Variable Sized Packet Routing in a Complete 12×12 Photonic Network

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Abstract: Packets with variable sized payloads between 96 and 384 bytes, depending upon the number of payload wavelengths, are simultaneously routed in an implemented 12×12 optical packet switching network with bit error rates better than 10^{-12}.

OCIS codes: (060.2310) Fiber optics; (060.4250) Networks

1. Introduction

Interconnection networks capable of providing ultra-high bandwidth communications with minimal access latencies are essential for numerous applications, including next-generation high-performance computing and data storage [1]. Recent work suggests that optical interconnection architectures may offer viable solutions for these systems, particularly when the full bandwidth available via dense wavelength division multiplexing (DWDM) is utilized to achieve multi-terabit capacities per port, and when latencies are minimized to nearly the optical time-of-flight [2]. The data vortex architecture has been designed to accommodate these capacities by utilizing multiple-wavelength packets while also leveraging deflection routing as a means of avoiding costly photonic buffering. A demonstration 12×12 data vortex network which contains 36 individual switching nodes was first presented last year [3]. Investigations of the behavior of the network have been performed recently as well, concerning the implemented network's power and timing flexibility [4],[5].

While the previous demonstrations focus on the physical layer aspects of the network, the flexibility of the network's data layer is also important. The experiments presented here investigate the effect of injecting packets with variable numbers of payload wavelengths into the network simultaneously. This emulation verifies the feasibility of dynamically varying the payload size in-situ by altering the number of payload wavelengths encoded. While the packet length is fixed in time, reducing the number of payload wavelengths in a packet can reduce the load on physical resources, both at input terminals and output terminals. Recently, similar experiments relating to variable packet size routing have been carried out on other architectures and network configurations as well, *viz.* [6]–[8]. The demonstration of the network's transparency to varying packet sizes is an important validation of the effectiveness of the data vortex architecture as a solution for high-bandwidth ultra-low latency interconnection.

2. Architecture

The data vortex optical packet switching network architecture was designed specifically for realization in the optical domain, taking into consideration the difficulty of implementing optical buffering and complex all-optical logic [3]. The architecture is a fully implemented directed deflection routing topology composed of simple single-packet 2×2 switching nodes. The nodes are arranged in hierarchal levels or cylinders, each affixing an additional bit in the packet's destination address, in a manner similar to banyan network addressing [3].

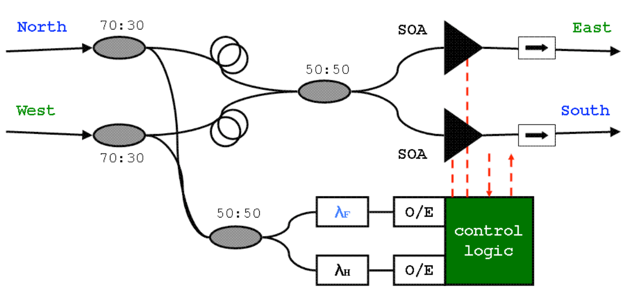

Fig. 1. Schematic of the photonic switching node design (ovals for optical couplers, λ filters, O/E photodetectors, and boxed arrows for isolators, dashed arrows for deflection signal input and output).

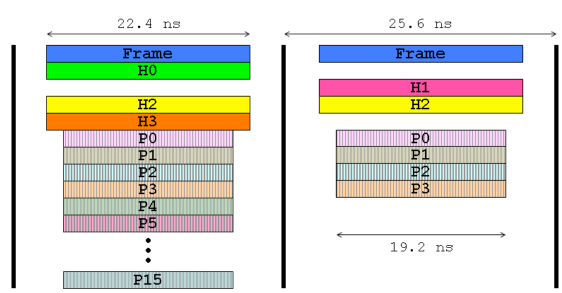

Fig. 2. Illustration of the multiple-wavelength packet format, with constant-value wavelength-parallel header bits. The left packet contains the maximum of 16 payload wavelengths (384 B), while the right one contains just 4 payload wavelengths (96 B).

The important feature of this simple switching node design is that it is made to be optically transparent: outgoing optical signals resemble incoming ones as closely as possible [9]. The switching nodes are implemented from conventional fiberoptic components, with semiconductor optical amplifiers (SOAs) used as the switching element (Fig. 1). The gain of the SOAs is set to balance the losses of the passive optical components at the former part of the switching node's optical pathway. The packet's header information is encoded in a wavelength-parallel manner with each address bit occupying a distinct wavelength that extends the duration of the packet. Thus, header detection is accomplished in an exceedingly simple manner by filtering constant-value wavelength signals [3],[9]. The packet payload is divided into segments, each encoded on an independent wavelength, so the size of a packet can thus be varied by altering the number of payload wavelengths employed. The header field and the multiple-wavelength payload traverse the network simultaneously (Fig. 2).

3. Experimental setup

In order to generate packets of the correct format for the implemented 12×12 data vortex architecture, five routing header wavelengths are required, in addition to the multiple-wavelength optical payload which itself contains at most 16 wavelengths. Four groups of four wavelengths are turned on and off with SOAs, resulting in packets with variable numbers of payload wavelengths. A subset of the payload wavelengths are turned on, modulated together with a 10-Gbps NRZ $2^7 – 1$ PRBS, and then decorrelated by approximately 450 ps/nm with 25 km of single-mode fiber. The wavelengths used for both the payload and header are channels designated by the ITU WDM grid, and some adjacent channels spaced by just 0.8 nm (100 GHz) are included. The payload is amplified by a high-gain booster SOA and gated into packets by a second SOA. This multiple-wavelength packet payload is then combined with the appropriate wavelength-parallel routing headers, and the whole packet is injected into one of the 12 input ports of the data vortex network (Fig. 3).

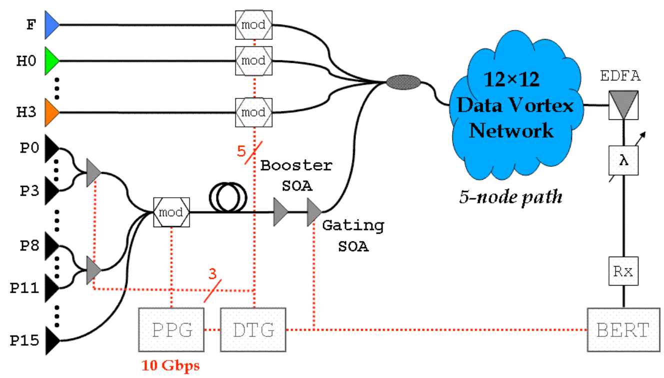

Fig. 3. Schematic of the experimental setup containing the implemented 12x12 data vortex switching fabric and the necessary input signal modulation with a PPG (pulse pattern generator) and DTG (data timing generator). At the output, one payload wavelength is selected by the tunable filter for gated BER measurement.

For the 12×12 topology under moderate load conditions, a five-node path represents the median and typical case for a packet. Thus, the packet traffic pattern encoded on the multiple-wavelength routing headers contains a packet with address [1111] which traverses five nodes within the network beginning at network input #4 [3]. This packet is extracted from the appropriate output terminal and then amplified with an EDFA and filtered for bit error rate (BER) measurement on one payload wavelength at a time. The BER tester is gated and synchronized to enable error testing only on the packet payload.

4. Results

In order to confirm that a variety of payload sizes can self-route and propagate simultaneously in the network, consecutive packets which are addressed to the same destination are made to carry varying numbers of payload wavelengths. SOAs turn on and off groups of four payload wavelengths so that packets with 4, 8, 12, and 16 payload wavelengths (i.e. 96-, 192-, 288-, and 384-byte data capacities, respectively) are all routed within the network (Fig. 4). Furthermore, because these payload sizes are generated for consecutive packets, the different payload sizes are present within the network concurrently.

When packets emerge from the network, BER measurements are made. Each payload size (i.e. 4,- 8-, 12-, and 16-wavelength payloads) is confirmed to preserve an error rate lower than 10^{-12} (Fig. 5). This error-free transmission verifies that the implemented data vortex architecture can simultaneously route a variety of packet sizes without reconfiguration.

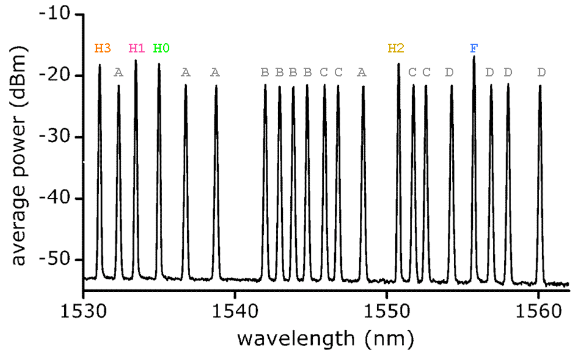

Fig. 4. Plot of the spectrum of the injected packets. *F* and *H0* through *H3* designate the parallel header wavelengths while the labels *A*, *B*, *C*, and *D* indicate the grouping of the payload wavelengths.

Fig. 5. Electrical eye diagrams of 10 Gbps signal on 1546.92 nm (C38) at (a) the system input and system output for (b) 4-, (c) 8-, (d) 12-, and (e) 16-wavelength packets.

5. Conclusions

This demonstration confirms that the implemented data vortex network first reported in [3] is capable of simultaneously routing packets of different sizes. Packets with 4, 8, 12, and 16 payload wavelengths are used, corresponding to payload data rates of 40, 80, 120, and 160 Gbps, and total data capacities of 96, 192, 288, and 384 bytes, respectively. Gated BERs of 10^{-12} are achieved for all packets. This experiment further supports the data vortex architecture comprised of SOA-based transparent switching nodes as a viable solution for large-scale ultra-high bandwidth interconnection networks.

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6. References

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