Signal Degradation through a 12×12 Optical Packet Switching Network

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Abstract *The Q factor for a 10 Gbps signal is extrapolated from eye diagram time and amplitude window measurements after each hop through a five-node path in a complete 12×12 optical packet switching fabric.*

Introduction

Recently, a fully implemented 12×12 optical packet switching fabric arranged in the data vortex topology was reported [1]. The network employs a wavelength-parallel packet (Fig. 1a), which contains a multiple-wavelength WDM payload and five header wavelengths that are each comprised of single bits over the duration of the packet. Because the 36 switching nodes utilise semiconductor optical amplifiers (SOAs) as switching elements (Fig. 1b), the nodes are able to maintain constant power as a packet traverses the network. This is possible because the SOAs provide the necessary gain to exactly compensate the node losses incurred on a packet by the couplers and passive optics. Since the SOAs can be operated in a low gain region, only a small amount of noise is added to the signal with each successive node hop, resulting in transparent payload transmission. Thus, a packet may pass through the entire network whilst experiencing a very minor amount of signal degradation.

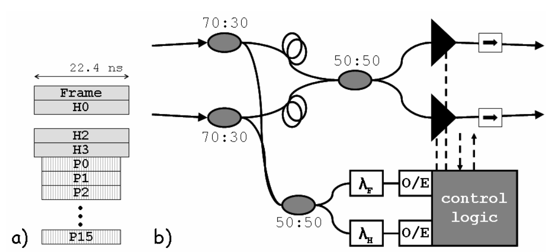

Fig. 1: *Switching fabric (a) packet structure and (b) transparent node design. The node consists of couplers (ovals with splitting ratios), filters (λ), PIN-TIAs (O/E), electronic control logic, fibre delay lines (loops), SOAs (triangles), and isolators (arrows). Optical and electrical connexions are shown with solid and dashed lines respectively.*

The current analysis focuses on experiments that evaluate the degradation of Q factor as a packet propagates through a five-node path in the network. The Q factor is extrapolated [2,3] from time and amplitude window measurements on six eye diagrams: the back-to-back case and after each node in the five-node path. Q factor degradation is a useful metric for determining signal quality and system scalability [4,5].

Previous analyses of this experimental system have reported the dynamic range through a five-node path and the power penalty of a single node [6,7]. These experiments have determined the operable power range of the payload channels at the input, and the power needed to overcome the signal degradation incurred by one node. In this work we provide a detailed and systematic understanding of the way in which a signal degrades through the network. Our analysis can be used to extrapolate performance for larger network sizes.

Experimental Setup

The setup for this experiment (Fig. 2) includes 16 lasers dedicated to payload wavelengths. The output signals of these lasers are multiplexed together, modulated at 10 Gbps, decorrelated by 450 ps/nm over 25 km of fibre, then amplified and gated into packets by two successive SOAs. Five additional lasers are used as header signals, which remain on or off for the duration of a packet. The output from each of these lasers must be modulated separately in order to encode the packet with the desired destination address. Following the modulators, all five header wavelengths are multiplexed together with the payload signals.

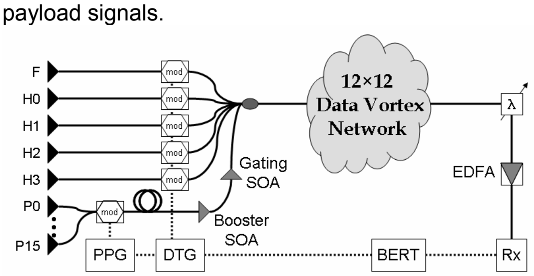

Fig. 2: *Experimental setup consisting of lasers (black triangles), a pulse pattern generator (PPG), a data timing generator (DTG), $LiNbO_3$ modulators (mod), a decorrelator (loops), SOAs (grey triangles), a coupler (oval), a tuneable filter (λ), an EDFA, a receiver (Rx), and a BER tester (BERT).*

The complete wavelength-parallel packet is then inserted into the data vortex network. The packet propagates through a five-node path in the network, which is the mean and median number of hops for a

12×12 system under small loads. The details of the chosen data vortex topology along with the switching node design are discussed at length in [6,8].

After propagating through a five-node path designated by the header patterns, a payload wavelength is filtered from the packet, pre-amplified, and detected for bit error rate (BER) measurements. The BER tester is gated and synchronised in order to sample only on the desired packet.

The back-to-back case is obtained by simply connecting the output of the final coupler to the tuneable filter, thus bypassing the switching fabric.

Methodology

The Q factors of detected payload signals, located on channel C38 in the ITU grid (1546.92 nm), have been determined from measurements on the eye diagrams [2-5]. The width and height of eye diagrams at BER thresholds of 10^{-9}, 10^{-8}, 10^{-7}, 10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}, and 10^{-2} were determined using a BER tester. A linear extrapolation of the Q factor (Fig. 3) was then obtained for both the time and amplitude window measurements. The minimum of the two resulting Q factor values was chosen to quantify the quality of the data signal.

For each number of node hops (up to five) and for the back-to-back case, two extrapolations were calculated: one for the time window measurement and one for the amplitude window measurement. The resulting R^2 correlation coefficients have a typical value of 0.99 and a minimum value of 0.95.

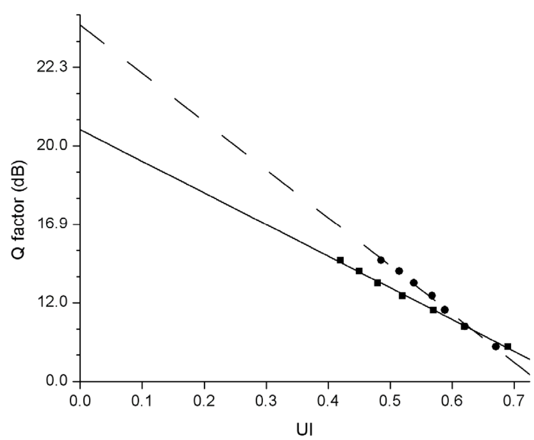

Fig. 3: *Extrapolation of Q factor for time (solid) and amplitude (dashed) measurements after two data vortex nodes. (A linear extrapolation was performed on the Q factor and plotted in logarithmic units.)*

Results

Figure 4 shows the measured Q factor after each node, along with the predicted range of possible values based on a linear curve fit. The Q factor starts at 11.5 (21.2 dB) for the back-to-back case, and degrades by an average of 0.44 dB per node, consistent with [6]. These results imply that a packet can traverse up to 13 nodes in this experimental network before incurring a BER of 10^{-12}, or up to 17 nodes for a BER of 10^{-9}.

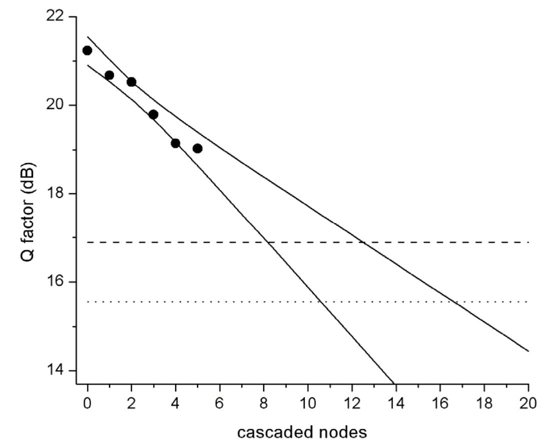

Fig. 4: *Plot of a packet's Q factor as a function of the number of nodes through which it has propagated. Solid lines represent the minimum and maximum projected Q factors based on a linear curve fit. The dashed and dotted lines signify BERs of 10^{-12} and 10^{-9} respectively.*

Conclusions

We have shown Q factor measurements taken after each hop in a fully implemented optical packet switching fabric with SOA-based switching nodes arranged in a data vortex topology. We conclude that a payload channel in the wavelength-parallel packet incurs an average Q factor degradation of 0.44 dB per node. Furthermore, we project that a packet may encounter up to 17 nodes in our experimental system before degrading below a BER of 10^{-9}. These results verify both the modularity of the switching nodes, by showing that a signal degrades uniformly through the network, and their scalability, by indicating that a large number of hops are possible.

References

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