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Optical Packet Compression in fibres based on time lens and solitonic effects

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Abstract: We experimentally demonstrate a novel optical packet compression scheme based on temporal imaging of TDM packets through time lensing in fibres, while maintaining the pulse width by virtue of soliton propagation during the compression stage. In particular, 4-bit packets at 10 Gbit/s were compressed into 4-bit packets at 40 Gbit/s. The time lens effect is based on switching the original 10 Gbit/s 4-bit packet with a suitably chirped square pulse and on compressing the chirped packet by propagating it in a standard single mode fibre.

1. Introduction

Optical packet switching technology is emerging as an attractive means to increase the functionality of the network optical layer. Particular advantages of this technology relate to the transparency of the approach with respect to modulation and coding formats, as well as to the high-bandwidth it offers. Local area networks typically operate with low speed data packets (155-622 Mbit/s) which require onward transmission to different networks through ultra-high-speed backbone lines and which in principle are capable of carrying data at aggregate rates in excess of a terabit per second. To access these ultra-high-speed backbones network nodes capable of terabit throughput are required and these nodes need to be capable of performing elementary functions such as packet routing, buffering and compression. Electronic routers can currently perform such functions at individual channel speeds of a few gigabit-per-second. If substantially higher speed processing is required then all-optical approaches will need to be developed.

In this paper we show preliminary results on a new scheme for all-optical packet compression. The techniques relies upon the switching of chirped linear pulses (generated at the desired compressed packet rate) using a higher data rate TDM baseline signal. The switching maps the individual adjacent data bits within the TDM signal on to pulses with different wavelengths. A dispersive nonlinear element (in our case an optical fibre) can then be used to control both the separation and width of those pulses to create a time compressed version of the initial base line data sequence. In our specific implementation we compress a 10Gbit/s TDM signal into 4 Bit packets with a packet data rate of 40Gbit/s and a corresponding packet rate of 2.5 GHz.

2. Principle of operation of the packet compression scheme

The principle of operation of the packet compression scheme comprises two stages. The first stage consists of mapping adjacent bits within the TDM signal onto different wavelengths, technique also known as TDM-to-WDM conversion. Different approaches have been reported for TDM-to-WDM conversion in particular supercontinuum slicing with time gating [1], and in-fibre nonlinear switching of linearly-chirped rectangular pulses [2]. The main application of TDM-to-WDM conversion has been shown as multiple output simultaneous demultiplexing [3]. However, recently packet compression and decompression based on supercontinuum slicing with time gating has also been reported [4]. Our approach is based on TDM-to-WDM conversion via nonlinear switching of linearly-chirped rectangular pulses, as shown in Fig. 1, followed by in-fibre compression.

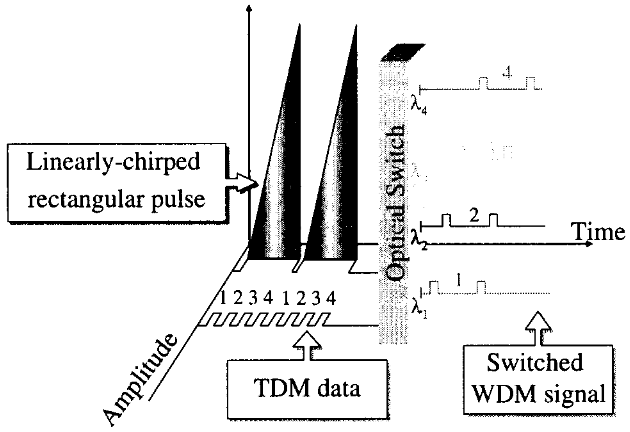

Fig. 1 TDM-to-WDM conversion based on switching of linearly chirped rectangular pulses.

In detail, this second stage of the packet compression scheme relies on the time lens mechanism, which principle of operation was firstly shown in [5]. In a time lens the object is initially chirped and propagated through a dispersive medium resulting on a stretched or squeezed image of it. Applying the same principle to the TDM packets linearly chirped on the first stage, correctly chosen length of fibre results on the desired packet compression. Pulse broadening was found to be a major limiting factor of this technique which led us to excite formation of fundamental solitons in the fibre.

3. Experiment, results, and discussion

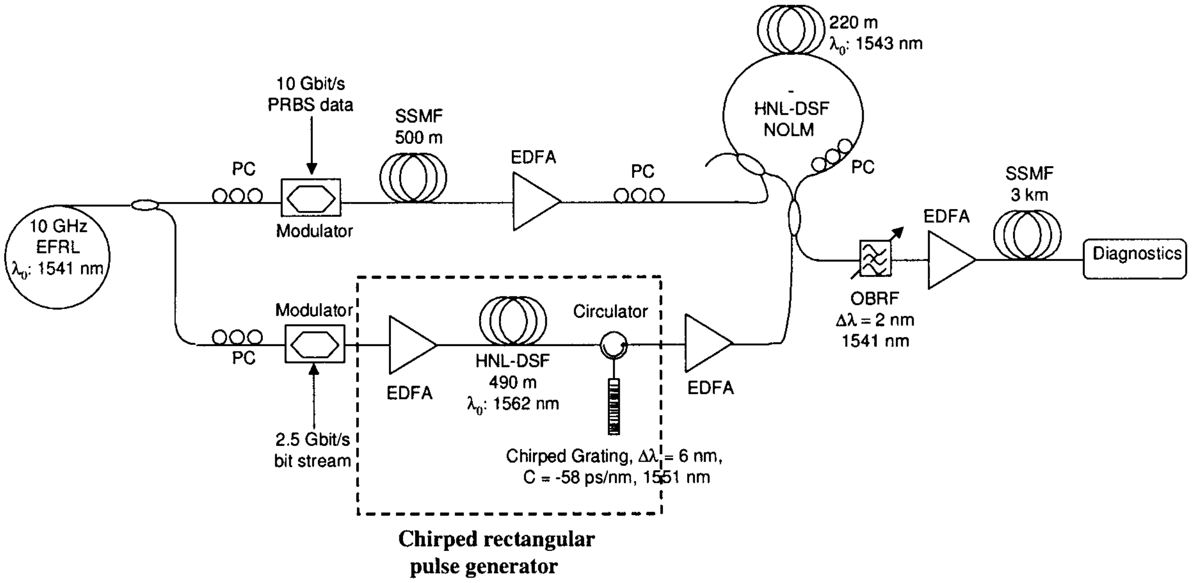

Fig. 2 Packet compression scheme experimental setup.

Our experimental setup is shown in Fig. 2. 2.5ps pulses at a 10 GHz repetition rate were generated using an actively mode-locked fiber ring laser (EFRL) operating at 1541 nm and which were then split into two separate pulse trains. The first pulse train was gated down to a repetition rate of 2.5 GHz and injected into the linearly-chirped rectangular pulse generator comprising a highly nonlinear fiber (zero dispersion at 1573 nm and with a nonlinear coefficient of ~18 $W^{-1}km^{-1}$) and a linearly chirped fiber Bragg grating (FBG). In the chirped rectangular pulse generator, the soliton pulses were spectrally broadened to around 20 nm (3dB bandwidth) via self-phase modulation in the highly nonlinear fiber, and were then shaped, by subsequent reflection from a linearly chirped FBG, into ~360 ps wide rectangular pulses with a linear chirp of -60 ps/nm and an almost-rectangular spectral profile of 6 nm bandwidth (see Fig. 3).

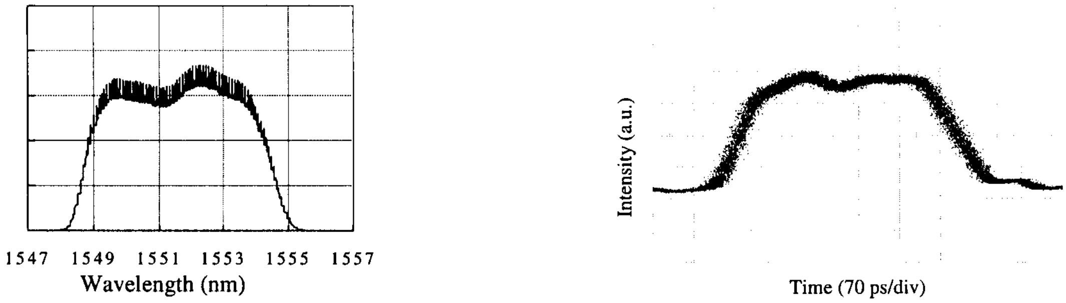

Fig. 3 (a) Optical spectrum and (b) oscilloscope trace of the linearly chirped rectangular pulse used in this experiment.

The second pulse train was first modulated with a pseudorandom data sequence in order to generate the 10 Gbit/s TDM baseline signal. The pulses were broadened to 5 ps via propagation through 500 meters of standard single-mode fiber and then amplified to an average power of 21 dBm and coupled onto the HNL-NOLM via its control port. The linearly-chirped 360 ps rectangular pulses were amplified to an average power of 10 dBm and injected into the signal port of the HNL-NOLM. The cross-phase modulation induced by the data pulses on the rectangular chirped signal switches the overlapping part of the chirped pulses to the NOLM output port, thereby generating 4 WDM channels at 2.5 Gbit/s. A 2 nm bandwidth fiber Bragg grating rejection filter centered at 1541 nm was used to filter out the original 10Gbit/s data signal. Figures 4 (a) and (c) show the WDM channel spectrum and the corresponding oscilloscope trace, respectively.

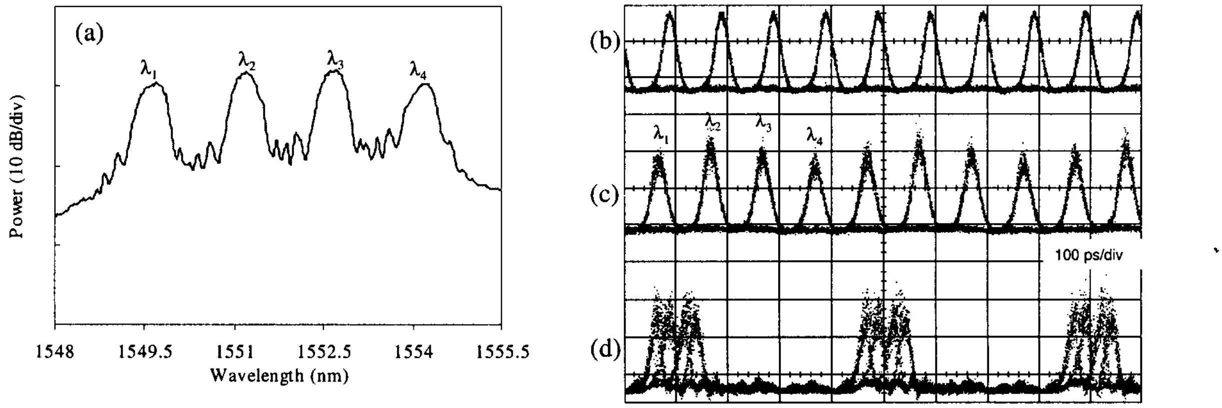

Fig. 4 (a) Optical spectrum and oscilloscope trace of the (b) original, (c) switched and (d) compressed signal.

As shown in the spectrum of Fig.4 (a) the WDM channels are roughly spaced by 1.6 nm, which is in good agreement with the anticipated 100 ps time delay between the control pulses and the -60 ps/nm linear chirp of the rectangular probe signal. Finally the switched signal was amplified to an average power of 24 dBm and propagated over 3 km of standard single-mode fiber which induced a relative group delay of +47 ps/nm. At the fiber output the consequent relative time delay between WDM channels was ~25 ps. The high-power launched into the fiber induced simultaneous pulse compression due to soliton effects. Figure 4 (d) shows the oscilloscope trace of the corresponding 4-bit packet at 40 Gbit/s. The autocorrelation trace in Fig. 5 shows that the spacing between pulses inside of the packet is reduced to ~25ps and the individual pulse width remains shorter than 8 ps.

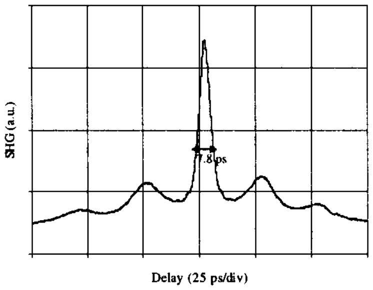

Fig. 5 Autocorrelation trace of the compressed 4-bit packet.

Although we have successfully demonstrated the basic principles of the approach, further work is required to improve the definition of the repetition rate of the compressed packet and to eliminate some of the amplitude noise evident in Fig.4 (c). Use of tunable chirped fiber Bragg gratings on the rectangular pulse generator would provide a means to control the packet length and thus wavelength separation of the individual WDM channels, whilst incorporation of a tunable grating should allow for fine control of the compression factor. To fully complete our compression demonstration we also require a further stage of optical switching (in for example a second NOLM) to map the multi-wavelength pulses within the compressed packet back onto the original wavelength.

4. Conclusion

In conclusion, we have demonstrated compression of 10Gbit/s data packets to rates equivalent to 40Gbit/s. The technique is based on time to wavelength mapping of optical packets, time lens and pulse shaping effects in nonlinear dispersive fibre.

5. References

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