Optical Frame Synchronizer for 10 G Ethernet Packets aiming at 1 Tb/s OTDM Ethernet

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Abstract: Synchronization of 10 G Ethernet packets to a local clock was demonstrated using a phase modulator and a SMF as retiming elements. Error free performances for the synchronized packets with different lengths were achieved.

OCIS codes: (060.2330) Fiber optics communications; (060.1155) All-optical networks

1. Introduction

Optical 10G Ethernet links are likely to become a building block in the design of ultra high throughput optically transparent switches/routers with Tb/s interfaces, aggregating traffic from several lower bit rate links. Optical time division multiplexing (OTDM) interfaces that aggregate traffic from several 10 G Ethernet links in serial optical data into a single fiber are a promising tool for designing and implementing optically transparent switch/routers for terabit communications, fulfilling the visions of terabit Ethernet suggested in [1].

To interface between Ethernet protocol and OTDM systems a number of challenges need to be faced, such as packet length varying from 64-1518 bytes, asynchronous arrival, and repetition rate variations. These features have introduced implications in the design of optically transparent switches, since OTDM is a bit-interleaved synchronous system based on return to zero (RZ) pulses.

In this paper, we demonstrate that the optical frame synchronizer can accommodate for the speed variations from nominal frequencies of lower bit rate links. For example: the 10 GE WAN PHY [2] can vary with up to $\pm$ 20 ppm of the nominal transmission rate, i.e. ± 200 kHz frequency offset between transmitter and receiver must be tolerated. Furthermore we demonstrate that we can synchronize and retime different packet lengths up to 12144 bits (corresponding to the longest Ethernet packet) to a local clock corresponding to the base rate of an OTDM signal, even if the two signals frequencies differ by 200 kHz (± 20 ppm). No extra clock recovery from the input packet signal is performed.

2. Operation principle

The concept of time-lens comes from the time-space duality for optical processing that refers to the analogy between the paraxial diffraction of beams through space and the dispersion of narrowband pulses through dielectric media in time [3-7]. Since a spatial lens can be used to obtain the Fourier transform of a spatial profile, a time lens can also be used to obtain the Fourier transform of a temporal profile. A time lens could be any device that imposes a quadratic phase onto an incoming electrical field in time. In our system the time lens is a phase modulator with sinusoidal phase modulation which approximates the quadratic phase within a small range. Like its spatial counterpart, if we detect a signal at the focal length, we can obtain the Fourier transformed signal. A dispersive element is corresponding to a temporal focus in the system. In the Fourier transformation the time shift only changes the phase in frequency domain and do not change the envelope, and it can be expressed as $x(t-t_0) \leftrightarrow X(\omega)e^{-j\omega t_0}$. Therefore, we can use the time lens to remove the timing difference between the local clock and the input frequency, and consequently synchronize the input packet with the local frequency as described as following.

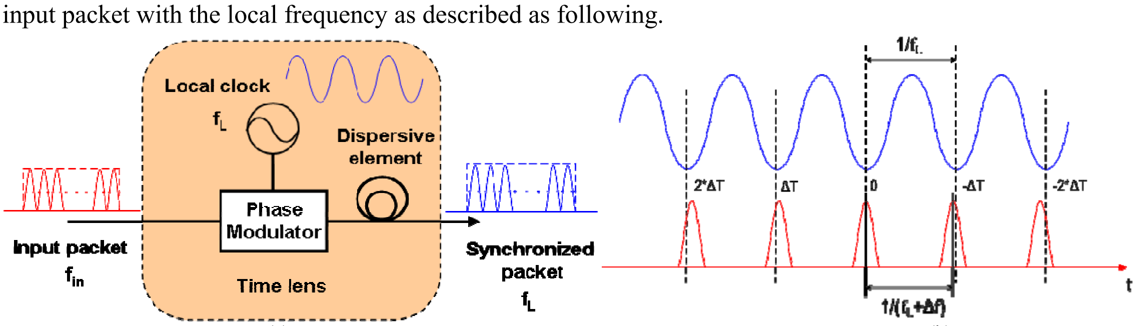


Fig. 1. (a) Concept of the time lens based optical frame synchronizer; (b) operation principle of the optical frame synchronizer.

As shown in Fig.1, the input optical frame with the repetition rate of f_{in} ($f_{in} = f_L+\Delta f$) is launched into the phase modulator which is driven by local clock (f_L). The input signal aligned with the minimum of the parabolic clock (approximated with a sinusoidal clock) is chirp-free as the time derivative of the parabolic phase is zero. The input signal on the right side will experience the negative chirp and the input signal on the left side will experience the positive chirp. The signal which is farer away from the central signal will have more chirps. If they pass through a dispersive element and chirps are removed, the signal will move to the minimum of the parabolic clock and the initial temporal misalignment will also be cancelled.

3. Experimental setup

The experimental setup for the time lens based optical frame synchronizer is shown in Fig. 2. It included a 10 Gb/s optical frame generator, a optical frame synchronizer and a 10 Gb/s receiver. The erbium glass oscillating pulse-generating laser (ERGO-PGL) produces pulses at 1549 nm with a 1.5-ps full-width at half-maximum (FWHM), which is synchronized with the frequency of 9.9535 GHz. The spectrum of the pulses is filtered with a 0.33-nm optical bandpass filter (OBF) and the pulses are broadened to 13 ps. The broadened pulses are then encoded by on-off keying (OOK) with 10 Gbit/s PRBS (2^7-1) signal in a Mach-Zehnder modulator. The modulated 10 Gbit/s RZ-OOK signal is passed through another intensity modulator which was driven by a square pulse from a pulse generator with the repetition rate of 50 KHz. Finally, we generated a 10 Gb/s optical frame and the packet length can be adjusted by the pulse generator. In the experiment, we used two packet lengths of 640 Bytes (5120 bits) and 1518 Bytes (12144 bits).

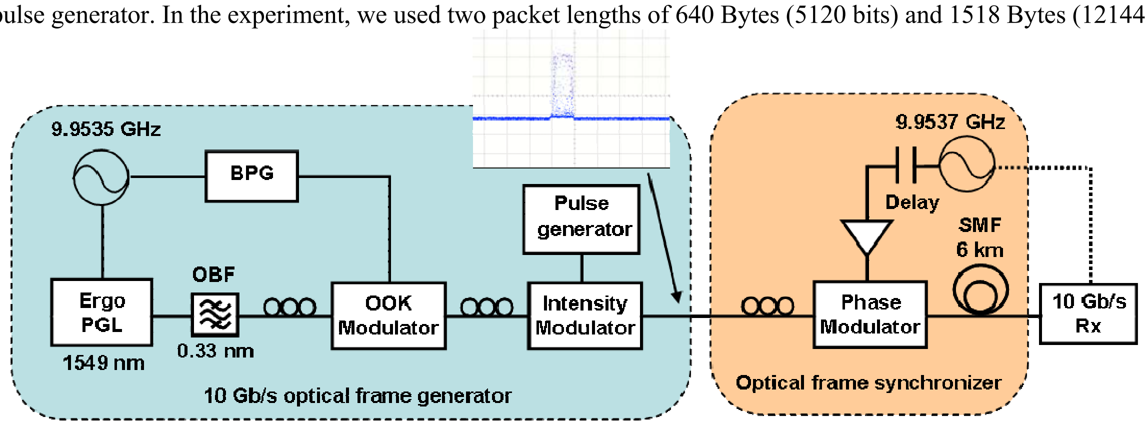
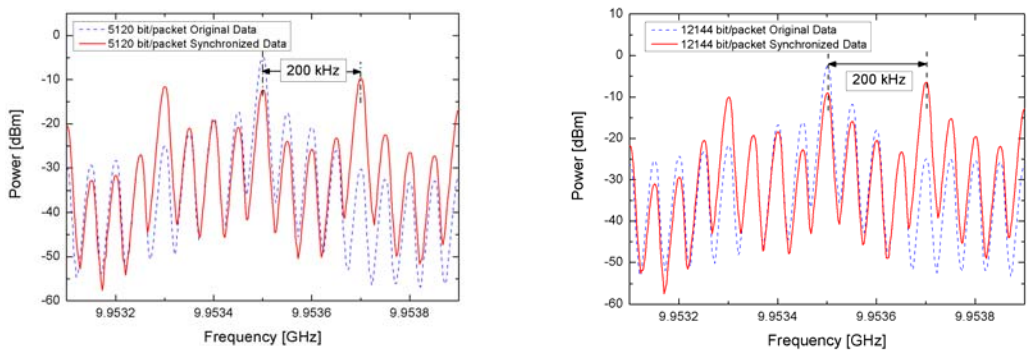


Fig. 2. Experimental setup for the time lens based optical frame synchronizer.

In the optical frame synchronizer, the 10 Gb/s optical frame was launched into a phase modulator driven by local clock (9.9537 GHz) and followed by a 6-km SMF as a dispersive element. The driven RF power was 28 dBm and about 2.7 π phase shift was obtained. In the 10 Gb/s receiver, the synchronized optical packet was measured by oscilloscope and error analyzer, and both of them were triggered by the local frequency.

4. Experimental results



(a) (b)

Fig. 3. (a) RF spectrum of original data and synchronized data for the 5120 bits frame; (b) RF spectrum of original data and synchronized data for the 12144 bits frame.

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We firstly measured the electrical radio frequency (RF) spectrum for the synchronized frames and compared them with the original data RF spectrum, as shown in Fig.3. The 50 KHz spacing peaks are due to the frame repetition rate. In both cases of 5120 bits packet length and 12144 bits packet length, we can clearly see the maximum frequency peak of the synchronized signal has been adjusted to local frequency of 9.9537 GHz.

Fig.4 shows the BER measurements and the eyediagrams for the synchronized frames with the packet length of 5120 bits and 12144 bits. Since the oscilloscope and the error detector are triggered by local clock, only if the data has been synchronized, the clear eyediagram can be seen. As shown in Fig.4 (b), the unsynchronized frame cannot show a clear eyediagram. As shown in Fig.4 (a), the synchronized frame with the 5120 bits length has only 0.7 dB penalty compared with the back-to-back case. The synchronized packet with the 12144 bits length shows 1.2 dB penalty, because some bits in the packet are out of the range of approximate quadratic phase modulation and experience nonlinear chirp which can not be compensated by a SMF and lead to waveform distortion. The penalty could be reduced if a quadratic phase modulation is applied.

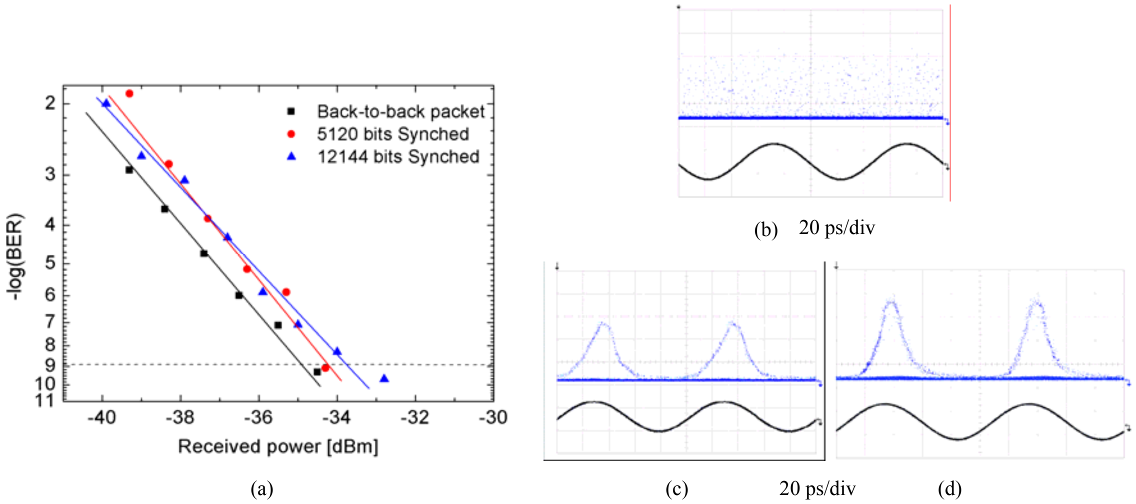

Fig. 4. (a) BER measurements for the back-to-back packet, synchronized packet with the length of 5120 bits, and synchronized packet with the length of 12144 bits; (b) eyediagram of the input packet without synchronization; (c) eyediagram of the synchronized packet with the length of 5120 bits; (d) eyediagram of the synchronized packet with the length of 12144 bits.

5. Conclusion

We demonstrate that we can synchronize and retime different packet lengths up to 12144 bits to a local clock corresponding to the base rate of an OTDM signal, even if the two signals frequencies differ by 200 kHz (± 20 ppm). Error free performances for the synchronized packets with different lengths were achieved.

6. Acknowledgment

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7. References

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