JTuB43.pdf

Electrically Processed OCDMA System Based on Spatial Coding and Subcarrier Multiplexing

Changjian Guo, Cheng Luo, and Sailing He
Center for Optical and Electromagnetic Research, Joint Laboratory of Optical Communications, Zhejiang University, Hangzhou 310058, China
guocj@coer.zju.edu.cn

Abstract: A low-cost electrically processed OCDMA system based on spatial coding and subcarrier multiplexing is proposed. The simulation shows that at least 10 simultaneous users can be supported in a 16-code OCDMA system with 40-dB OSNR.

OCIS codes: (060.2330) Fiber optics communications; (060.4230) Multiplexing; (060.4080) Modulation

1. Introduction

Optical Code Division Multiple Access (OCDMA) has been attracting much research interests during recent years. OCDMA techniques can offer various advantages, including the possibility of full asynchronous operation, flexible network management, the potential of security enhancement for the physical layer, etc. Various encoding and decoding techniques have been employed, among which the most commonly used are reconfigurable spatial light spectral phase modulators [1], super structured fiber Bragg gratings (SSFBGs) [2]-[3] and planar waveguide base en/decoders [4]. These all-optical en/decodes are capable of processing at the speed of up to 640-Gchip/s [2]. However, several expensive devices, including ultra-short pulse lasers, optical thresholders and optical time gating are required in the optical en/decoder based OCDMA systems. These devices increase the overall system cost.

Electrically processed OCDMA systems using CCDs [6], FIR filters [5], etc as chip-rate en/decoders have been proposed recently [5]-[7]. These chip-rate en/decoders are very difficult to achieve high speed or long code lengths due to their limited processing speed. Another work by Shin Kaneko, et al [7], used a spectral M-ary ASK technique based on electrical-domain spatial code spreading to perform data-rate processing. In that scheme, each tributary data steam generated by the spatial encoder is modulated separately using an external modulator with an LD of different emitting frequency. At the receiver side, each spectral component is photo detected separately. This spatial coding technique avoids chip-rate processing and can therefore support high speed transmission. However, as the number of users and the code lengths increase, the number of optical devices (LDs, PDs, MZ-modulators, optical filters, etc) used in this scheme increases dramatically, which also leads to high cost.

In this paper, we propose a high-capacity, low-cost electrically processed OCDMA system based on data-rate spatial coding and subcarrier multiplexing. The proposed scheme avoids optical thresholding, time gating, chip-rate processing and intensive use of optical devices. Moreover, the proposed scheme can be easily integrated with OFDM and DSP techniques to provide long code length, high spectral efficiency and high speed OCDMA transmission.

2. Proposed scheme

Fig. 1 shows the structure of the proposed OCDMA system using spatial coding and subcarrier multiplexing. At the transmitter side, each input baseband data stream is firstly bit-mapped to an M-QAM constellation to enhance the spectral efficiency, where M can be 4, 16, 64, etc. The output I and Q signals from the bit-mapper are sent into two identical spatial encoders, where the signals are split into k parts (k is the code length), spatially encoded, and then combined (see fig. 2). The tributary data steams generated by the combiners are then modulated using subcarriers with the same frequency spacing. For the same output ports of the two spatial encoders, the same subcarrier frequency is used, only with a 90 degree phase shift. Note that the choice of the channel width of the subcarriers is a tradeoff between spectral efficiency and system performance. After subcarrier modulation, the signals are multiplexed and linearly modulated to an optical frequency using a Mach-Zehnder intensity modulator biased at the quadrature point. At the receiver side, the transmitted optical signal is O/E converted using an photo detector, and then demodulated to baseband, and then decoded to recover both I and Q signals, and finally sent to a M-QAM decoder to retrieve the baseband binary data.
The structure of the spatial encoder plus the combiners is shown in fig. 2 [7]. A code length of 4 is used to illustrate the mechanism of spatial encoding. The input signals are split into 4 parts and then followed by 4 switches. The

JTuB43.pdf

states of the switches (on or off) depend on the code assigned to that channel, e.g., for code word ‘1, 0, 1, 0’, the first and the third switches are on, while the second and the last switches are off. The output signals after the switches are combined with the counterpart of other channels.

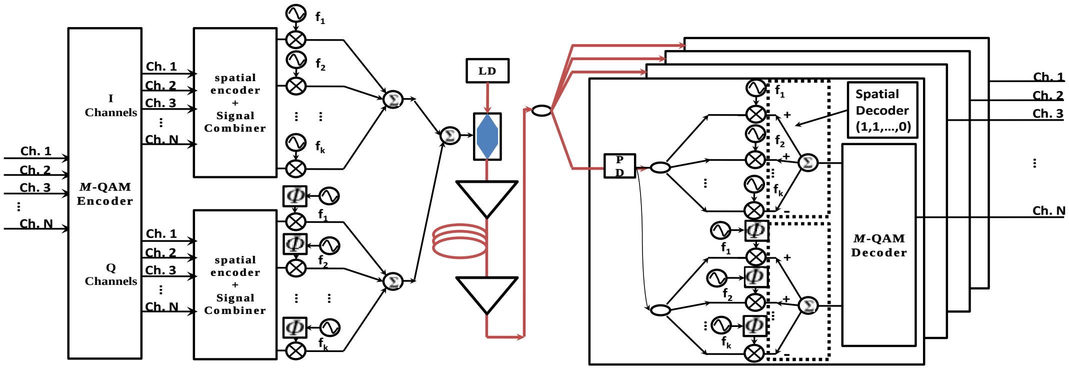

Fig. 1. Schematic diagram of the proposed OCDMA system

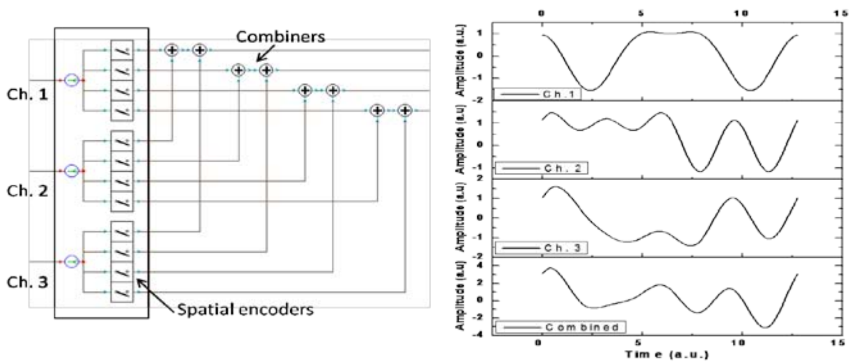

Fig. 2. The spatial encoder plus combiners (left) and their input/output signals (right).

The codes that can be used in this scheme are Walsh codes, which can be generated by the following matrices:

$$H(0)=[1],\;\; H(1)=\begin{bmatrix}1 & 1\\ 1 & 0\end{bmatrix},\;\; H(2)=\begin{bmatrix}1&1&1&1\\1&0&1&0\\1&1&0&0\\1&0&0&1\end{bmatrix},\; \ldots,\; H(n)=\begin{bmatrix}H(n-1) & H(n-1)\\ H(n-1) & !H(n-1)\end{bmatrix} \qquad (1)$$

where the symbol ‘!’ stands for NOT operation. Each column (or row) of the matrix $H(n)$ can be used as a code word. The Walsh codes are mathematically orthogonal codes that are commonly used in CDMA communication systems.

The proposed OCDMA system has the following advantages: 1) as the bit-mapping, en/decoding, and subcarrier multiplexing procedures are all processed in electrical domain, this makes it very easy for system integration; 2) This scheme can be naturally integrated with OFDM and DSP techniques to provide high spectral efficiency, large number of users, and high speed OCDMA transmission; 3) Subcarrier multiplexing illuminates the intensive use of optical components; 4) The spatial en/decoder plus combiners structure can enable truly asynchronous access; 5) No multiple access interference (MAI) cancellation process and thresholding devices needed.

3. Simulation results

The proposed electrically processed OCDMA system was simulated using VPI transmissionmaker v8.3. At the transmitter side, each 1.25-Gb/s input binary data stream was firstly bit-mapped to a QPSK constellation. The code length of the spatial encoder was set to 16, which in theory can support at most 15 users when Walsh codes were employed. The frequency spacing of adjacent subcarriers was set to 1.25-GHz, which is the bandwidth of the QPSK signals. The subcarrier multiplexed signals were E/O modulated using a Mach-Zehnder intensity modulator biased at the quadrature point and a laser diode with a spectrum line width of 100-KHz. The extinction ratio of the Mach-Zehnder modulator was set to 17-dB. The modulation power of the electrical signals was carefully tuned to 11-dB to get optimum symbol error rate (SER) performance. An OSNR emulator with a bandwidth of 0.1-nm was used afterwards. At the receiver side, a photo detector with dark current of 10-nA and thermal noise of 10-pA/√Hz was used as the O/E convertor. A DC block was added after the PD to remove the strong DC component existed in the converted signal. The signal was then split, demodulated to baseband, and then decoded by adding and subtraction according to the assigned code. The decoded I and Q signals were used for SER counting using Monte-Carlo method after timing recovery.

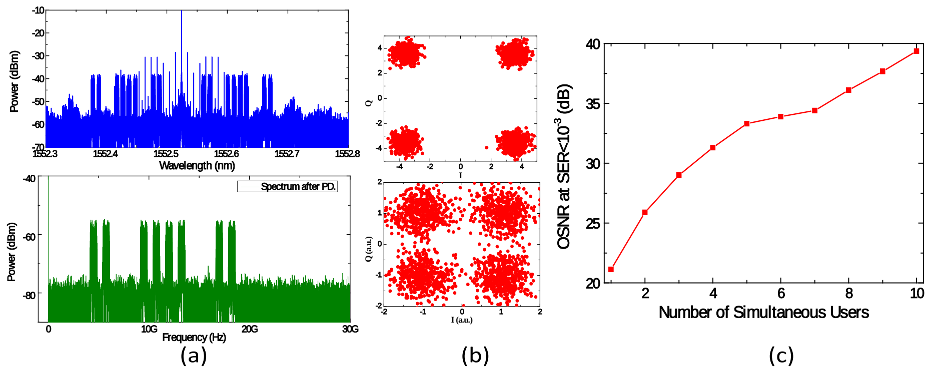

Fig. 3. Simulation Results.

Fig. 3 (b) shows the received QPSK constellations in one user case (upper) and six simultaneous users case (lower) after decoding at an OSNR of 25-dB. Fig.3 (c) depicts the OSNR penalty versus the simultaneous number of users when the SER is below 10^{-3}. It can be seen that without any MAI cancellation and thresholding, at least 10 simultaneous users can be supported for simultaneous transmission given an OSNR of 40-dB. As the optical modulation formats used in this simulation is double side band (DSB) linear modulation, the power of the optical carrier is very large compared with that of the side bands. This large un-modulated optical carrier causes OSNR performance degradation. One possible way that might solve this problem is to use the carrier-suppressed Optical SSB modulation.

4. Conclusions

We have proposed and demonstrated a novel electrically processed OCDMA system configuration based on spatial coding and subcarrier multiplexing. The proposed scheme avoids using chip-rate processing, optical MAI cancellation, optical thresholding and massive use of optical components, leading to a low cost OCDMA solution. Moreover, this scheme can be easily integrated with OFDM and DSP techniques to provide high spectral efficiency, large number of users, and high speed OCDMA transmission. The proof-of-concept simulation shows that without any MAI cancellation, at least 10 users can be supported for simultaneous transmission in a 16-code OCDMA system given an OSNR of 40-dB.

5. References

[1] Jiang, Z.; Seo, D.S.; Yang, S.-D.; Leaird, D.E.; Roussev, R.V.; Langrock, C.; Fejer, M.M.; Weiner, A.M., "Four-user, 2.5-Gb/s, spectrally coded OCDMA system demonstration using low-power nonlinear processing," J. Lightw. Technol. , vol.23, no.1, pp. 143-158, Jan. 2005

[2] Hamanaka, T.; Xu Wang; Naoya Wada; Nishiki, A.; Kitayama, K., "Ten-user truly asynchronous gigabit OCDMA transmission experiment with a 511-chip SSFBG en/decoder," J. Lightw. Technol., vol.24, no.1, pp. 95-102, Jan. 2006.

[3] Richardson, D.J.; Teh, P.C.; Roelens, M.A.F.; Thomsen, B.C.; Tian, C.; Zhang, Z.; Petropoulos, P.; Ibsen, M., "Direct sequence OCDMA systems based on fibre grating technology," ECOC'2005 , vol.4, no., pp. 867-870, Sept. 2005.

[4] Jing Cao; Broeke, R.G.; Fontaine, N.K.; Ji, C.; Du, Y.; Chubun, N.; Aihara, K.; Anh-Vu Pham; Olsson, F.; Lourdudoss, S.; Yoo, S.J.B., "Demonstration of Spectral Phase O-CDMA Encoding and Decoding in Monolithically Integrated Arrayed-Waveguide-Grating-Based Encoder," IEEE PTL , vol.18, no.24, pp.2602-2604, Dec.15, 2006.

[5] J. Rosas-Fernandez, J. Ingham, R. Penty, and I. White, "18 Gchips/s Electronically-Processed OCDMA Spread Spectrum for Access Networks," in OFC'08, paper PDP30, Mar. 2008.

[6] Gupta, G.C.; Kashima, M.; Iwamura, H.; Tamai, H.; Ushikubo, T.; Kamijoh, T., "Over 100km Bidirectional, Multi-channels COF-PON without Optical Amplifier," in OFC'06 , paper PDP51, March 2006.

[7] S. Kaneko, H. Suzuki, N. Miki, H. Kimura, and K. Kumozaki, "Beat-Noise-Free OCDM Technique Employing Spectral M-ary ASK Based on Electrical-Domain Spatial Code Spreading," in OFC'09, paper OThI5, Mar. 2009.