Field Trial of 3-WDM×10-OCDMA×10.71 Gbps, Truly-asynchronous, WDM/DPSK-OCDMA Using Hybrid E/D Without FEC and Optical Threshold

Xu Wang[1], Naoya Wada[1], Tetsuya Miyazaki[1], Gabrilla Cincotti[2] and Ken-ich Kitayama[3]

1. National Institute of Information and Communication Technology (NICT), 4-2-1 Nukui-Kitamachi, Koganei, Tokyo 184-8795 Japan, e-mail: xwang@nict.go.jp

2. Department of Applied Electronics, University of Roma Tre, Rome, Italy

3. Department of Electrical, Electronics and Information Systems, Osaka University, Osaka 565-0871, Japan

Abstract: A cost-effective WDM/DPSK-OCDMA sharing a single multi-port encoder in central office, tunable decoders in ONU was demonstrated in field trial. 111 km error-free transmission of truly-asynchronous, 3-WDM×10-OCDMA×10.71Gbps/user has been achieved without FEC and optical thresholding.

OCIS codes: (060.2330) Fiber optics communication; (060.5060) Phase modulation; (060.4230) Multiplexing; (999.9999) optical code division multiple access (999.9999) balance detection (999.9999) Field trial

Introduction Recently, optical code division multiple access (OCDMA), particularly coherent OCDMA technique, is being extensively investigated in many ways [1-7]. Most of the approaches are synchronous OCDMA, which operates under the best-case situation by proper timing coordination in chip- or slot-level to carefully avoid the overlaps between signal and interferences [2-5]. Time gating and optical thresholding have also been used to suppress multiple access interference (MAI) enabling data-rate detection. Synchronous OCDMA can increase frequency efficiency for transmission [2~3, 5], however, for practical access network application, the capability of asynchronous multi-user access is of key attribute. In asynchronous OCDMA, signal and interferences are received with random overlap, therefore, the system should be able to operate in the worst-case scenario to guarantee truly asynchronous OCDMA. With the techniques used in synchronous OCDMA, it is very difficult to achieve even 2-user OCDMA at 10Gbps in a truly asynchronous environment [2-5]. Employing ultra-long optical codes (OC), optical thresholding and forward-error-correction (FEC) technique can effectively suppress the beat noise as well as MAI in asynchronous environment to enable multi-user OCDMA at data rate as high as 10 Gbps [6-7]. However, this is still not a cost-effective solution, which is the major concern for practical application.

In this paper, we for the first time demonstrated the field trial of a cost-effective truly-asynchronous WDM/OCDMA network using multi-port encoder/decoder (E/D) in the central office, tunable transversal-filter (TVF) type decoder in optical network unit (ONU), and differential-phase-shift-keying (DPSK) data format. Truly-asynchronous signals of 3 wavelengths (400GHz spacing), 10-OCDMA users at 10.71Gbps/user has been successfully transmitted with bit-error-rate (BER)<10^{-9} without using FEC, optical thresholding.

Design of the cost-effective WDM/OCDMA Wavelength division multiplexing (WDM) technique is very successful in current fiber optic communication networks. One prospective broadband access network will be a hybrid WDM/OCDMA network [8]. Figure 1 shows the architecture of the proposed cost-effective WDM/OCDMA network, which uses a large scale multi-port E/D in the central office, and a low cost E/D in the ONU. The multi-port E/D [9] has very high power contrast ratio (PCR) between auto- and cross-correlation signals, which can significantly suppress MAI and beat noise with a short OC [7]. The multi-port E/D with periodic spectral response can process multiple OCs in multiple wavelength bands with single device as shown in the inset, and the cost will be shared by all the subscribers. At the ONU side, fixed superstructured FBG (SSFBG) or TVF can be used as the low cost E/D. The SSFBG and TVF-type E/D has already been verified that can be hybrid used for

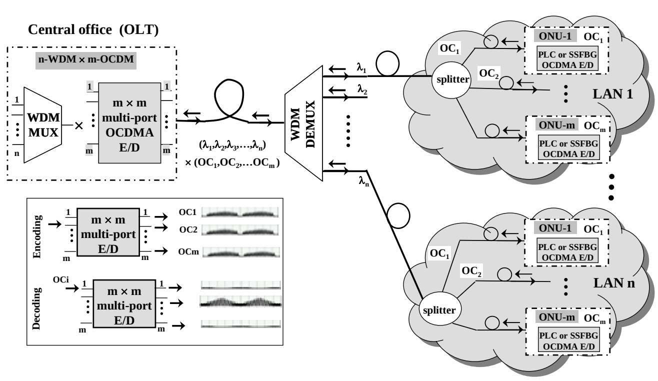

Fig. 1. Proposed WDM/OCDMA network architecture

OC en/decoding [10]. Here we used multi-port E/D as encoder and tunable TVF-type E/D as decoder to verify that hybrid using different types of E/Ds can work properly in a system. Figure 2 (a) shows the waveforms of a generated 16-chip, 200Gchip/s OCs from the 16×16 multi-port E/D (upper) and TVF-type E/D (lower). The phase pattern of the represented OC is shown on the top of the figure. The auto-/cross-correlations of hybrid using the multi-port encoder/tunable TVF decoder (hybrid E/D) are shown in Fig 2(b). The measured PCRs are shown in Fig. 2(c) together with those of a multi-ports E/D for four different OCs. They are in good agreement with each other, and the values range 12~22 dB, which is one key to enable multi-user asynchronous OCDMA by suppressing the noises.

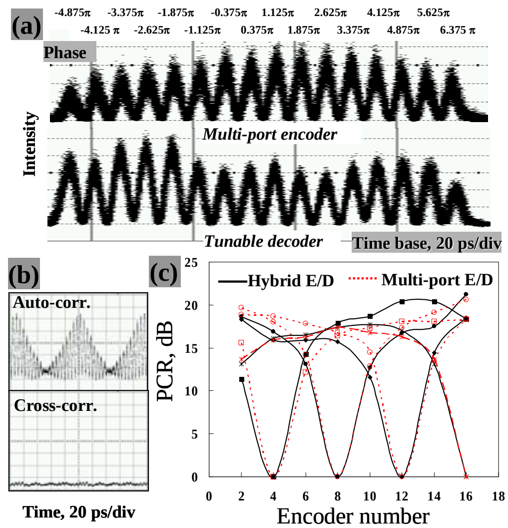

Fig. 2 Performance of multi-port encoder with TVF decoder

On the other hand, optical threshold was one critical technique in coherent OCDMA system to enable data-rate detection instead of chip-rate detection [4-6]. The only alternative technique so far is using FEC to enhance the noise tolerance [7]. As an emerging technique, DPSK-OCDMA with balanced detection has been shown to have superior noise tolerance over conventional on-off-keying (OOK)-OCDMA [11], which could allow it accommodating more active users. In addition, it also has the advantages of improved receiver sensitivity, no need for dynamic threshold level setting, and enhanced security compared to OOK-OCDMA [11]. DPSK is another key to enable multi-user asynchronous OCDMA at 10Gbps without optical threshold and FEC by enhancing noise tolerance of the system.

Experiment Figure 3 shows the experimental setup. Three mode-lock laser diodes (MLLD) generated 3 WDM pulse signals with about 3.2 nm (400 GHz) channel spacing. The generated ~1.8 ps optical pulses are at a repetition rate of 10.709 GHz with central wavelengths of 1550.2 nm, 1553.4 nm and 1556.6 nm, respectively. Each signal was modulated by Lithium Niobate phase modulator (LN-PM) separately with 2^{31}-1 pseudo random bit sequence (PRBS) from independent data sources. The signals were then multiplexed and go to the port #1 of the 16×16 ports E/D. Inset α shows the spectrum of this multiplexed signal. 16 different OCs were generated at the 16 output ports, and

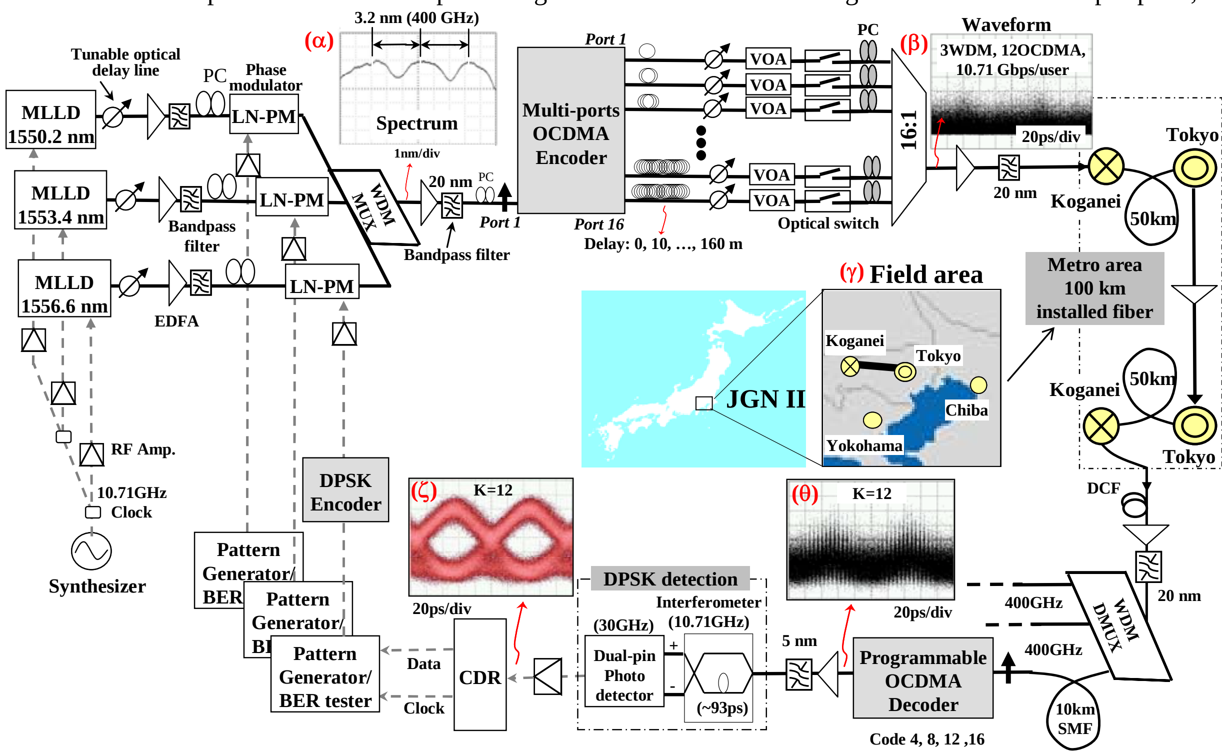

Fig. 3. Experimental setup

then were mixed in a truly-asynchronous manner with balanced power, random delay, random bit phase and random polarization states. Inset β shows the waveform of the mixed signals of 3 WDM, 12 OCDMA users. This signal was then launched into 100 km SMF, which is part of JGNII [12] installed in the field between our laboratory in Koganei city and Otemachi of downtown Tokyo in a loop-back configuration as shown in the inset γ. The WDM×OCDMA signal was then de-multiplexed by the WDM DEMUX with 400 GHz channel spacing, and further transmitted thru ~11km SMF before arrived in the 16-chip programmable TVF-type decoder. The decoder was programmed to decode four different OCs correspond to those of encoder ports 4, 8, 12, 16. A fiber based interferometer and balanced detector perform the DPSK detection. The data was finally tested by the BER tester with clock signal from the clock-data-recovery (CDR) circuit.

Figure 4 shows the measured BER performances as well as several eye diagrams. Figure 4(a) shows those for 4 different decoders with 3 WDM, single and 12 active OCDMA users (K=1, 12) in back-to-back (B-to-B) case. Error-free (BER<10^{-9}) has been achieved for all the OCDMA users in 3 WDM channels. The average power penalty for K=12 to K=1 is about 8 dB. Figure 4(b) shows a comparison of BERs between DPSK-OCDMA and OOK-OCDMA with and without FEC for K=12 [7]. The performance has been significantly improved in DPSK compared to OOK without FEC. Compared to OOK with FEC, the sensitivity at BER=10^{-9} was improved more than 2 dB. Figure 4(c) shows the BER performance degradation after field transmission. For K=12, error floor around 10^{-9} has been observed in several cases due to impairments during the 111 km transmission. Figure 4(d) shows that error free has been successfully achieved for all the 4 decoders with 3-WDM and up to 10 OCDMA users in the field trail.

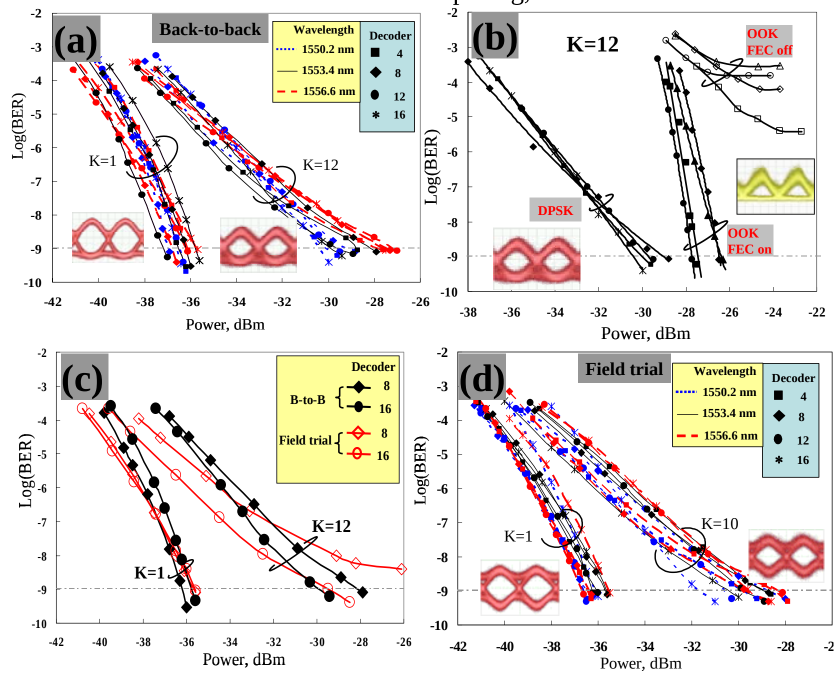

Fig. 4. BER performances

Finally, it is worth noting that all the measurements were taken under the worst-case scenario by adjusting the tunable optical delay lines and polarization controllers (PC) to guarantee the truly-asynchronous operation [6-7]. The threshold level was fixed to 0 in the measurement independent of K. Therefore, dynamic threshold level setting requirement could be released in the receiver as well. The frequency efficiency (η) is about 0.32 and 0.27 bit/s/Hz for B-to-B and field transmission, respectively. As a comparison, [2] and [3] have reported WDM/OCDMA experiments with η=1.6 and 0.125, respectively. However, they are synchronous approaches with stringent timing coordination combining with time gating [2-3] and polarization multiplexing [2]. For asynchronous OCDMA, our result is the highest reported result so far.

Conclusions The field trial of a cost-effective truly-asynchronous WDM/DPSK-OCDMA using hybrid E/D has been successfully demonstrated with frequency efficiency of 0.27 bit/s/Hz in truly-asynchronous environment. The total capacity is 3-WDM×10-OCDMA×10.71Gbps and transmission distance is 111 km. Frequency efficient asynchronous OCDMA could be expected by using a large scale multi-port E/D with higher PCR, polarization multiplexing and FEC.

References

1. K. Kitayama, *et al.*, ECOC'04, Tu4.6.1, 2004.
2. H. Sotobayashi, *et al.*, IEEE Photon. Tech. Lett., **14**, 555-557 (2002).
3. S. Etemad, *et al.*, IEEE PTL, **17**, 929- 931, 2005.
4. Z. Jiang, *et al.*, IEEE Photon. Tech. Lett., **17**, 705-707, 2005.
5. R. P. Scott, *et al.*, IEE Electronics Lett., **41**, 1392-1393 (2005).
6. X. Wang, *et al.*, OFC'05 postdeadline, PDP33, 2005.
7. X. Wang, *et al.*, ECOC 2005 post-deadline, Thu 4.5.3, 2005.
8. K. Kitayama, *et al.*, to appear in J. Lightwave Technol.
9. G. Cincotti, J. Lightwave Technol., **22**, 642-1650, 2004.
10. X. Wang, *et al.*, ECOC 2005, We1.4.5, 2005.
11. X. Wang, *et al.*, to appear in IEEE Photon. Tech. Lett.
12. www.JGN.nict.go.jp