All-Optical Packet Compression of Variable Length Packets From 40 to 1500 B Using a Gated Fiber Loop

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***Abstract*—A scalable loop-based packet compression scheme capable of handling variable length Internet protocol packets, from 40 to 1500 B, is proposed and demonstrated. The technique uses per packet variable compression ratio to achieve fixed compressed output packet size independent of input packet size. This technique allows variable length packets to be stored in fixed delay optical buffers and has application to optical packet switching, optical multiplexing, and optical grooming. These results demonstrate the largest packet size compressed to date. Error-free compression and verification of 1500-B packets compression from 2.5 to 10 Gb/s is demonstrated with a measured power penalty of ~2.2 dB.**

***Index Terms*—Buffers, compressors, label switching, packet switching.**

I. Introduction

OPTICAL packet switching (OPS) technology has the potential to reduce the power dissipation and space requirements of future high capacity routers [1]. Routers based on OPS must forward and buffer packets in order to realize the statistical multiplexing function of a router. OPS routers that support Internet protocol (IP) packets directly must support the fact that Internet packets today are variable in length, ranging from 40 to 1500 B [2] and possible larger. However, there are many practical reasons that make it difficult to handle variable length packets all-optically. The only practical buffer technology today is based on optical delay lines. One approach to using fixed delay lines is to design multiple fiber buffers of varying length that can be selected on a per packet basis [3]. Another approach is to segment packets into fixed length cells [4] that are routed, buffered, and reassembled. A third approach is to assemble multiple packets into fixed duration frames like is done in optical burst switching (OBS) [5]. However there are tradeoffs with these approaches. Per packet selection of different sized buffers may increase implementation complexity while segmenting packets into fixed cells increases overhead and may result in the need for packet reassembly due to misordering. Burst assembly at the edges, as in OBS, requires traffic engineering between end-points and can result in increased latency.

In this letter, we present experimental results of a technique to compress variable length packets and its application to buffering of variable length packets using fixed delay line buffers. The technique uses variable ratio packet compression to fit variable length fixed bit rate packets within a single sized time frame.

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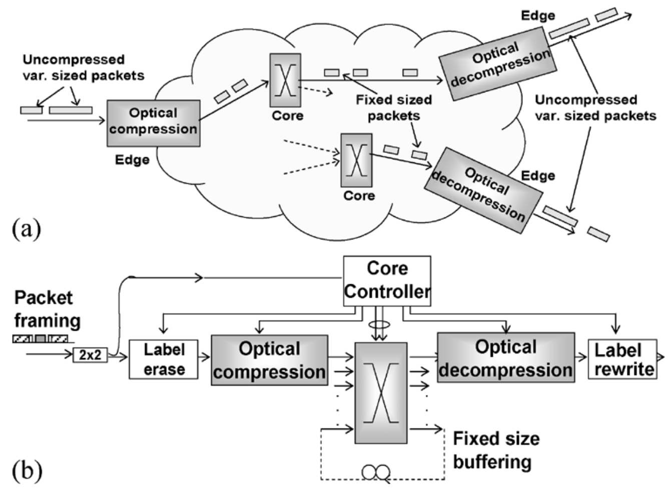

Fig. 1. (a) Compression and decompression placement at network edge and (b) at the core nodes.

The work reported here also demonstrates the largest packet compressed to date (1500 B) and the largest dynamic range of packet sizes compressed (40–1500 B) to date. Compression of variable sized packets from 2.5 to 10 Gb/s is demonstrated using a gated fiber loop. Bit-error-rate (BER) measurements were performed on 1500-B compressed packets to verify complete packet integrity after compression with a measured ~2.2-dB power penalty after compression. Previously published techniques such as fiber loop, passive feed forward split and combine delays, and spectral slicing have been demonstrated [6]–[9] and supported packet sizes up to 16 bits. These designs required complex control or permanent setup changes to achieve variable compression ratio control on a per packet basis. Moreover, due to the bit-by-bit feed nature of these approaches, system complexity increases rapidly with the length of the packet, making it very difficult to support 1500 B due to the large number of compression elements required to provide compression delays.

II. Routing Architecture and Compression Principle

The proposed technique may be directly used to adapt variable sized packets into fixed duration either at the ingress/egress to an optical network [Fig. 1(a)] or at the ingress/egress to a core node router [Fig. 1(b)] This technique is compatible with packet switching architectures such as all-optical label swapped networks [10]. This technique does not suffer the disadvantage of previously demonstrated compression techniques that preserve the order of bits in the compressed packets, requiring a unique delay for each bit and leading to complicated compression architectures. Fig. 1(b) illustrates the application of com-

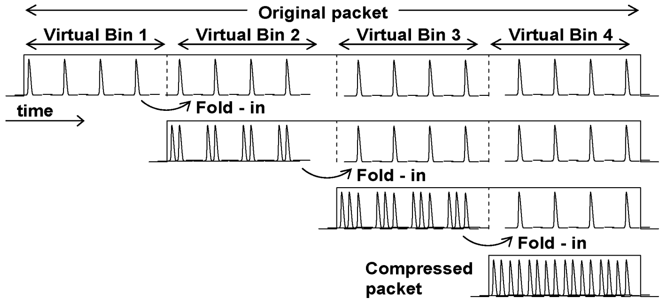

Fig. 2. Packet compression principle.

pression in a core node. Information on the length of optical packets entering the core node is detected using payload envelope recovery type techniques as reported in [11]. The core controller erases any optical framing on the packet and generates signals to control the optical compressor based on the payload length. The purpose of the optical compression is twofold, to adapt slow speed IP packets to the core capable of switching high-speed traffic and for temporal resizing of incoming variable sized payload into a fixed size for fixed delay line-buffering. After switching, packets are decompressed, their optical frames rewritten, and exit the core node. The tradeoffs between doing compression/decompression at the network edge versus the core are in added number of compressor/decompressors versus transporting high speed data.

The principle behind the packet compression scheme is shown in Fig. 2. Packets entering the compressor are 40–1500 B long and are compressed to fit into a fixed size or bin given by the maximum compression factor and the longest packet entering the compressor. The input packet at the base rate undergoes nonreturn-to-zero to return-to-zero conversion with pulsewidths suitable for compression to the maximum compression rate. Each incoming packet may be viewed as "N" contiguous equal sized virtual bins entering the compressor one bin at a time. Each virtual bin of the incoming optical packet is buffered in the compressor, delayed and bit aligned separately in a manner that multiplexes the bins in time into a compressed output packet of a single bin size. It is preferable to choose the maximum compression ratio such that the maximum packet size (e.g., 1500 B) occupies the same time duration as the minimum packet size (e.g., 40 B). Otherwise, a 40-B packet will require padding to fill a single bin size while an uncompressed 1500-B packet would occupy N virtual bins at base rate, N being the highest compression ratio achievable and would occupy only a single bin after compression. The core controller identifies the number of virtual bins each uncompressed packet occupies and controls the compression ratio accordingly to compress the packet to a single bin. By a proper choice of compression elements, the compressor can be made insensitive to input wavelength. The compression buffer must be flushed after compression before the next packet can be compressed. Decompression of packets can be performed by reversing the process and time demultiplexing individual virtual bins of the packet. Parallel pipeline techniques must be to process line-rate compressed packets, and this is a subject of current work to be published. Large packet sizes can be handled by this compression scheme as unlike other compression schemes demonstrated [2]–[5], the number of control signals and elements required scales only with the compression factor and not the maximum number of bits in the packets.

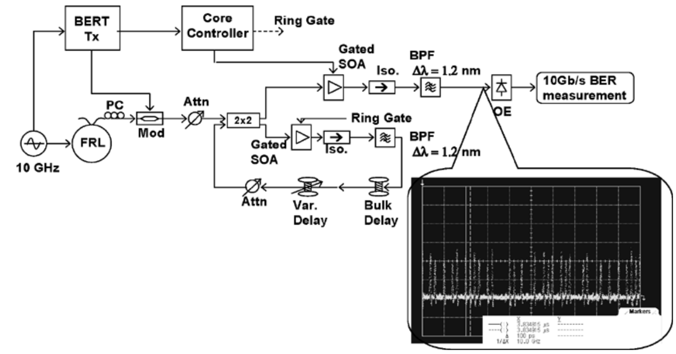

Fig. 3. Experimental setup for compression of variable sized packets from 2.5 to 10 Gb/s. (PC: Polarization controller. Attn: Attenuator. Iso: Isolator. BPF: Bandpass filter. FRL. Fiber ring laser.)

III. Experiment and Results

Two experiments were performed to demonstrate the compression scheme and measure its performance. The experimental setup for compression of 40–1500-B packets from 2.5 to 10 Gb/s is shown in Fig. 3. The final compressed packets are generated using pulses from a mode-locked fiber ring laser operating at 1556.6 nm with output pulsewidth of 17 ps and 10-GHz repetition rate. The 2.5-Gb/s packets to be compressed were varied in size from 40 B ($\sim$128 ns) to 1500 B ($\sim$4.8 μs) with a 25-μs interpacket gap. The input average power was set to an optimal level before entering the loop. A gain controlled semiconductor optical amplifier (SOA) compensates for losses in the loop and is used as a gating element to flush the compression loop when each packet has been compressed. The SOA gating was adjusted to turn on the SOA only when packets exist in the loop to eliminate noise buildup and amplifier transient response due to bursty nature of the packet traffic. A 1.2-nm filter centered at 1556.6 nm was used to reject amplified spontaneous emission noise in the loop. A bulk fiber delay of $\sim$210 m and a picosecond precision delay line were used to adjust the total loop length to be 1.2 μs which is selected as the bin size for this experiment. A variable attenuator was used to obtain precise balance between gain and losses in the loop; this is critical to maintaining constant bit heights between multiplexed bins.

The principle of operation is as follows. The compression loop serves as a buffer to hold the packet while compression takes place as well as to time multiplex the virtual bins of the packet as they enter the loop. A second gated SOA at the output of the compression loop samples the compressed packet when all input virtual bins have entered the loop and compression is complete. Picosecond control signals are not required since time multiplexing is achieved by accurately controlling the length of the compression loop. The gated SOAs used in this experiment have rise and fall times of $\sim$2 ns. Fig. 4 shows the input packets and the compressed output for different packet sizes. The compression ratios for the 1500-, 1024-, 560-, and 40-B packets are 4 : 1, 2.73 : 1, 1.49 : 1, and 1 : 1, respectively. To match the compressed bin size to that of an uncompressed 40-B packet, a

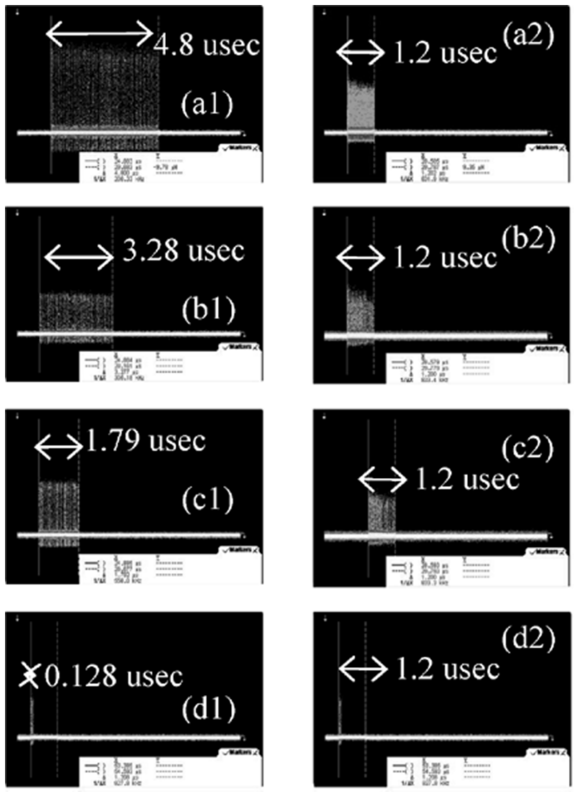

Fig. 4. (1) Uncompressed and (2) compressed packet traces taken at a 1-μs/div scale for different input packet sizes. (a) 1500, (b) 1024, (c) 560, and (d) 40 B.

maximum compression ratio of 37.5 : 1 is required. In this experiment, uncompressed packets of sizes smaller than one bin size (1.2 μs) require padding to occupy one bin. The output packet size is measured to be $\sim$1.2 μs or one bin size for all input packet sizes except for 40-B packets [Fig. 4(d)]. The inset in Fig. 3 shows the output bit quality and the bit period to be 100 ps. It can be observed that the adjacent pulses in the compressed packet from the multiplexed virtual bins of the packet have uniform heights.

A second experiment was performed to test the Layer-1 quality of the compressed packets. In this case, a 1500-B packet stream with a 25-μs interpacket gap was input to the compressor. The input 12 000 bit packet was made up of four virtual bins such that when correctly time multiplexed, they form a compressed 10-Gb/s 12 000-bit packet with a repeating pseudorandom binary $2^7 - 1$ sequence (PRBS). The output of the compressor is detected with a 10-Gb/s receiver and fed to a bit-error-rate detector (BERT). The BERT is gated by the core controller board in order to make measurements only when packets enter it. Fig. 5 shows the measured BERs. A back-to-back measurement made on the system for both continuous and emulated PRBS packet traffic shows a receiver sensitivity of -18 dBm. BER measurement on compressed 1500-B packet was measured and a total power penalty of $\sim$2.2 dB was observed.

IV. Conclusion

A scalable packet compression technique capable of compressing variable packet sizes from 40 to 1500 B to a fixed size is proposed and demonstrated. Packet compression from 2.5 to 10 Gb/s and BER measurements on the compressed packets showed a penalty of $\sim$2.2 dB. A fixed output packet size of $\sim$1.2 s was obtained for all packet sizes greater than one bin size. Padding may be used for smaller packet sizes. The compression scheme is applicable to any switching architecture such as all-optical label switching and optical multiplexing and grooming, where compressed packets do not require examination until after decompression has been performed.

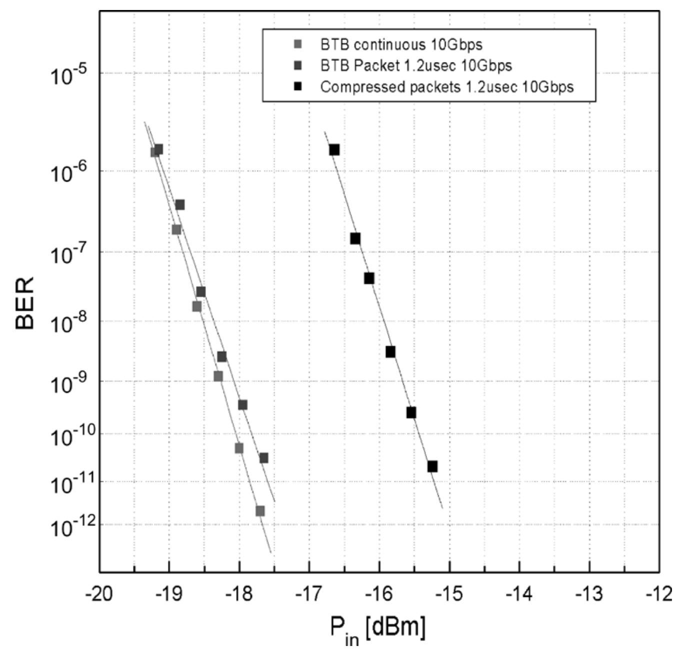

Fig. 5. BER measurement on compressed 1500-B packet at 10 Gb/s.

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