Why we should consider virtual topologies for OBS

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Abstract— **This paper motivates virtual topologies for more advanced network design in OBS. It discusses their principal characteristics both qualitatively and quantitatively and derives conclusions toward their resource efficient design. Finally, the OBTN approach is outlined and representative performance results are presented.**

I. INTRODUCTION

Optical burst switching (OBS) [1] and optical packet switching (OPS) [2] attracted interest as highly dynamic optical network architectures capable of statistical multiplexing directly in the optical domain. Although a broad scope of research is reported in literature, network design considerations so far have mostly concentrated on isolated, green-field scenarios.

Today, dynamic optical networks, popularly referred to as *Lambda Grid*, are introduced based on the Automatically Switched Optical Network (ASON) and Generalized Multiprotocol Label Switching (GMPLS) architectures. They will likely remain an integral part of future transport networks due to their scalability and manageability benefits. Transparent wavelength-routed networks offer multiservice integration as they transport and switch arbitrary client services in the same infrastructure. Also, virtual topologies of lightpaths enable network designers to bypass expensive client layer nodes, e. g., IP routers, and offload transit traffic to the more cost-efficient optical layer.

Integration of OBS and wavelength-routed networks has been embraced in hybrid optical networking concepts [3], [4], which select one of the network technologies depending on service or traffic requirements. In contrast, virtual topologies as a client-server combination as depicted in Figure 1 did not play a major role, yet. Still, they should be considered due to following reasons:

- OBS architectures can migrate into wavelength-routed transport networks as traffic aggregators at the edge of the core network [5], [6]. In this scenario, lightpaths in the underlying wavelength-routed network interconnect these aggregation nodes forming a virtual topology.
- Typical transport network topologies have mean hop distances ranging from 2 to 3.5 [7], i. e., transit traffic amounts to 50–70 % of all traffic in the network. Intermediate OBS nodes have to switch this transit traffic which requires a high number of costly burst switch ports and can cause physical node scalability problems [8]. Here, virtual topologies create new design opportunities, by offloading transit traffic to underlying lambda grids.
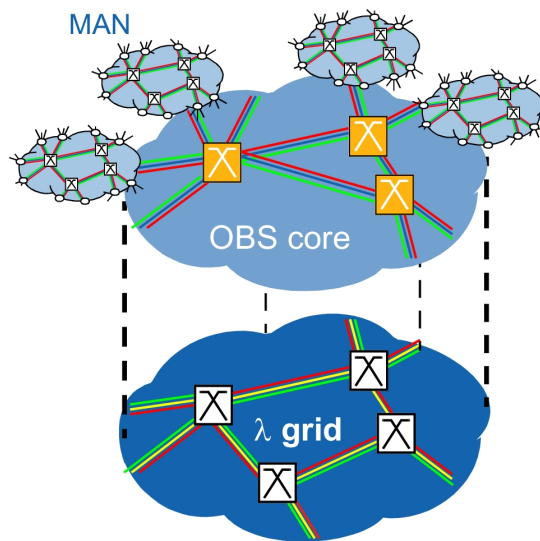

Fig. 1. Transport network scenario comprising an OBS and a wavelength-routed network layer

- Finally, a lambda grid can offer functions for resilience and for capacity adaptation on higher time-scales to the OBS layer.

Section II describes the mentioned burst transport scenario in more detail while Section III analyzes design trade-offs for virtual topologies in OBS. Finally, Section IV briefly outlines the Optical Burst Transport Network (OBTN), a burst-switched architecture employing a virtual topology to balance node complexity and network efficiency.

II. NETWORK SCENARIO FOR BURST TRANSPORT

Commonly, interconnection of huge core routers in transport networks is proposed as the main application scenario for OBS. However, highly aggregate traffic flows in such routers are less bursty and an only limited capacity improvement may not justify the transition from circuit-switched to burst-switched transport network architectures.

In future OBS scenarios, optical networking could reach farther out toward the user than in current networks. Instead of repeated aggregation and consolidation of bursty data traffic in the electronic domain, it could be assembled and handed over to the optical domain earlier, e. g., at the edge of the
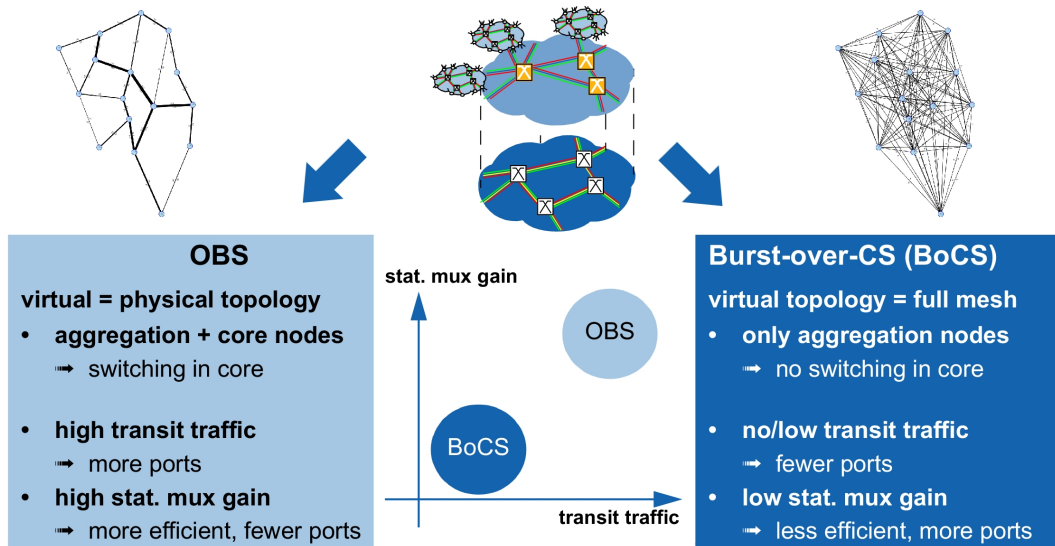
Fig. 2. Principal design options and trade-offs for virtual topologies in optically burst-switched networks

MAN as in [9], [10]. Then, traffic at the ingress to the optical network would be less aggregate, i. e., more bursty, and would thus better suit the ideas of burst transport.

As OBS core nodes would mainly aggregate/disaggregate optical burst traffic at the edge of the transport network, bursts would not have to be switched in all intermediate transport nodes. Instead, optical bursts with the same OBS aggregation/disaggregation nodes could be switched together through the transport network in a direct lightpath [5], [6]. Thus, we refer to this approach as *burst-over-circuit-switching* (BoCS).

Summarizing, the interconnection pattern of OBS switches in this scenario constitutes a major application case for virtual topologies in OBS.

III. TOPOLOGY DESIGN AND STATISTICAL MULTIPLEXING

In the design and analysis of OBS architectures, network efficiency and node complexity—*cost of transport* and *cost of switching*—always have to be considered together [11], [12]. On the one hand, the still limited functionality and mostly *analogue* nature of agile optical systems [11] indicate that their implementation cost will remain high for some years to come. On the other hand, the cost of transport will decrease due to the huge available bandwidth of optical networks. Accounting for both trends, switching will continue to dominate the cost of optical networks in general and of OBS networks in particular. Therefore, the number of interfaces of OBS nodes, which are one indicator of their realization complexity, is critical and should be minimized at first place even at the cost of additional network capacity.

A. Qualitative Arguments

In networks with dynamic traffic, topology design is not a straightforward task as it involves conflicting arguments regarding statistical multiplexing gain and node size.

- On a typical physical topology like in regular OBS, traffic streams share the transport resources which are assigned to relatively few links. While this requires additional switch ports for transit traffic, it yields a high statistical multiplexing gain on all links.
- A very densely or fully-meshed virtual topology like in BoCS corresponds to the other extreme. On the one hand, nodes do not switch any or hardly any transit traffic which reduces the number of switch ports significantly. On the other hand, as more links comprise fewer capacity each, traffic streams can only share less resources, which yields a much lower statistical multiplexing gain.

These two extreme scenarios and the trade-offs are also depicted in Figure 2. Note that full-mesh interconnection patterns are not as uncommon as they seem. For instance, they frequently occur in dynamic multi-layer networks (IP/WDM, SDH/WDM) [13], [14].

In network dimensioning, a lower statistical multiplexing gain translates into a higher overprovisioning factor for link and switch resources to meet a QoS objective, e. g., a burst-loss probability, and vice versa. The positive effect of reduced transit traffic and the negative effect of higher necessary overprovisioning both decide on the number of switch ports. Consequently, virtual topologies for highly dynamic networks like OBS have balance these effects to find optimal solutions.

Existing work on virtual topologies for OBS focuses on reducing the number of contention situations and the control processing overhead in intermediate nodes. In [15], this is achieved by minimizing the maximum shortest path length. However, it does not capture any of the conflicting effects.

B. Quantitative Arguments

In order to quantify the potentials and limits of virtual topology design, we look at basic relations of node and
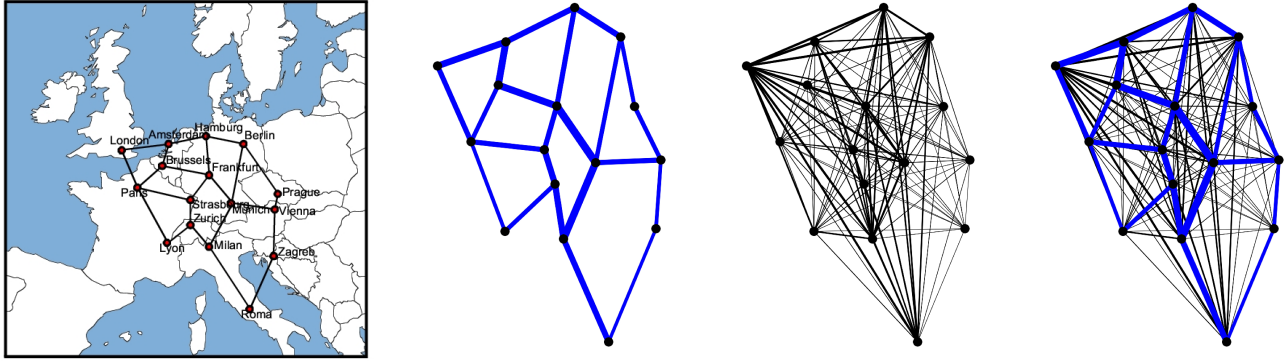
Fig. 3. Burst layer topologies: (a) European reference network topology (b) OBS physical topology (c) BoCS virtual topology, and (d) OBTN virtual topology.

network dimensioning for the two extreme cases of a physical and a full-mesh topology. We restrict the discussion to the number of (sending) OBS trunk interfaces and the number of wavelength hops in the fiber infrastructure. We neglect rounding effects and assume that the number of add/drop interfaces do not differ.

The product of total traffic demand A in the network, the mean overprovisioning factor α, and the mean hop distance per bit d in the OBS layer determine the number of trunk interfaces as $\alpha \cdot d \cdot A$. The virtual topology characterizes both, the overprovisioning factor and the mean hop distance. While the mean hop distance per bit usually is slightly lower than the mean shortest path length in typical physical network topologies [16], it equals 1 in the full-mesh topology. Based on the qualitative discussion above we conclude that the overprovisioning factor α_p for a physical topology is lower than α_{fm} for a full-mesh topology. We can directly see that the total number of trunk interfaces for the full-mesh virtual topology ($\alpha_{fm} \cdot A$) is smaller than for the physical topology ($\alpha_p \cdot d \cdot A$) if $\alpha_{fm}/\alpha_p < d$. Consequently, densely-meshed virtual topologies have to achieve a low α_{fm} and a low ratio α_{fm}/α_p to yield gains in the number of switch ports. Advanced contention resolution strategies should thus be applied in these cases. Also, the larger a network is in terms of mean hop distance, the greater the benefits are that could be realized.

To study network resources, we derive the number of wavelength hops in the physical fiber infrastructure from the number of trunk interfaces. For the physical topology case, each trunk interface corresponds to one wavelength hop. In the full-mesh topology, a virtual topology link can span several hops in the underlying physical topology. Thus, the number of trunk interfaces is multiplied by the mean length of virtual topology links, which approximately corresponds to the mean hop distance per bit d. Comparing the virtual topologies, the number of wavelength hops in the physical infrastructure is always higher for the full-mesh topology ($\alpha_{fm} \cdot d \cdot A$) than for the physical topology case ($\alpha_p \cdot d \cdot A$) as $\alpha_p < \alpha_{fm}$. Again, a densely-meshed topology has to be engineered to achieve a small ratio of overprovisioning factors α_{fm}/α_p. However, our previous discussion also emphasized that reducing the

number of node interfaces has precedence over the number of wavelength hops.

This discussion of extreme scenarios exhibits the principal trade-offs and bound the margins for improvement in intermediate scenarios. [17] presents a unified performance comparison of OBS and BoCS including systematic traffic and network size studies.

IV. OBTN ARCHITECTURE

This section briefly outlines the Optical Burst Transport Network architecture (OBTN) which defines a a virtual topology design together with contention resolution strategies in order to reduce the number of OBS switch ports and to keep a high network efficiency at the same time. For a more detailed presentation, the reader is referred to [17].

First, OBTN applies a virtual topology, in which OBTN nodes are interconnected by direct end-to-end lightpaths in a dense virtual topology based on traffic demand or operational criteria.

Second, as statistical multiplexing on a large number of network links with small capacity each can be inefficient alone, OBTN comprises two additional complementing concepts: (i) bursts are allowed to use an alternate path in case of contention on the direct lightpaths and (ii) a small amount of shared overflow capacity is allocated to links used by the alternate paths.

Assigning alternate routes and shared overflow capacity to the physical topology links avoids burst reordering and increases the efficiency of shared overflow capacity.

For illustration, Figure 3 depicts the OBS physical, BoCS full-mesh, and OBTN virtual topologies.

Evaluations presented in Figure 4 quantify the trade-off between number of burst-switched ports and number of wavelength hops for all three topology approaches. This study uses the European reference network scenario depicted in Figure 3a [7], [18]. Node and network complexity [12] are derived for a given QoS (a burst loss probability in the network of 10^{-4} and 10^{-5}). All values are normalized to the respective minima, i.e., $d \cdot A$ following the notation in Section III-A. For OBTN, three different dimensioning combinations of direct lightpaths and shared overflow capacity are included.
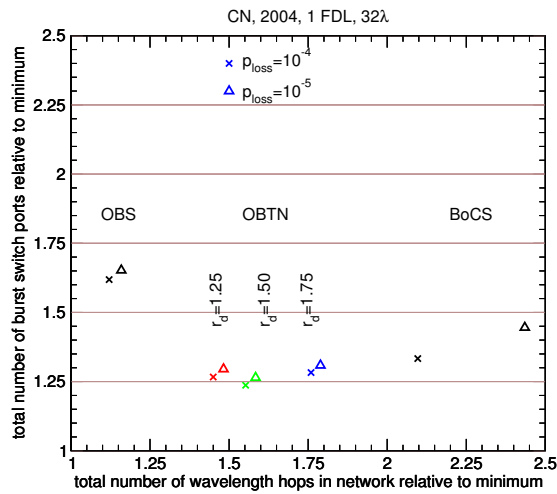
Fig. 4. Integrated architecture comparison of node complexity and network efficiency for two QoS values

Basically, the greater the factor r_d, the less shared overflow resources are available.

Figure 4 clearly exhibits the principal trade-offs discussed in Section III. On the one hand, OBS requires the smallest number of wavelength hops due to the high statistical multiplexing gain, on the other hand, it also needs the highest number of burst ports due to the high transit traffic. BoCS which does not switch any transit traffic, requires less burst-switched ports, however, at the cost of a significantly increased number of wavelength hops. Finally, OBTN successfully and very insensitive to the QoS level balances the required number of ports and wavelength hops

Applying the cost relations for Lambda Grid scenarios outlined in Section III, in which bandwidth is considered a commodity and node equipment the major cost driver, OBTN constitutes an effective solution to reduce cost.

V. Summary and Future Work

This paper presented application scenarios for virtual topologies in the context of OBS. It discussed key trade-offs with respect to statistical multiplexing and network size and derived consequences for network design. It is shown that network architectures with efficient contention resolution can be expected to benefit from densely-meshed virtual topologies in terms of the number of burst-switched interfaces. Finally, the OBTN approach is outlined and representative performance results are presented.

Future work should research optimized combinations of wavelength-routed and burst-switched networks. Particularly, virtual topologies should be considered to migrate toward and efficiently implement OBS networks.

Due to the space limitations of an extended abstract, more material will be presented during the workshop.

VI. Acknowledgment

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