $S = 0.8$. Afterwards the influence of LP traffic decreases more and more as also the share of this traffic goes to zero.

Contrary to this the BLP of HP traffic increases. While for small S HP traffic encounters a nearly empty system and has therefore almost no losses, this is not the case anymore for $S > 0.7$. At $S > 0.9$ the BLP due to HP traffic outweighs the LP traffic and finally dominates the total BLP.

Although the share of LP traffic decreases, the BLP of LP traffic stays over a long period nearly constant. The reason is, that the LP bursts have nearly maximum size until $S = 0.8$. As more and more resources are already occupied by HP bursts and fitting of LP bursts into voids becomes more difficult, the loss probability of LP bursts increases. This compensates the effect due to decreasing share on the total BLP.

It should be also mentioned that altogether the differences in the BLP for OBS are within a very small corridor at load 0.6. Fig. 3 indicates that this differences increase for lower loads but this is not examined further.

In case of OpMiGua a clear tendency to smaller BLPs for an increasing share of high priority traffic can be seen in Fig. 4. For $S = 1$ the BLP is zero as no losses occur anymore.

Furthermore as LP traffic is not aggregated, OpMiGua does not suffer like OBS from the fragmentation due to HP traffic. The results do not even indicate any increased losses.

Finally, the reason for the large gap between the BLP of OpMiGua and that of LP traffic in OBS remains open. Again both differences of OBS and OpMiGua have impacts. On the one hand LP traffic is not aggregated and fits therefore better into voids of HP traffic. On the other hand HP traffic in case of OpMiGua behaves much more amicable and smooth due to the fixed assignment of incoming and outgoing wavelength. Understandably the LP traffic also profits from this smoothness of HP traffic.

To quantify the impact of each difference between OpMiGua and OBS further studies are necessary.

5 Conclusion

With OBS and OpMiGua two transport network architectures are compared in this paper. Based on the current technological development status OBS has less stringent requirements, as switching is done on a bigger granularity.

Both architectures allow different traffic classes including prioritization. With respect to delays, the predominant part (besides propagation) originates from aggregation in ingress nodes. Here OpMiGua might have a disadvantage in case of very bursty high priority traffic. On the other hand in OBS high priority traffic has an additional delay due to the offset between header control packet and burst.

Under the assumption that all nodes exchange high priority traffic with each other and the amount of LP traffic is not sufficient to fill the remaining voids in the lightpaths, OpMiGua needs a higher provisioning. In OBS this is not a problem, as wavelengths can be shared by all traffic streams.

Observed performance differences between OpMiGua and OBS are caused by different traffic conditions of the high priority traffic and different aggregation of LP traffic. When applying the same conditions to OBS those differences should diminish.

An interesting area for future studies concerning the comparison of OBS and OpMiGua is on the one hand a quantitative examination of the differences as well as a quantitative evaluation of delays. On the other hand we investigated in this paper only basic node architectures. As performance of OBS as well as OpMiGua can be improved by the usage of buffers, further studies in this direction are worthwhile.

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