Enhanced Tolerance to Demultiplexing Misalignment in an OTDM System with Hybrid RZ-ASK/DPSK Formats

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Abstract: We propose a novel OTDM scheme with hybrid RZ-ASK/RZ-DPSK formats and investigate its demultiplexing performance. Experiment showed the tolerances to demultiplexing timing misalignment were improved by 180% and 70%, for RZ-ASK and RZ-DPSK channels, respectively.

OCIS codes: (060.4080) Modulation; (060.4230) Multiplexing

1. Introduction

In recent years, the data rate per channel is continually increasing with the ever-growing demand on the communication bandwidth. Optical time division multiplexing (OTDM) is a promising technique to upgrade the bit rate in each wavelength channel [1-4]. At the receiver side, an aggregated high-speed OTDM signal is time demultiplexed to the channel rate before detection. Various OTDM demultiplexers have been proposed and demonstrated, including electro-absorption modulator (EAM) [3], and optical switches based on nonlinear effects, such as four-wave mixing, cross-phase modulation, etc. [1-2]. Generally, although the latter ones could realize narrow switching window, the EAM based demultiplexer is more preferred in practice, because of its simpler configuration and better controllability.

The switching window of an OTDM demultiplexer should have a reasonable width to avoid crosstalk from the adjacent channels and to have some tolerance against timing misalignment in demultiplexing. Usually, EAM based demultiplexers can meet such requirements, as they offer switching window a little smaller than or comparable to the bit period of an OTDM signal [3,4]. Thus, even with a small amount of timing misalignment $\Delta\tau$ in demultiplexing, the signal pulse of the target demultiplexed channel can still be contained in the switching window. However, part of an adjacent bit may still be included in the misaligned switching window, and the target channel would be degraded due to the crosstalk from the adjacent channels. A scheme was proposed to enhance the tolerance by altering the pulse position of different OTDM channels [3]. However, it was complicated and impractical as it required additional precise timing control. Previously, we have proposed a novel hybrid two-channel OTDM scheme with an optical return-to-zero (RZ) amplitude-shift-keying (ASK) channel and an RZ differential phase-shift-keying (DPSK) channel, which does not require time demultiplexing at detection [5]. In this paper, we extend our investigation to study the demultiplexing issue of such hybrid OTDM in case of multiple ASK and DPSK OTDM channels. Our study shows that the scheme can offer much enhanced tolerance against timing misalignment in OTDM demultiplexing, as compared with the conventional OTDM system having homogenous modulation format.

2. Proposed OTDM with Hybrid Modulation Formats and Its Demultiplexing

Fig. 1(a) depicts the signal frame of the proposed OTDM with hybrid modulation formats. In a conventional OTDM signal, all channels employ either RZ-ASK [3] or RZ-DPSK [4] formats. However, in our proposed hybrid OTDM scheme, every even channel is in RZ-ASK format while every odd channel is in RZ-DPSK format, as illustrated in Fig. 1(a). In other words, the RZ-ASK channels are interleaved with the RZ-DPSK channels. One of the main advantages of this hybrid OTDM system is that every channel suffers much less crosstalk induced error from its two adjacent channels, in case of improper demultiplexing. Fig. 1(b) shows the demultiplexing of an RZ-ASK channel in which the time gating (switching window) has some timing misalignment. The width of the switching window is comparable with a bit period. With some timing misalignment, part of the signal in the adjacent channel is also gated in the window. In a conventional ASK OTDM case (all channels in ASK format), the gated adjacent bit may have no power (ASK “0”) or may have some power (ASK “1”). This crosstalk causes the target channel to become having multiple levels, which would induce significant errors in detection. However, for an ASK channel in the proposed hybrid OTDM case, the gated adjacent DPSK bit always have the same power, which would not lead to crosstalk induced erroneous decision. Similarly, for a DPSK channel, demultiplexing with timing misalignment will gate part of the adjacent ASK bits. However, in the process of DPSK demodulation, the gated part of the ASK bit will destructively interfere with that of its previous bit. After the demodulation, the gated power of the ASK bit will disappear or become as little as a quarter of its original power, depending whether its two consecutive bits are the same or not. Therefore, the DPSK channel demodulation process can greatly alleviate the crosstalk from the adjacent ASK channel.

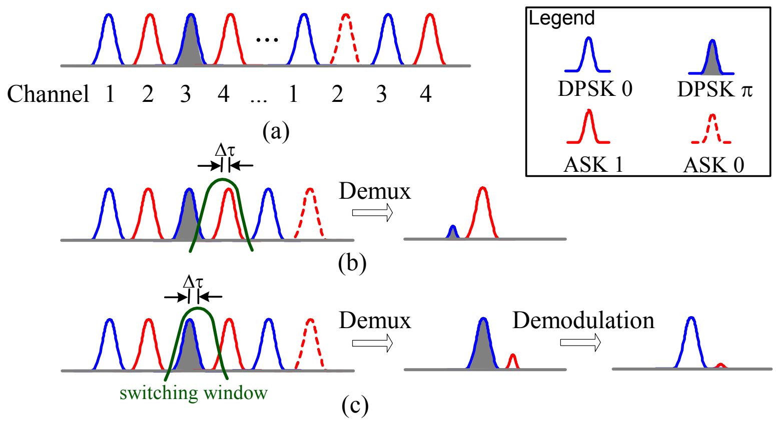

Fig. 1. Proposed OTDM with hybrid modulation formats and its demultiplexing in case of timing misalignment.

3. Experimental demonstration

We have carried out an experiment to show the effectiveness of the proposed hybrid OTDM in enhancing the demultiplexing misalignment tolerance. Fig. 2 depicts the experimental setup. A semiconductor mode-locked laser diode (MLLD) generated an optical pulse train with a pulse width of about 1.5 ps (FWHM) at a repetition rate of 10.61 GHz. After power boosting, it was separated and modulated by decorrelated patterns via an optical phase modulator and an intensity modulator, respectively to generate an RZ-DPSK and an RZ-ASK tributaries. The two channels were properly time multiplexed to 21.22 Gb/s via the tunable optical delay line (ODL). A polarization controller and a variable optical attenuator (VOA) were used, to assure the two tributaries having the same peak power and polarization. The hybrid OTDM signal was upgraded to 42.44 Gb/s via a second stage of multiplexer. After proper amplification, the 42.44-Gb/s was fed into an EAM, driven by a 10.61-GHz clock signal for demultiplexing. The RZ-ASK channels were directly detected while the RZ-DPSK channels were first demodulated via a delay interferometer (DI) with a relative delay of 94.3 ps before single-ended detection.

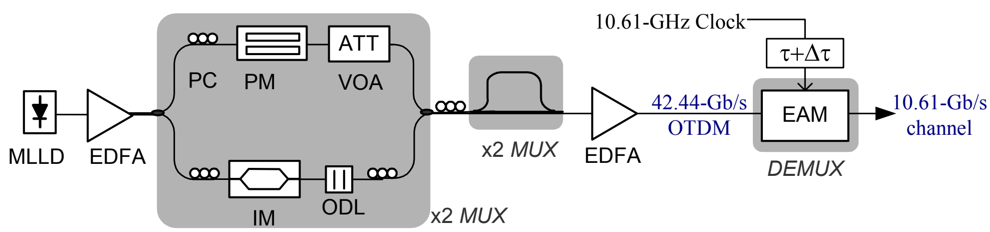

Fig. 2. Experimental setup.

We have measured the BER performance of the demultiplexed signals both in the 42.44-Gb/s hybrid OTDM and the conventional 42.44-Gb/s OTDM cases. The results are depicted in Fig. 3. For conventional OTDM using either ASK or DPSK, the four demultiplexed channels had similar performance, thus the respective BER of only one channel is plotted ("▾" for RZ-ASK OTDM case and "▽" for RZ-DPSK OTDM case), for clarity. In the hybrid OTDM case, the results for one demultiplexed RZ-ASK channel ("●") and one RZ-DPSK channel ("○") are plotted. It is found that all of them had very similar performance, which means the switching window extracted the target channel only and the demutiplexing timing is properly aligned. Under this condition, the demultiplexed channel suffered nearly no crosstalk from adjacent channels.

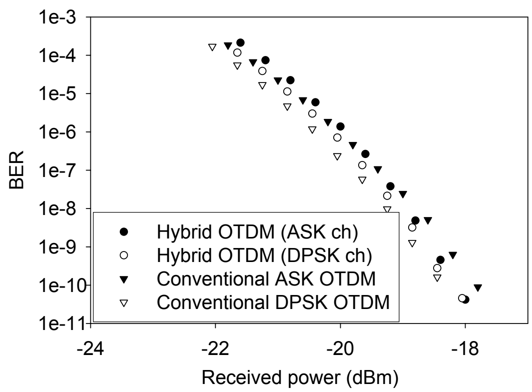

Fig. 3. BER of a demultiplexed ASK channel (●) and a DPSK channel (○) from the hybrid OTDM signal; and BER of a demultiplexed channel from the conventional ASK (▾) OTDM and DPSK (▿) OTDM, respectively.

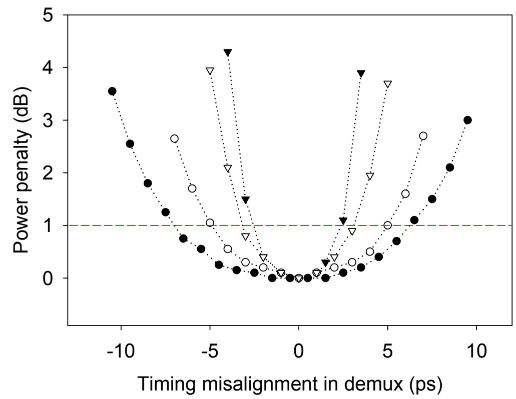

Fig. 4. The power penalty of respective demultiplexed signals under the condition of timing misalignment. Demultiplexed ASK channel (●) and DPSK channel (○) from hybrid OTDM; from conventional ASK (▾) OTDM and DPSK (▿) OTDM.

Fig. 4 depicts the measurements of the demultiplexing performance under the condition of timing misalignment. With the EAM based demultiplexer driven by a 10.61-GHz clock signal (switching window ~20 ps), the 1-dB tolerance of timing misalignment was around ±2.5 ps and ±3 ps, for conventional RZ-ASK OTDM and RZ-DPSK OTDM, respectively. With our proposed hybrid OTDM scheme, the 1-dB tolerance for RZ-ASK channels was greatly enhanced by 180%, to around ±7 ps (almost three times). The tolerance for RZ-DPSK channels also had an obvious enhancement by 70%, to ±5 ps. In case of demultiplexing timing misalignment, if the target demultiplexed channel is an RZ-ASK one, the switching window gated adjacent DSPK bits always added same amount of power to each ASK bit (either "0" or "1") at detection. However, if the target demultiplexed channel is a DPSK one, the gated adjacent ASK bits had different amount of power depending on the bit patterns, which would cause the target channel having power fluctuation after demodulation. This explained why the RZ-ASK channels performed better than the RZ-DPSK channels in case of demultiplexing timing misalignment.

From the experimental results, the 1-dB tolerance of timing misalignment for 40-Gb/s conventional OTDM signal was about 2.5 ps, i.e. 10% of the 40-Gb/s bit period. It could be enhanced to around 20% to 30% of the bit period by using our proposed hybrid OTDM. This advantage would be more significant in 80-Gb/s or 160-Gb/s OTDM systems.

4. Summary

We have investigated the demultiplexing performance of a novel OTDM scheme with hybrid modulation formats of RZ-ASK and RZ-DPSK. In normal operation with proper switching window and timing alignment, the demultiplexing performance is similar with the conventional OTDM with homogeneous modulation format. In case of timing misalignment in demultiplexing, our proposed hybrid OTDM performed much better than the conventional one. Demultiplexing of 40-Gb/s OTDM signal showed the 1-dB misalignment tolerance could be improved by 180% and 70% for RZ-ASK and RZ-DPSK channels, respectively. It is expected the significance of such improvement would be more important in higher-bit rate OTDM systems, in which the requirement on the switching window and timing is even more stringent.

References

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