Abstract: We report on the first experimental demonstration of all-optical compression and decompression of variable length packets (40-1500 bytes), into fixed temporal sized packets using variable compression ratios. End-to-end (compression and decompression) packet BER was measured with a penalty of ~1.65dB.

1. Introduction

All-Optical Packet Switching (OPS) has potential benefits in lower power, footprint and scalability of packet forwarding rate [1]. As the bit rate increases, it becomes crucial to bridge the gap between high speed core optics performing forwarding operations and low speed edge node electronics. For asynchronous packet switched systems, these multiplexing functions must be achieved on a per packet basis rather than temporally interleaving as in synchronous systems. In addition, today’s buffering technologies are based on fixed delay (length) buffers, yet must be capable of handling the variable packet lengths found in today’s IP traffic. We demonstrate a new technique that compresses low speed, variable length packet traffic into high speed packets occupying fixed time slots by temporally squeezing each packet. We also demonstrate a decompression mechanism to re-expand the packets to their original bit rate for processing at edge node electronics. These compression/decompression techniques can be applied to variable length packet buffering using fixed delay line buffers as well as adaptation multiplexers at the edge nodes. Previously published techniques such as fiber loop, passive feed forward split and combine delays, and spectral slicing [2]-[4] only support packet sizes of up to 16 bits. These bit-by-bit feed designs also impose hard to meet requirements on control signals or require significant setup changes to achieve variable compression ratio control on a per packet basis.

In this paper, we present the first experimental results of an approach that overcomes these previous limitations and supports compression and decompression of variable length packets to and from a fixed time slot. The work reported here also demonstrates the largest packet compressed/decompressed (1500 bytes) to date and the largest dynamic range of packet lengths compressed (40 to 1500 bytes) to date.

2. All-Optical Compression - Decompression Scheme

Compression and decompression of variable length packets to and from fixed time slots may be done at the network edges as in fig. 1(a) or at the core node as shown in Fig. 1(b). In a core node application, the payload is compressed to a higher bit rate small fixed time slot that can be buffered using fixed size delays and switched using high speed optical switch fabric. After forwarding, packets are decompressed back to the base rate before leaving the core node after label rewrite. It is important that the compression and decompression operations be done without imposing stringent requirements on control signals both on rise/fall times and signal granularity.

The principle behind the all-optical compressor is shown in Fig. 2(a). To understand the operation of the compressor, each incoming packet may be viewed as occupying contiguous virtual bins. The virtual bin size is a fixed time slot occupied by compressed packets at the output of the compressor. This fixed duration may be chosen based on the maximum compression ratio and compressed data rate. As each virtual bin of the incoming packet enters the compressor, it is passively bit interleaved with preceding virtual bins of the packet that had been buffered. This process is repeated until the entire incoming packet is interleaved into one compressed output packet occupying
the time slot of a single virtual bin. The interleaver output which includes all information present in the incoming packet is then gated at the compressor output. Packet adaptation to tolerate rise/fall times and compression control signal granularity is done at the edge nodes when packets enter/leave the optical network. Fig. 2(b) shows the schematic of the decompressor where each incoming packet is made into multiple copies by buffering and bit shifting each copy appropriately. The decompressor gating then simply selects the appropriate set of bits from each bit shifted copy, thereby generating the original variable sized packets with bit level integrity.

![Fig. 2. (a) Compression scheme (b) Decompression Scheme](image)

3. Experimental Setup

The experimental setup used is shown in Fig. 3. The output of a fiber ring laser (13psec pulses at 1542.3nm) was modulated by 2.5Gbps NRZ optical packet data. The compression buffer loop length is selected to be one bin size (~1.2μsec) offset by one compressed bit period to achieve proper virtual bin interleaving. A Semiconductor Optical Amplifier (SOA) used to compensate for loop losses, is gated to eliminate transient gain behavior due to the bursty traffic. The SOA also serves to flush the compression loop when each packet has been compressed. Fiber delays in the loop are chosen for the desired buffer time and a variable attenuator is used to adjust the loop gain. A 1.2nm filter centered at 1542.3nm was used to reject ASE noise in the loop. Interleaving of different sections (virtual bins) of the incoming packet takes place at the output of the compression loop. A second gated SOA is used to select the compressed packet with all bins completely interleaved.

A packet decompressor was then connected to the output of the compressor. The decompressor buffer loop is used to make copies of the compressed packet occupying contiguous virtual bins. An EAM is used to gate appropriate set of bits at each bin. However, the copy of the compressed packet occupying each bin must be shifted in time by 1 compressed bit from the previous copy to align the correct set of base rate bits in each virtual bin to the EAM gate. This is achieved by adjusting the buffer loop size to be one bin size offset by one compressed bit period. Variable compression ratios (1:1, 1:2, 1:3 and 1:4) necessary to implement compression and decompression of variable byte size packets to and from a fixed compressed packet time slot may be achieved by controlling the length of the ring gating signals. Fig. 3(a) shows incoming 1500 byte packets at 2.5Gbps occupying 4.8μsec being compressed to 10Gbps and occupying a fixed time slot of ~1.2μsec shown in Fig. 3(b). Fig. 3(c) shows the decompressed packet back at base rate and occupying a full 4.8μsec. Fig. 3(d) shows the output spectrum of the decompressed packet stream at 1542.3nm. Both compression and decompression schemes are scalable to higher compressed bit rates and compression ratios due to the simple bin alignment nature of the compression and decompression schemes and their high tolerance to slow edges and granularity of control signals.

![Fig. 3. Experimental Setup for compression and decompression of variable sized packets.](image)

4. Measurements and Results

In the first experiment, packet streams consisting of different packet sizes (40, 560, 1024 or 1500 bytes) spanning the common IP packet size distribution are transmitted through the compressor and subsequently through the decompressor. Figs. 4(a-d) show a 40, 560, 1024 or 1500 byte packet stream at the different stages of the system. Figs. 4(a2-d2) show the packets at 10Gbps compressed rate, each compressed to fit a fixed compressed time slot of ~1.2μsec regardless of input packet size by achieving a 1:1, 1:2, 1:3 or 1:4 compression ratio chosen based on input packet size. Packets occupying less than a single bin size are padded to occupy the fixed compressed time slot. Figs. 4(a3-d3) show the compressed packets after decompression to the original sizes and at a base rate of 2.5Gbps.
The bit amplitude variation was attributed to the optimization limitations to the loop gain due to low saturation power of the decompression SOA and may be minimized using non-linear regeneration techniques at base rate.

![Input](image1)

![Compressed](image2)

![Decompressed](image3)

Fig. 4. Packets at input, after compression and after decompression for (a) 40 byte, (b) 560 byte, (c) 1024 byte and (d) 1500 byte packet sizes

To measure end-to-end compressor/decompressor BER performance, a 1500 byte packet stream containing PRBS 2^1 payload was used. BER measurements were made for packets constructed from a PRBS 2^1 sequence for proper sequence detection for integrity check. 1500 byte packets were used due to the minimum synchronization time requirement of the BERT receiver. Fig. 5(a) shows a measured decompressed packet sequence and the expected sequence. The received decompressed packets showed error free performance when sent to a gated bit error receiver, confirming the integrity of the received packet. A \(-1.65\) dB power penalty is seen in the BER measurements from the test shown (Fig. 5(b)) through both the compressor and decompressor and was identified to be caused due to SOA pattern dependence and bin amplitude variations.

![Graph](image4)

Fig. 5. (a) Output decompressed bit quality and bit level integrity (b) Bit Error rate measured over entire 1500 byte packet

5. Summary

We demonstrate for the first time a scalable all-optical compression and decompression scheme capable of adapting variable sized packet traffic at low base rate to high bit rate packets occupying fixed time slots by varying the packet compression ratio. Bit level integrity verification was shown on the packet through error free performance and a \(-1.65\) dB BER power penalty was observed through compression and decompression. Compression/decompression of 1500 byte packets, the largest packet compression/decompression to date, and packets from 40 to 1500 bytes, the largest dynamic range to date is described.

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7. References