Demonstration of 16-user OCDMA over 3-wavelength WDM using 511-chip, 640 Gchip/s SSFBG en/decoder and single light source

Taro Hamanaka[1], Xu Wang[2], Naoya Wada[2], and Ken-ichi Kitayama[1]

[1]*Department of Electronics and Information Systems, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*

[2] *National Institute of Information and Communication Technology (NICT),, 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795 Japan.*

Abstract: We experimentally demonstrated 16-user OCDMA over 3-wavelength, 100-GHz spacing WDM system using 640 Gchip/s super-structured FBG en/decoder and single light source, with the frequency interval far narrower than 640GHz.

OCIS codes: (060.2330) Fiber optics communication (060.4230) Multiplexing (060.4370) Nonlinear optics, fibers

Introduction Optical code division multiple access (OCDMA), which provides other dimension multiple access than time- and wavelength-domain multiple accesses, is a candidate for next-generation broadband multiple access technique to apply to symmetric bandwidth FTTH services. It has attractive features of all high-speed optical processing, full asynchronous transmission, low access delay, soft capacity on demand, and flexibility in controlling the quality of service (QoS) [1]. High capacity access network can be achieved by combining OCDMA with wavelength division multiplexing (WDM) technique [2].

In this paper, we experimentally demonstrated OCDMA over 100-GHz spacing WDM system with single light source, using 511-chip super-structured FBG (SSFBG) en/decoder, tuned to 1550, 1550.8 and 1551.6 nm respectively. MAI noise and the effect of interchannel crosstalk were overcome due to record-long 511-chip SSFBG and optical thresholder based on cascaded SHG and DFG in PPLN [3].

OCDM over WDM PON Fig.1 shows the architecture of OCDMA over WDM PON. On each WDM grid λ_x (x = 1,…,m) n users can be accommodated by assigning each user to an unique optical code OC_y (y = 1,…,n). The code sequences can be reused on every WDM grid to improve the spectral efficiency. However, this system will suffer from not only multiple access interference (MAI) but also the WDM interchannel crosstalk.

SSFBG en/decoder can generate ultra-long optical code with excellent correlation property, polarization independent performance, compactness, and potentially low-cost [4][5]. Another advantage is that the SSFBG decoder can act as WDM demultiplexer, thus eliminating an expensive AWG used as the splitter. In a previous WDM/OCDMA experiment using 255-chip, 320 Gchip/s SSFBG, the channel spacing has been set to be about 500 GHz, which is ~1.6 times larger than the chip-rate, to reduce the interchannel crosstalk [4]. This large channel spacing results much low spectral efficiency (~0.005) 0f the system. Fig.2 shows spectra of 511-chips, 640 Gchip/s SSFBG. The first notch appears about 5 nm (640 GHz) apart from the central wavelength. In a WDM/OCDMA system with this SSFBG encoder/decoder, the crosstalk can be minimized if the WDM channel spacing equals to the chip-rate so that the central wavelength of the adjacent channel is set on the first notch of the SSFBG. The spectral efficiency can be improved to ~0.02. In a compromise between the channel spacing and number of active users (K), the channel spacing can be further narrowed down to 100 GHz to further improve the spectral efficiency with acceptable power penalty [2]. In this paper, we verify the feasibility of this scheme in a set of experiments.

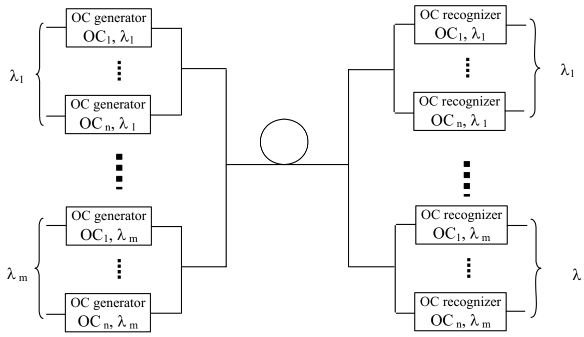

Fig. 1. Architecture of OCDMA over WDM PON

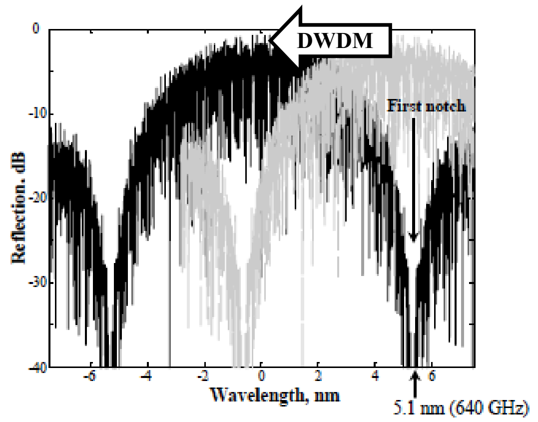

Fig. 2. Spectra of OCDMA over WDM system with 511-chip SSFBG

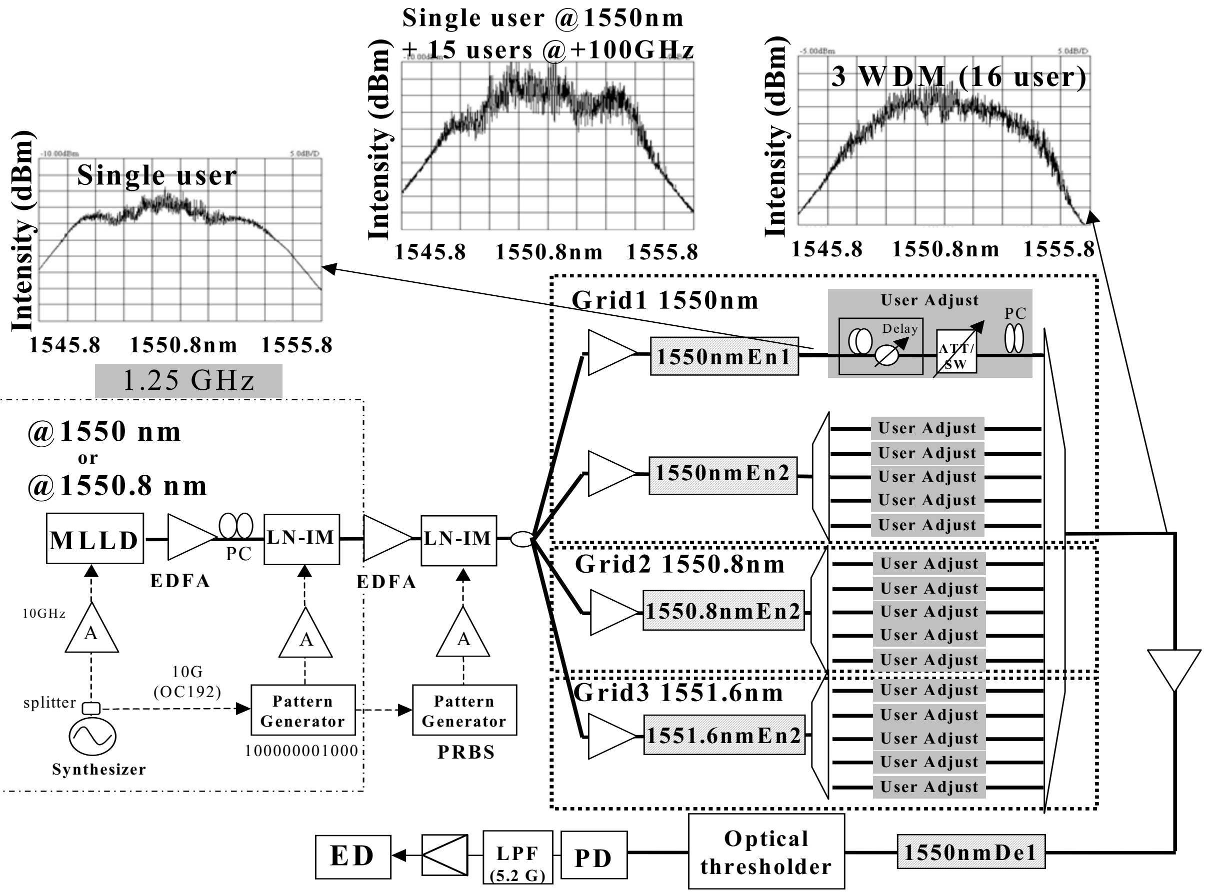

Fig. 3. The setup of OCDMA over 3-wavelegth WDM experiment, and spectra of single 2-WDM and 3-WDM (16-user) encoded signal

Experiment The experiments were carried out with single-, 2- and 3-wavelength. Figure 3 shows the experimental setup. The optical pulse train generated from a single mode-locked laser diode (MLLD) was modulated by 2^{23}-1 pseudo-random bit sequence (PRBS) at 1.244 Gbps with lithium niobate intensity-modulators (LNIMs). The amplified signal was split and encoded by 511-chip SSFBG encoders tuned to different wavelengths. Fixed fiber delay line with different length, tunable optical delay line (TODL) and polarization controller (PC) were used to investigate system performance in the worst-case scenario [5]. Tunable attenuator (ATT) with switch was also used to balance the power level from each channel and adjust the number of K. In this experiment, 15 branches were setup after three encoders (1550-nm, 1550.8-nm and 1551.6-nm Code2) to emulate multiple interfering channels. In single user experiments, we used the SSFBG en/decoders tuned to different wavelengths and measured the maximum K that can be accommodated with the error free (BER<10^{-9}) on different wavelengths. In the 2-wavelength experiments, we demonstrated; (a) single user @1550nm + (K-1) users with the channel spacings of 100GHz (@1550.8nm) and 200 GHz (@1551.6nm), and (b) K/2 users @ 1550nm + K/2 users with the channel spacings of 100 GHz and +200 GHz. In the 3-wavelength experiments, the central wavelength of MLLD was set at 1550.8 and the other two WDM channels were set with ±100GHz apart. Multiplexed signals were amplified and an SSFBG decoder decoded the target signal at the given wavelength. Eye diagrams of 16-user encoded and decoded signals are shown in the top and middle of Fig. 4. It is obvious that the decoded signals are suffered from severe MAI and beat noise. These noises could be suppressed by employing the optical thresholder based on cascaded SHG and DFG in PPLN after the decoder [3] as shown in the lower diagrams of fig. 4. Photodiode (PD) followed by a 5.2 GHz low-pass-filter (LPF) was used to perform data-rate detection, and bit error rate (BER) was finally measured by error detector (ED).

Fig. 5 (a) shows measured BERs for different K in the single-wavelength experiment. The maximum K is 10 for all the three wavelength same as our previous results [5]. Fig. 5 (b) shows measured BERs in 2-wavelength experiments with single user at 1550 nm and multiple users at +100 or +200 GHz. Figure 5 (c) shows BERs of 2-wavelength with (K/2 + K/2) at +100 or +200 GHz channel spacing and 3-wavelength experiments. In each measurement, 16-user error free transmission was achieved. Fig. 5 (d) summarizes measured power penalties for BER = 10^{-9} as a function of K for different experiments. The power penalties are smaller with +200 GHz than +100 GHz channel spacing due to smaller interchannel crosstalk. In the 2-wavelength with 100 GHz spacing result, error free for 8 users in each channel has been achieved. In the 3-wavelength result, error free for 6 users @ 1550 nm and 5 users @ 1550.8 nm and 1551.6 nm has been achieved. The total capacity was limited to 16 users by the experimental setup. Assume a 1.24-Gbps OCDMA system can accommodate 10 active users on a single WDM grid [5], and the channel spacing is 100 GHz. The spectral efficiency can be ~0.125 [bit/s/Hz]. It is noteworthy that a single MLLD can cover 5 WDM channels with more than 50 users.

Conclusions We experimentally demonstrated 16-user OCDMA over 3 WDM with 100-GHz channel spacing using 511-chip, 640 Gchip/s SSFBGs en/decoder, single MLLD light source and PPLN optical thresholder based on cascaded SHG and DFG. The spectral efficiency has been significantly enhanced by setting the channel spacing far narrower than the chip-rate in a WDM/OCDMA system using SSFBGs.

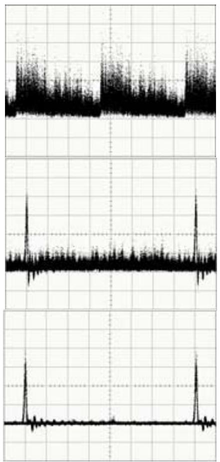

Fig. 4. The waveforms of 16-user encoded signal (top), decoded signal (middle) and output from the optical thresholder (bottom)

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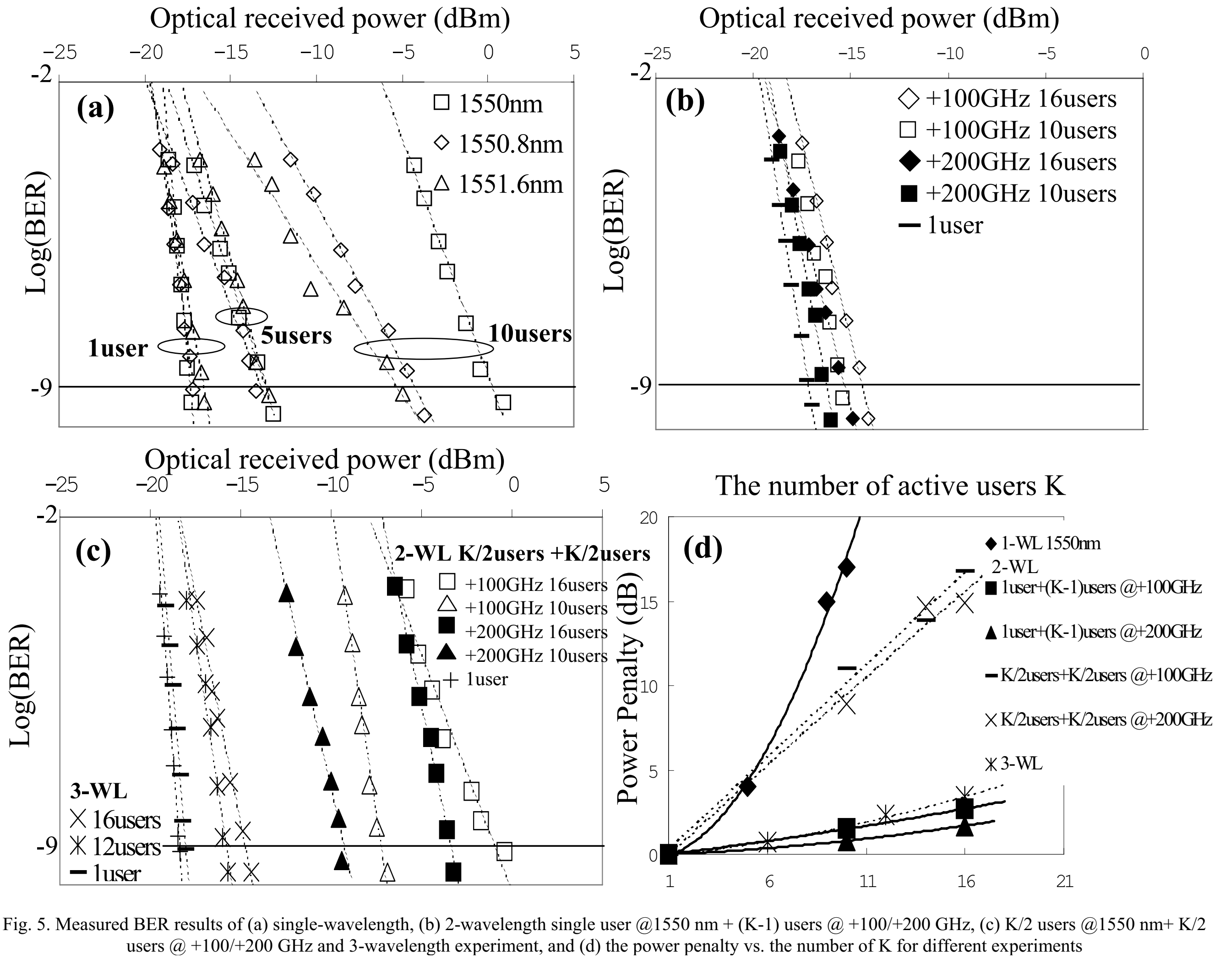

Fig. 5. Measured BER results of (a) single-wavelength, (b) 2-wavelength single user @1550 nm + (K-1) users @ +100/+200 GHz, (c) K/2 users @1550 nm+ K/2 users @ +100/+200 GHz and 3-wavelength experiment, and (d) the power penalty vs. the number of K for different experiments