Optical Engineering

SPIEDigitalLibrary.org/oe

Single-feeder fiber colorless wavelength-division-multiplexing passive optical network using differential quadrature phase-shift keying downstream and intensity remodulated upstream signals

Yousaf Khan
Xiangjun Xin
Idress Afridi
Aftab Husain
Abdul Latif

SPIE

Single-feeder fiber colorless wavelength-division-multiplexing passive optical network using differential quadrature phase-shift keying downstream and intensity remodulated upstream signals

Yousaf Khan
Xiangjun Xin
Idress Afridi
Aftab Husain
Abdul Latif
Beijing University of Posts and Telecommunications
State Key Laboratory of Information Photonics and Optical Communications
Beijing 100876, China
E-mail: yousafkhalil@gmail.com

Abstract. Wavelength-division-multiplexing passive optical network (WDM-PON) has been considered as a promising next generation access network solution. A centralized light-wave colorless WDM-PON architecture based on a single feeder fiber. At the optical line terminal, differential quadrature phase shift keying (DQPSK) modulated signal at 10 Gbps is utilized for downstream transmission is proposed and demonstrated. At the optical line unit, part of the downstream signal is remodulated using an intensity modulated on/off keying technique for upstream transmission. Simulation results show that downstream and upstream signals achieved error-free transmission at 10-Gbps symmetric data rate with negligible power penalties. The proposed scheme exhibit improved tolerance to Rayleigh backscattering over 20 km standard single mode fiber. [DOI: 10.1117/1.OE.52.1.015001]

Subject terms: wavelength division multiplexing; passive optical network; Rayleigh backscattering; differential quadrature phase shift keying.

Paper 121259 received Sep. 6, 2012; revised manuscript received Nov. 11, 2012; accepted for publication Nov. 30, 2012; published online Jan. 4, 2013.

1 Introduction

In recent years, traffic trends in access networks have shifted from simple web based services to video based interactive and multimedia services. The mismatch between current traffic trends and static network infrastructure is a major driving force for migration towards the next generation optical networking.[1] Passive optical networks (PONs) have been considered as a promising access network solution due to its high bandwidth provision, and its low maintenance cost. In such a system, the architecture design and technique of millimeter wave generation for upstream and downstream signal plays an important role in efficient network deployment.[2] Using a single feeder fiber for both downstream and upstream transmission in a full duplex arrangement can further reduce the deployment cost of the wavelength-division-multiplexing passive optical network (WDM-PON).[3] However, the performance of a single fiber colorless WDM-PON system undergoes from the transmission impairments due to Rayleigh backscattering (RB) induced noise. It causes degradation in upstream signal and deteriorates receiver bit-error-rate (BER) at optical line terminal (OLT).[4]

In recent years, various remodulation schemes have been proposed to achieve robust performance of both downstream and upstream transmission.[5] WDM/TDM-PON scheme based on reflective semiconductor optical amplifier (RSOA) was reported.[6] However, RSOA-based optical line unit (ONUs) may suffer from serious transmission penalties due to bidirectional transmission on the same wavelength in the same fiber. More specifically, in single feeder-fiber WDM/TDM PON architectures, RB limits the maximum distance between OLT and ONUs. A WDM/TDM-PON using downlink DPSK signal has been proposed,[7] a narrow band array waveguide grating (AWG) was used at remote node (RN) to demodulate downlink DPSK signals for both downlink data detection and uplink injection-locking. However, the downlink residual data causes downlink-to-uplink crosstalk and severely degrades the uplink transmission performance. However, these schemes either use complex modulation formats, high deployment cost or need extra circuits and devices at ONU. Further applications and technical issues for commercial deployment of Hybrid WDM/TDM-PON have been reviewed and reported.[8,9]

Differential quadrature phase shift keying (DQPSK) for its constant envelope and excellent transmission qualities can be used as downstream signal as well as an optical source of upstream in the ONU, using on/off keying (OOK) modulation.[10,11] Zhang Wei-Feng[11] proposed a scheme based on downstream DQPSK and upstream OOK signals in dual feeder fiber architectures to achieve full duplex transmission in WDM-PON. However, the use of DCF in uplink will had a significant effect on the deployment cost. In this paper we propose and demonstrate a colorless 10-Gbps WDM-PON employing downstream DQPSK and intensity remodulated upstream OOK signals in single-feeder fiber architecture. The upstream transmission is achieved without using DCF to alleviate the deployment cost.

2 Working Principles and Network Architecture

There are two basic components of RB which interferes with the upstream data signal when it propagates from ONU to OLT in a conventional single feeder WDM-PON. The first component, the carrier backscattering P_{CB} is generated by

0091-3286/2013/$25.00 © 2013 SPIE

the carrier being delivered to ONU. The mathematical expression for P_{CB} is as given below:[12]

$$P_{CB} = P_C B(1 - e^{-2\alpha L}), \quad (1)$$

where P_C is the carrier power injected into the fiber, $B = S_{\alpha_S}/2\alpha$ with the α_S [Km^{-1}] fiber scattering co-efficient, S the fiber recapture co-efficient (dimensionless), α_S [Km^{-1}] the attenuation co-efficient and L indicate the fiber length. The second component, the signal backscattering P_{SB} is generated by the modulated upstream data signal. The back scattered lights re-enters the ONU where it is remodulated and reflected toward the receiver at OLT. The mathematical expression for P_{SB} is given as:

$$P_{SB} = P_C B(1 - l^2) l^2 g^2. \quad (2)$$

This noise again will create RB resulting in continues iterative process. Thus Eq. (2) develops into

$$P_{SB} = P_C l^2 \sum_{n=1}^{\infty} B^n (1 - l^2)^n g^{n+1}. \quad (3)$$

The spectrum of P_{CB} remains the same as the CW carrier, whereas the spectrum of P_{SB} becomes broaden, as it is modulated twice at ONU. It has noted that under normal conditions, this expression depends on the squared gain which may lead to systems limitations.

The proposed WDM-PON architecture is shown as in Fig. 1. An OLT consists of distributed feedback laser diode (DFB-LD) arrays which offer wavelengths from $\lambda 1$ to $\lambda 4$ for DQPSK modulated downstream data signal. For the DQPSK downstream transmission, a pseudo random binary sequence (PRBS) is used to generate 10-Gbps binary data to produce electrical stream, after serial to parallel conversion signal passes through Precoder. In optical DQPSK system, Precoder is essentially used to avoid iterative decoding, reduce hardware complexity and accuracy at receiver for detection and demodulation. After precoding, signal is split into two 5-Gbps sequences with four binary patterns (00, 01, 10, 11) for the in-phase (I) and quadrature-phase (Q) parts of the DQPSK signals, corresponding to four phases (0, $\pi/2$, π, $3\pi/2$). To achieve this, π and $\pi/2$ phase shifted two phase modulators has been used in series instead of parallel combination.[8] The generated downstream DQPSK signals are multiplexed and transmitted over 20 km standard single mode fiber (SSMF) using a single feeder fiber configuration. On the other end, de-multiplexer is used to demultiplex the downstream signal and send them to respective ONU. At ONU, a portion of the downstream received optical power is tapped off by a half power splitter. The constant intensity downstream DQPSK signal is demodulated by DQPSK receiver. The rest of the downstream optical signal is remodulated by an intensity modulation technique of 10-Gbps RZ-OOK. The generated upstream signal is transmitted back to the OLT using SSMF through a complete path. However, regarding typical OLT configurations, the up and down-link paths are merged by means of an optical circulator and therefore a possible reflection is strongly attenuated. By using circulator at ONU, upstream input signal can be isolated from backscattering reflections of upstream transmitted signals thereby minimizes backscattering.

Figure 2 shows the waveforms of four downstream DQPSK and upstream OOK multiplexed signals. For upstream signal, downstream signal power is used as a carrier for remodulation of OOK upstream data via intensity modulator and transmitted towards OLT in central office (CO). Since downstream signal carrier is re-used for the upstream data therefore no additional dedicated wavelength light source is required at the ONU and thus a cost-effective WDM-PON with scalable and flexible wavelength management is achieved.[13]

DQPSK is very popular transmission technique for multilevel, spectral efficient and high data rate transmission. Since it transmits 2 bits per symbol therefore only half spectral occupancy is required as compare to DPSK.[14] Due to four-level phase modulation and approximately constant envelope in intensity, DQPSK modulation provides better performance against nonlinear effects, reduces the cost of electric drive components and improves the flexibility towards polarization mode dispersion (PMD). Also transmission capacity of DQPSK system is twice of DPSK at the same symbol rate. As compared to OOK modulation, DQPSK provides better performance against nonlinear effects and much

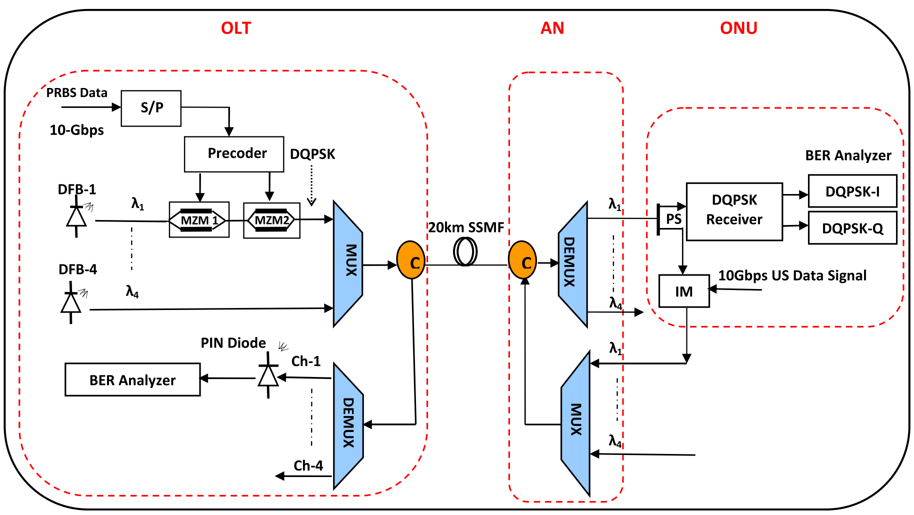


Fig. 1 Schematic diagram of single feeder full duplex WDM-PON system.

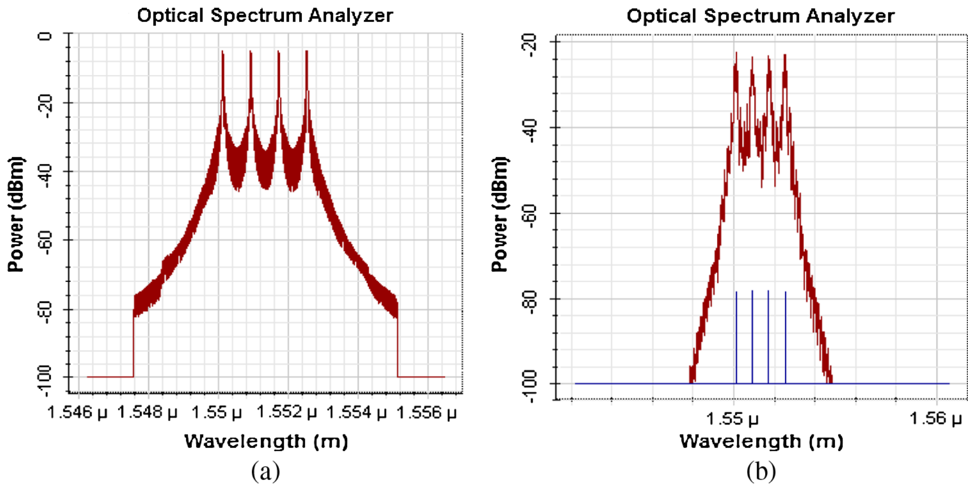


Fig. 2 (a) Four downlink multiplexed DQPSK signal, (b) four uplink multiplexed OOK signal.

improved receiver sensitivity due to balanced receiver design as well as reduced OSNR requirements.[15] By reducing the modulation of the DQPSK signal in downstream signal will degrade the extinction ratio (ER). The narrow spectrum of the downstream signal will broaden after remodulation by the upstream data due to full modulation depth and high ER. On the contrary, as the spectrum of Rayleigh backscattered signal towards the OLT is as narrow as the downstream reduced modulated depth DQPSK signal hence RB noise considerably rejected.[16]

At the DQPSK receiver, Two Mach-Zehnder delay interferometers (MZDI) are used for realizing the coherency and optical signals cancellation with delay T and phase shifts $\pi/4$ and $-\pi/4$. To produce phases in I and Q branches $T = 2/B$ delay is set in MZDI, where B is the transmission bit rate. Two balanced detectors are used after MZDI for separately applying the phase difference in I and Q branches of DQPSK, which provides enhanced receiving sensitivity than the OOK modulation.[15]

3 Simulation Setup and Operation

To discuss the performance of the proposed WDM-PON system, we establish a model for simulation using Optisystem v.8.0 according to the network architecture as shown in Fig. 1. A 10-Gbps pseudorandom bit stream (PRBS) data of order $2^7 - 1$ is used for four DQPSK channels downstream transmission, using ITU-T grid of 100 GHz channel spacing. Four continuous light waves, having a launch power of 10 dBm are generated using distributed feedback (DFB) lasers at wavelengths of 1552.52, 1552.12, 1551.72, and 1551.32 nm for four different channels, respectively. They are multiplexed and transmitted over 20 km SSMF. At the access node, a 3 dB optical splitter divides downstream signal into two parts. An intensity modulation technique of 10-Gbps OOK is used to remodulate the first half of the power splitter to generate upstream data signal. The second half of the power splitter is demodulated by the DQPSK receiver. However, regarding typical OLT configurations, the up-link and down-link paths are merged by means of optical circulators. The general settings of the fiber used in our simulation are given in Table 1.

Table 1 Simulation parameters.

SMF parameters	Values
Length	20 km
Dispersion parameter	16.75 ps/nm/km
Dispersion slop	0.075 ps/nm^2/km
Attenuation coefficient	0.2 dB/km
Effective core area	80 μm^2
Non linear index-coefficient	$2.6 \times 10 - 20$
Responsitivity of photo detector	1 A/W
Dark current of photo detector	10 nA
Rayleigh backscattering	5e-005 (1/km)

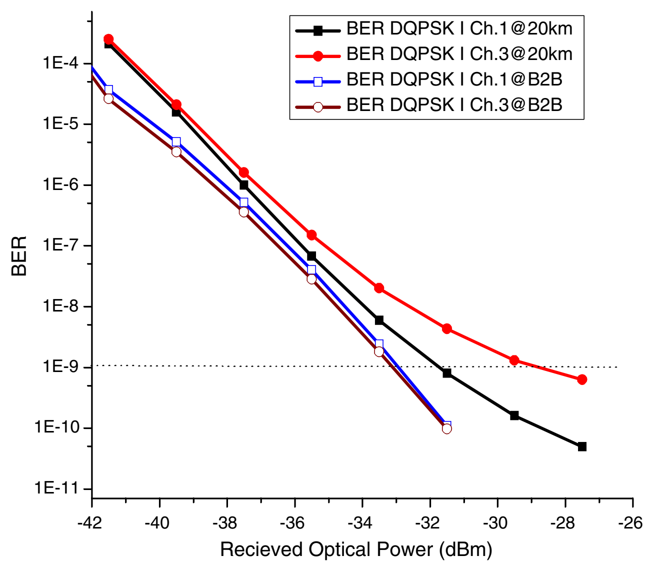


Fig. 3 BER versus R x power DQPSK-I.

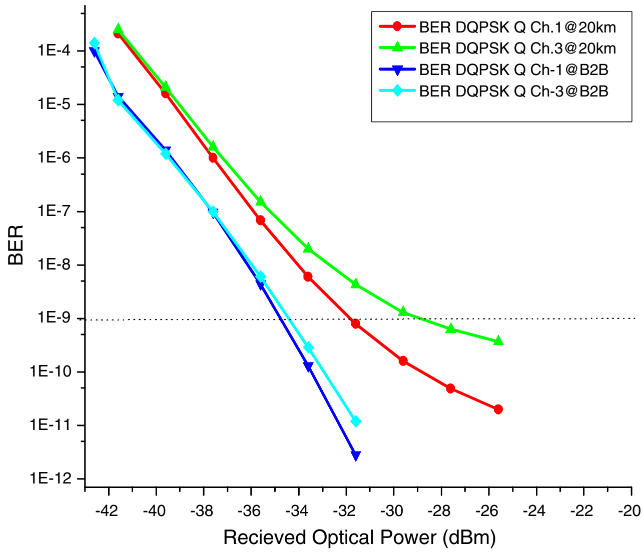


Fig. 4 BER versus R x power DQPSK-Q.

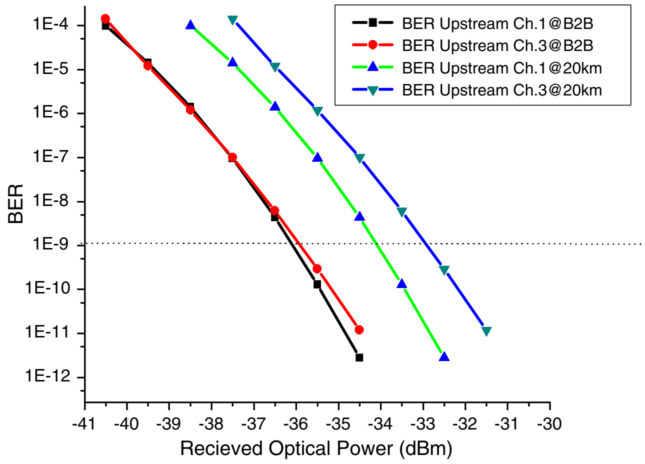


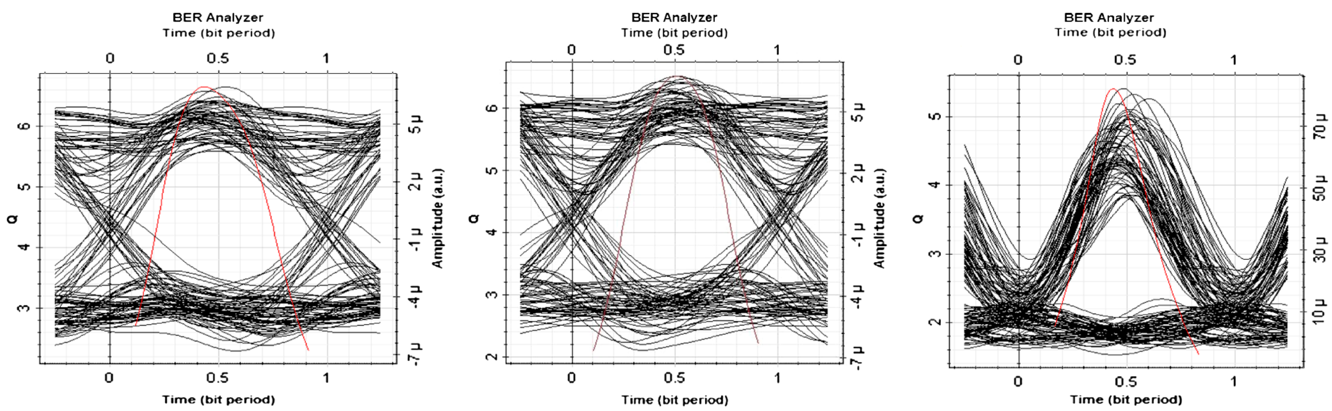
Fig. 5 BER versus R x power OOK.

4 Performance Analysis and Results

We analyzed transmission performance of proposed WDM-PON in Optisystem v.8.0 software.[17] For convenience, the performances of ch.1 and ch.3 are investigated by the assistance of constellation diagrams, eye diagrams and bit error rate (BER) measurements. To measure transmission power penalties of downstream and upstream channels in WDM-PON, received optical power of every channel with respect to BER is analyzed in back to back (B2B) and after 20 km transmission.

Figure 3 shows BER versus received optical power of DQPSK-I for the two selected channels in downstream transmission. We compared these channels in back to back (B2B) and after 20 km transmission setup at BER of 10^{-9}, transmission power penalties of the chosen channels are found 1.5 and 3.0 dB, respectively. Figure 4 shows BER versus received optical power of DQPSK-Q for the two selected channels in downstream transmission. We compared these channels in back to back (B2B) and after 20 km transmission setup at BER of 10^{-9}, transmission power penalties of the chosen channels are found 2.5 and 3.2 dB, respectively. Figure 5 shows BER versus received optical power of OOK for the two selected channels in upstream transmission. We compared these channels in back to back (B2B) and after 20 km transmission setup at BER of 10^{-9}, transmission power penalties of the chosen channels are found 2.5 and 3.0 dB, respectively. Such a power penalties are largely attributed to two basic components of RB i.e., the carrier backscattering and the signal backscattering along with chromatic dispersion,[18,19] however the constant performance of both downstream and upstream signals clearly illustrates the applicability of such a cost effective scheme for the implementation in future WDM-PONs. Therefore, it is evident from the above results that an error-free transmission has been achieved for both downstream and upstream direction using a single feeder fiber and without using any dispersion compensation modules[9] to alleviate the system complexity and cost.

Eye diagrams of DQPSK-I, DQPSK-Q and OOK channels are shown in Fig. 6. Good eye openings ensure high transmission performance in both downstream and upstream of proposed WDM-PON. A constellation diagram is a representation of digital modulated signal, such as quadrature amplitude modulation (QAM) or phase shift keying (PSK), by which two-dimensional scatter diagram in the complex plane is shown for the possible sampling symbols that may be chosen by a particular modulation scheme. It identifies the interference and distortion in the signal. Constellation diagram of DQPSK signal of ch.1 is shown as in Fig. 7, with good symbol sampling instants in the complex plane, indicates high transmission performance in downstream of proposed WDM-PON.



(a) (b) (c)

Fig. 6 Eye diagrams: (a) DQPSK-I, (b) DQPSK-Q, (c) OOK from channel 1.

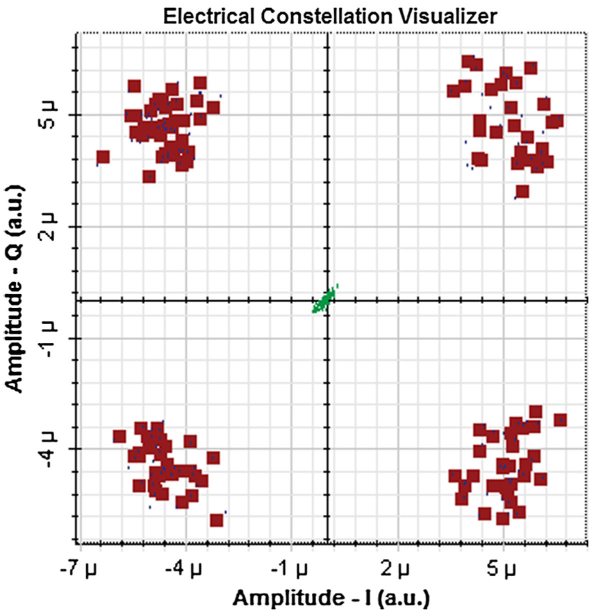


Fig. 7 Electrical constellation diagram.

5 Conclusion

We proposed and demonstrated a centralized light-wave colorless WDM-PON architecture based on single-feeder fiber. DQPSK modulated signal at 10-Gbps is utilized for downstream transmission while part of the downstream signal is remodulated using an intensity modulated OOK technique for upstream transmission. The power penalties of symmetric 10-Gbps downstream and upstream data signals at BER of 10^{-9} are 2.5 and 3.0 dB, respectively. An error free colorless transmission are achieved over a distance of 20 km without using any optical amplifier or dispersion compensation modules to alleviate the system complexity and cost. The proposed scheme exhibit improved tolerance to RB over 20 km SSMF.

Acknowledgments

The financial support from National Basic Research program of China with No. 2010CB328300, National Natural Science Foundation of China with No. 61077050, 61077014, 60932004, BUPT Young Foundation with No. 2009CZ07 is gratefully acknowledged. The project is also supported by the Fundamental Research Funds for the Central Universities with No. 2011RC0307, 2011RC0314 and open foundation of state key laboratory of optical communications technologies and networks (WRI) with No. 2010-OCTN-02.

References

1. R. Lin, "Next generation PON in emerging networks," in *Optical Fiber communication/National Fiber Optic Engineers Conference (OFC/NFOEC)*, IEEE, San Diego, CA (2008).
2. Z. Jia et al., "Key enabling technologies for optical–wireless networks: optical millimeter-wave generation, wavelength reuse, and architecture," *J. Lightwave Technol.* **25**(11), 3452–3471 (2007).
3. E. Wong, "Current and next-generation broadband access technologies," in *Optical Fiber Communication Conference and Exposition, and the National Fiber Optic Engineers Conference (OFC/NFOEC)*, pp. 1–4, IEEE, Los Angeles, CA (2011).
4. M. Fujiwara et al., "Impact of back-reflection on upstream transmission in WDM single-fiber loopback access networks," *J. Lightwe Technol.* **24**(2), 740–746 (2006).
5. L. Banchi et al., " Enhanced reflection tolerance in WDM-PON by chirped RZ modulation," *Electron. Lett.* **46**(14),1009 (2010).
6. G. de Valicourt et al., "High Gain (30 dB) and high saturation power (11 dBm) RSOA devices as colorless ONU sources in long-reach hybrid WDM/TDM-PON architecture," *IEEE Photon. Technol. Lett.* **22**(3), 191–193 (2010).
7. N. Calabretta et al., "A bidirectional WDM/TDM-PON using DPSK downstream signals and a narrowband AWG," *IEEE Photon. Technol. Lett.* **19**(16), 1227–1229 (2007).
8. K. Iwatsuki and J. Kani, "Applications and technical issues of wavelength-division multiplexing passive optical networks with colorless optical networks units," *J. Opt. Commun. Netw.* **1**(4), 17–24 (2009).
9. J. Hyuan Lee et al., "First commercial deployment of Gigabit WDM/TDM hybrid PON system using remote protocol terminator," *J. Lightwe Technol.* **28**(4), 344–351 (2010).
10. D. van den Borne, S. L. Jansen, and E. Gottwald, "DQPSK modulation for robust optical transmission," in *Optical Fiber communication/National Fiber Optic Engineers Conference (OFC/NFOEC)*, pp. 1–3, IEEE, San Diego, CA (2008).
11. Z. Wei-feng et al., "Centralized light-wave WDM-PON employing DQPSK downstream and OOK remodulated upstream signals," *J. Chin. Univ. Posts Telecommun.* **17**(4)125–128 (2010).
12. D. Derickson (Ed.), *Fiber Optics Test and Measurement*, Hewlett-Packard Professional Books, Prentice-Hall, Englewood Cliffs, NJ (1997).
13. C. K. Chan and L. K. Chen et al., "WDM PON for Next-Generation Optical Broadband Access Networks," in *Opto-Electronics and Communications Conference (OECC)*, 5E2-1-1, Light Wave Communications Laboratory, Kaohsiung, Taiwan (2006).
14. X. Liu et al., "Optical technologies and techniques for high bit rate fiber transmission," *Bell Labs Tech. J.* **11**(2), 83–104 (2006).
15. L. Li and J. Zhanga et al., "Analysis modulation formats of DQPSK in WDM-PON system," *Optik Int. J. Light Electron Opt.* **123**(22), 2050–2055 (2012).
16. E. Wong et al., "Rayleigh backscattering and extinction ratio study of optically injected-locked 1.55 μm VCSELs," *Electron. Lett.* **43**(3), 182–183 (2007).
17. http://www.optiwave.com/.
18. Q. Guo and A. V. Tran, "Reduction of backscattering noise in 2.5 and 10 Gbit/s RSOA-based WDM-PON," *Electron. Lett.* **47**(24), 1333 (2011).
19. C. H. Yeh and C. W. Chow, "Signal remodulation ring WDM passive optical network with Rayleigh backscattering interferometric noise mitigation," *IEEE Commun. Lett.* **15**(10), 1114–1116 (2011).

Yousaf Khan received his BE and MSc in electrical engineering from N-W.F.P University of Engineering and Technology Peshawar, Pakistan in 2000 and 2003, respectively. He worked at Pakistan Telecommunication Company Limited as senior engineer of Switching Networks. Currently he is working toward his PhD from Beijing University of Posts and Telecommunications, Beijing, China. His research interests are optical communications, passive optical access networks, and radio over fiber.

Xiangjun Xin achieved his PhD in 2003 from Beijing University of Posts and Telecommunications. His research interests now focus on optical communication and satellite communication. He has presided over more than 20 great projects supported by Chinese government, such as 863 and 973 program, National Natural Science Foundation, etc. More than 100 members, including research staff now work in his group.

Idress Afridi received his BE in electrical engineering from Mehran University of Engineering and Technology Jamshoro, Pakistan in 1996 and MS in electrical engineering from N-W.F.P University of Engineering and Technology Peshawar in 2005. He worked at Pakistan Telecommunication Company Limited as Senior Engineer in Optical Fiber Networks. Currently he is working toward his PhD from Beijing University of Posts and Telecommunications, Beijing, China. His research interests are optical communications, passive optical access networks, and broadband services.

Aftab Hussain received his BE degree from NED Karachi in 1999, and MSc in electrical engineering from N-W.F.P University of Engineering and Technology Peshawar, Pakistan in 2004, respectively. He worked at Pakistan Telecommunication Company Limited as Senior Engineer Optical Fiber/ System Networks. Currently he is working toward his PhD from Beijing University of Posts and Telecommunications, Beijing, China. His research interests are optical communications, passive optical access networks, and radio over fiber.

Abdul Latif received his BE and MSc in electrical engineering from M-U.E.T University of Engineering and Technology Jamshoro, Pakistan in 1995 and 2006, respectively. He worked at Pakistan Telecommunication Company Limited as Senior Engineer Switching Networks. Currently he is working towards his PhD from Beijing University of Posts and Telecommunications, Beijing, China. His research interests are optical communications, optical code division multiplexing access (OCDMA), passive optical access networks, and radio over fiber.