Demonstration of 3-λ×8×10 Gbps WDM/DPSK-OCDMA using 31-chip, 640 Gchip/s SSFBG En/decoder for 10 G Flexible Access Network

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Abstract *We demonstrate a high data-rate SSFBG-based WDM/OCDMA experiment (3 wavelengths with 100 GHz spacing, 8 OCDMA, 10 Gbps/user) using 31-chip, 640 Gchip/s en/decoders, DPSK modulation, time gating and FEC.*

Introduction

Optical code division multiple access (OCDMA) is a promising candidate for next-generation broadband access network [1~2]. Recently, coherent OCDMA using ultra-short optical pulse is receiving increasing attention with the progress of reliable and compact en/decoder devices, such as planar lightwave circuit (PLC), spatial light phase modulator (SLPM) [3], micro ring resonator (MRR) [4], superstructured fiber Bragg grating (SSFBG) [5] and arrayed waveguide grating (AWG) multi-port device [6]. The SSFBG was used mainly for time spreading (TS) OCDMA, while SLPM and MRR were used for spectral encoding (SPE) OCDMA schemes. The SSFBG-based TS-OCDMA scheme is very attractive because the SSFBG en/decoders have the ability of ultra-long optical code (OC) generation, polarization independent operation, good compactness and low loss. The longer the code length is, more the active users can be accommodated [5]. However, it's difficult to achieve high throughput in this scheme because of the compromise between code length and data-rate [7]. Previously, the highest throughput of SSFBG-based TS-OCDMA system was 10×1.25 Gbps [5]. To our knowledge, there has been no report on multi-user SSFBG en/decoder-based OCDMA with above 10 Gbps data-rate.

Generally, in an OCDMA system the asynchronous access capability is essential for providing low latency access with simplified management and soft capacity on demand. However, total capacity (and the throughput) is limited by high multiple-access-interference (MAI) and beat noises for the asynchronous operation [5~6]. Using differential-phase-shift-keying (DPSK) and forward-error-correction (FEC) could significantly enhance the system performance [3~4, 6]. On the other hand, if high throughput and the degree of security are the major considerations, synchronous SPE-OCDMA using slot- or chip- level timing coordination and time gating can mitigate the impairments of MAI and beat noise to achieve high throughput OCDMA [3~4]. These techniques have not been used in SSFBG-based multi-user TS-OCDMA system.

In this paper, we demonstrate for the first time a 10 Gbps/user multi-user SSFBG-based TS-OCDMA system with 31-chip, 640 Gchip/s en/decoders, DPSK modulation and time gating. By combining with WDM technique [4,6,8] and FEC, high throughput SSFBG-based TS-OCDMA system will be achieved.

Experiment

Figure 1 shows the experimental setup. 10.7 GHz optical pulses were generated by a super-continuum (SC) light source and a 15 nm band pass filter (BPF) centred at 1550.8 nm. This signal was then modulated by Lithium Niobate phase modulator (LN-PM) with optical transmission network (OTN) frame, which contains of 2^{31}-1 pseudo random bit sequence (PRBS) payload data and FEC parity. Then the data were split into 3 paths to a multi-user WDM/OCDMA setup with SSFBGs serving as WDM multiplexer and OCDMA encoders simultaneously [8]. The three paths are for signals at wavelengths of λ_1(1550nm), λ_2(1550.8nm) and λ_3(1551.6nm), respectively.

The upper branch is for λ_2. Encoder 1 to 4 are 31-chip, 640 Gchip/s SSFBGs with central wavelength of λ_2 to generate four different BPSK 31-chip Gold codes, the first row in Fig. 2 shows the waveforms of the generated four codes. The duration of the generated OCs is about 50 ps. The waveforms of auto-correlations and several cross-correlations are shown in the second and third rows of Fig. 2, respectively. The peak discrimination ratio between auto-/cross-correlation is very high. The user adjust units consist of fixed fiber delay lines, tunable optical

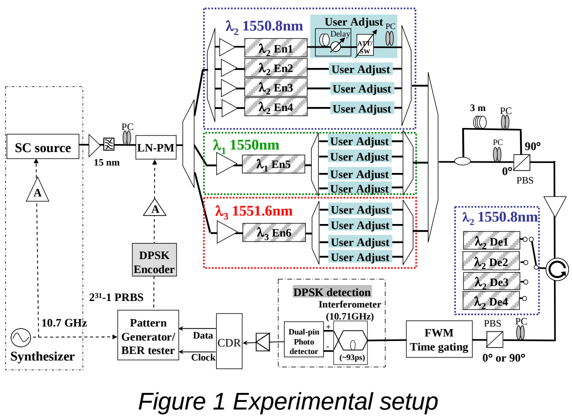

Figure 1 Experimental setup

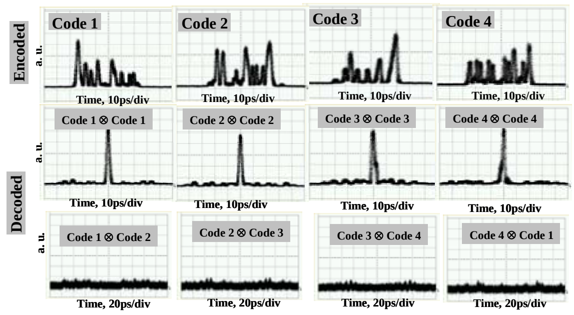

Figure 2 Waveforms of encoded and decoded signal

delay lines, tunable optical attenuator and polarization controllers for controlling the timing, power and polarization of signals of each OCDMA user. Another two branches are for λ_1 and λ_3, respectively. Encoder 5 and 6 are 63-chip, 640 Gchip/s SSFBGs with central wavelength of λ_1 and λ_3. Each encoded signals were split into four paths with user adjust units to emulate interferences in adjacent WDM channels. The multiplexed WDM/OCDMA signals were split into two and combined by a polarization beam splitter (PBS) for polarization multiplexing in order to emulate eight simultaneous OCDMA users in one wavelength [4]. Fig. 3(a) shows the waveform of the multiplexed 3-$\lambda\times$8-OCDMA$\times$10.7 Gbps signal and its spectrum is shown in Fig. 4 by the doted grey line.

At the receiver, the multiplexed signal was decoded by four decoders with central wavelength of λ_2 and a PBS performed the polarization demultiplexing. Fig. 3(b) shows one waveform of decoded signal from decoder 1 and its spectrum is also shown in Fig. 4 by the solid red line. The black and blue lines in Fig. 4 are the spectra of decoded signals of adjacent wavelength channels with $\pm$100 GHz spacing. The SSFBGs thus serve as WDM demultiplexer and OCDMA decoder simultaneously.

In the case of data-rate detection, the MAI outside the auto-correlation peak is a very severe issue [4~5]. Therefore, a four-wave-mixing (FWM) based time gating was employed to provide MAI rejection. The generated signal is much clear and the waveform is shown in Fig. 3(c). The signal was further forwarded to an interferometer with one bit delay for DPSK decoding and a balanced detector followed by 7.5 G low-pass-filter performed data-rate detection. Fig. 3(d) shows the eye diagram of the detected signal. The clear eye opening verifies that the phase information has been preserved after the all optical time-gating. Finally, the clock-data-recovery (CDR) circuit generated data and clock signals for bit-error-rate (BER) testing.

Fig. 5 shows the measured BER performances. In the single wavelength case, error-free (BER<10^{-9}) has been achieved for 8 OCDMA users without FEC. While in the 3-$\lambda\times$8-OCDMA$\times$10.7 Gbps case, error free has been achieved with the assists of FEC.

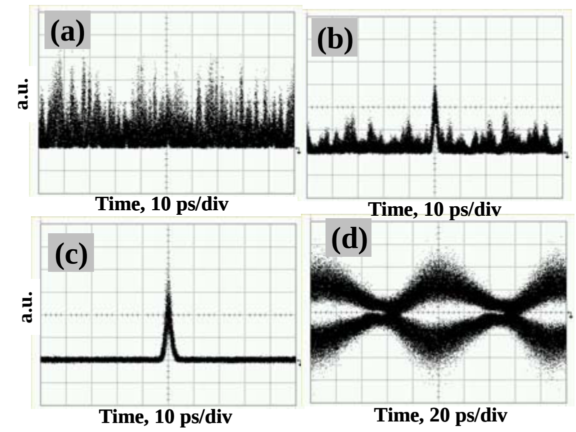

Figure 3 Measured waveforms of (a) multiplexed signal; (b) Decoded signal; (c) signal after time gating and (d) eye diagram after balanced detection

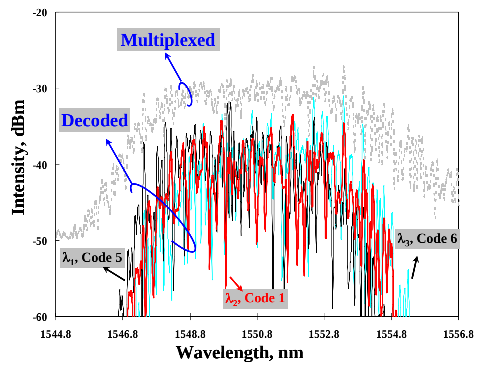

Figure 4 Spectra of the multiplexed and decoded 3-λ $\times$8-OCDMA signals

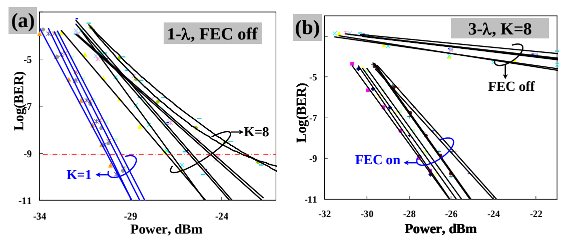

Figure 5 BER performances with (a) single and (b) three wavelengths

Conclusions

10 Gbps/user multi-user SSFBG en/decoder-based WDM/DPSK-OCDMA system has been demonstrated for the first time. The channel spacing is 100 GHz and the total throughput is ~240 Gbps. Better performance could be expected by further optimizing the channel spacing and code selection to enable flexible 10 G access network.

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