Front. Optoelectron. China 2010, 3(4): 343–346
DOI 10.1007/s12200-010-0116-7

RESEARCH ARTICLE

In-band clock distribution concept for ultra-high bit rates OTDM system

Shangjian ZHANG (✉), Lei XU, Yong LIU, Yongzhi LIU

School of Optoelectronic Information, University of Electronic Science and Technology of China, Chengdu 610054, China

Abstract A novel clock distribution concept based on in-band phase-modulated pilot insertion is demonstrated. This method avoids the need for an ultrafast phase comparator and a phase-locked loop in the receiver. Experimental results show that the clock can be successfully extracted from 160 Gbit/s optical time-division multiplexing (OTDM) data signal and employed for demultiplexing of 40 Gbit/s tributaries. The in-band clock distribution introduces 1.5 dB of power penalty with an error-free performance.

Keywords optical time-division multiplexing (OTDM), clock recovery, in-band clock distribution, phase-modulated pilot insertion

1 Introduction

In an optical time-division multiplexing (OTDM) transmission system, it is necessary to retrieve a clock running at the base rate of the constituent channels of the received OTDM data signal. This clock recovery enables access to the individual channels, which is required for operations, such as demultiplexing and time-division add-drop multiplexing (TADM). However, the basic problem of OTDM clock recovery is that a perfectly multiplexed OTDM data signal does not contain a frequency component at the base rate for direct extraction. Therefore, typical clock recovery implementations are based on the interaction between the harmonics of the data signal and the locally generated clock in a phase comparator whose output is used in a phase-locked loop (PLL) for synchronization. Different nonlinearities, such as four-wave mixing [1] or cross-phase modulation [2] in semiconductor optical amplifier, three wave-mixing in a periodically-poled lithium niobate (PPLN) waveguide [3], or electro-absorption modulation [4], have been exploited to provide the phase comparator functionality. The major difficulty present in these approaches is that a PLL is required to accomplish the synchronization whose phase comparator must hold a very high time-resolution of the order of the bit-slot duration.

In this paper, we demonstrate an in-band clock distribution concept based on extracting an inserted phase-modulated pilot in the data spectrum. This approach eliminates the need of an ultrafast phase comparator and a PLL, which simplifies the standard OTDM system. In the experiment, error-free demultiplexing from 160 Gbit/s to 4×40 Gbit/s is performed using the proposed concept.

2 Experiment

The experimental setup to demonstrate the in-band clock distribution concept is shown in Fig. 1. The data signal is generated by a fiber-based mode-locked laser (FMLL) at the repetition frequency of 40 GHz tuned to 1555.50 nm. The pulses are return-to-zero (RZ) on-off keying (OOK) modulated with a pseudo-random bit sequence (PRBS) of 2^7-1 at one single polarization and subsequently multiplexed up to 160 Gbit/s through a polarization-maintaining fiber-delay multiplexer.

The pilot is generated by a continuous wave (CW) laser tuned to 1552.50 nm, which is phase modulated at 10 GHz by the master clock. The wavelength of the pilot is chosen to avoid crosstalk with the 160 GHz spectral lines of the data signal in order to eliminate distortions and noise as much as possible. The modulation power is optimized to intensify the first-order sidebands produced by the phase modulation [5]. Subsequently, the phase modulated signal is coupled with the data signal to get the pilot inserted in the data signal band. In the receiver end, the in-band pilot is extracted at port 3 of the circulator by means of a fiber Bragg grating centered at 1552.50 nm. Later on, a tunable optical bandpass filter is used to select the optical carrier and the first-order upper sideband, and thus, the clock is

Received July 6, 2010; accepted July 29, 2010

E-mail: sjzhang@uestc.edu.cn

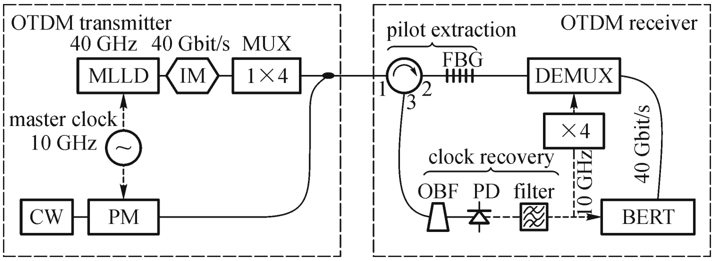

Fig. 1 Experimental setup (MLLD: mode locked laser diode; IM: intensity modulator; MUX: optical time-domain multiplexer; PM: phase modulator; FBG: fiber Bragg grating; PD: photodetector; DEMUX: demultiplexer; OBF: optical band-pass filter; BERT: bit-error-rate tester)

recovered by optical mixing detection associated to a photodetector (PD) and then amplified and filtered by an electrical high *Q* band-pass filter. Finally, the data signal after pilot extraction and the recovered clock are used as an input and driver of the electro-absorption modulator (EAM) demultiplexer, respectively, in order to perform bit-error-rate (BER) tests on the tributaries.

3 Results and discussion

Figure 2 illustrates the spectrum of the pilot inserted in the data signal band. The inset on the top-left side shows a zoom-in of the pilot where it can be seen several sidebands generated by phase modulation. The inset on the top-right side shows the 160 Gbit/s traces after pilot insertion.

The extraction of the pilot creates a carve in the data signal spectrum as depicted in Fig. 3. The extracted pilot is filtered by an OBF with 0.25 nm bandwidth to select the pilot carrier and its first-order upper sideband, which is shown in the inset.

To investigate the performance of the proposed clock recovery technique, we carried out single sideband (SSB) phase noise measurements on the recovered clock using an electrical spectrum analyzer (Fig. 4). Integrating the SSB phase-noise over the frequency range from 100 Hz to 10 MHz yields a timing jitter of 164 fs. In the demultiplexing stage, the clock frequency is quadrupled to 40 GHz and in turn used to drive the EAM demultiplexer in order to extract 40 Gbit/s tributaries. In Fig. 5, the filled squares illustrate the BER performance of the four extracted channels corresponding to the back-to-back configuration employing the master clock. Error-free operation is achieved with a received power of -6.5 dBm. The open squares represent the BER performance of the data after pilot insertion and extraction employing the master clock, where the configuration employing the recovered clock shows an error-free performance with a recovered power of -5 dBm. This turns out in a power penalty of 1.5 dB, which includes the clock pilot insertion, extraction, and clock recovery.

4 Conclusion

We have demonstrated a novel in-band clock distribution

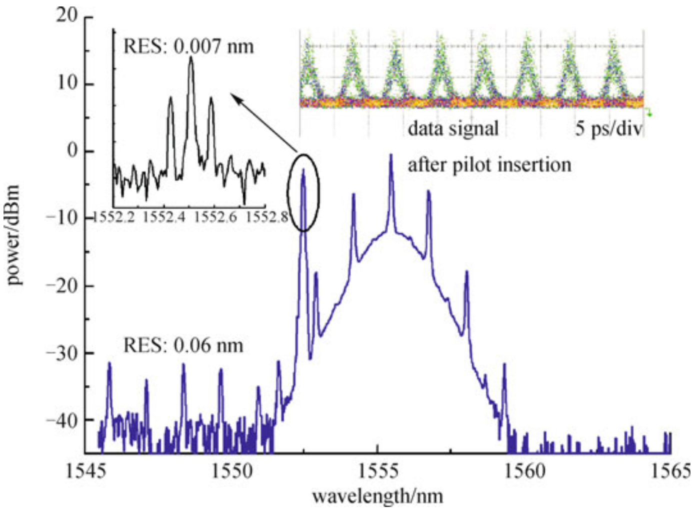

Fig. 2 Optical spectra and eye diagram of data signal after pilot insertion (RES: resolution)

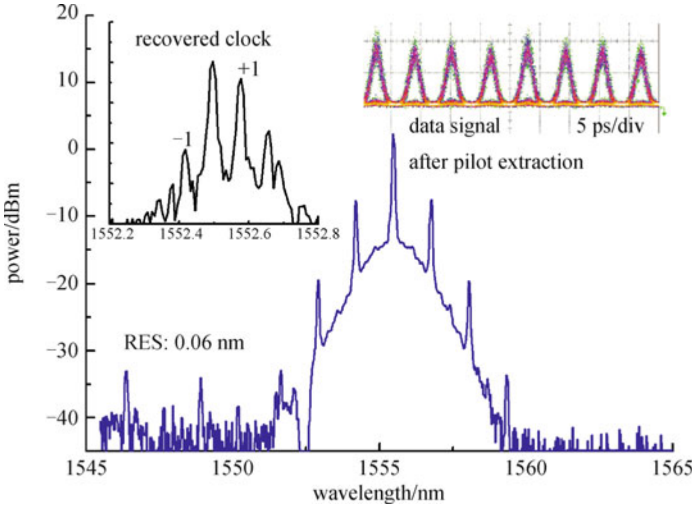

Fig. 3 Optical spectra and eye diagram of data signal after pilot extraction (top-left inset: optical spectrum of recovered clock)

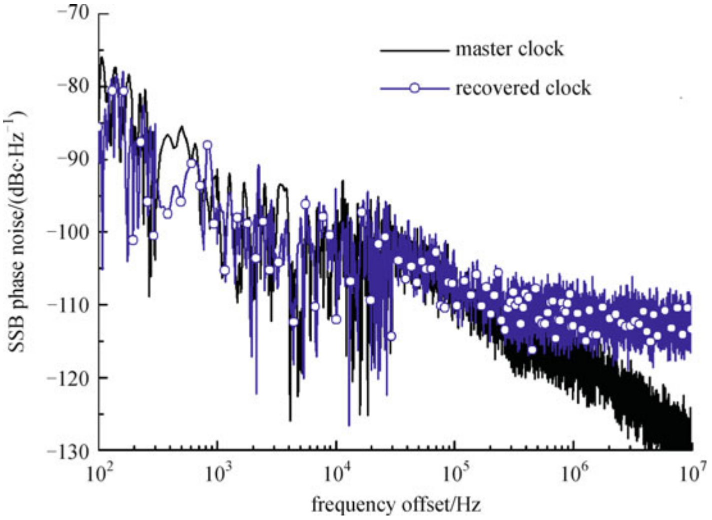

Fig. 4 SSB phase noise of master clock and recovered clock

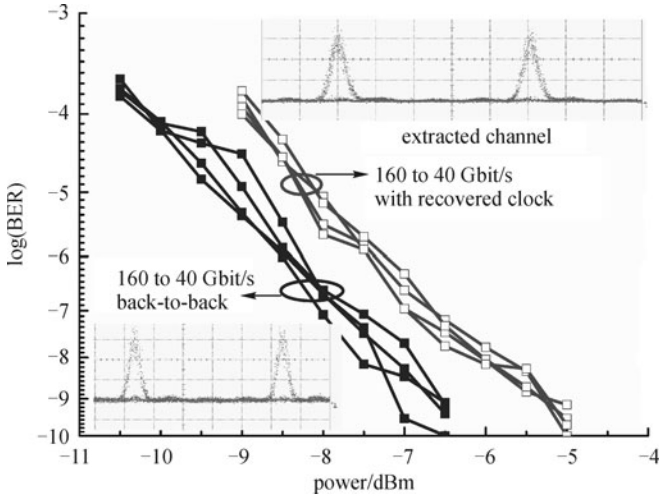

Fig. 5 BER of tributaries using master clock and recovered clock

method for ultra-high speed OTDM signals. The clock insertion and extraction was successfully achieved with a power penalty of about 1.2 dB. No ultrafast phase comparator is required for the clock recovery in the receiver end.

Acknowledgements The authors would like to thank Prof. Harm J S Dorren from Eindhoven University of Technology for useful discussion and collaboration. This work was supported by the National Natural Science Foundation of China (Grant Nos. 60736038, 60907008, and 60925019) and the Education Ministry Funds of China for New Teachers (Nos. 200806141102 and 20090185120027).

References

1. Kamatani O, Kawanishi S. Ultrahigh-speed clock recovery with phase lock loop based on four-wave mixing in a traveling-wave laser diode amplifier. Journal of Lightwave Technology, 1996, 14(8): 1757–1767
2. Hansen Mulvad H C, Tangdiongga E, de Waardt H, Dorren H J S. 40 GHz clock recovery from 640-Gbit/s OTDM signal using SOA-based phase comparator. Electronics Letters, 2008, 44(2): 146–147
3. Oxenløwe L K, Gomez-Agis F, Ware C, Kurimura S, Mulvad H C H, Galili M, Kitamura K, Nakajima H, Ichikawa J, Erasme D, Clausen A T, Jeppesen P. 640 Gbit/s clock recovery using periodically poled lithium niobate. Electronics Letters, 2008, 44(5): 370–371
4. Boerner C, Marembert V, Ferber S, Schubert C, Schmidt-Langhorst C, Ludwig R, Weber H G. 320 Gbit/s clock recovery with electro-optical PLL using a bidirectionally operated electroabsorption modulator as phase comparator. In: Optical Fiber Communication Conference, OSA Technical Digest Series. 1996, 2: 349–351
5. Qi G, Yao J, Seregelyi J, Paquet S, Belisle C. Optical generation and distribution of continuously tunable millimeter-wave signals using an optical phase modulator. Journal of Lightwave Technology, 2005, 23 (9): 2687–2695