Pump-Phase-Noise-Tolerant Wavelength Conversion for Coherent Optical OFDM using Coherent DFB Pumping

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Abstract: We experimentally demonstrate an OWC scheme for CO-OFDM using coherent DFB pumping. The tolerance against pump phase noise with coherent pumping enables the use of low-cost 2MHz-linewidth DFB as pump to realize OWC of 12Gbps QPSK-CO-OFDM with 1dB penalty.

OCIS codes: (060.1660) Coherent communications; (130.7405) Wavelength conversion devices; (060.5060) Phase modulation; (060.1155) All-optical networks

1. Introduction

Coherent optical orthogonal frequency-division multiplexing (CO-OFDM) is one of the most promising candidates for realizing spectrum-efficient high-speed optical transmission systems due to its excellent spectrum efficiency, modulation flexibility, and outstanding performance in combating fiber chromatic dispersion and polarization-mode dispersion [1]. However, the CO-OFDM signal is extremely sensitive to phase noise, which will cause common phase error (CPE) noise and inter-carrier interference (ICI). Intensive efforts have been put forward to mitigate the phase noise in CO-OFDM. However, some of proposed algorithms or approaches could not work well with laser linewidth larger than 1MHz [2]. Therefore, phase noise is one of the most important issues to be concerned when constructing systems with CO-OFDM signals.

As one of the important functionalities in future dynamic optical transparent networks, optical wavelength conversion (OWC) has been extensively studied through nonlinearities in nonlinear fiber [3], semiconductor optical amplifier (SOA) [4], periodically-poled Lithium Niobate (PPLN) [5], or silicon waveguide [6]. Due to the vulnerable sensitivity to phase noise of CO-OFDM, to avoid extra phase noise introduced by local pumps in OWC, narrow-linewidth lasers like external cavity lasers (ECLs) are deployed as pump laser sources to perform OWC for CO-OFDM signals [3-4, 6]. Nevertheless, this increases the implementation cost of the OWC systems. Recently, coherent pumping scheme has been proposed to realize OWC for single-carrier high-order quadrature amplitude modulation (QAM) signals with tolerance against the phase noise from local pumps [7]. The scheme allows the use of low-cost DFB laser as pump source, effectively reducing the implementation cost with superior performance in terms of tolerance against pump laser linewidth.

In this paper, we extend the coherent pumping scheme to demonstrate an OWC of CO-OFDM signal with subcarriers modulated in quadrature phase-shift keying (QPSK) and 16-quadrature amplitude modulation (16QAM). The tolerance against phase noise from pumps enables the use of 2MHz-linewidth DFB as pump source. The experimental results show that around 1-dB optical signal-to-noise ratio (OSNR) penalty is obtained at bit-error rate (BER) of 10^{-3} after conversion with coherent DFB pumping with respect to the input signal. In contrast, the converted CO-OFDM signal is severely deteriorated by the pump phase noise with free-running DFB pumping.

2. Experiment

To realize OWC of CO-OFDM signal with tolerance against phase noise from pumps, dual-pump four-wave mixing (FWM) in highly-nonlinear fiber (HNLF) is deployed in the experiment. As shown in the inset of Fig.1, with two pumps at ω_1 and ω_2, and input signal at ω_s, two new components at ω_{1s2*} and ω_{2s1*} are generated alongside of the input signal, where the original phase and intensity information of input signal are well preserved with phase components of $\phi_1+\phi_s-\phi_2$ or $\phi_2+\phi_s-\phi_1$, respectively. Obviously, with coherent pumps ($\phi_1=\phi_2$), the phase noise from pumps could be cancelled out. The experimental setup is illustrated in Fig. 1 as well. To avoid the phase noise from input signal, an ECL laser with a linewidth of around 100kHz emitting at 1550.7 nm is used as light source for CO-OFDM. The light is then modulated by an in-phase/quadrature (IQ) modulator with a 3-dB bandwidth of 23GHz and a 3.5V half-wave voltage. To drive the IQ modulator for CO-OFDM synthesis, arbitrary waveform generator (AWG) is operated at 12GSamples/s. The CO-OFDM is constructed by 256 subcarriers, in which 128 subcarriers are data-modulated and pilot subcarriers are used for phase noise estimation (8 for QPSK-CO-OFDM, 16 for 16QAM-CO-OFDM). Inverse fast Fourier transform (IFFT) with a size of 256 is used to convert the signal to time domain. A cyclic prefix of 12.5% of the symbol duration is applied for the margin of synchronization offsets and the inter-symbol interference. With the subcarrier modulation of QPSK and 16QAM, the corresponding bit rates are 12Gbps and 24Gbps, respectively.

For performance comparison, two different pumping schemes, coherent and free-running pumping, are adopted in the experiment. In the coherent pump configuration, to generate coherent two-tone pump, light from a DFB laser is modulated by a 10GHz Mach-Zehnder modulator (MZM) driven by a 12.5GHz RF clock, which resulting in a 25GHz frequency separation. As shown in Fig. 2(a), more than 50dB OSNR is obtained in the obtained coherent two-tone pump. In the free-running pumping case, two independent DFB lasers emitting at 1551.7nm and 1551.9nm are used as pumps with 25GHz spacing. For each pump configuration, DFB lasers with linewidth of around 2MHz are used as pump laser sources. After individual power amplification and ASE noise filtering, the input CO-OFDM signal and pumps are combined in a 1:1 coupler before feeding to a piece of HNLF, which has a length of 996 meter, a measured nonlinear coefficient of 11.7 /W/km, a zero dispersion wavelength at 1549nm, and a dispersion slope of 0.019 ps/nm^2/km at 1550nm. Polarization controllers (PCs) are used in signal and pump branches for optimizing the conversion efficiency. After the HNLF, the converted signal at 1550.5nm is detected by a digital coherent receiver after filtering. The receiver consists of another 100kHz-linewidth ECL laser acting as a local oscillator, an optical 90-degree hybrid and two balanced photo-detectors (PDs). After detection by the PDs, the data is digitized at 50GSamples/s using a digital storage oscilloscope. The captured data is then processed off-line through digital signal processing, including carrier frequency estimation and synchronization, fast Fourier transform (FFT), channel estimation, phase-noise estimation, constellation decision and BER calculation. Note that, to provide a fare comparison, the same DSP configuration, especially the same phase-noise estimation method, is deployed in the receiver.

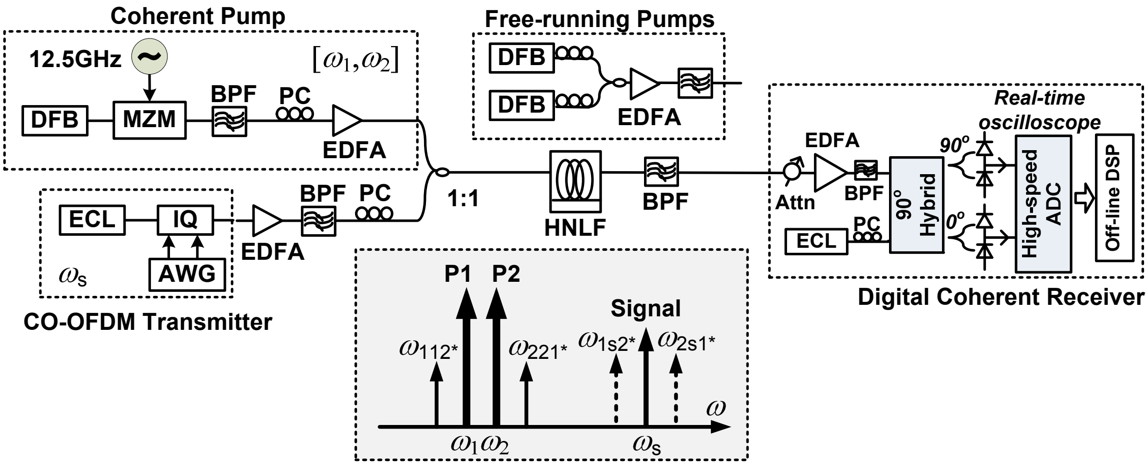

Fig. 1. Experimental setup.

3. Results and discussion

In the experiment, the input CO-OFDM power and total pump power launched to HNLF are optimized at 11.8 dBm and 1 dBm, respectively. Fig. 2(a) shows the spectrum of coherent two-tone pump with more than 50 dB OSNR. As shown in Fig. 2(b), with the optimized launch power, around -20dB conversion efficiency is observed for the converted CO-OFDM signal. Here, the conversion efficiency is defined as power ratio of the converted signal to the input signal. Further improvement in the conversion efficiency is expected by further optimizing the wavelength arrangement of the pump and signal.

Figure 3 shows the measured constellations of the input and converted QPSK-CO-OFDM signals with different pumping configurations. Even using DFB as pump source, clear constellation could be observed with coherent pumping. It shows comparable error vector magnitude (EVM) to the input signal. However, in the case of free-running pumping, as shown in Fig. 3(c), although the common phase rotation in constellation points is corrected in DSP, the phase noise from DFB pumps cause server ICI, which could not be removed and results in enlarged EVMs. As shown in Fig. 3(d)~(e), similar results are observed with input 16QAM-CO-OFDM. After conversion, clear constellation of 16QAM-CO-OFDM is observed with comparable EVM to input signal with coherent DFB pumping. However, the synchronization fails when detecting the converted 16QAM-CO-OFDM constellation with free-running pumps due to the severe phase noise from pumps.

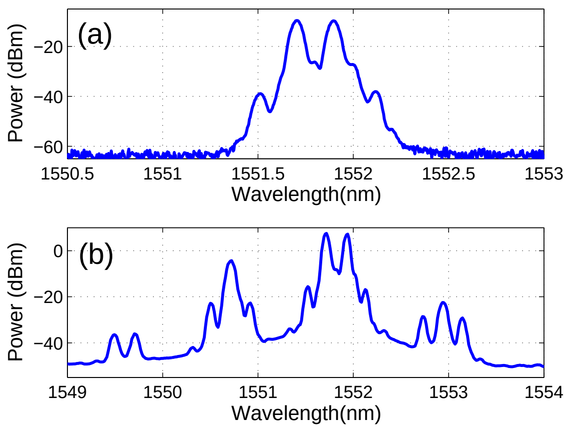

Fig. 2. Measured spectra of (a) coherent two-tone pump, and (b) FWM after HNLF.

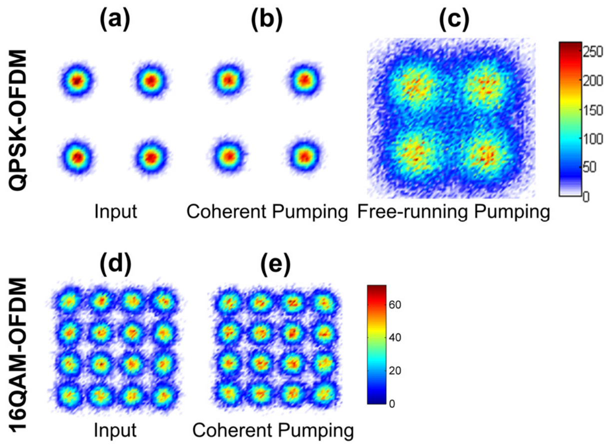

Fig. 3. Measured constellations: QPSK-OFDM of (a) the input and converted signals with (b) coherent pumping, and (c) free-running pumping; 16QAM-OFDM of (d) the input and (e) converted signal with coherent pumping (OSNR=12dB)

Figure 4 depicts the measure BER curves as function of OSNR (0.1nm). With coherent DFB pumping, at BER of 10^{-3}, around 1dB OSNR penalty is obtained with respect to the input QPSK-CO-OFDM signal. Further improvement is expected when optimizing the conversion efficiency in FWM. On the other hand, with free-running DFB pumps, it becomes impossible to obtain reasonable BER plot for the converted CO-OFDM signal. This verifies the effectiveness of the elimination of the pump phase noise in the OWC for CO-OFDM with coherent pumping.

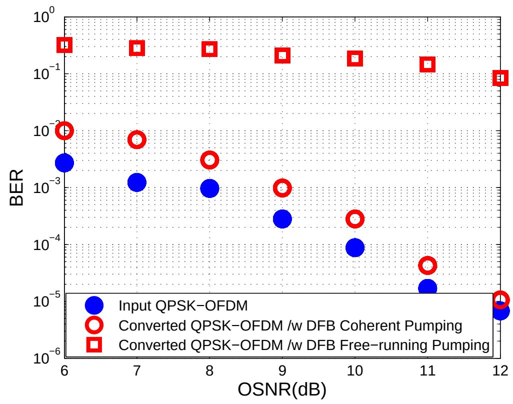

Fig. 4. Measured BER vs. OSNR (at 0.1nm) of QPSK-CO-OFDM before and after conversion with different pumping schemes.

4. Conclusions

We have experimentally demonstrated an OWC of CO-OFDM signal based on FWM in HNLF using coherent pumping. The immunity to phase noise from pumps enables the use of low-cost 2MHz-linewidth DFB as pump source with ~1dB OSNR penalty at BER of 10^{-3} for converted 12Gbps QPSK-CO-OFDM signal.

References

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