Enabling Techniques for Multi-user Asynchronous OCDMA System

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Abstract

Key techniques enabling asynchronous coherent OCDMA include: lowering the interference level by ultra-long superstructured FBG, optical thrtesholder and multi-port encoder/decoder; enhancing noise tolerance of system by forward-error-correction and differential-phase-shift-keying with balanced detection; and security enhancement by code-shift-keying.

Introduction

Optical code division multiple access (OCDMA) is one promising technique for next-generation broadband access network [1]. Figure 1 shows the architecture and working principle of an OCDMA network. It has advantages of full asynchronous transmission, low latency access as well as soft capacity on demand. Recently, coherent OCDMA using ultra-short optical pulse is receiving increasing attention with the progress of reliable and compact en/decoder (E/D) devices, such as spatial light phase modulator (SLPM) [2-4], micro ring resonator [5], planar lightwave circuit (PLC) [6], superstructured FBG (SSFBG) [7-8] and arrayed waveguide grating (AWG) multi-port device [9-11].

A multi-user coherent OCDMA system could suffer from severe signal-interference (SI) beat noise if the signal and interferences overlap each other. If the receiver is fast enough to perform the chip-rate detection, the SI beat noise will be the dominant noise source and eventually limits the maximum number of active users that can be supported [1]. However, in a practical multi-user coherent OCDMA system, data-rate detection

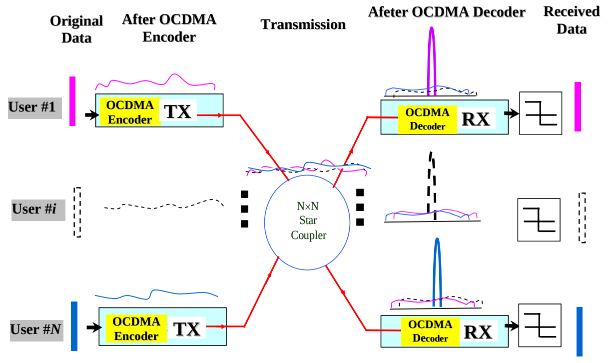

Fig.1. Architecture and working principle of an OCDMA network

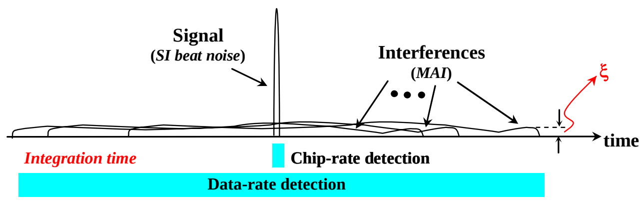

Fig.2. Received signal and interferences in asynchronous OCDMA

in the receiver is essential. In this case, another major noise source is the multiple access interference (MAI) noise, which refers to the incoherent interferences [12]. The MAI could be suppressed by employing time gating [3, 6] or optical thresholding techniques [2-6]. But the SI beat noise could not be suppressed effectively as it accompanies with the recovered signal pulse.

In an asynchronous OCDMA network with K active users, the received signal of target user could overlap with the K-1 interferences from undesired users asynchronously as illustrated in Fig.2. Therefore, the challenge is to enable multi-user asynchronous OCDMA in the presence of SI beat noise as well as MAI with data-rate detection.

Enabling techniques

a. Ultra-long OC generation/recognition with SSFBG

Employing ultra-long optical code (OC) with uniform cross-correlations to lower the interference level ξ is an effective approach to suppress the noise level. Theoretical analysis has predicted that to support up to K=10 error free (BER<10^{-9}) transmission with chip-rate detection, ξ should be lower than -28 dB [1]. Phase-shifted SSFBG E/D is one desired candidate that has the capability to process OC as long as 511-chip with chip-rate as high as 640 Gchip/s [8]. SSFBG also has advantages of polarization independent performance, low and code-length independent insertion loss, which is also essential for ultra-long OC generation compared to PLC type E/D, inherent compatibility with fiber-optic system, high compactness as well as potential low cost for mass producing.

b. Multi-port E/D with high PCR

AWG-based multi-port OCDMA E/D has the unique capability of simultaneously processing multiple time-spreading OCs with one device [9], which makes it a potential cost-effective device to be used in the central office of OCDMA network to reduce the number of E/Ds [10-11]. Another attractive feature of the AWG E/D is that it has very high power contrast ratio (PCR) between auto- and cross-correlation signals compared to other coding devices. The AWG E/D can reach 15~20 dB PCR, while the PCR of the SSFBG is around 1 dB and SLPM is 0 dB. That means the ξ value could be significantly reduced (up to 20 dB) using the AWG decoder with the same length of code [10]. Moreover, flexibility of the OCDMA network can be improved by hybrid using different type of the E/D in a network [11].

c. Optical thresholding In the coherent OCDMA with ultra-short optical pulse, the properly decoded signal is rather narrow (in a chip time) compared with the bit duration. In a practical system that employs “data-rate” instead of “chip-rate” detection, applying optical thresholding (OT) technique to remove the MAI noise is essential to enable data-rate detection for achieving a practical asynchronous OCDMA system [12]. Optical thresholding techniques have been demonstrated by using nonlinear effect in periodically-poled lithium niobate (PPLN) and optical fibers to enable data-rate detection.

Another kind of approaches to improve the multi-user capability is to enhance the system noise tolerance by:

d. Forward-error-correction (FEC) which is a powerful technique to enhance the system performance.

e. Differential-phase-shift-keying (DPSK) with balanced detection

Coherent OCDMA with DPSK modulation format and balanced detection (DPSK-OCDMA) offers the advantages of improved receiver sensitivity, better tolerance to beat noise and MAI noise without OT, and no need for dynamic threshold level setting [11,14]. Theory predicts that for a given K, DPSK-OCDMA can tolerate about 4 dB higher interference level comparing to OOK-DPSK with optimal threshold, therefore, DPSK-OCDMA is superior to OOK-OCDMA for multi-user coherent OCDMA system.

f. Security enhancement in by CSK-OCDMA

If an eavesdropper can tap the signal in an OCDMA network before multiplexing, it could easily break the security by simple data-rate power detection without any information about the OC. Therefore the OOK-(also DPSK)-OCDMA has vulnerable security.

Coherent OCDMA with code-shift-keying data modulation and balanced detection (CSK-OCDMA) scheme has better multi-user capability and simpler threshold setting in the receiver than OOK-OCDMA. In particular, CSK-OCDMA has superior security to both OOK- and DPSK-OCDMA that the security can not be broken without code information as it is shown in Fig.3 [15]. Therefore, CSK-OCDMA is an attractive candidate for secure transmission systems.

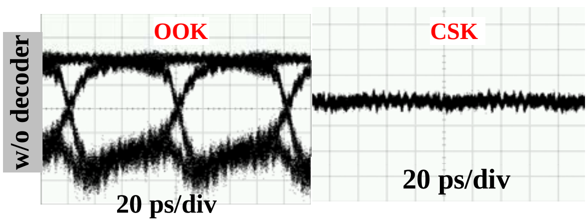

Fig. 3. Enhanced security in CSK-OCDMA

Multi-user asynchronous OCDMA experiments

The general experimental setup of multi-user asynchronous OCDMA system is shown in Fig. 4 [8, 10-11]. Fixed fiber delay lines with different lengths were used to randomly set the transit delays and de-correlate the signals from different OCDMA users. Tunable optical delay lines (TODL) were used to investigate the impact of different phases of signal-interference overlapping. Variable optical attenuators were employed to balance the optical power of signals from different users and optical switches were placed to adjust the number of active users. Polarization controllers (PC) were placed as well for investigating the system performance in different scenario. To guarantee that the system can operate in a truly-asynchronous environment, we tested the performances in the worst scenario by adjusting the PCs and TODLs. In the experiment, up to 12 active OCDMA users have been supported at 10 Gbps with BER$<10^{-9}$[11].

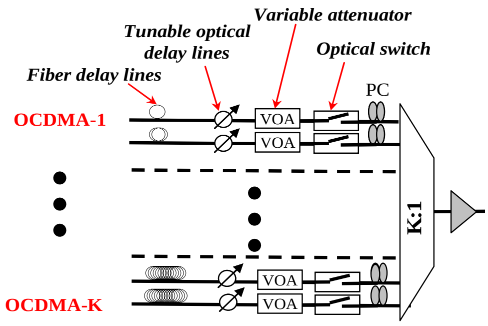

Fig. 4. BER Experimental setup of multi-user asynchronous OCDMA

Summary

Several approaches to enable multi-user asynchronous OCDMA in the presence of SI beat noise as well as MAI with data-rate detection are discussed. Further interesting research topics could include high performance OT, OCDMA with advanced modulation formats, and the application of OCDM technique in secure communication

References

1 X. Wang *et al.*, J. Lightwave Technol, **22**, 2226-2235 (2004).
2 Z. Jiang, *et al.*, IEEE Photon. Tech. Lett., **17**, 705-707, 2005.
3 R. P. Scott, *et al.*, IEE Electronics Lett., **41**, 1392-1393 (2005).
4 S. Etemad, *et al.*, IEEE PTL, **17**, 929- 931, 2005.
5 A. Agarwal, et al., OFC’05 postdeadline, PDP 6, 2005.
6 H. Sotobayashi, *et al.*, IEEE Photon. Tech. Lett., **14**, 555-557 (2002).
7 P. C. Teh, *et al.*, J. Lightwave Technol. **9**, pp. 1352-1365, 2001.
8 X. Wang, *et al.*, OFC’05 postdeadline, PDP33, 2005.
9 G. Cincotti, J. Lightwave Technol., **22**, 642-1650, 2004.
10 X. Wang *et al*, IEEE PTL, **18**, 1603-1605, 2006.
11 X. Wang *et al.*, OFC 2006 post-deadline, PDP 44. 2006.
12 X. Wang *et al.*, LEOS 2005, WW2, 2005.
13 J. Faucher *et al*, ECOC 2006 Th3.6.3, 2006.
14 X. Wang *et al.*, IEEE PTL, **18**, pp.826-828, 2006.
15 X. Wang *et al*, OECC’06, 6E2-2, 2006