Advanced Modulation Techniques in OCDMA System

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Abstract *Advance modulation techniques such as differential phase-shift keying (DPSK), differential quaternary phase shift keying (DQPSK) and code-shift-keying (CSK) modulation with balanced detection has been proposed and demonstrated in high capacity asynchronous optical code division access (OCDMA) system using different encoding/decoding schemes to beat the MAI noise and enhance the security.*

Introduction

Optical code division multiple access (OCDMA) technique, which allows multiple users share the same transmission media by assigning different optical codes (OCs) to different users, is an attractive candidate for next generation broadband access networks [1]. Figure 1(a) illustrates the basic architecture and the working principle of an OCDMA passive optical network (PON) network.

Partricularly, coherent OCDMA technique is receiving much attention for the overall superior performance over incoherent OCDMA and the development of compact and reliable en/decoders (E/D) like spatial light phase modulator (SLPM), superstructured fiber Bragg grating (SSFBG) and multi-port array waveguide grating (AWG)-type E/D .

Previously, on-off-key (OOK) is mostly used as modulation format for payload data in OCDMA system, which is refered as OOK-OCDMA. In a multi-user asynchronous coherent OOK-OCDMA system, the major noise sources are the coherent signal-interference (SI) beat noise (coherent noise) and the incoherent MAI (incoherent noise), which limit the number of active users in a network [1]. Therefore, it is essential to combat the SI beat and MAI noises in such a network. Time gating and optical thresholding techniques can be used to suppress the MAI enabling data-rate detection. Meanwhile, the SI noise can be mitigated by proper timing coordination in either chip- or slot-level to carefully avoid the overlaps between signal and interferences in synchronous OCDMA [2, 3]. Up to 32-user, 10 Gbps/user synchronous OCDMA has been demonstrated by combining these techniques together with polarization and time division multiplexing [3]. However, for practical access network application, the capability of multi-user asynchronous access is of key attribute, while, the beat noise is still a big issue in asynchronous OCDMA [1].

Using ultra-long OCs [1, 4] and AWG-type E/D with very high power contrast ratio (PCR) between auto-/cross-correlation [5] is one effective way to suppress the interference level in asynchronous environment. Another approach is to use forward-error-correction (FEC) technique to

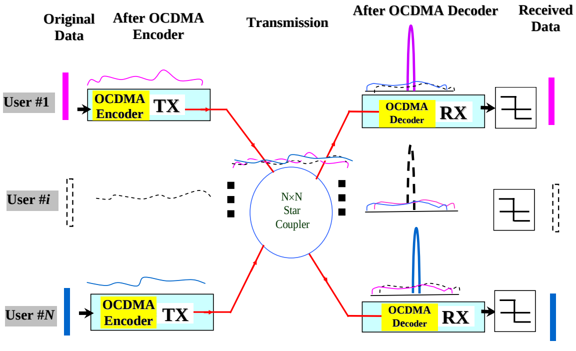

Fig. 1 Working principle of OCDMA PON

enhance the noise tolerance of the system. However, these are still not a cost-effective solution.

Meanwhile, in a multi-user asynchronous OOK-OCDMA system, with the changing of the active users' number, dynamic threshold level setting is required to maintain a wider power margin in the decoder/receiver setup [1]. However, both the real-time active users number estimating and dynamical threshold setting are still practical issues in OCDMA receivers and will result in additional cost.

In addition, the security issue has been brought forward recently that the OOK-OCDMA is vulnerable in terms of the security that could be easily broken by simple power detection without any knowledge of the code [6]. Therefore, much advanced modulation techniques are required in OCDMA in order to ensure the confidentiality of the network.

In this paper, we will introduce multi-user OCDMA systems with differential phase-shift keying (DPSK), *differential quaternary phase shift keying (DQPSK)* and code-shift-keying (CSK) modulation and balanced detection.

Multi-user DPSK- and DQPSK-OCDMA

Coherent OCDMA with DPSK modulation format and balanced detection (DPSK-OCDMA) is superior over the OOK-OCDMA with advantages of improved receiver sensitivity, better tolerance to beat noise and MAI noise without OT, and no need for dynamic Th level setting [5].

Fig. 2 shows an experimental setup of a field trial for high capacity WDM/DPSK-OCDMA. The field trial was done on an optical testbed of JGNII (Japan Gigabit Network II). Three mode-lock laser diodes (MLLD) generated 3 WDM pulse signals with about 3.2 nm (400 GHz) channel spacing. The ~1.8 ps optical pulses were generated at a repetition rate of 10.709 GHz with central wavelengths of 1550.2 nm, 1553.4 nm and 1556.6 nm, respectively. Inset (β) in Fig. 2 shows the waveform of the mixed signals of 3 WDM, 12 OCDMA users. This signal was then launched into 100 km installed SMF. Insets (θ) and (ζ) in Fig. 2 show the decoded signal and the electrical signal after the balanced detector respectively. The data was finally tested by the BER tester.

The measured BER performances are shown in Fig. 3. Error free transmission has been successfully achieved for all the 4 decoders with 3-WDM, up to 12 OCDMA users in the B-to-B experiment and 10 OCDMA users in the field trail. The spectral efficiency (ξ) is about 0.32 and 0.27 bit/s/Hz , respectively.

For further enhancing the spectral efficiency, DQPSK-OCDMA has been demonstrated in synchronous condition together with FEC and polarization multiplexing [7]. Figure 4(a) and (b) show the experimental setup and BER performance, respectively. Total spectral efficiency is 0.87 bit/s/Hz.

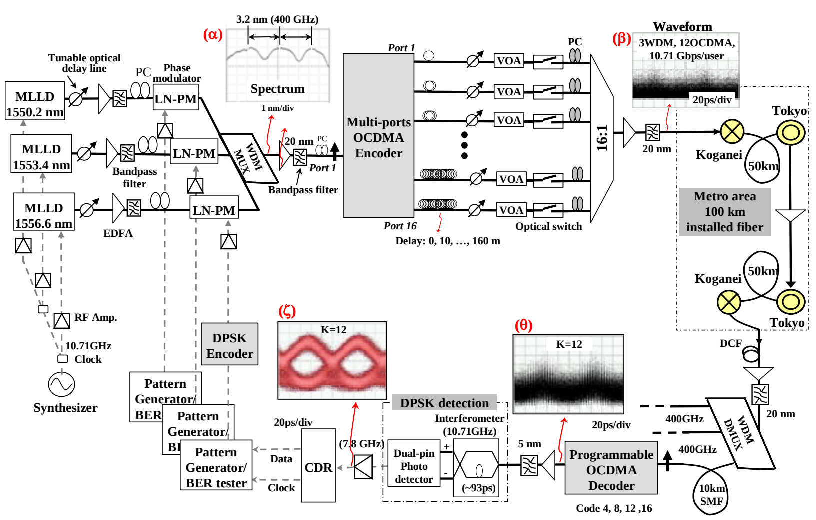

Fig. 2 Field trial of WDM/DPSK-OCDMA experiment

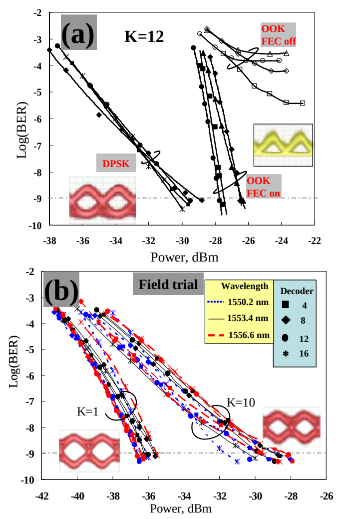

Fig. 3 BER performance

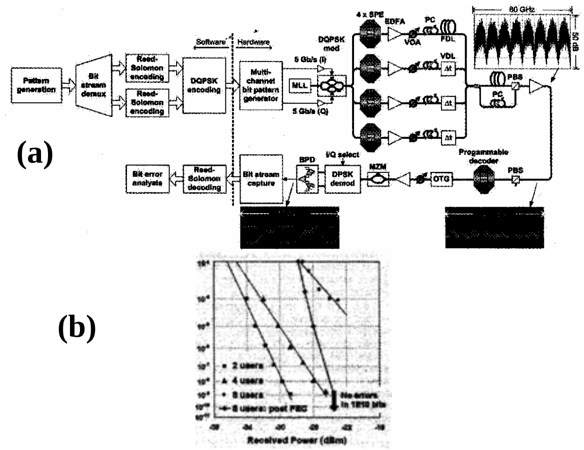

Fig. 4(a) DQPSK experiment (b) BER

Asynchronous CSK-OCDMA system

CSK-OCDMA with balanced detection (BD) can also improve multi-user capability with respect to OOK-OCDMA. The requirement for real-time K estimation and dynamic threshold level setting are relaxed in CSK-OCDMA scheme, in the same way as in the DPSK-OCDMA with balanced detection. And more importantly, the confidentiality can be significantly improved in the CSK-OCDMA system because an eavesdropper could not decipher the signal without knowing the OCs [8].

Fig. 5 shows the experimental setup of a multiuser CSK-OCDMA system. Inset η shows the eye diagram of the multiplexed signals of 8 CSK-OCDMA users. Fig. 6(a) shows the measured BER performance vs. the received optical power for different K. BER<10^{-9} has been achieved with up to 8 active users without the using of forward-error-correction (FEC) and optical thresholding. Fig. 6(b) shows the power penalty vs. K at BER=10^{-9}. This result is largely better than in OOK-OCDMA, where asynchronous multi-user OCDMA transmission was assisted by FEC or optical thresholder.

Conclusion

Comparing to conventional OOK-OCDMA, using other advance modulation techniques, such as DPSK, DQPSK and CSK in OCDMA system has advantages of (1) Improved receiver sensitivity; (2) Better tolerance to beat noise and MAI noise; (3) No need for optical thresholding; (4) No need for dynamic threshold level setting; and (5) Enhanced security. High capacity, spectral efficient OCDMA systems have been demonstrated using these techniques.

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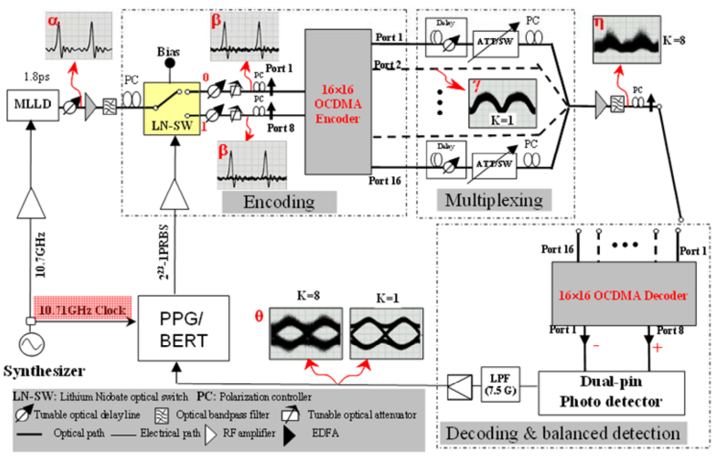

Fig. 5 Experimental setup

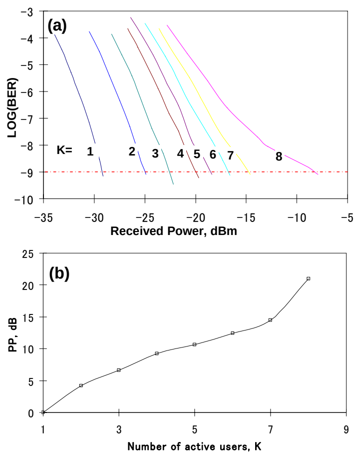

Fig. 6 BER performances