Research Article

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A Bidirectional Hybrid WDM-PON with High Data Rate Transmission for Wired and Wireless Users in Long-Reach with Enriched Noise Tolerance Capacity against Rayleigh Backscattering

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Transportation of 10 Gbps, 10 Gbps/40 GHz, 10 Gbps/200 MHz data for downlink (DL) and 6 Gbps data for uplink (UL) transmission with Rayleigh backscattering (RB) noise mitigation for wired and wireless users even in radio-frequency sensitive areas have been proposed and investigated. A 2×2 wavelength-division-multiplexing mux/demux is employed to separate DL and UL to avoid RB noise. Power penalty of < 1 dB at Bit error rate value of 10^{-9} and clear eye-diagrams express the reliability and fruitfulness of the proposed network.

Key words: Rayleigh backscattering (RB) noise, wireless transmission, wavelength-division multiplexing (WDM), radio-over fiber (RoF).

1. Introduction

The thirst of broadband capacity is increasing exponentially day by day. Due to the advantageous characteristics such as high power affordable, enormous bandwidth, strengthen security, long reach, good quantifiability, wavelength-division-multiplexing passive-optical-networks (WDM PONs) are considered to be an appreciable solution [1–7]. A hybrid WDM network not only becomes the cornerstone of the single mode fiber (SMF) based network but also plays the same role for wireless, optical, RF based systems owing to its vast bandwidth, very high speed data rate and enormous coverage area [8]. Fusion of radio over fiber (RoF) system with WDM-PON delivers huge amount of superiority on flexibility, high capacity and cost effectivity too [9]. But, the system performance might be degraded due to RB noise especially in bidirectional transport system whenever both downlink (DL) and uplink (UL) signals of same wavelengths are transmitted through a same feeder fiber. Several research groups have already proposed various types of techniques to reduce RB noise [10–14]. A more effectual method to diminish the RB noise is constructed on cross re-modulation network [15]. Nevertheless, this system faces the re-modulation noise owing to the presence of downstream data in remodulated upstream signal [16]. Amid numerous types of proposed methods, crosstalk from reflection can be excellently lessened by crossed wavelength technique reported by C. H. Yeh et al. [14, 16]. This paper presents a transport system to transmit 10 Gbps, 10 Gbps/40 GHz, 10 Gbps/200 MHz DL signal along with RB noise minimisation for wired and wireless users even in RF prohibited areas and 6 Gbps UL signal for wired users. A 2×2 WDM mux/demux is utilized here to separate DL and UL signal to avoid the interferometric crosstalk due to RB noise. Feasibility of the proposed network is characterised in terms of bit error rate (BER) value and clear eye opening. As per authors knowledge based on literature survey, this is the very first time where, the proposed network has ability to transmit high data rate over long distance for wired, wireless users even in the RF prohibited areas like hospitals, kinder garden schools etc. with minimum RB noise.

2. Experimental set up

Block diagram of proposed transport system is depicted in Fig. 1. A Fabry-Perot laser diode (FPLD) is utilized as a source of optical carrier. A carrier waves of central wavelength 1550.72 nm is coming from FPLD and after passing through tuneable optical filter (TOF) it is split by a polarisation beam splitter (PBS) into two signals of opposite polarization states (P and S). Among them one (S state) is fed into Mach-Zehnder Modulator (MZM) via polarisation controller (PC) and modulated by 20 GHz RF signal and mixed with 10 Gbps on-off keying (OOK) data stream with pseudo random bit sequence (PRBS) of word

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length 2^{31}-1. The bias point of MZM is fine-tuned at a null operation point to generate carrier suppressed side bands. On the other hand, the P-polarised signal is fed into an another MZM and modulated with 10 Gbps PRBS data. These two modulated signals are combined by polarisation beam combiner (PBC). Simultaneously, another carrier signal of central wavelength 1551.12 nm is selected from FPLD via TOF and fed into an another MZM driven by 10 Gbps/200 MHz signal. Now, all the modulated signals are transmitted over 50 km SMF from optical line terminal (OLT) to remote node (RN). A 2×2 WDM mux/demux is employed here to separate DL and UL signal which reduces the RB effect in transport system. Here port "A" allows the DL signal while UL signal are passed through port "B". Finally, after RN, these signals are de-multiplexed and split according to their polarisation states and further communicated to the wired and wireless users. Signal of wired link is evaluated by bit error rate taster (BERT) after detection of photo diode (PD) and low pass filter (LPF). Whether, 40 GHz wireless signal is communicated through 15 m wireless link with the assistance of two horn antenna (HA) after detection of PD and amplified by PA. After wireless transmission, it is finally fed into BERT via low noise amplifier (LNA), error detector (ED), LPF and clock-data recovery (CDR). Through wireless link whenever the signal transmits, the phase and amplitude of the signal differs with wireless link distance. The LNA is used here to amplify the signal and eliminate the unwanted noise. After that, the deformed signal after transmission through wireless link is compensated, filtered and regenerated by CDR. CDR and LNA both lessen the fluctuation of phase and amplitude simultaneously that ensues the enhancement of BER value and quality of eye diagram upgradation. Similarly, one part of 10 Gbps/200 MHz signal after optical splitter (OS) in optical network unit (ONU) also detected and communicated over 15 m wireless distance with the assistance of PD, PA, HAs, LNA, ED, LPF, CDR and BERT. So, this system is also able to communicate information in RF sensitive areas like hospitals, kinder garden schools etc. Another part of signal from OS is launched into FPLD as an injection light for injection locking of wavelength 1550.32 nm wavelength of multi-wavelength source and modulated by 6 Gbps data and transmitted back through port "B" of WDM mux/demux over 50 km SMF, detected in OLT for wired users.

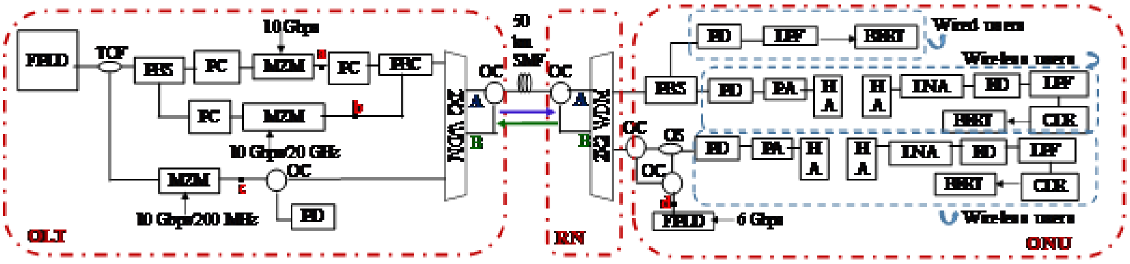

Fig. 1. Block diagram of proposed bidirectional hybrid WDM-PON for transportation of RB noise mitigated information to wired and wireless users.

The periodic output characteristic of 2×2 WDM mux/demux is used here to separate DL and UL for mitigation of RB noise [13]. To make it easy to understand a detail pictorial representation is given by assuming $2 \times N$ WDM mux/demux in Fig. 1.A. Fig. 1.A indicates the optical output characteristic of $2 \times N$ WDM multiplexer. As clarified in Fig. 1.A, the WDM wavelengths of λ_1 to λ_N and λ_2 to λ_{N+1} can pass through the WDM multiplexer from the input/output ports of "A" and "B", respectively. Henceforth, the output/input ports of "1" to "N" could permit the wavelengths of λ_1 and λ_2, λ_2 and λ_3, λ_3 and λ_4, and λ_4 and λ_5 and so on for passing, correspondingly. Owing to the periodic wavelength arrangement of $2 \times N$ WDM multiplexer, the output/input ports of "1" to "N" could also allow the wavelengths of λ_5 and λ_6, λ_6 and λ_7, λ_7 and

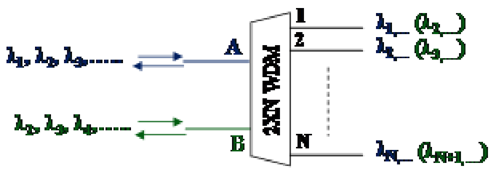

Fig. 1.A. Periodic output characteristics of $2 \times N$ WDM mux/demux.

λ_8, and λ_8 and λ_9 and so on sequentially, as per Fig. 1.A. Here, the principle of $2 \times N$ WDM mux/demux is exploited in a 2×2 WDM mux/demux furthermore the DL and UL wavelengths of 1550.72 nm, 1551.12 nm and 1550.32 nm are applied in the demonstration, individually. So, according to the designed WDM architecture, we employed the DL and UL signals with different wavelengths to evade the RB noise as this noise is arisen for transmission of more than one signals of same wavelengths through a single feeder fiber. In our proposed architecture, use of different wavelengths for DL and UL channel ensues the mitigation of RB noise in addition, the allowance of two ports of WDM mux/demux for two different purpose i.e. for transmission of DL and UL signal confirms the avoidance of cause of rising the noise due to RB.

3. Results and Discussions

Obtained optical and electrical spectra at some important points are depicted in fig. 2(a)–(h). Fig. 2(a)–(c) show the modulated optical spectra for DL after the modulator MZM, PM and MZM respectively. Fig. 2(d) depicts the optical spectra of modulated signal for UL transmission. The detected electrical spectra after PD for DL 10 Gbps wired, 10 Gbps/40 GHz wireless and 10 Gbps/200 MHz wireless users are shown in fig. 2(e)–(g) sequentially. Fig. 2(h) shows the detected electrical spectra after PD for 6 Gbps UL wired signal.

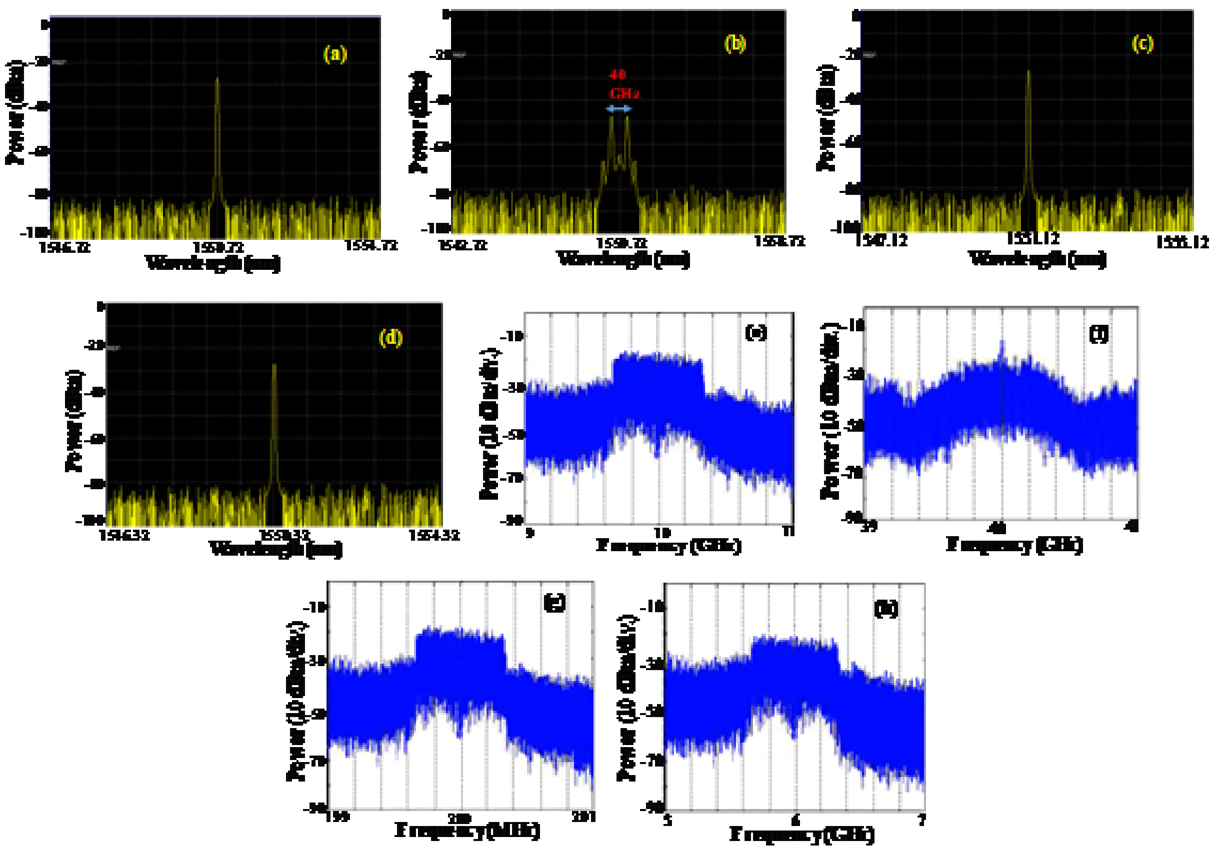

Fig. 2. (a)–(d). optical spectra of the modulated signals at ‘the output of the modulators [at point ‘a’–‘d’ insert fig. 1], (e)–(g) electrical spectra detected after PD for DL 10 Gbps wired, DL 10 Gbps/40 GHz MMW wireless, DL 10 Gbps/200 MHz wireless and (h) UL 6 Gbps wired signal.

The performance of proposed system is analysed in terms of power penalties, receiver sensitivities at the BER of 10^{-9}, clarity of eye diagram etc. BER curves with different received optical powers along with eye diagrams for DL 10 Gbps wired signal, DL 10 Gbps/40 GHz signal, DL 10 Gbps/200 MHz signal and UL 6 Gbps wired signals are shown in fig. 3(a)–(d) sequentially. Receiver sensitivities of −20.04 dBm, −19.54 dBm, −19.55 dBm and −15.65 dBm at BER of 10^{-9} for all signals respectively and power penalties of 0.65 dB, 0.8 dB, 0.8 dB, 0.85 dB are recorded sequentially for the aforementioned cases between B2B and over 50 km SMF. Clear and open eyes in fig. 2(a) to (d) prove the feasibility of the proposed network.

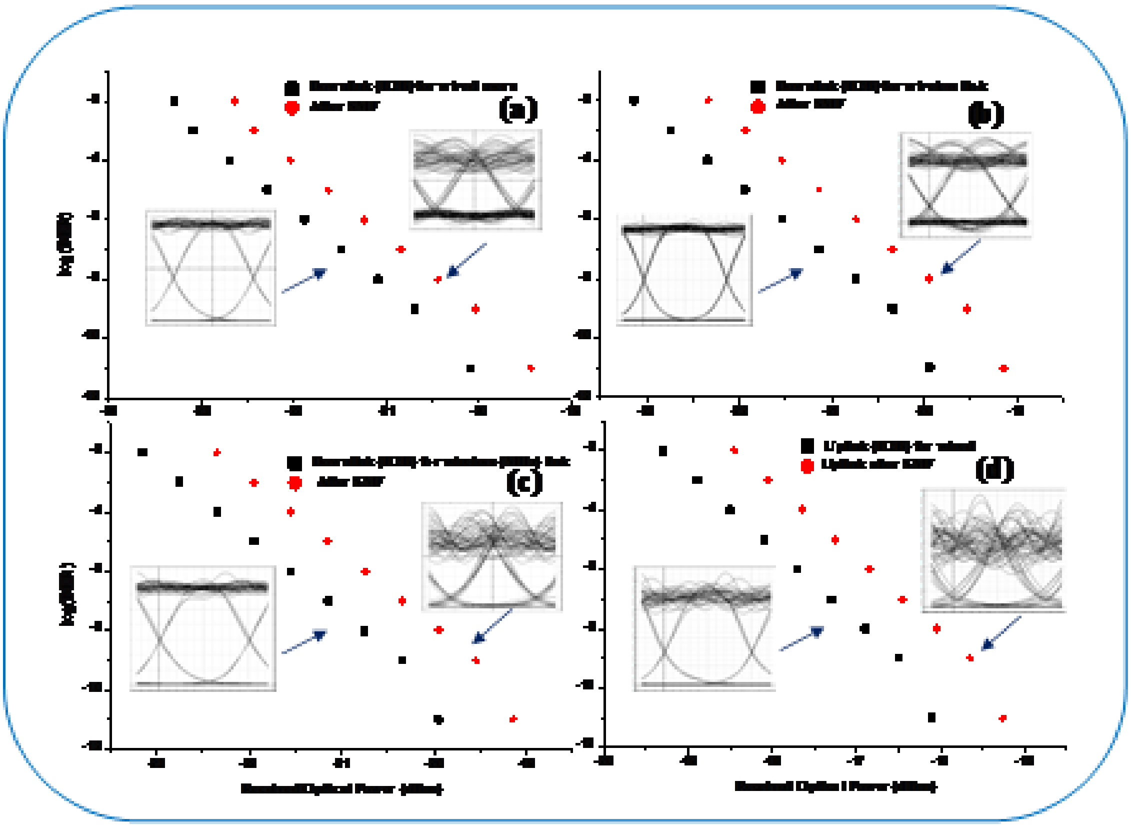

Fig. 3. Measured BER curves with different received optical power for DL (a) 10 Gbps wired (b) 10 Gbps/40 GHz wireless (c) 10 Gbps/200 MHz wireless (d) UL 6 Gbps wired signal.

4. Conclusion

A scheme for RB noise mitigation and transportation of 10 Gbps, 10 Gbps/40 GHz, 10 Gbps/200 MHz DL signal for wired and wireless users and 6 Gbps UL signal for wired users is proposed and demonstrated. Receiver sensitivities of −20.04 dBm, −19.54 dBm, −19.55 dBm, −15.65 dBm are achieved at the BER of 10^{-9} by DL 10 Gbps, 10 Gbps/40 GHz, 10 Gbps/200 MHz and UL 6 Gbps signal respectively. Very low power penalties (0.65 dB, 0.8 dB, 0.8 dB, 0.85 dB) for both DL and UL, clear and open eyes ensure the potential of the proposed scheme and also show the efficiency of giving a reliable platform for high data rate transmission in long reach along with RB noise elimination to the next generation communication world.

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References

[1] P. K. Choudhury, In-band simultaneous transmission of baseband and broadcast signals in wavelength reused bidirectional passive optical network, Opt. Commun. 355 (2015) 296–300.

[2] G. C. Mandal, R. Mukherjee, B. Das, A. S. Patra, A full-duplex WDM hybrid fiber-wired/fiber-wireless/fiber-VLC/fiber-IVLC transmission system based on a self-injection locked quantum dash laser and a RSOA, Optics Communications. 427 (2018) 202–208. https://doi.org/10.1016/j.optcom.2018.06.048.

[3] G. C. Mandal, R. Mukherjee, B. Das, A. Sekhar Patra, Bidirectional and simultaneous transmission of baseband and wireless signals over RSOA based WDM radio-over-fiber passive optical network using incoherent light injection technique, AEU—International Journal of Electron-

ics and Communications. 80 (2017) 193–198. https://doi.org/10.1016/j.aeue.2017.07.030.

[4] C. Ni, C. Gan, W. Li, H. Chen, Bandwidth allocation based on priority and excess-bandwidth-utilized algorithm in WDM/TDM PON, International Journal of Electronics and Communications (AEU). 69 (2015) 1659–1666.

[5] F. Y. Shih, C. H. Yeh, C. W. Chow, C. H. Wang, S. Chi, Utilization of self-injection Fabry–Perot laser diode for long-reach WDM-PON, Optical Fiber Technology. 16 (2010) 46–49. https://doi.org/10.1016/j.yofte.2009.10.001.

[6] E. Wong, Next-generation broadband access networks and technologies, J. Lightwave Technol. 30 (2012) 597–608.

[7] C. H. Yeh, C. W. Chow, C. H. Wang, F. Y. Shih, Y. F. Wu, S. Chi, Using four wavelength-multiplexed self-seeding Fabry–Perot lasers for 10 Gbps upstream traffic in TDM-PON, Opt. Exp. 16 (2008) 18857–18862.

[8] C. Y. Li, H. H. Lu, C. Y. Lin, C. A. Chu, B. R. Chen, H. H. Lin, C. J. Wu, Fiber-wireless and fiber-IVLLC convergences based on MZM-OEO-based BLS, IEEE Photon. Technol. J. 8 (2016) 7902810.

[9] S. Pan, Y. J. P., IR-UWB over fiber systems compatible with WDM-PON networks, IEEE/OSA J. Lightw. Technol. 29 (2011) 3025–3034.

[10] A. Chiuchiarelli, R. Proietti, M. Pres, P. Choudhury, G. Contestabile, E. Ciaramella, Symmetric 10 Gbit/s WDM-PON based on cross wavelength reuse to avoid Rayleigh backscattering and maximize band usage, Electron. Lett. 45 (2009) 1343–1345.

[11] P. K. Choudhury, Enhanced noise tolerance for 10Gb/s Bi-directional cross-wavelength reuse colorless WDM-PON by using spectrally shaped OFDM signals, Optical Fiber Technology. 42 (2018) 6–10.

[12] P. Mandal, K. Mallick, B. Dutta, B. Kuiri, S. Santra, N. Sarkar, A. S. Patra, Intensification of Noise Tolerance against Rayleigh Backscattering for Bidirectional 10 Gbps WDM-FSO Network by Employing Dual Band of OFDM Signal, Results in Optics. (2021) 100108. https://doi.org/10.1016/j.rio.2021.100108.

[13] P. Mandal, K. Mallick, S. Santra, B. Kuiri, B. Dutta, A.S. Patra, A bidirectional hybrid WDM-OFDM network for multiservice communication employing self-injection locked Qdash laser source based on elimination of Rayleigh backscattering noise technique, Opt Quant Electron. 53 (2021) 263. https://doi.org/10.1007/s11082-021-02948-2.

[14] P. Mandal, K. Mallick, B. Dutta, B. Kuiri, S. Santra, A.S. Patra, Mitigation of Rayleigh backscattering in RoF-WDM-PON employing self coherent detection and bi-directional cross wavelength technique, Optical and Quantum Electronics. 53 (2021). https://doi.org/10.1007/s11082-020-02720-y.

[15] S. C. Lin, S. L. Lee, H. H. Lin, G. Keiser, R. J. Ram, Cross-seeding schemes for WDMbased next-generation optical access networks, J. Lightwave Technol. 29 (2011) 3727–3736.

[16] C. H. Yeh, C. W. Chow, H. Y. Chen, Simple Colorless WDM-PON with Rayleigh Backscattering Noise Circumvention Employing m-QAM OFDM Downstream and Remodulated OOK Upstream Signals, J. Lightw. Technol. 30(2012) 2151–2155.