Demonstration of 10Gbps, 4-user, OCDMA Transmission over 59km Single Mode Fiber without Inline Dispersion Compensation

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Abstract: Multi-user, 10Gbps, optical code division multiple access (OCDMA) transmission over 59 km of standard single mode fiber without inline dispersion compensation is experimentally demonstrated for the first time.

OCIS codes: (060.2330) Fiber optics communication; (060.4230) Multiplexing

1. Introduction

Optical code division multiple access (OCDMA) is one promising candidate for the next generation FTTH system [1]. It has unique features of full asynchronous transmission, low latency access, soft capacity on demand as well as optical layer security. There are two different approaches for the multi-user coherent OCDMA system: synchronous and asynchronous OCDMA. In the synchronous OCDMA, proper timing coordination is required to carefully avoid the overlaps between signal and interferences [2, 3]. In contrast, the asynchronous capability is essential in practical OCDMA systems [4]. Recently, for the coherent time-spreading (TS-) OCDMA, the multi-port OCDMA encoder/decoder (E/D) has the unique capability of simultaneously processing multiple time-spread optical codes (OCs) with single device, which makes it a potential cost-effective device to be used in the optical line terminal (OLT) of an OCDMA network to reduce the number of E/Ds [5]. Meanwhile, the phase-shifted superstructured fiber Bragg grating (SSFBG) E/D is another attractive TS-OCDMA E/D for the optical network unit (ONU) because it has the polarization independent performance, low and code-length independent insertion loss, compactness as well as low cost for mass production [6]. Therefore, hybrid using different types of the E/D in an OCDMA network is expected to significantly improve the system flexibility and performance. Recently, we have successfully demonstrated fully-asynchronous, 10 Gbps, OCDMA systems with hybrid E/D [7, 8]. However, in all these experiments, the total chromatic dispersion of the transmission fiber is almost zero using a pair of a standard single mode fiber (SSMF) and a dispersion compensation fiber (DCF). The conventional and future FTTH systems don't support the dispersion compensation because of its high cost and complexity [9, 10]. In addition, these systems have to support at least 0~20 km of SSMF transmission.

In this paper, we propose the inline-dispersion-compensation-free OCDMA transmission using the bandwidth optimization of OC's spectrum. With this scheme, 10Gbps, 4-user, OCDMA transmission over 59 km of the SSMF without inline dispersion compensation is experimentally demonstrated for the first time.

2. Experimental setup

In our OCDMA system, we use 16-chip, 16-level phase-shifted SSFBGs and 16x16-port E/Ds. The SSFBG E/D has the following characteristics: the center wavelength is 1551 nm, chip length is ~0.52 mm, total length of grating is 8.32 mm, and the 16 phase levels are generated by shifting the chip grating by a step of +/- $\lambda/8$. The patterns for SSFBGs OC-1 to 4 (used in this experiment) correspond to the OCs generated from the 16x16 port encoder with input 1, 5, 9, 13 ports, output port 8, respectively. The frequency deviation (channel spacing) between neighboring ports of 16x16 port encoder is 12.5 GHz. The duration of the generated OCs is ~80 ps (chip-rate: 200 Gchip/s). In other words, each OC has 200 GHz (1.6 nm) spacing spectrum component. Therefore, to transmit the SSMF, each OC is susceptible to the chromatic dispersion due to the difference between each spectrum component. To solve this issue, we employ a rectangular shape optical band pass filter (OBPF) after the encoder to extract only one spectrum component from OC to reduce the chromatic dispersion effect.

Figure 1 shows the experimental setup. A mode-locked laser diode (MLLD) generated 1.8 ps optical pulses at the repetition rate of 10.71 GHz with the central wavelength of 1551 nm. The generated signal was modulated by a $LiNbO_3$ intensity modulator (LN-IM). The frame contains 2^{31}-1 pseudo random bit sequence (PRBS) payload and forward error correction (FEC) parity. Please note that the use of FEC at 10Gbps in FTTH systems will likely become a real-world scenario because of the low-cost. The FEC is Reed-Solomon code (RS(255, 239)). The data rate is 10.71 Gbps (10 G for payload + 7% FEC overhead). The generated data was split into 4 branches in a truly-asynchronous manner with equal power, random delay, and random bit phase, and launched into each SSFBG encoders, which generates 16-chip (200 Gchip/s), 16-level-phase-shifted OCs. For investigating the system performance in the worst scenario where the interference becomes most serious, polarization controllers (PCs) were placed to align the polarization states of all the signals. These 4 signals were multiplexed and then passed through a tunable OBPF (TOBPF) (Alnair Labs.: BVF-100). In this experiment, we adjusted two kinds of the bandwidth (2.1 and 7.5 nm) by the TOBPF. These OCDM signals were launched into 59 km SSMF. Figures 1 show the measured (a) group delay and (b) total chromatic dispersion of the SSMF. The total chromatic dispersion at 1551 nm is around 1190 ps/nm. After the fiber transmission, these OCDMA signals were simultaneously decoded by the 16x16-port decoder. The decoded signal was detected by an O/E converter. For the bit error rate (BER) measurement, the detected signal was recovered by the clock-and-data-recovery (CDR) circuit and forwarded to the error detector (ED).

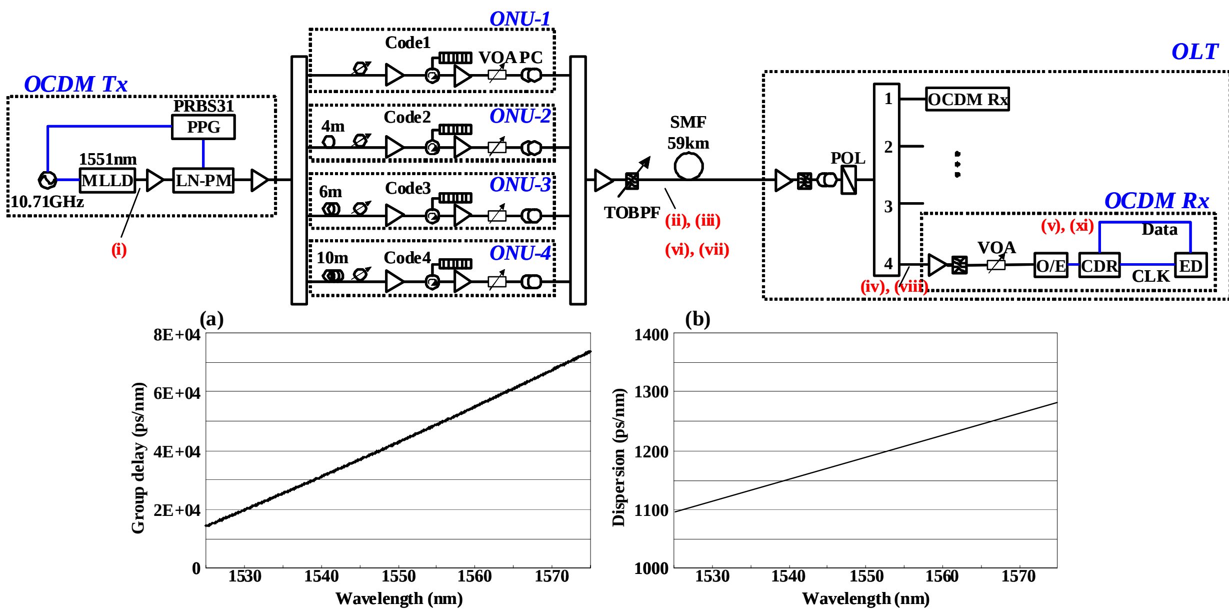

Fig. 1. Experimental setup and measured (a) group delay and (b) total chromatic dispersion of the 59km SSMF.

3. Experimental results

Figures 2 show the experimental results. Figure 2 (i) shows the waveform and spectrum of 1.8 ps optical short pulse generated by MLLD. Figures 2 (ii)-(v) and (vi)-(xi) show waveforms and spectra of the encoding, 4 OCDM, decoding after 59 km SSMF transmission, and after CDR in case of 2.1 and 7.5 nm filter, respectively. After SSMF, the decoding waveform of 2.1 nm filter case is clearer than 7.5 nm one.

Figures 3 show the measured BERs in case of filtered at (a) 2.1 nm and (b) 7.5 nm with/without FEC, respectively. In back-to-back (B-to-B) with FEC, error free (BER<10^{-9}) transmissions have been achieved for all codes of both 2.1 and 7.5 nm filter cases. In back-to-back (B-to-B) without FEC, 7.5 nm filter case has achieved error free for all codes. However, the BER curve of 2.1 nm filter case has an error floor. It is caused by the poor optical signal-to-noise ratio (ONSR) compared with 7.5 nm filter case.

On the other hand, after 59 km SSMF transmission without FEC, all codes of 2.1 nm filter case could acheive FEC limit (BER < 10^{-3}) operation. Meanwhile, 7.5 nm filter case could not achieve the FEC limit (BER<10^{-3}) due to the effective of the chromatic dispersion. As a result, 2.1 nm filter case is suitable for the SSMF transmission without inline dispersion compensation in 10 Gbps, 4-user, OCDMA system with hybrid 16x16-port and SSFBG E/Ds.

4. Conclusion

We have proposed the inline-dispersion-compensation-free OCDMA transmission to optimize the bandwidth of OC's spectrum. Error free transmissions of asynchronous, 4-user, 10Gbps OCDMA system over 59-km SSMF with no inline dispersion compensation have been successfully demonstrated for the first time.

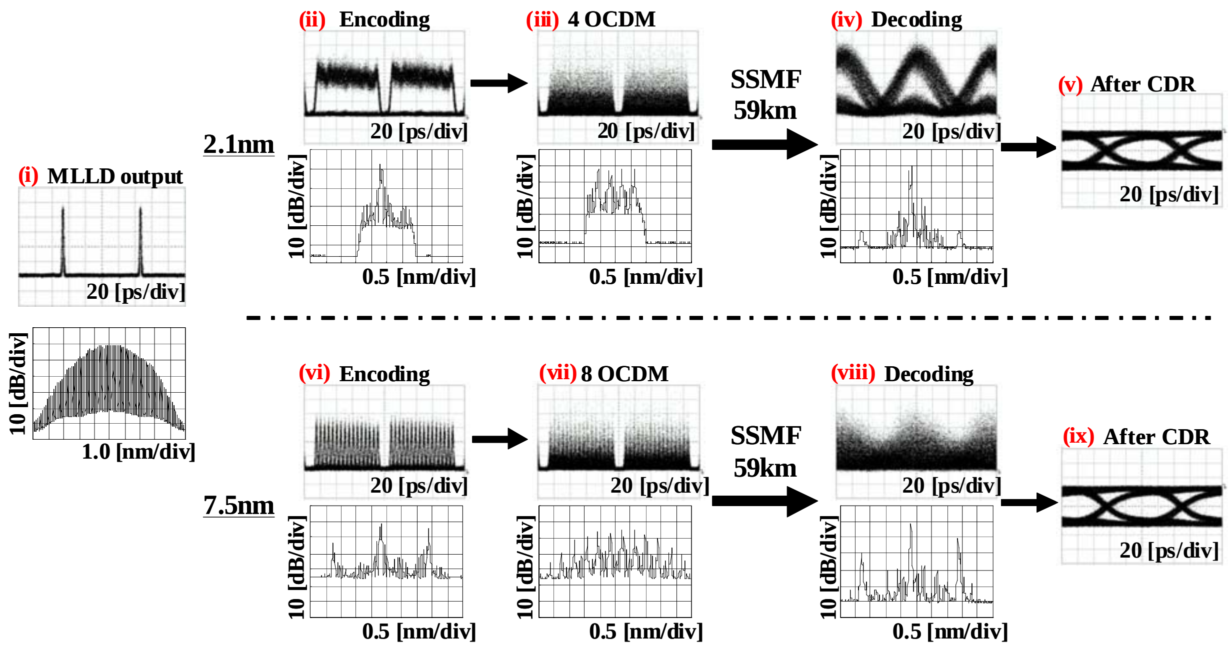

Fig. 2. Experimental results.

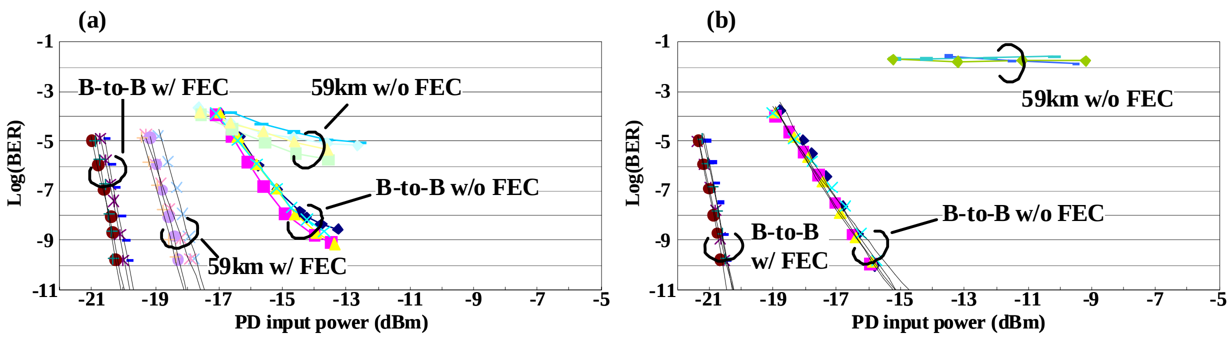

Fig. 3. Measured BERs: (a) 2.1 nm and (b) 7.5 nm filter case.

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