Simultaneous transmission of high-speed point-to-point data and double broadcast services in a WDM-PON system with source-free ONUs

Qingjiang Chang[a], Mingfang Huang[b], and Yikai Su[a*]

[a] State Key Lab of Advanced Optical Communication Systems and Networks, Department of Electronic Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China.

Email: yikaisu@ sjtu.edu.cn.

[b]School of Electrical & Computer Engineering, Georgia Institute of Technology, GA 30332, USA

ABSTRACT

We propose that double broadcast services can be overlaid over high-speed point-to-point downlink data in a WDM-PON with source-free optical network units (ONUs). In the optical line terminal (OLT), a set of single-drive Mach-Zehnder modulators (MZMs) are driven by downlink point-to-point data to generate a differential phase-shift keying (DPSK) format. The downlink DPSK signals from different wavelengths are multiplexed and then fed to a following dual-parallel MZM (DPMZM) as a double broadcast services transmitter. The broadcast service_1 is an optical carrier suppression (OCS) format, while the broadcast service_2 is an inverse return-to-zero (IRZ) forma. After the transmission, at each ONU, the optical signals are separated by an optical filter. The filtered OCS signal is detected to retrieve the broadcast service_1. The DPSK/IRZ signals are split into three parts, one part is detected by an IRZ receiver to recover the broadcast service_2, the second part is detected by a DPSK receiver to retrieve the downlink data and the third part is re-modulated by the upstream amplitude shift keying (ASK). We also perform an experiment to verify the feasibility of the proposed scheme, where the power penalties of less than 1.5 dB are obtained after 25-km transmission with 1.25-Gb/s data rate.

Keywords: Point-to- point data, broadcast services, WDM-PON, optical SCM, DPSK/IRZ

Optical Transmission, Switching, and Subsystems VI, edited by Ken-ichi Kitayama, Pierpaolo C. Ghiggino, Kim Roberts, Yikai Su, Proc. of SPIE Vol. 7136, 71360S · © 2008 SPIE · CCC code: 0277-786X/08/$18 · doi: 10.1117/12.803587

1. INTRODUCTION

Wavelength division multiplexed-passive optical network (WDM-PON) is a promising technology for future broad bandwidth access networks, since it can offer advantages including high capacity, security, and upgradeability [1]. Recently, many efforts have been paid to enable broadcasting functions in WDM-PONs [2-4], where single broadcast video service is overlaid over the downlink point-to-point data. However, with the growth of different emerging services such as video-on-demand (VOD) and high-definition television (HDTV), it is valuable to provide multiple broadcast services to the customers. A cost-effective structure is desired for delivering broadcast services in next generation networks [5-6].

In this paper, we propose and experimentally demonstrate that double broadcast services can be overlaid over high-speed point-to-point downlink data with centralized light sources and shared fiber infrastructure in a WDM-PON system. Moreover, upstream data re-modulation is also achieved, which avoids the need of a light source for upstream signal modulation and eliminates complicated wavelength management in optical network units (ONUs). The centralized light source, the shared fiber infrastructure, and the re-modulation of upstream could effectively reduce the network deployment cost.

2. PRINCIPLE

The schematic diagram of the proposed WDM-PON system is depicted in Fig.1. In the optical line terminal (OLT), the downstream carrier of each wavelength channel is fed into a differential phase-shift keying (DPSK) transmitter, which is driven by downlink point-to-point data to produce a DPSK format. The generated DPSK signals from the different wavelength are combined by an arrayed waveguide grating (AWG) and then launched into a following dual-parallel Mach-Zehnder modulator (DPMZM) as a double-broadcast services transmitter. The DPMZM [7] is comprised a pair of x-cut $LiNbO_3$ MZMs (MZMA, MZMB) in each arm within a main MZM structure. The MZMA is biased at its null point and driven by a radio frequency (RF) signal loaded with broadcast service_1 to obtain a carrier suppressed optical sub-carrier multiplexing (SCM) format. Because the downlink data is phase-modulated on the optical carrier and the SCM signals are intensity-modulated by the DPSK signal, there is no crosstalk between two modulation formats. The MZMB is biased at the quadrature point of the negative slope of its transmission curve and driven by a RZ-shaped electrical signal to generate an inverse return-to-zero (IRZ) format for broadcast service_2. Then the generated IRZ signal is

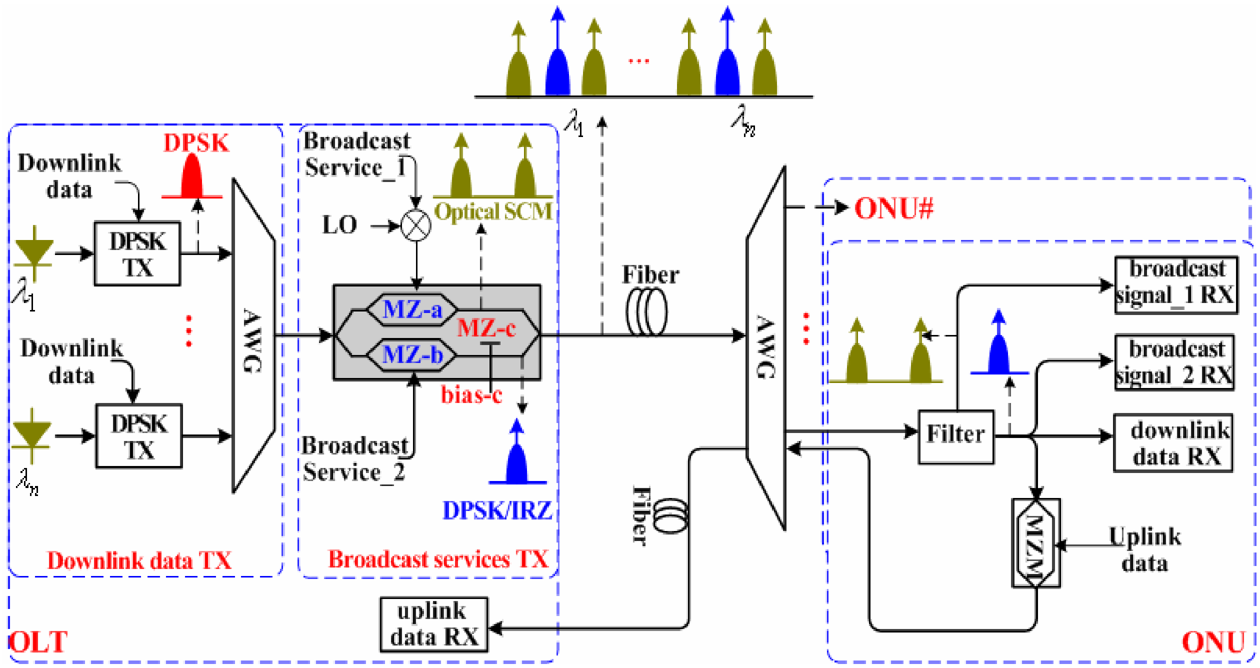

Fig. 1 Schematic diagram of the proposed scheme.

superimposed onto the DPSK signal to form an orthogonal DPSK/IRZ format [8]. The outputs of the MZMA and the MZMB are added constructively by adjusting the bias of the main MZM, and they do not interfere with each other, since the carrier of the optical SCM signals are suppressed.

After transmission, another AWG is used to demultiplex the optical signals and route to individual ONUs. At each ONU, an optical filter is employed to separate the optical SCM and the DPSK/IRZ signals. The filtered optical SCM is directly detected by a low-speed optical receiver to retrieve the broadcast service_1. The DPSK/IRZ signals are split into three parts, one part is directly detected by an IRZ receiver to recover the broadcast service_2, and the second part is detected by a DPSK receiver to retrieve the downlink data. Since the IRZ signal carries optical power at both the mark level and the space level in each bit period, and the DPSK signal is a constant-intensity optical phase-modulated format, the DPSK/IRZ modulation format can be considered as the optical carrier for upstream signal re-modulation. Thus, the third part of the DPSK/IRZ format is re-modulated by the upstream amplitude shift keying (ASK) and then sent back to the OLT. Therefore, simultaneous delivery of downlink data and double-broadcast services and re-modulation of upstream signal are realized in a simple and compact manner.

3. EXPERIMENTAL SETUP AND RESULTS

To verify the feasibility of the proposed scheme, we perform an experiment as shown in Fig.2. A phase modulator (PM) with an input light at 1549.88 nm is driven by a 1.25-Gb/s pseudorandom bit sequence (PRBS) data1 of 2^7-1 word length to obtain a DPSK signal, the generated DPSK signal was then fed into a following 10-GHz DPMZM. The DPSK transmitter can be based on a DFB laser to reduce the size and the cost [10]. The electrical SCM signal is obtained by mixing a 1.25-Gb/s PRBS data2 of 2^7-1 with a 10-GHz RF signal. The sub-MZMA is biased at the null and driven by the mixed SCM signal to generate an optical SCM signal of 20-GHz repetition rate, the optical eye diagram and the optical spectrum are shown in Fig. 3 (i) and (ii), respectively. The downstream orthogonal DPSK/IRZ format is obtained by driving the sub-MZMB using an RZ pulse-shaped signal, which is generated by a logic AND operation between a 1.25-GHz clock signal and a 1.25-Gb/s PRBS data3 with a word length of 2^7-1, with the optical eye diagram shown in Fig. 3 (iii). The outputs from the MZMA and the MZMB are amplified by an erbium-doped fiber amplifier (EDFA) to 6 dBm before transmission, the optical spectrum is provided in Fig. 3 (iv). A tunable optical filter (TOF) is used to suppress amplified spontaneous emission (ASE) noise.

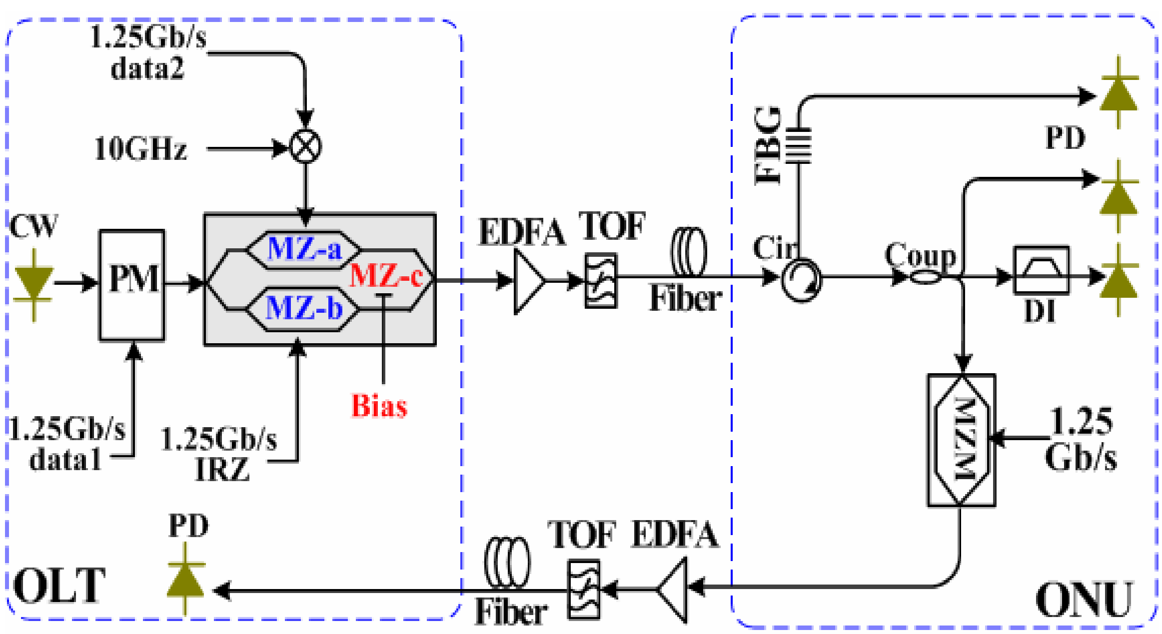

Fig. 2. Experimental setup of the proposed scheme. PM: phase modulator. TOF: tunable optical filter. Cir: circulator. FBG: fiber brag grating. Coup: coupler. DI: delay interferometer.

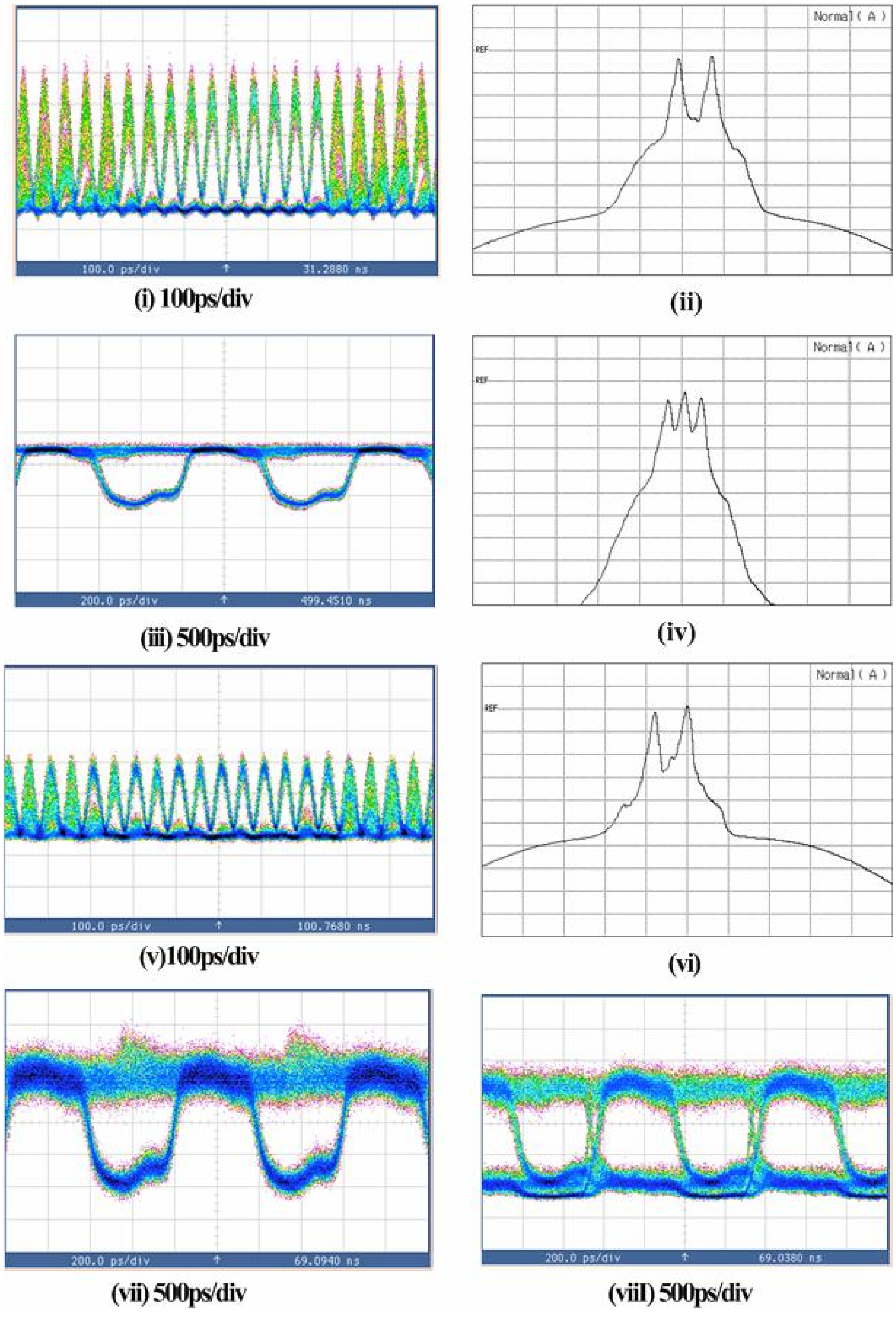

Fig.3 (i) The eye diagram of optical SCM signal; (ii) The spectrum of optical SCM signal; (iii) The eye diagram of optical DPSK/IRZ signal; (iv) The spectrum of main modulator output; (v) The eye diagram of passing optical SCM signal; (vi) The spectrum of passing optical SCM signal; (vii) The eye diagram of reflected optical DPSK/IRZ signal; (viii) The eye diagram of re-modulation ASK signal. Optical spectrum resolution: 0.07nm.

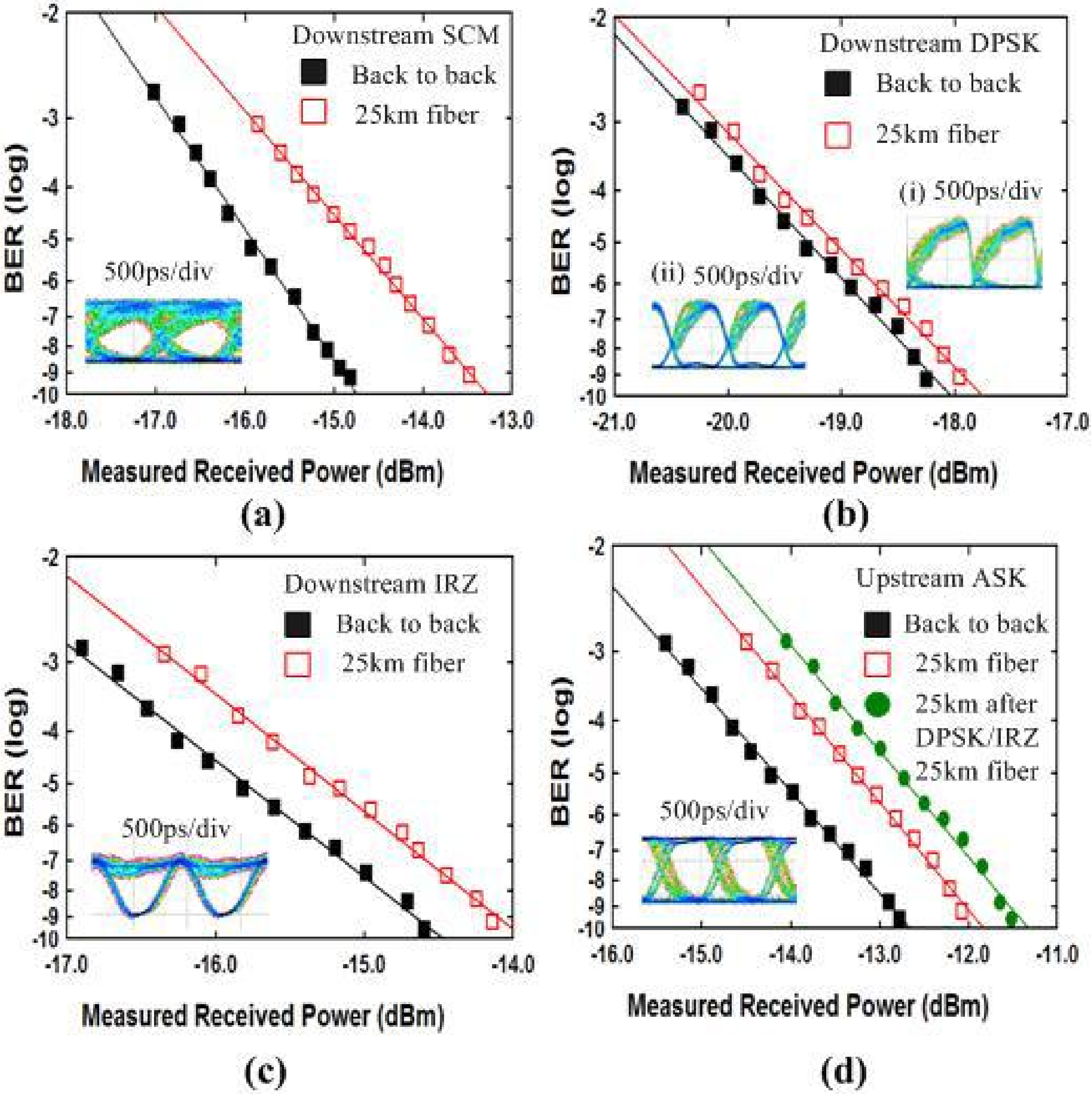

Fig.4. BER curves and eye diagrams. (a) Downstream SCM signal; (b) Downstream DPSK signal; (c) Downstream IRZ signal; (d) Upstream re-modulated ASK signal.

After transmission over 25-km standard single-mode fiber (SMF), at the ONU, a fiber brag grating (FBG) (0.1-nm 3-dB bandwidth and 90% reflection ratio) with an optical circulator is used to reflect the DPSK/IRZ format and pass the optical SCM signals. Fig. 3 (v) and (vi) indicates the optical eye diagram and optical spectrum of the passing optical SCM signals with data2, and the optical eye diagram of the reflected DPSK/IRZ format are shown in Fig. 3 (vii) . The

SCM signals are directly detected using a 2.5-GHz PIN. For the reflected DPSK/IRZ signals, it is divided into three parts. Among them, the IRZ signal is directly detected by a 2.5-GHz PD; the DPSK signal is firstly converted into the intensity signal by a 1-bit Mach-Zehnder delay interferometer and then detected by a 2.5-GHz PIN. The third part is re-modulated by a 1.25-Gb/s upstream data with a word length of 2^7-1 to produce an ASK signal, the optical eye diagram of the re-modulated ASK signal is provided in Fig. 3 (viii). After transmission of 25-km SMF, the upstream ASK signal is sent back to the OLT and detected using a 2.5-GHz PIN. Fig.3 shows the BER curves and the eye diagrams. For the SCM signals, after the transmission of 25 km, the power penalty is ~1.3 dB, the electrical eye diagram is shown in inset of Fig. 4 (a). For the downstream DPSK signal, compared with the back-to-back case, the power penalty is ~0.2 dB, the optical eye diagram after the delay interferometer and the detected electrical eye diagram are provided in insets (i) and (ii) of Fig. 4 (b), respectively. About 0.7-dB power penalty is observed for the IRZ signal, with the electrical eye diagram shown in inset of Fig. 4 (c). We also measured the BER performance of the re-modulated upstream ASK signal, Fig.3 (d) indicates that upstream signal suffers ~1.3-dB power penalty after the 25-km transmission of the DPSK/IRZ signals at the OLT and its electrical eye diagram is shown in inset of Fig. 4 (d).

4. CONCLUSIONS

We have proposed and experimentally demonstrated a novel WDM-PON architecture for simultaneously providing high-speed point-to-point downlink data and double-broadcast services with 1.25-Gb/s data rate. Moreover, the symmetrical upstream data re-modulation based on the DPSK/IRZ format is also performed. Because this WDM-PON system employs centralized light sources, shared fiber infrastructure, and re-modulation of upstream data, it can provide significant improvement on both implement cost and system reliability.

REFERENCES

[1] S. Park, C-H. Lee, K-T. Jeong, H-J. Park, J-G. Ahn, and K-H. Song, "Fiber-to-the-Home Services Based on Wavelength-Division- Multiplexing Passive Optical Network," *J. Lightw. Technol.*, vol. 20, no. 11, pp. 2582-2591, Nov. 2004.

[2] E. S. Son, K. H. Han, J. K. Kim, and Y. C. Chung ,"Bidirectional WDM passive optical network for simultaneous transmission of data and digital broadcast video service," *J. Lightw. Technol,* 21, pp.1723-1727, Aug. 2003.

[3] Qingjiang Chang, Junming Gao, Qiang Li, Yikai Su, "Simultaneous Transmission of Point-to-Point Data and Selective Delivery of Video Services in a WDM-PON Using ASK/SCM Modulation Format," in Proc. OFC 2008, paper OWH2.

[4] P. P. Iannone, K. C. Reichmann, and N. J. Frigo, "High-speed point-to-point and multiple broadcast services delivered over a WDM passive optical network," *IEEE Photon. Technol. Lett.*, 10, pp. 1328-1330, Sep. 1998

[5] J-H. Moon, Ki-Man Choi and Chang-Hee Lee ,"Overlay of broadcasting signal in a WDM-PON", OFC 2006, paper OThK8.

[6] M. Birk P. P. Iannone, K. C. Eeichmann, N. J. Frigo, "System for flexible multiple broadcast service delivery over a WDM passive optical network based on RF block-conversion of RF service bands within wavelength bands,"patent, US 7085495 B2 (2006).

[7] K. Higuma, S. Oikawa, Y. Hashimoto, H. Nagata, and M. Izutsu, "X-cut lithium niobate optical single-sideband modulator," *Electron. Lett.*, vol. 37, no. 8, pp. 515–516, Apr. 2001.

[8] S-S. Pun, C-K. Chan and L-K. Chen, "Demonstration of a Novel Optical Transmitter for High-Speed Differential Phase-Shift-Keying /Inverse-Return-to-Zero (DPSK/Inv-RZ) Orthogonally Modulated Signals," *IEEE Photon. Technol. Lett.*, vol. 17, no. 12, pp. 2763-2765, Dec. 2005.