第43卷第7期 光 子 学 报 Vol. 43 No. 7
2014年7月 ACTA PHOTONICA SINICA July 2014

doi:10.3788/gzxb20144307.0706018

40 Gbps OFDM-PON系统采用偏振复用技术实现上行链路传输

张娜娜,周娴,施浚飞,夏莉敏,严冬,吴小云
(北京科技大学 融合网络与泛在业务工程技术研究中心,北京 100083)

摘　要:为了提高PM-CO-OFDM-PON系统中上行数据的传输速率,提出采用偏振复用结构与相干检测技术相结合,通过光载波源方式实现上行链路光网络单元无色化传输的技术方案.利用光学软件VPI和Matlab,搭建了基于偏振复用技术的40Gb/s PM-CO-OFDM-PON系统仿真平台,结果表明:该方案可有效提高PM-CO-OFDM-PON系统中上行数据传输速率,并实现光网络单元无色化;利用相干检测比直接检测可以更高地提高接收端的灵敏度.

关键词:正交频分复用;无源光网络;偏振复用;ONU无色化;相干检测
中图分类号:TP915.31　　**文献标识码**:A　　**文章编号**:1004-4213(2014)07-0706018-4

40 Gbps OFDM-PON System Using Polarization Division Multiplexing for Upstream Transmission

ZHANG Na-na, ZHOU Xian, SHI Jun-fei, XIA Li-min, YAN Dong, WU Xiao-yun
(*Engineering and Technology Research Center for Convergence Networks and Ubiquitous Services, University of Science and Technology Beijing, Beijing* 100083 *China*)

Abstract: A polarization multiplexing scheme for polarization division multiplexing orthogonal frequency division multiple with coherent detected-based passive optical networks was proposed, in which polarization multiplexing was used at the Optical Network Unit(ONU) for the upstream transmission to increase the transmission data rates and double the spectral efficiency. ONU colorless was realized by optical carrier way. VPI and MATLAB were used for the PM-CO-OFDM-PON simulation platform. The results show that the proposed PM-CO-OFDM-PON architecture is scalable, improves the data rates in the upstream of PM-CO-OFDM-PON, and ONU colorless is realized effectively. Moreover, with coherent detected, the receiver sensitivty is improved.

Key words: Orthogonal Frequency Division Multiple; Optical network unit colorless; Polarization division multiplexing; Coherent detection
OCIS Codes: 060.4510; 060.4230; 060.4250

0 Introduction

Recently, the research and development is being focused on the next generation passive optical access networks, such as Time Division Multiplexing(TDM)-Passive Optical Networks (PON) and Wavelength Division Multiplexing (WDM)-PON. Up to now, Orthogonal Frequency Division Multiplexing(OFDM) has spurred for the next generation passive optical networks due to its high tolerance to Chromatic Dispersion (CD) and Polarization Mode Dispersion (PMD), high spectral efficiency[1], and natural

---

Foundation item: The National Key Basic Research and Development Program of China (No. 2012CB315905) and the National Natural Science Foundation of China (Nos. 61172050, 61172048)

First author: ZHANG Na-na (1987—), female, M. S. degree candidate, mainly focuses on optical communication. Email: zhang.nana.com@163.com

Supervisor (Contact author): ZHOU Xian (1982—), female, professor, Ph. D. degree, mainly focuses on digital signal information processing. Email: zhouxian219@gmail.com

Received: Oct. 22, 2013; **Accepted**: Dec. 18, 2013

compatibility with Digital Signal Processing (DSP)-based implementation. As we all know, Direct Detection Optical OFDM (DD-OFDM)[2-3] and Coherent Optical OFDM (CO-OFDM)[4] have been independently proposed to combat chromatic dispersion. Moreover, CO-OFDM has also been shown as the immunity to polarization-mode dispersion [5]. In 2007, Dayou Qian firstly proposed and experimentally demonstrated the system architecture based on Orthogonal Frequency Division Multiple Access (OFDMA)-PON [6], besides allocating the resources not only in the time domain but also in the frequency domain, each Optical Network Unit (ONU) enables to support of various applications transparently, as well as dynamic bandwidth allocation in the system. According to the detection scheme in the OLT receiver, CO-OFDM is being regarded as an attractive technology for optical communications. Compared to DD-OFDM, CO-OFDM has shown its great robustness against the fiber CD and PMD using the polarization diversity technology and higher receiver sensitivity[7-8]. Polarization multiplexing (POLMUX) technology is a considerable effective method for improving spectrum efficiency for transmission systems[9-12]. It has been shown that direct-detected POLMUX has a reduced tolerance to Polarization Mode Dispersion (PMD)[13]. Instead of direct detection, coherent detection is a good way to overcome this PMD sensitivity in which digital equalization is used to solve this problem. On the other hand, due to using a same wavelength for different ONUs, coherent detection is indispensable in the upstream link of OFDM-PON[14-15]. Therefore, POLMUX-CO-OFDM is simulated for upstream transmission in this paper.

1 Set of OFDM-PON system

The proposed POLMUX-OFDM-PON architecture is illustrated in Fig. 1. At the OLT, OFDM baseband signal is generated offline. After the 40 Gb/s binary bit data is 16QAM modulated, the input to the IFFT is constrained to have Hermitian symmetry so that the imaginary component of the IFFT output is zero. The IFFT size is 512 with 1～256 data bearing subcarriers and the CP size is 64. In order to realize the ONU colorless, the OLT features two laser sources: λ_1 (optical frequency is 193.1 THz, line width is 100 KHz) as the optical carrier for downstream transmission and λ_2 (optical frequency is 193.14 THz, line width is 100 KHz) as the optical source for upstream transmission. Then a MZM is used to generate a double sideband optical signal onto λ_1 and one sideband is suppressed using an optical band pass filter. In order to realize linear modulated, the MZM DC bias is set $0.7V_{\mathrm{pi}}$. The modulated optical OFDM signal is transmitted to the ONUs, while the upstream Continuous Wave (CW) laser at λ_2 is distributed to all the ONUs through 100 Km fiber.

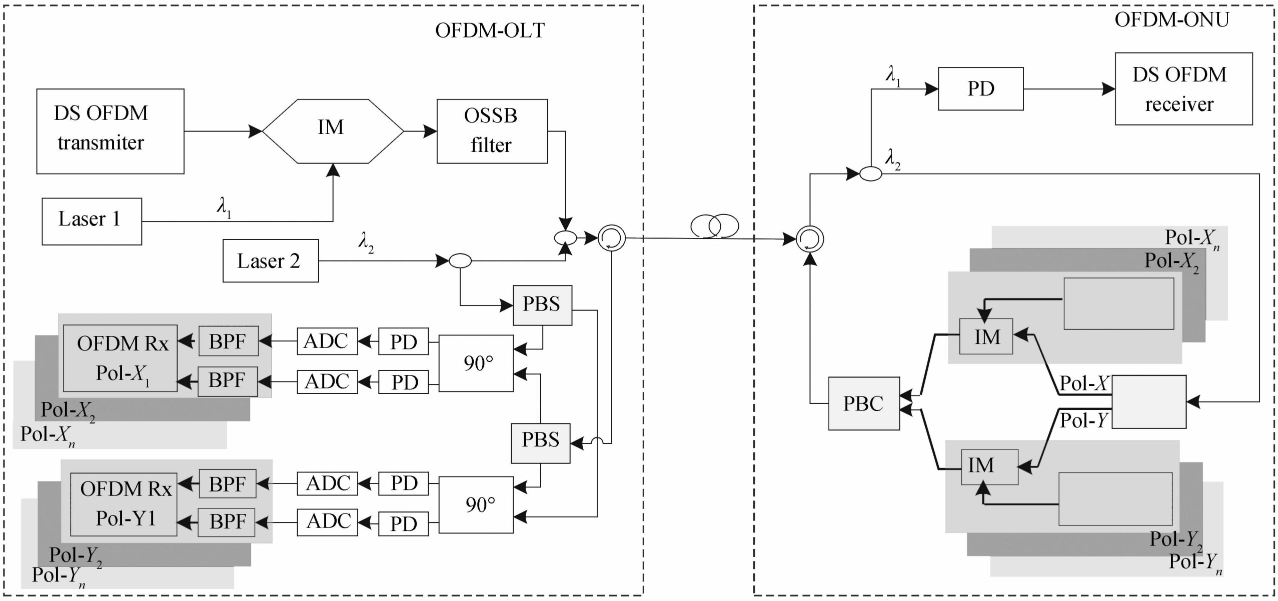
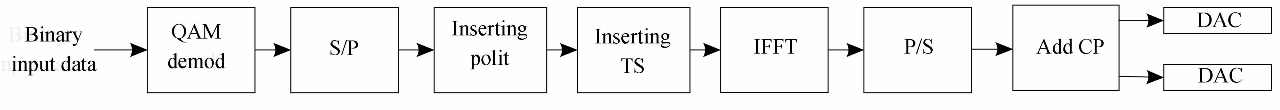


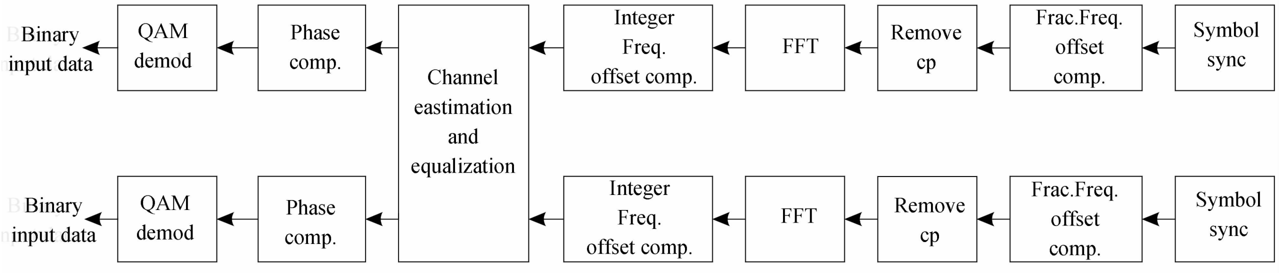
Fig. 1 The proposed OFDM-PON system architecture

At the ONU, an optical filter separates the downstream signals from the laser source (λ_2) which is used to modulate the upstream OFDM signals. The optical carrier at λ_2 is split into two orthogonal polarization states by Polarization Beam Spliter (PBS), then they modulate the OFDM signals in each ONU respectively. The architecture of OFDM transmitter in the ONU is shown in Fig. 2(a). The random binary data stream is converted from serial to parallel and symbol mapping is applied. Inserting pilots as follows is to compensate the phase noise which is caused by laser line width. Training Sequences are then added for symbol synchronization, frequency offset estimation and channel estimation. Subsequently, the signal is modulated onto orthogonal carriers by applying the Inverse Fast Fourier Transform (IFFT). The IFFT length is 128 and inserting 20 zeros to realize DAC oversampling. After the IFFT, we insert the Cycle Prefix (CP) length of 32 per OFDM symbol to mitigate impairments caused by CD and PMD. Baseband OFDM signals split into a real part and an imaginary part before they are converted to analogue signals using Digital-to-Analogue Converter (DAC). Each ONU occupies different bandwidth with OFDMA mode for each polarization state. Then the baseband OFDM signals are modulated onto each orthogonal polarization states by the MZM. Before transmitted to the fiber, the modulated optical OFDM signals are combined with a Polarization Beam Combiner (PBC) to generate a POLMUX-OFDM signal with POLMUX carriers having orthogonal polarizations. Through the 100 km fiber, the signals transmitted to the OLT. The fiber dispersion is 16 $\mathrm{ps \cdot nm^{-1} \cdot km^{-1}}$ and PMD is $0.1/31.62\ \mathrm{ps \cdot m^{-1/2}}$.

At the OLT receiver, the signals split into two random orthogonal polarizations and are detected with a polarization-diverse 90 degree optical hybrid with the Local Oscillator (LO) at λ_2. The received electric OFDM signals are sampled and DSP done off-line and the process is shown in Fig. 2 (b). Symbol synchronization is first applied for the received electrical OFDM signals, then fraction frequency offset compensation as follows. After removing the CP, the OFDM signal is converted back to frequency domain by applying the FFT. Following is integer frequency offset compensation, then the training sequences are used for channel estimation and equalization. Finally, polits are used to compensate the phase noise and QAM demodulation is completed.



(a) OFDM transimitter at the ONU

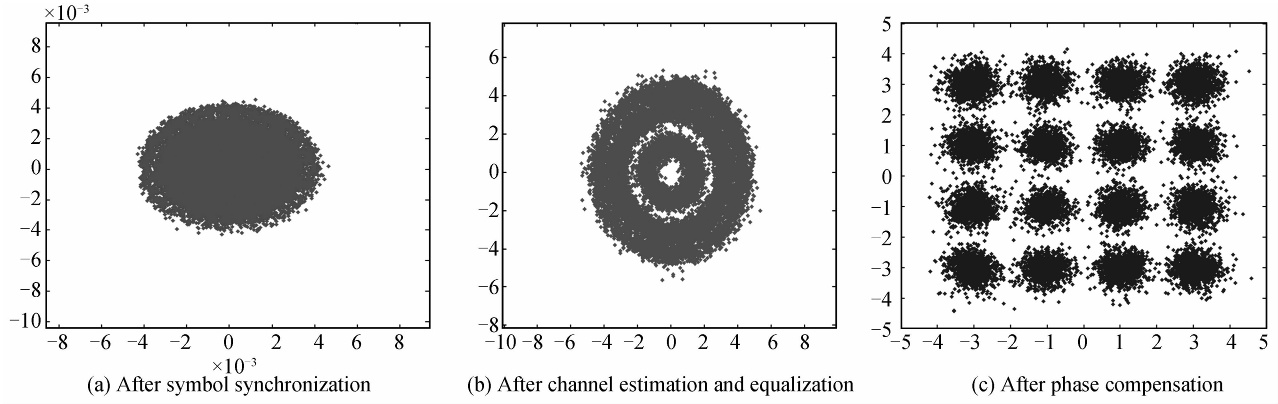


(b) ODFM reveiver at the OLT

Fig. 2 OFDM transmitter and receiver

2 Results

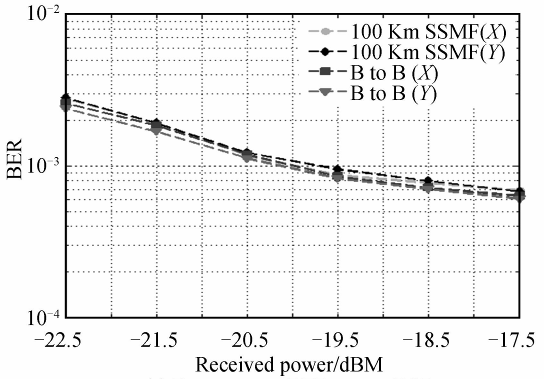
Fig. 3 depicts the constellation at the OFDM receiver in the OLT for upstream transmission. After symbol synchronization, the constellation is illustrated by Fig. 3 (a). In our experiments, frequency compensation is negligible. After channel estimation and equalization, the constellation is shown in Fig. 3 (b), next to phase compensation, we get the correct constellation, as depicted in Fig. 3(c).



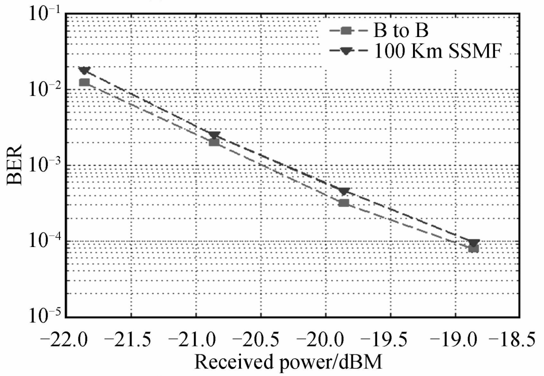
(a) After symbol synchronization (b) After channel estimation and equalization (c) After phase compensation

Fig. 3 The constellation at the OFDM receiver in the OLT for upstream transmission

Fig. 4 (a) and Fig. 4 (b) plots the Power Of Received (POR) versus Bit Error Rate (BER) performance for both B to B (back to back) and 100 Km SSMF for downstream and upstream transmission respectively. The receiver sensitivity reaches about −20.5 dBm for downstream transmission and −20 dBm for upstream transmission.



(a) Downstream BER versus POR



(b) Upstream BER versus POR

Fig. 4 Measured BER curves

3 Conclusion

We have proposed and simulated the OFDMA-PON architecture using polarization division multiplexing for upstream transmission. The ONU data rates and spectrum efficiency doubled. Through coherent detection, the receiver sensitivity improved compared with direct detection. Consequently, the proposed OFDM-PON architecture is scalable and it is promising for application in the next generation passive optical access networks.

Reference

[1] ARMSTRONG J. OFDM for optical communications [J]. *Journal of lightwave technology*, 2009, **27**(3): 189-204.

[2] LOWERY A, Du L, Armstrong J. Orthogonal frequency division multiplexing for adaptive dispersion compensation in long haul wdm systems[C]. The National Fiber Optic Engineer Conference, 2006.

[3] DJORDJEVIC I, VASIC B. Orthogonal frequency division multiplexing for high-speed optical transmission [J]. *Optical Express*, 2006, **14**(9): 3767-3775.

[4] SHIEH W, Athaudage C. Coherent optical orthogonal frequency division multiplexing[J]. *Electronic Letters*, 2006, **42**(10): 587-589.

s[5] SHIEH W, Chen W, Tucker R. Polarization mode dispersion mitigation in coherent optical orthogonal frequency division multiplexed syslems[J]. *Electronic Letters*, 2006, **42**(17): 996-997.

[6] QIAN D, HU, J, YU J. Experimental demonstration of a novel OFDM-A based 10 Gb/s PON architecture [C]. Optical Communication On Optical Conference, 2007.

[7] HAN Y, LI G, Coherent optical communication using polarization multiple input-multiple-output [J]. *Optical Express*, **13**(19): 7527-7534, 2005.

[8] JANSEN S, Morita I, Tanaka H. 16 _ 52. 5-Gb/s, 50-GHz spaced, POLMUX-COOFDM transmission over 4, 160 km of SSMF enabled by MIMO processing[C]. European Conference on Optical Communication, 2007.

[9] SHIEH W, Yi X, Ma Y, *et al*. Theoretical and experimental study on PMD-supported transmission using polarization diversity in coherent optical OFDM systems [J]. *Optical Express*, 2007, **15**: 9936-9947.

[10] HAN Yan, LI Gui-fan. Coherent optical communication using polarization multiple input-multiple-output [C]. Optical Society ofAmerica, 2005.

[11] XIONG F, ZHONG W, KIM H. A broadcast-capable WDM passive optical network using offset polarization multiplexing [J]. *Journal of Lightwave Technology*, 2012, **30**(14): 2329-2336.

[12] HILL P, OLSHANSKY R, Burns W. Optical polarization division multiplexing at 4 Gb/s [J]. *IEEE Photonics Technology Letters*, 1992, **4**(5): 500-502.

[13] JANSEN S, MORITA I, SCHENK T, *et al*. Long-haul transmission of 16 × 52. 5 Gbits/s polarization division multiplexed OFDM enabled by MIMO processing[J]. *Journal of Optical Networking*, 2008, **7**(2): 173-182.

[14] CVIJETIC N, QIAN Da-you, HU Jun-qiang, *et al*. Orthogonal frequency division multiple access PON (OFDMA-PON) for colorless upstream transmission beyond 10 Gb/s[J]. *IEEE Journal on Selected Areas in Communications*, 2010, **28**(6): 781-790.

[15] CVIJETIC N. OFDM for next-generation optical access networks[J]. *Journal of lightwave technology*, 2012, **30**(4): 384-398.