Coherent Optical Transmission with Frequency-domain Equalization

Koichi Ishihara, Takayuki Kobayashi, Riichi Kudo, Yasushi Takatori,
Akihide Sano, Eiichi Yamada, Hiroji Masuda, and Yutaka Miyamoto
NTT Network Innovation Laboratories, NTT Corporation, 1-1 Hikari-no-oka, Yokosuka, Kanagawa, 239-0847, Japan, email: ishihara.koichi@lab.ntt.co.jp

Abstract *We demonstrated 25-Gb/s (21.7-Gb/s after coding) single-carrier (SC) transmission with QPSK format over 240km of SMF (4080ps/nm) by employing frequency-domain equalization (FDE).*

Introduction

Optical transmission schemes based on coherent detection and digital signal processing (DSP) have been attracting much attention because of their superior tolerance against chromatic dispersion (CD) compared to differential direct detection (DD). Orthogonal frequency division multiplexing (OFDM) [1-5] is a promising technique because it can virtually eliminate the influence of CD by using a cyclic prefix (CP) with lower DSP calculation costs than time-domain linear equalization [6]. However, OFDM signals have high peak-to-average power ratio (PAPR), and this enhances the waveform distortion caused by nonlinear effects in the transmission fiber [7]. It was recently shown that the use of frequency-domain equalization (FDE) significantly improves the bit error rate (BER) performance of single-carrier (SC) transmission in wireless communication systems [8-10]. SC with FDE gives similar performance to OFDM with essentially the same overall DSP complexity although SC signals have much lower PAPR than OFDM.

In this paper, we report for the first time, optical SC transmission robust against CD enabled by FDE operation. SC transmission of 25-Gb/s with FDE is achieved over 240km of single mode fiber (SMF) without performance degradation even though optical dispersion compensation is not used.

Principle of DSP with FDE

The DSP block structure of FDE at a receiver is illustrated in Fig. 1. The difference between OFDM and SC with FDE is as follows. In OFDM transmission, inverse fast Fourier transform (IFFT) and fast Fourier transform (FFT) are used at the transmitter and the receiver, respectively. On the other hand, in SC with FDE, both are used at the receiver. At the transmitter, the symbol sequence is divided into blocks of N_d symbols each; the CP of N_{cp}-symbol length is then inserted at the end of each block as shown in [8]. After preamble insertion, the symbol sequence is transmitted. At the receiver, timing detection and frequency offset compensation are carried out by using the preamble. FDE weight based on minimum mean square error (MMSE) criterion is then estimated at the preamble duration. At the data symbol duration, N-point FFT is applied to decompose the received signal into N frequency components. 1-tap equalization based on MMSE criterion is then carried out in the frequency-domain. After IFFT operation, data demodulation is carried out to obtain the transmitted data sequence.

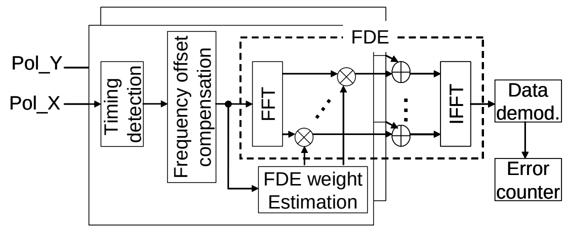

Figure.1 DSP block diagram with FDE at a receiver

Experimental setup

Fig. 2 shows the experimental setup. At the transmitter, the CW optical carrier from external cavity laser (ECL) was modulated by an optical IQ-modulator. We used a signal wavelength of 1552.12 nm on the ITU-GRID. A pulse pattern generator (PPG) was used to generate continuous binary IQ baseband signals to which CP and preambles were applied. The transmission line consisted of 3 spans of 80-km ITU-T G.652 SMF and erbium doped fiber amplifiers (EDFAs). The average dispersion was 17ps/nm/km. CD was compensated by FDE; no optical dispersion compensation fiber was used. We also employed distributed Raman amplification to improve the received OSNR. The on/off Raman gain was 7dB. The input power to every span ranged from -4dBm to 0dBm. At the receiver, the transmitted NRZ-QPSK signal was combined with the signal from a local oscillator (LO) in polarization-diversity optical 90 degree hybrid. The in-phase (I) and quadrature (Q) parts of two polarizations were fed to four balanced photo detectors (BPDs). LO was an ECL with 100-kHz linewidth tuned to the transmitted signal wavelength. BPD outputs were sampled and digitalized at 50GS/s using a digital storage oscilloscope. These four digitized signals were post-processed offline. In the offline process, DSP based on FDE was carried out, see previous section. Subsequently, the BER was estimated. 4.8 million bits were transmitted to obtain the BERs. The bit rate before coding was 25Gb/s, of which

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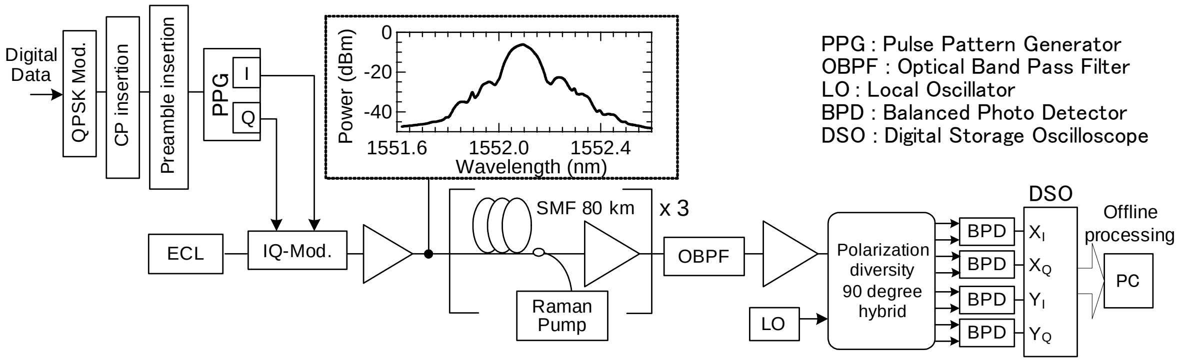

Figure.2 Experimental setup for single carrier transmission

0.6% was used for preamble and 6.2% for CP. Taking an additional 7% for FEC coding into account, this results in the transmission data rate of 21.7-Gb/s.

Experimental result

Fig. 3 shows the constellation of the data symbols with and without FDE after 240km SMF transmission for NRZ-QPSK in SC system, respectively. After SMF transmission, the transmitted symbols become distorted due to the influence of CD as shown in Fig. 3 (a). However, Fig. 3 (b) shows that the influence of CD is reduced by employing FDE and a clear constellation is observed.

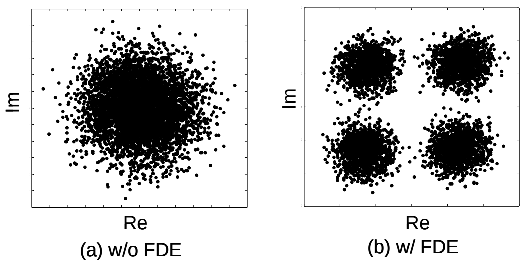

Figure.3 Constellation after 240km SMF transmission (a) without and (b) with FDE

Fig. 4 shows the BER performance of SC with FDE as a function of OSNR for back-to-back and after transmission. For comparison, we also plot the BER performances with DD for back-to-back and 800ps/nm transmission. It can be seen that the BER performance with FDE is about 2dB better than DD in the back-to-back case since SC with FDE employs coherent detection. Furthermore, the performance of SC with FDE after 240km SMF (CD of 4080ps/nm) transmission is not degraded while that of DD is significantly deteriorated even in 800ps/nm transmission. This result confirms that FDE successfully offsets the CD of 240km SMF.

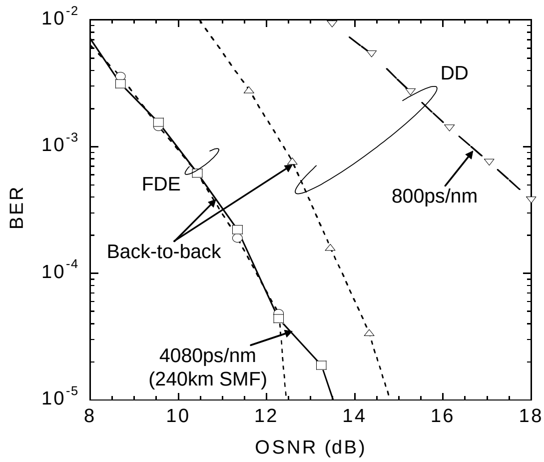

Figure.4 BER performance of 25-Gb/s QPSK: FDE compared to DD

Conclusions

We proposed for the first time, optical SC transmission with FDE that exhibits almost the same DSP complexity as OFDM with lower PAPR. We successfully demonstrated 25-Gb/s SC with FDE over 240km SMF (4080ps/nm) without optical dispersion compensation.

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