Node Architectures for Optical Packet and Burst Switching

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***Abstract*— Optical Packet Switching (OPS) and Optical Burst Switching (OBS) are optical networking concepts based on fully exploiting fast dynamic allocation of (D)WDM channels. Compared to more static approaches focussing on providing end-to-end optical channels, OPS and OBS aim at providing greater bandwidth efficiency, granularity and flexibility. In this paper we give an overview of the issues arising when designing an optical switch for either OPS or OBS, including packet formats, contention resolution techniques, and switching fabrics.**

***Index terms*— (D)WDM, Optical Packet Switching, Optical Burst Switching.**

A. Introduction

THE deployment of (D)WDM is generally adopted to satisfy the ever-increasing demand for bandwidth. Current standardisation efforts (GMPLS in the IETF, ASON related work in ITU) address the move from the currently predominant point-to-point systems, to real optical networking supporting circuit-switched optical paths. Longer term strategies for optical networking that exploit the full potential of optical switching technologies, and thus the fast dynamic optical channel allocation, are Optical Packet Switching (OPS) and Optical Burst Switching (OBS). This paper discusses the issues arising when designing an optical switch for either OPS or OBS. In Section B, we discuss alternatives for the packet format. We continue in Section C with a high-level view of the switch architecture, focussing on the different phases in packet processing. Section D treats contention resolution. Approaches for the actual switching fabric are presented in Section E. The paper is concluded in Section F.

B. Packet Format

The key concept of packet switching in general, including OPS and OBS, is to take full advantage of the available resources by only occupying bandwidth when there effectively is data to be sent. To this end, data is packetized: a chunk of data is assembled as payload, and a preceding header is added, containing at least information on the payload's destination. Transporting the header can be done in various ways: it can be (i) sent in-band just in front of the payload, using the same wavelength, (ii) transmitted on an orthogonal channel, e.g. through FSK-based modulation, or (iii) provided on a separate control channel. The main advantage of the latter is that control information and payload are physically separated, thus facilitating independent processing (e.g. electronic vs. optical). Yet, it calls for precise synchronization between data (payload) and control (header) channels.

Towards the implementation of packet switching in optics, two fundamentally different approaches exist: one can either opt for fixed length optical packets (necessitates fragmentation and reassembly functions interfacing to the client layers), or for variable length packets. The network can be operated in either a time-slotted manner, or rather an asynchronous mode. Usually the slotted approach is taken for fixed length packets, whereas the asynchronous operation is adopted in case of variable length packets. These different approaches are illustrated in Fig. 1 for in-band headers and single-wavelength packets. Note that some approaches spread the header info over multiple wavelengths, and jointly switch a whole waveband.

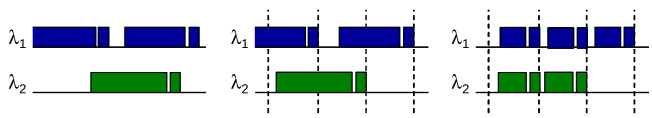

Fig. 1. Illustration of the various options for packet switching: fixed length packets, variable length packets, either in slotted or unslotted mode of operation.

OPS usually denotes the use of fixed length packets, in a slotted mode of operation, whereas OBS [1] uses variable length packets. In addition, the granularity of OBS is taken to be coarser than OPS. Compared to OBS, the advantages of OPS are that due to its finer granularity it allows a more efficient bandwidth usage, and that logical performance

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(e.g. Packet Loss Rate, PLR) of switches operating in slotted mode is better than unslotted ones. Clearly, there is a reverse side of the medal: the finer granularity implies a larger amount of overhead (cf. less data per header) and the need for faster switches, while the slotted operation requires synchronization of the different inputs of the switch.

C. Node Architecture

A generic view of the architecture for an optical packet switch comprises three stages [2]: an input interface, a switching core, and an output interface. Alternatives for the switching fabric are discussed in the next Section D.

The input interface will at least have to provide extraction of the packet headers for appropriate processing, as the header will dictate the routing of the payload. In case of in-band headers, this implies that the different wavelengths will need to be demultiplexed, since the headers of different packets need to be isolated. To date, the architectures proposed by various projects dealing with optical packet switching foresee O/E/O conversion of the headers: they will be processed electronically to set and control the optical devices, esp. those in the switching stage. This control and routing in the resulting network can be based on Generalized Multi-Protocol Label Switching (GMPLS), e.g. in [3]. To avoid elaborate O/E/O header conversion, all-optical header processing techniques recently have been proposed, e.g. [4]. The payload, which does not need processing, can be kept in the optical domain, and thus be transparently transported from in- to outputs. Also note that the header's bitrate can be different (much lower) than that of the payload.

In the final output stage, packets destined for a same outgoing fibre will be multiplexed. Also, in this stage the packet headers may be (re-)written. Indeed, depending on the routing mechanism and accompanying header info, the header could need to be updated. In this case, the input stage could strip the original header and the output stage could add the new one. If the switch stage does not affect the channel on which the headers are transported, the new header clearly could already be inserted at the end of the input stage. When the switching stage would degrade the signal too much (e.g. due to crosstalk), the output stage needs to include regeneration, possibly 3R, preferably all-optical.

D. Switching Matrix

The core functionality of an optical packet switch is to selectively transmit packets from a particular input port to a particular output port. Here, a "port" implies a certain wavelength on a certain fibre. Three well-known optical switching approaches are: micro-electromechanical systems (MEMS, [3]), a broadcast-and-select architecture, and an Arrayed Waveguide Grating (AWG). Since MEMS suffer from slow switching times, it is not suitable for packet switching.

The broadcast-and-select architecture (B&S) has been proposed e.g. in the European research projects KEOPS [5] and DAVID. A simplified view of the switching fabric proposed by the latter is depicted in Fig. 2 for 16 input fibres with each 16 wavelengths [6]. The first stage multiplexes different wavelengths into a single fibre, and jointly amplifies them to compensate for the subsequent power splitting stage. For each output wavelength, two switching stages are foreseen: the first selects one of the 16 input fibres, and thereof the second selects a single wavelength. Advantages of such a B&S architecture are that it's non-blocking, and that it can perform multicasting.

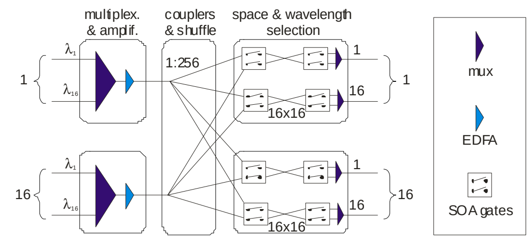

Fig. 2. A broadcast-and-select architecture as proposed in DAVID.

Another optical switching technique is based on a passive component: the AWG. This is an approach taken by e.g. the WASPNET [7] project, and the more recent STOLAS [8]. The wavelength of a signal offered at one of the AWG's input ports determines via what output port it will leave the AWG. Thus, through using tuneable wavelength converters at the inputs, an AWG can be used as a switching fabric. If the AWG is used for F fibres, each carrying W wavelengths, then in principle we can operate the switch with wavelength converters ranging only over the W wavelengths in use. Unfortunately, the resulting switch then is a blocking one, meaning that there is no guarantee that all packets can be forwarded to a certain output fibre, even if we have only to switch W (or less) packets to each of the output fibres. To minimize the blocking probability, ingenious combination of the AWG's outputs into single fibres is needed [9]. The node can be made non-blocking by using converters tuneable over F·W wavelengths. In this case, additional wavelength converters at the outputs are needed (or F·W wavelengths will be present on a single fibre, of which only max. W will carry a packet).

With the advent of DWDM, the number of wavelengths on a single fibre has significantly increased. This means that the dimensions of the switching fabrics in the core of optical packet switches need to be huge as well. Therefore, multi-stage switching fabrics will need to be devised. This problem has been solved for circuit-switching by e.g. Clos. A three-stage Clos-network is depicted in Fig. 3. The number of intermediate stages required differs whether the structure is intended for slotted, fixed length OPS, or rather unslotted OBS: in the latter case one needs k=2n–1 intermediate stage switches, whereas k=n suffice for OPS. For an AWG switch, using multiple stages also reduces the tuneability range needed for wavelength converters.

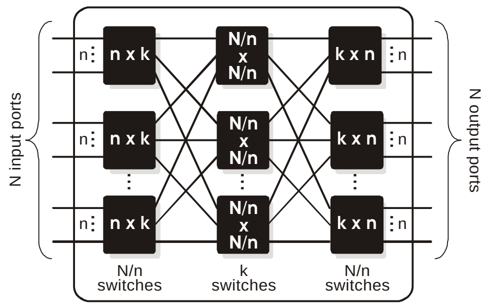

Fig. 3. A multi-stage Clos network for large switch dimensions.

E. Contention Resolution

A major issue that needs to be resolved in any form of packet switching is contention resolution. In the case of optical packet switching, three approaches (or any combination thereof) can be adopted: (i) use deflection routing, (ii) provide buffering, and/or (iii) exploit the wavelength domain and use wavelength conversion. Note that providing buffering in the optical domain requires Fibre Delay Lines (FDLs), unless we can afford to convert it to and from electronics (which may be the case in exceptional cases, e.g. for low priority traffic). From a performance point of view, exploiting wavelength conversion greatly lowers the PLR, as shown in e.g. KEOPS work [5]. Deflection is only effective when the network is not too highly loaded, such that there is enough free bandwidth available along deflected routes. A logical performance comparison of the approaches can be found e.g. in [10].

The use of buffering has a major impact on the switch structure. From an architectural viewpoint, FDL buffers can be classified into either feed-forward or feed-back. Feed-forward buffers comprise input- and output-buffering schemes, whereas feed-back refers to a recirculating buffer: some of the switching fabric's output ports are connected through a FDL back to the input ports. Also, one can distinguish between single-stage and multi-stage FDL architectures. In feed-back buffers, usually a single buffering stage is used: the multi-stage approach, using multiple switching stages, is limited to feed-forward schemes. For feed-back configurations, the parameters are the number of switching fabric ports sacrificed to buffering, and the length of the recirculating FDL(s). When using multiple FDLs with different lengths, it is clear that lower PLRs are reached due to the larger buffer capacity [11]. The downside of different FDL lengths is that it is no longer possible to guarantee that packet reordering will not occur.

F. Conclusion

OPS and OBS are packet switched approaches to optical networking, requiring fast switches. In this paper we have discussed various possible architectures for such switches, tackling packet formats, switching fabrics and contention resolution schemes. We summarised the pros and cons of the approaches in a qualitative manner, but also referred to results of performance studies.

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