Experimental demonstration of a centralized light source OCDMA-PON based on polarization multiplexing

*Jie Liu, Changjian Guo, Dawei Wang and Sailing He
Centre for Optical and Electromagnetic Research, State Key Laboratory for Modern Optical Instrumentation, Zhejiang University, Hangzhou 310058, China

ABSTRACT

A novel centralized light source OCDMA PON without wavelength filters is proposed and experimentally demonstrated. The OCDMA coded signals and the unmodulated clock pulses are polarization-multiplexed and simultaneously transmitted in the downlink. Then the received clock pulses at the ONU side are used as the source for the uplink transmission. The experiment results based on a two-user 2.5 Gb/s OCDMA system show that excellent performance can be achieved after a 20-km transmission.

Keywords: Optical Code Division Multiple Access (OCDMA), passive optical network (PON), polarization, access network

1. INTRODUCTION

There is a growing demand for future access networks capable of providing secured, high-bandwidth and multi-protocol data services [1]. Optical Code Division Multiple Access (OCDMA) is one such access technique which utilizes optical codes for transporting and multiplexing data bits. OCDMA techniques can offer various advantages including asynchronous operation, protocol transparency, simplified network control and more importantly, the potential of security enhancement due to its encoding characteristics [2, 3]. Recently, the centralized light source (CLS) architecture has emerged as an attractive way for the passive optical network (PON). In this architecture, all the light sources are located at the optical line terminal (OLT) to eliminate the costly light source at the user side. The CLS architecture has been introduced to the OCDMA networks by utilizing wavelength filters to separate the uplink source from the modulated downlink [4-6]. However, for the coherent OCDMA system, such wavelength filters will cause pulse broadening and distortion of the optical pulse source at the transmitting terminal, and consequently degrade the performance of system.

In this paper, we propose a novel CLS architecture without any wavelength filter for the OCDMA PON. The OCDMA coded signals and the unmodualted clock pulses are polarization-multiplexed and simultaneously transmitted to the users from the OLT. The clock pulses can then be modulated and coded at the users' side for the uplink transmission, eliminating the expensive ultra-short pulse lasers at the subscriber's terminal. In addition, such a system may be ideal for use in short-distance optical access networks, where polarization states remain fairly stable [7]. A two-user 2.5 Gb/s OCDMA system using super structured fiber Bragg gratings (SSFBGs) as en/decoders is set up to test this architecture. It is shown that effective reception after 20-km transmission and robust performance can be achieved.

2. PROPOSED SYSTEM ARCHITECTURE

Figure 1 shows the schematic diagram of our proposed system architecture. The same optical pulse source, which is often mode locked laser diode (MLLD), is used at the OLT, for both downlink and uplink transmission. A polarization beam splitter (PBS) is used to separate the two states of polarization. One polarization state will be modulated and encoded for the downlink transmission, and the other will be transmitted to the optical network units (ONUs)' side as

*liujie@coer.zju.edu.cn; phone: +86 571 88206516 ext 220

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their light source for uplink communication. Here, note that through the multi-user modulators and encoders, the polarizations of coded signals for different users can nearly keep still, because the polarization-maintaining modulators and encoders will not cause obvious polarization rotation. As a result, the coded OCDMA signals and the unmodulated clock pulses can be combined by a polarization beam combiner (PBC), keeping them in two orthogonal states of polarization, and then transmitted to the ONUs through an optical coupler at the remote node (RN). At the ONU, the received signals are polarization-demultiplexed using a polarization demultiplexer, to recover both OCDMA signals and clock pulses. Afterwards, a matched decoder at the receiving end is used to decode the desired channel, while data for uplink transmission are modulated onto the clock pulses, coded by the specific encoder and then transmitted back to the OLT using the same fibre link.

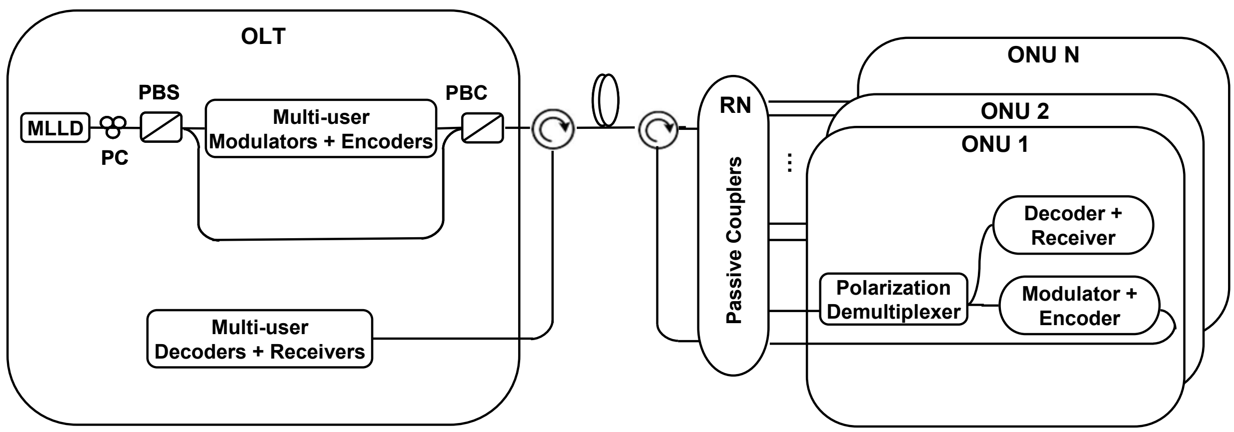

Fig. 1. Centralized light source OCDMA PON based on polarization multiplexing. MLLD: mode locked laser diode; PBC: polarization beam combiner; PC: polarization controller.

3. EXPERIMENTAL DEMONSTRATION

The experimental setup of a two-user 2.5-Gb/s OCDMA system is illustrated in Figure 2. For the downlink transmission, the 1.76ps pulses, generated by the MLLD with the repetition rate of 9.953GHz and wavelength centered at 1552.3nm, were first split into two orthogonal states of polarization by a PBS. And then the pulse train in one branch was converted to a 2^{23}-1 pseudorandom bit sequence (PRBS) at 2.5-Gb/s by a Mach-Zehnder modulator (MZM). The resultant data stream was split into two paths by a 3-dB coupler and encoded by two different SSFBGs with chip length of 127. In the other branch, a 2-km standard single mode fibre (SMF) was used to decorrelate the two polarization states. The OCDMA coded signals were finally combined with the clock pulses by a PBC and launched into a 20-km SMF, which is followed by a dispersion compensation module (DCM). After amplified by an erbium doped fibre amplifier (EDFA), the signals were split by a 3-dB optical coupler and broadcast to the two ONUs at the receiving end.

At each ONU, a PBS was used to polarization-demultiplex the OCDMA coded signal and the clock pulses. Then the OCDMA signal was decoded by a matched SSFBG and directly detected by a 10-Gb/s photo detector (PD) for bit error rate (BER) analysis. Simultaneously, the received clock pulses were modulated by 2^{15}-1 PRBS at 2.5-Gb/s and then encoded by another 127-chip SSFBG. The coded signals from the two ONUs were combined by another optical coupler and transmitted back to the OLT through the same fibre link. Finally, a 12.5-Gb/s error detector (ED) was used for the BER measurement.

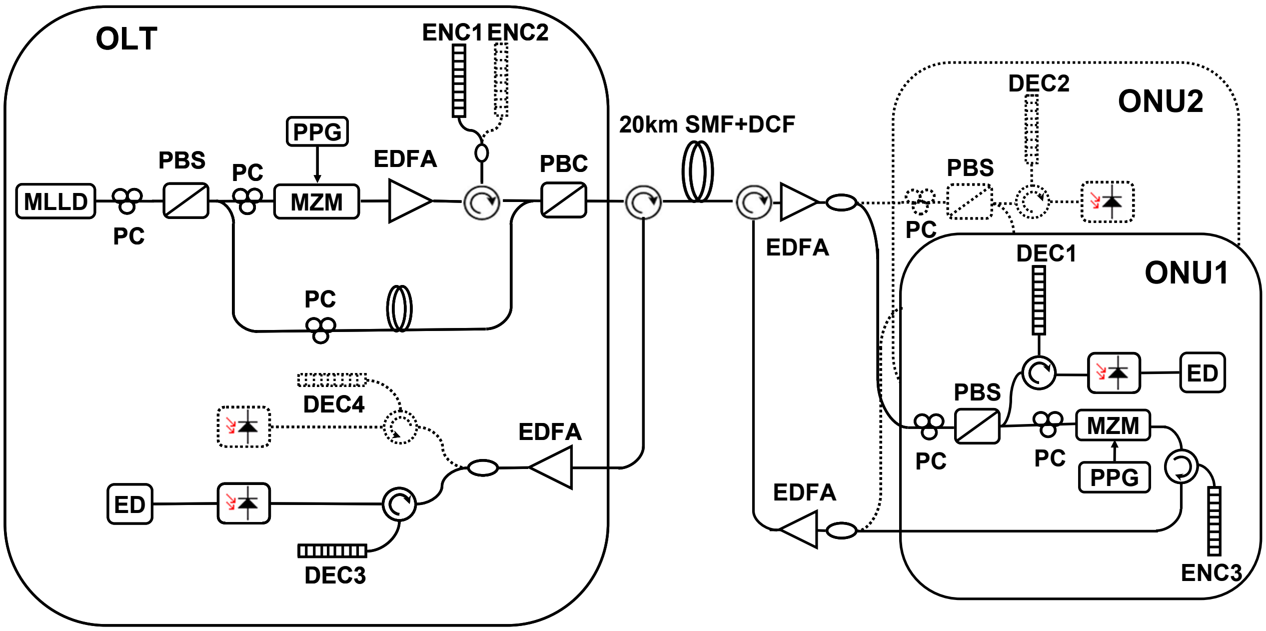

Fig. 2. Experiment setup. MZM: Mach-Zehnder modulator; PPG: programmable pattern generator; SMF: single mode fibre; DCM: dispersion compensation module; EDFA: erbium doped fibre amplifier; PBS: polarization beam splitter; ENC: encoder; DEC: decoder; ED: error detector.

4. RESULTS AND DISCUSSION

The optical spectra of the OCDMA coded signals (the lower one) and clock pulses (the upper one) are shown in Figure 3. Note that they were adjusted to approximately the same power level to ensure a similar gain after amplification. Figure 4 illustrates the eye diagrams of the OCDMA signals and the unmodulated clock pulses. The eye diagrams of the modulated 2.5-Gb/s signal before and after the encoders for downlink transmission are shown in Figure 4(a) and (b). The pulses are extended to the whole bit period after encoding, and the eyes are closed. For downlink transmission, the unmodulated clock pulses from MLLD, eye diagrams of the decoded downlink signal in the cases of one user and two users after 20-km transmission are shown in Figure 4(c)-(e), respectively. One can see that the multiple access interference (MAI) occurred in the case of two users. For the uplink, the received clock pulses at the ONU are shown in Figure 4(f). Compared to the original pulses from MLLD (shown in Figure 4(c)), the clock pulses received by the users have a bit broadening due to the chromatic dispersion in the fibre link. And this gives some impact on the upstream signal, which can be reflected in Figure 4(g) and (h).

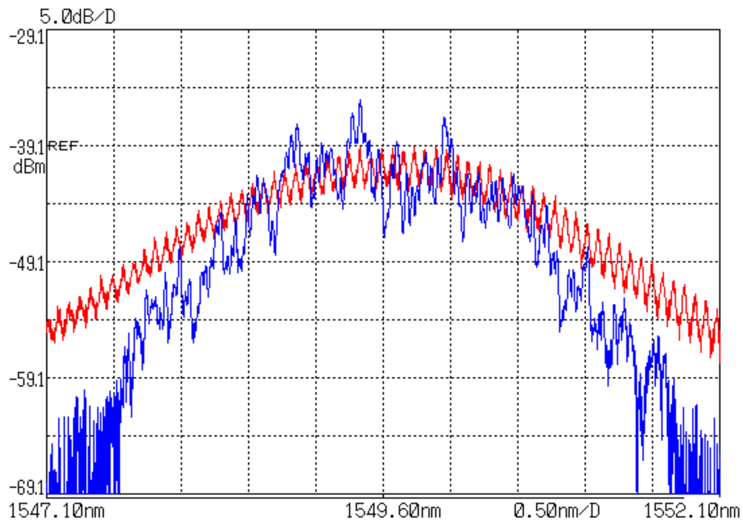

Fig. 3. Spectra of OCDMA coded signals (the lower one) and clock pulses (the upper one).

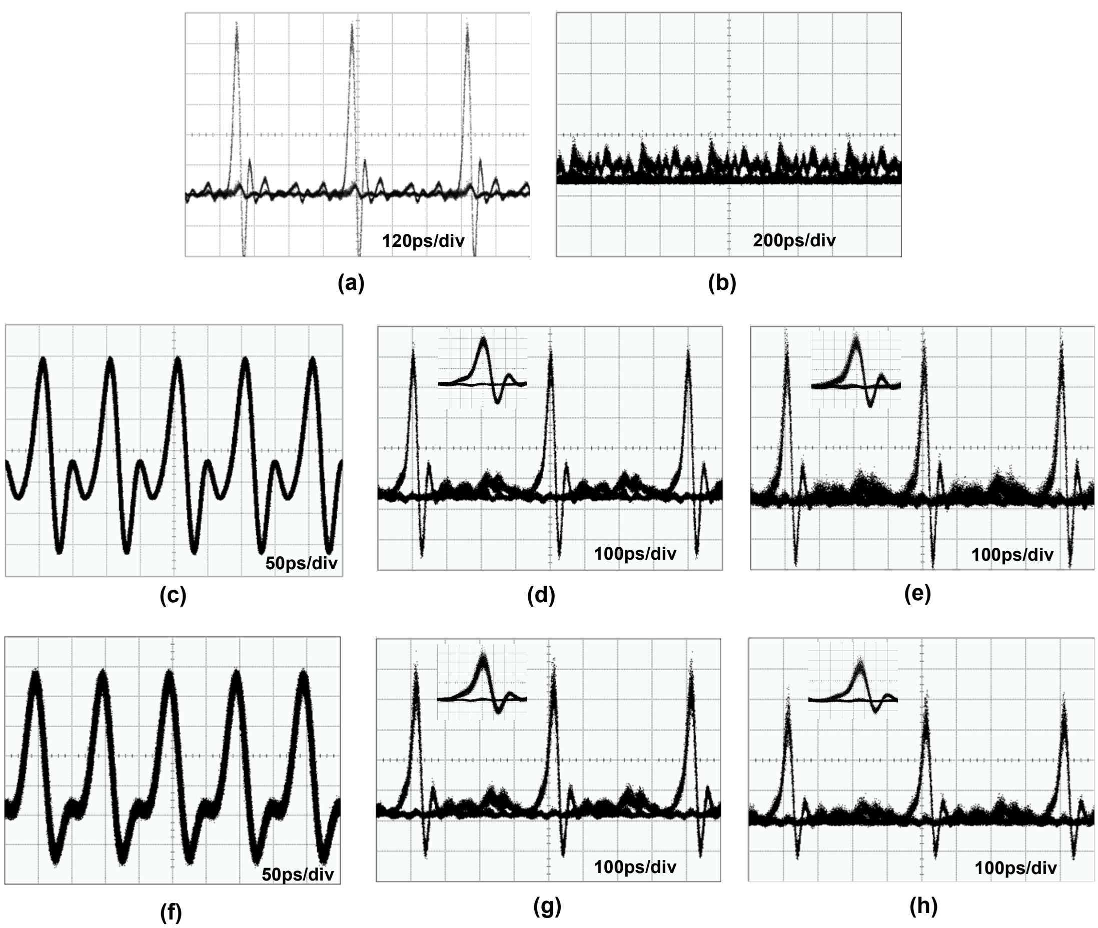

Fig. 4. Eye diagrams for (a) modulated signal before encoders; (b) encoded signal in the case of two users; (d) decoded downlink signal in the case of one user; (e) decoded downlink signal in the case of two users; (g) decoded uplink signal in the case of one user; (h) decoded uplink signal in the case of two users. Clock pulses (c) generated from MLLD; (f) received at the ONU.

Figure 5 plots the various BER measurements both in the cases of one user and two users. Compared to the back-to-back measurements, excellent performance with about 0.8-dB power penalty can be obtained for uplink channel, while almost no power penalty is observed for the downlink channel, after transmission over 20-km fibre span in the case of one user. In the case of two users, there is about 0.4-dB and 1-dB power penalty for downlink and uplink channels, respectively, when it is compared to the back-to-back measurements after transmission over 20-km fibre span.

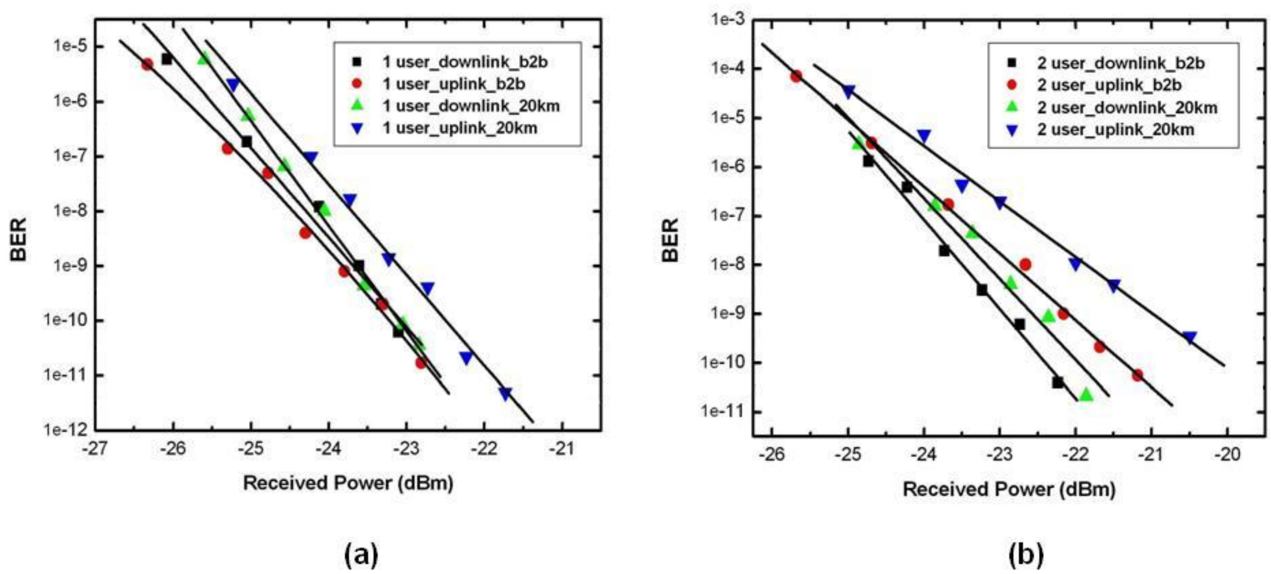

Fig. 5. BER curves in the case of (a) one user; (b) two users.

5. CONCLUSION

We have proposed and experimentally demonstrated a novel CLS OCDMA PON architecture, by polarization-multiplexing the OCDMA coded signals and the clock pulses in the downlink. The clock pulses received at the users' terminal are then modulated and encoded for the upstream transmission. This architecture not only eliminates the expensive ultra-short pulse lasers at the subscriber's terminal, but also avoids the use of any wavelength filter and thus there is no initial broadening and distortion of ultra-short pulses from the MLLD. The experiment results based on the two-user 2.5 Gb/s OCDMA system confirm the feasibility of our scheme.

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