Ultra-High Speed Optical OFDM Transmission Technologies

Akihide Sano and Yutaka Miyamoto

Abstract—This paper reviews recent progress in 100-Gb/s-class ultra-high speed optical OFDM transmission technologies. We describe system configuration based on optical multiplexing/demultiplexing and transmission performances.

Index Terms—OFDM, digital coherent receiver, chromatic dispersion, polarization-mode dispersion.

I. INTRODUCTION

Due to the rapid increase in IP data traffic, large-capacity and cost-effective transmission systems are strongly required for realizing future optical transport networks (OTN). Current commercial SONET/SDH interfaces offer the 40-Gb/s line rate, and higher speed client interfaces such as 100-Gb/s Ethernet are expected in the near future. Therefore, 100-Gb/s-class transmission technologies are being extensively investigated for backbone OTNs based on WDM transmission systems [1]. In addition to the requirement of high-speed channel accommodation, future WDM systems are expected to offer 10-Tb/s-class total capacity in order to handle the increase in data traffic. To realize such high-speed large-capacity WDM systems, high spectral efficiency (SE) modulation/multiplexing schemes are indispensable.

In 100-Gb/s-class transmission based on direct detection schemes, the waveform distortion caused by chromatic dispersion (CD) and polarization-mode dispersion (PMD) severely restricts the attainable distance. Optical orthogonal frequency-division multiplexing (OFDM) is very attractive because of its superior tolerance to PMD and CD [2]. In this paper, we review recent progress in 100-Gb/s-class optical OFDM transmission technologies. Section II describes transmitter (Tx) and receiver (Rx) configurations that utilize optical multiplexing/demultiplexing techniques in order to enable 100-Gb/s-class OFDM transmission. Section III discusses the transmission performance of high speed optical OFDM signals.

II. TX AND RX CONFIGURATIONS

In the conventional OFDM system configuration based on digital signal processing (DSP), the OFDM signal is synthesized by inverse FFT operation followed by digital-to-analog converters (DACs) at the Tx (Fig. 1-a), and demodulated by FFT operation after sampling at analog-to-digital converters (ADCs) at the Rx (Fig. 1-d). In 100-Gb/s-class transmission, however, the operation speed of electronics limits the channel line rate. One approach to overcome this limitation is the subcarrier multiplexing of low-speed OFDM signals in the electrical domain [3]. In this approach, higher order modulation such as 8-QAM format is used to avoid the bandwidth limitation imposed by EO/OE conversion. Another approach utilizes optical multiplexing/demultiplexing techniques. In this approach, bandwidth requirements on EO/OE conversion can be relaxed, and thus the use of higher order modulation is not obligatory. Therefore, higher tolerance towards optical signal-to-noise ratio (OSNR) can be expected compared to the former approach. Tx/Rx configurations using optical multiplexing/demultiplexing techniques proposed for 100-Gb/s transmission are shown in Fig. 1. In all-optical OFDM, multiplexing and demultiplexing is done in the optical domain [4, 5]. At the Tx (Fig. 1-b), optical subcarriers are generated by modulating a CW light using external intensity/phase modulators. Each optical subcarrier is then divided, individually modulated with conventional single-carrier modulation, and finally coupled to create an OFDM signal. At the receiver (Fig. 1-e), each optical subcarrier is demultiplexed by an optical discrete Fourier transformer (DFT), which consists of a splitter, optical delay lines, phase-shifters, an optical gate, and an optical coupler. This configuration allows low-cost direct detection Tx/Rx modules to be used for subcarrier modulation/demodulation. In the electro-optical OFDM configuration, each optical subcarrier is modulated by a multi-carrier modulation technique, in which an optical IQ modulator is used to generate a multi-carrier signal around the optical subcarrier frequency (Fig. 1-c). In the electro-optical OFDM Rx is based on the digital coherent receiver configuration (Fig. 1-f): the received OFDM signal is divided into several blocks by anti-alias filters in either optical or electrical domain, and each block is demodulated by an FFT-based DSP. In both all-optical and electro-optical OFDM, low optical subcarrier numbers are preferable in order to minimize cost and complexity. We recently proposed no-guard-interval coherent optical (CO-) OFDM [8, 9]. This
scheme adopts the Tx configuration of Fig. 1-b with two optical subcarriers and polarization multiplexing: a two-subcarrier QPSK modulator is realized by hybrid integrating PLC and LN lightwave circuits. The Rx consists of a single polarization-diversity digital coherent receiver; polarization-and subcarrier-demultiplexing is done by DSPs. This configuration is very simple and thus appears cost-effective compared to the other 100-Gb/s-class OFDM systems.

III. TRANSMISSION PERFORMANCE

In high-speed channel transmission such as 100 Gb/s, waveform distortion due to CD and PMD is a crucial issue. In optical OFDM based on digital coherent receivers, it is possible to significantly improve the tolerance towards CD and PMD by adopting guard intervals to suppress inter-symbol interference. To date, 1000-km transmission of G.652 single-mode fibers (SMF) has been demonstrated at the channel rate of 100 Gb/s without using CD compensation [3, 7]. These experiments, however, required the use of guard intervals and training sequences such that the line rate was increased by the overhead. On the other hand, in no-guard interval CO-OFDM, CD compensation is done by fixed-tap finite impulse response (FIR) filters, and blind equalization with adaptive digital filters is used to compensate PMD, so there is no line rate increase due to overhead or training sequences.

Up to now, most reports of OFDM transmission used G.652 SMF. Terrestrial applications, however, require various types of existing fibers such as dispersion-shifted fibers (DSFs) and non-zero DSFs to be supported. OFDM transmission over these low dispersion fibers should be carefully investigated because narrow subcarrier spacing causes strong nonlinear interaction. One solution is DSP-based nonlinear compensation of fiber nonlinearity [10]. The use of a small number of subcarriers is also effective because this lowers the peak-to-average power ratio (PAPR). We used 2-subcarrier CO-OFDM to demonstrate 111-Gb/s transmission over 2100 km of dispersion-shifted fibers (DSFs) [9].

Because of its narrow subcarrier spacing, OFDM exhibits compact signal spectra, and so is suitable for ROADM/OXC networks, in which cascaded filtering at the optical nodes limits the attainable distance. We have demonstrated 1300-km 10-node transmission with 100-GHz-spaced WDM [5], and 20-node transmission with 50-GHz spaced WDM [9].

IV. CONCLUSION

We have discussed 100-Gb/s-class ultra-high speed optical OFDM transmission technologies focusing on system configuration and transmission performances. No guard interval CO-OFDM is promising because of its simple configuration, high tolerance to CD/PMD and cascaded filtering, and applicability to various types of fibers.

REFERENCES


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Fig. 1 Tx and Rx configurations