Spectrally Efficient Direct-Detected Optical OFDM Transmission Using Carrier-Data Timely Multiplexing Technique

Wei-Ren Peng

Department of Photonics & Institute of Electro-Optical Engineering, National Chiao Tung University, HsinChu, Taiwan 300, R.O.C. pwr.eo92g@nctu.edu.tw

Abstract *We timely multiplex the carrier and data symbols for DD-OFDM that improves the spectral efficiency, receiving sensitivity, and tolerances to PMD and optical filtering effects, when compared with the previous DD-OFDM transmission. It also reduces the receiver's sampling rate.*

Introduction

Optical frequency division multiplexing (OFDM) has attracted lots of interests due to its robustness against both the fibre chromatic dispersion (CD) and polarization mode dispersion (PMD) enabled by the powerful electrical signal processing[1,2]. Within the topics of OFDM, the direct-detected approach (DD-OFDM)[1] requires simpler hardware and electrical signal processing, thus being an alternative low-cost candidate for long-haul transmission other than the coherent approach (CO-OFDM)[2].

Typically, the single sideband OFDM (SSB-OFDM) has broadly been used for long-term transmission since it alleviates the CD fading problem inherently in a double sideband (DSB) transmission[1]. However, in spite of its improved CD tolerance, the SSB format has the following issues: 1. Poor spectral efficiency (SE) due to the inserted frequency gap[1,3]. 2. Much poorer sensitivity (6-8 dB) than coherent approach[4]. 3. Vulnerability to PMD fading since the larger frequency spacing between the carrier and data subcarriers. 4. Vulnerability to strong optical filtering due to the edge allocation of the carrier. 5. High receiver sampling rate requirement, typically at least twice of its optical bandwidth. Thus, based on these issues relevant to SSB-OFDM, a laudable goal would be to provide an alternative solution that could improve the SE, receiving sensitivity, PMD and optical filtering tolerances, and relax the requirement for high receiver sampling rate.

In this paper, we transmit the 4-QAM, 10-Gbps OFDM signal via timely manipulating the optical carrier and the OFDM data symbols. For direct detection, the delay interferometers (DIs) with one arm delayed by a length equal to the symbol duration are used before the balanced receivers. With the proposed method, we show the SE can be enhanced by a factor of ~1.33 and the receiving sensitivity can be improved by ~1.8 dB, compared with the previous gapped SSB-OFDM. Both the tolerances against the PMD and optical filtering effects are effectively enhanced, and the sampling rate for direct down-converted receiver (mixer-less receiver) is reduced by a factor of ~2.66.

Working principles

Shown in Fig. 1(a) are the previous SSB-OFDM[1,3] and the proposed OFDM systems. For the SSB-OFDM, the carrier and the data sideband are separated by a frequency gap with the same width as the sideband, and are transmitted equally in each OFDM symbols[1,3]. The signal bandwidth is denoted as BW, which should include the sideband bandwidth and the gap width. For the proposed OFDM, the carrier and the data symbols are separately transmitted with time division multiplexing (TDM) technique. The optical carriers are sent in the (1+3*m*)-*th* symbol with *m* the nonnegative integer, while the other symbol slots are dedicated for the data symbols. Since only 1/3 symbols are wasted for transmitting the carrier, its SE is 1.33 times better than the SSB-OFDM which wastes half the bandwidth for the gap. For detection two orthogonal sets of DIs, each with one arm delayed by the OFDM symbol length, are used before the following balanced detectors, as shown in Fig. 1(b). The transmitted data can be extracted via processing the two outputs from the paired balanced detectors.

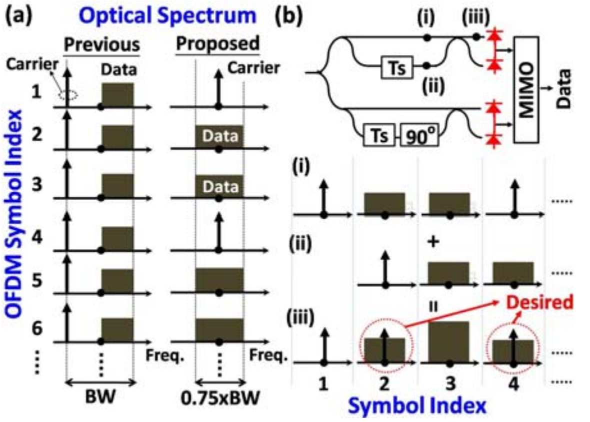

Fig. 1: (a) Concepts of the previous gapped SSB-OFDM and the proposed carrier-data timely multiplexing OFDM, and the (b) receiver of the proposed OFDM. Ts: OFDM symbol duration.

The relevant signal spectra in the DIs are shown in the inset (i)-(iii) of Fig. 1(b). The desired data symbol can be extracted via the beating between the carrier and the data symbol, which will happen on the (2+3m) and (4+3m)-*th* received symbol. The following balanced detectors can remove the signal-signal beat interference (SSBI) so that the frequency gap, used for allocating the SSBI, is not needed with this proposal[1,3].

978-3-8007-3173-2

Results and discussions

To demonstrate the performance of the proposed OFDM, we setup a numerical model with 4-QAM, 10-Gbps OFDM transmission. The previous gapped SSB-OFDM[1,3] is also simulated for comparison. In Fig. 2 we show the optical spectra and received RF spectra of the previous and proposed OFDM. For the proposed method, the optical bandwidth and the required sampling rate at the receiver are reduced by a factor of ~1.33 and ~2.66, respectively, compared to the previous OFDM.

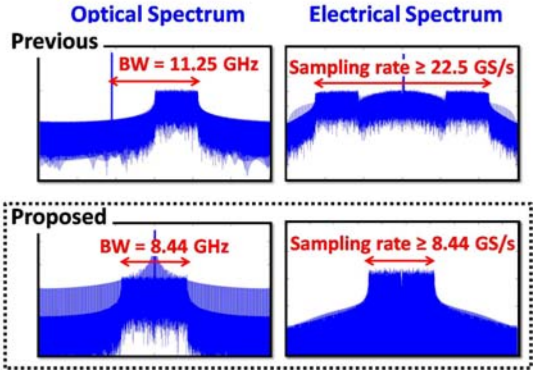

Fig. 2: Optical and received RF spectra for previous and proposed 4-QAM, 10-Gbps OFDM, showing the narrower bandwidth and the lower receiver sampling rate of the proposed method.

In Fig. 3 we show BER performance as a function of OSNR. The proposed OFDM has ~2 dB OSNR gain compared with previous SSB-OFDM while it has ~4.2 dB OSNR penalty compared with the CO-OFDM due to the extra optical carrier in DD-OFDM. Note in Fig. 3 we set the laser linewidth (LLW) = 0 Hz to explore the signal's ideal sensitivity. For the following results, we will use LLW = 100 kHz considering a practical system[5].

Fig. 4 depicts the OSNR performance vs. the normalized optical bandwidth. The normalized optical bandwidth is defined as the ratio between the optical bandwidth (BW_O) and the signal bandwidth (BW_S). For a wider bandwidth the difference between the two systems is found to be ~1.8 dB, and becomes as large as > 5.5 dB when the normalized bandwidth reduces to ~0.6. This is because for the gapped OFDM the filter would easily attenuate the edged carrier and make the signal's CSPR deviate from its optimum value (0 dB)[1,3], and thus degrade more the system performance.

Shown in Fig. 5 we compare the 1st order PMD tolerances. For 3-dB penalty, the proposed method can sustain ~doubled DGD than the previous method, which could be attributed to the reduced frequency spacing between the carrier and data subcarriers.

In Fig. 6 we show the CD tolerance (dispersion parameter = 16 ps/nm.km). The results show that with the two orthogonal sets of DIs, the CD fading could be alleviated even the double sideband detection applied in our proposal. The CD tolerance is retained as robust as the previous method.

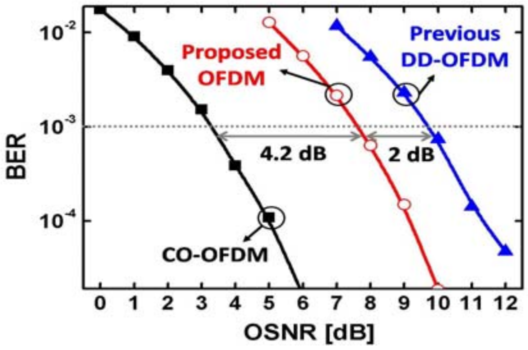

Fig. 3: BER vs. OSNR for 4-QAM, 10-Gbps OFDM. Laser linewidth (LLW) = 0 Hz.

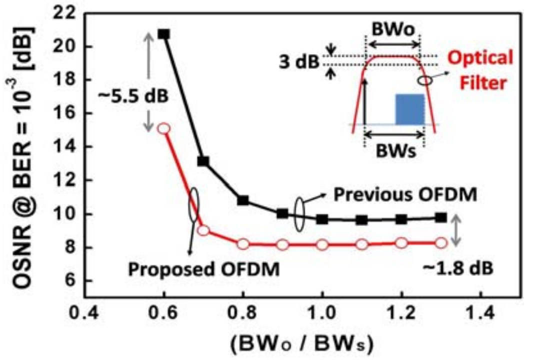

Fig. 4: OSNR vs. normalized bandwidth. The optical filter is modelled by a 2nd order Gaussian type filter. LLW = 100 kHz.

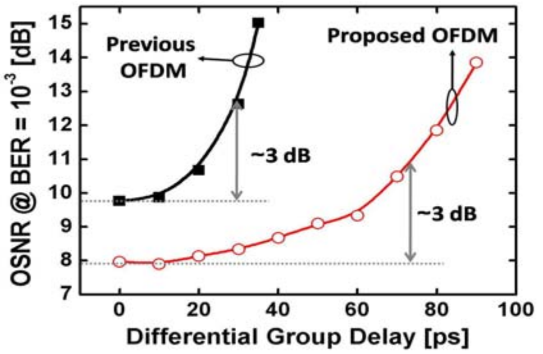

Fig. 5: OSNR vs. 1st order PMD effect with LLW =100 kHz

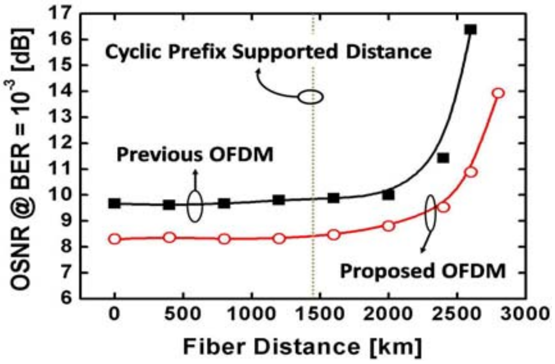

Fig. 6: OSNR vs. fiber distance with LLW = 100 kHz.

References

1 B. J. C. Schmidt et al., JLT **26**, 196 (2008).
2 W. Shieh, OFC'09, OWW1 (2009).
3 W.-R. Peng et al., OFC'08, OMU2 (2008).
4 A. J. Lowery, Optics Express **16**, 860 (2008).
5 X. Yi et al., JLT **26**, 1309 (2008).