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Performance Enhancement of Bidirectional TWDM-PON by Rayleigh Backscattering Mitigation

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Abstract. A bidirectional time wavelength division multiplexing-passive optical network (TWDM-PON) with a centralized light source (CLS) is designed and evaluated. TWDM-PON is the promising solution for PON future expansion and migration. The most important issue that limits optical fiber transmission length is the interferometric noise caused by Rayleigh backscattering (RB). In this study, we demonstrate a TWDM-PON architecture with subcarrier at the remote node (RN) to mitigate the RB effect. A successful transmission with 8 optical channels is achieved using wavelength division multiplexing (WDM). Each optical channel is splitted into 8 time slots to achieve TWDM. The proposed scheme is operated over 20 km bidirectional single mode fiber (SMF). The proposed system has the advantage of expanding the downstream (DS) capacity to be 160 Gb/s (8 channels×20 Gb/s) and 20 Gb/s (8 channels×2.5 Gb/s) for the upstream (US) transmission capacity. This is accomplished by a remarkable bit error rate (BER) and low complexity.

1. Introduction

Recently the time and wavelength division multiplexed passive optical network (TWDM-PON) has been chosen by the Full Service Access Network (FSAN) as a primary solution for next generation PON stage2 (NG-PON2), owing to its features of backward compatibility, components availability and technical ripeness [1, 2]. Moreover, with increasing the bandwidth due to the requirement of intensive applications, the main aim of future high capacity PON system is to prepare a high access rate for an increased number of subscribers [3].

Besides high capacity and large subscriber numbers, the important matter that is very concerned by the users is the low cost and effective system upgrade. The scheme of employing CLS to remodulate the DS signal for US transmission without power source at ONU side is the attractive solution to laser saving and to reduce complexity [4, 5]. Also, CLS schemes suffer from the cross talk that occurs due to the utilization of the same wavelength for DS and US and reflections [5]. Before remodulating DS, it has been exposed to several reflections and RB in the DS direction. These reflections are amplified

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and highly affect the US data [6]. Researches designed and evaluated various architectures to compensate the RB effect leading to a remarkable performance. Reduction and mitigation are the main two strategies that are used to compensate the RB [5, 7, 8].

In this paper, a bidirectional TWDM-PON scheme is proposed and evaluated to mitigate the RB interferometric noise. This is carried out using a Mach-Zehnder modulator (MZM) that works as a carrier suppressor and a subcarrier generator at RN. A successful transmission is achieved with 8 optical channels using wavelength division multiplexing (WDM). Each optical channel is splitted into 8 time slots to achieve TWDM. The proposed scheme uses differential-phase-shift-keyed (DPSK) for 20 Gb/s DS and on-off key (OOK) for 2.5 Gb/s US and operates over 20 km bidirectional single mode fiber (SMF).

The remainder of the paper is organized as follows. Section 2 is devoted for a detailed description of the proposed system. System evaluation and simulation results are presented in Sec. This is followed by the main conclusions to show the merits of this work in Section 4.

2. Proposed WDM-PON system architecture

2.1. Introduction

Fig. 1 illustrates the proposed system architecture: a full-duplex 8-channels TWDM-PON centralized light source. This architecture is capable of transmitting 20 Gbit/s DS and 2.5 Gbit/s US per channel. The eight generated downstream return-to-zero differential-phase-shift-keyed (RZ-DPSK) signals are multiplexed with a multiplexer (MUX). The multiplexed signals are transmitted over a 20 km bidirectional optical fiber.

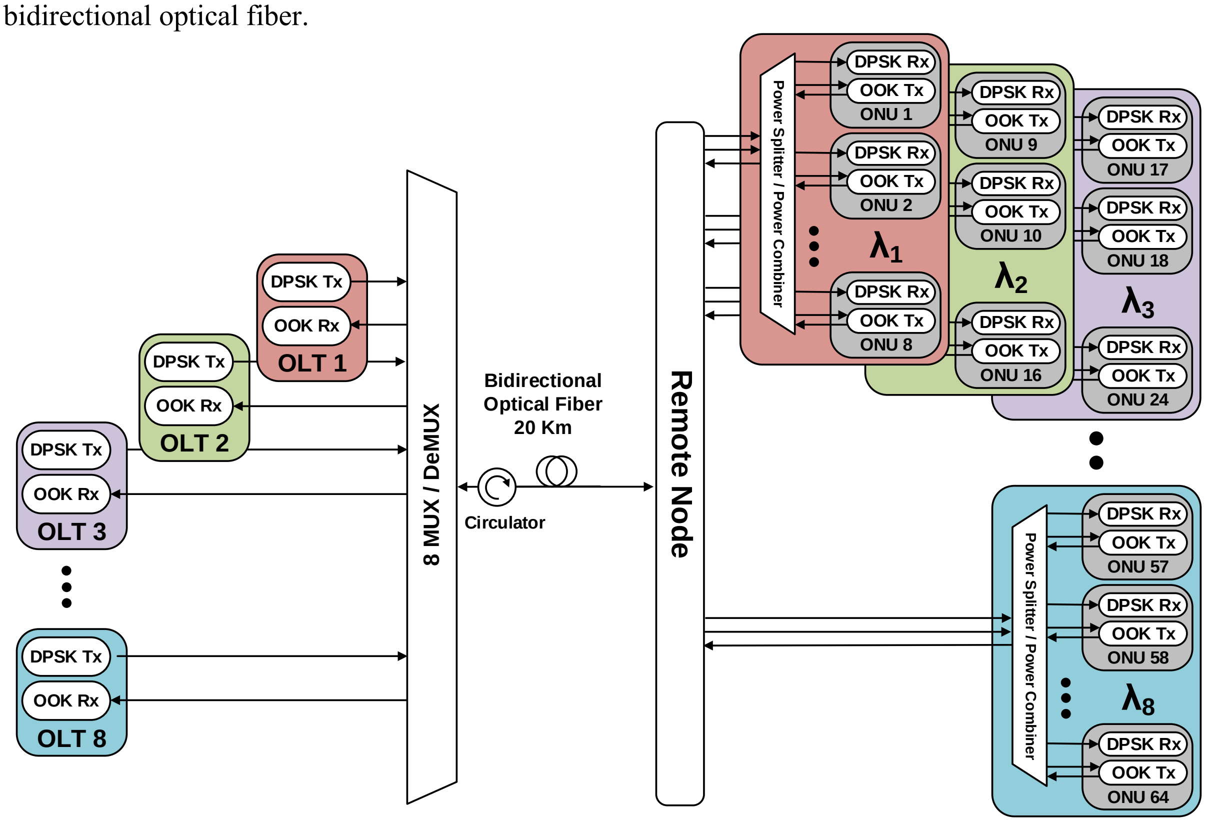

Figure 1. A full-duplex 8-channels TWDM-PON CLS.

At the RN, a MZM is used to suppress 8 carriers (8 DS signals) which contain the main power of RB and generates two subcarriers for each carrier. A demultiplexer (DeMUX) at RN is used to demultiplex the downstream signals (2×8 subcarriers). After demultiplexing 16 subcarriers, each two subcarriers (one is used to detect DS signal and the other to be remodulated for the US) send to their

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respective ONU. Each ONU splits the optical signal into 8 time slots. OOK modulation technique is used for US signals to retransmit to their respective OLT. Table 1 represents the operating parameters applied to the proposed system and that are extracted from literatures and standards.

Table 1. WDM-PON system parameters.

Parameter	Value	Unit
Bit Rate Downstream	20	Gb/s
Bit Rate Upstream	2.5	Gb/s
Distance [a]	20	km
Channel Spacing [b]	50	GHz
Channels Center Frequency	193.1	THz
No. of WDM Channels	8	N/A
No. of Time slots	8	N/A
Signal Power	10	dBm

[a] Distance matches the standards [9].
[b] Channel Spacing matches fixed-grid nominal central frequencies for WDM [10].

2.2. *System Structure*

2.2.1. DPSK Transmitter at OLT. The transmitter (Tx) consists of a continuous wave (CW) laser source with 10 dBm launched power which is supplied to one of the input of Mach-Zehnder modulator 1 (MZM1) as shown in Fig. 2. A 20-Gb/s non-return-to-zero (NRZ) pattern is generated with a duobinary precoder and is applied to the second input of MZM1 to form the DPSK. After that, the DPSK is applied to the second modulator, MZM2 (pulse carver), that cuts out only the amplitude-modulation-free center portions of the bits, thereby, largely eliminating any residual dips [11].

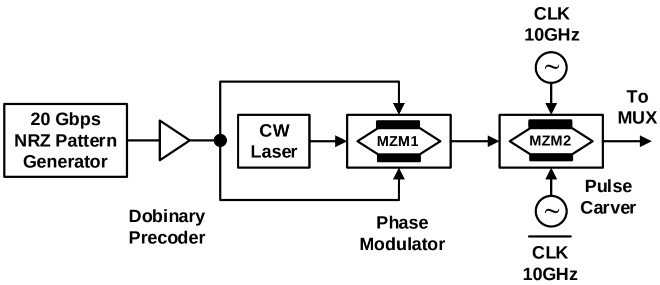


Figure 2. DPSK transmitter internal structure.

2.2.2. Bidirectional Fiber. Now, the 8 optical channels are prepared for multiplexing using MUX and are transmitted over a 20 km bidirectional single-mode fiber (SMF). The SMF specifications are tabulated in Table 2 [12, 13].

Table 2. Optical fiber parameters.

Parameter	Value	Unit
Dispersion	16.75	ps/km/nm
Dispersion Slope	0.075	ps/nm^2/km
RB coefficient	5e-005	km^{-1}

2.2.3. Remote Node. Figure 3 illustrates the RN structure. A MZM receives the 8 channels and the 12.5 GHz sinusoidal wave to suppress the carriers and generate two subcarriers for each carrier. A 16 subcarriers are generated with 25 GHz spacing. Then, they are demultiplexed using 1×16 DeMUX. Eight subcarriers are used to extract the DS information at DPSK receiver (Rx). The other eight subcarriers are used for US remodulation. By using one MZM at RN for the 8 channels, the US channels are shifted by 12.5 GHz from the DS channels to mitigate the RB. This is the main contribution of our proposed TWDM-PON with low complexity.

In Ref [7], the architecture uses two bidirectional fibers to mitigate the RB carrier. A DPSK modulation is utilized at ONU of architecture Ref. [8] to reduce the RB effect. In [14], a pair of electrical orthogonal codes is generated to mitigate RB.

2.2.4. DPSK Receiver at ONU. At each ONU, there are 8 DPSK receivers for the 8 times slots. Each consists of a delay interferometer (DI) with a delay (1/DS bit rate) and a coupling coefficient of 0.5. The two outputs of DI are applied into two PIN photodetectors to convert the optical signal into electrical signal. A low pass filer (LPF) is used to refine the electrical signal before subtracting. The DPSK receiver is shown in Figure 4.

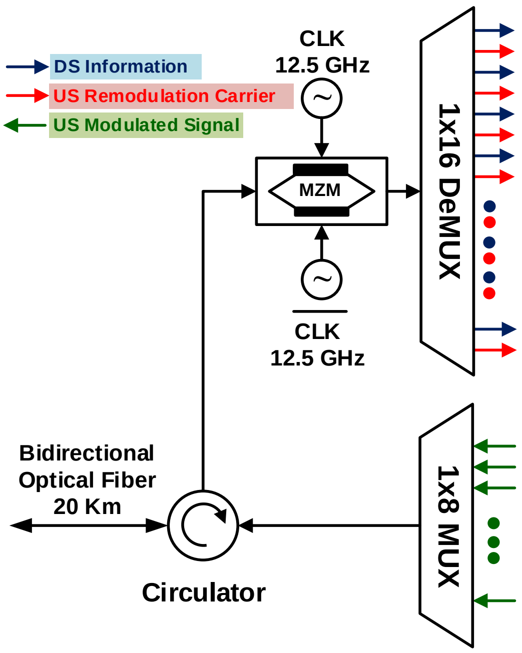


Figure 3. Remote Node internal structure.

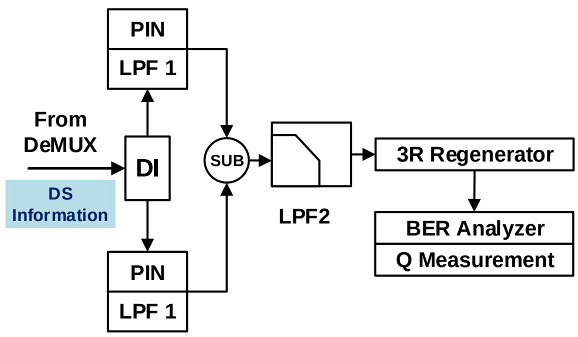


Figure 4. DPSK receiver internal structure.

2.2.5. OOK Transmitter at ONU. The OOK transmitter is a simple modulation format shown in Figure 5. A MZM modulates the US subcarrier with a 2.5-Gb/s NRZ pattern generator. Each ONU contains 8 OOK transmitters for 8 time slots. After remodulating the US signals, they are multiplexed by using MUX and are retransmitted over 20 km bidirectional fiber.

2.2.6. OOK Receiver at OLT. Each OLT receives its own optical signal, after demultiplexed by DeMUX, on PIN photodetector to convert the optical signal into electrical signal. A LPF is used to refine the electrical signal and prepare it for data extraction. Figure 6 illustrates the internal structure of the OOK receiver.

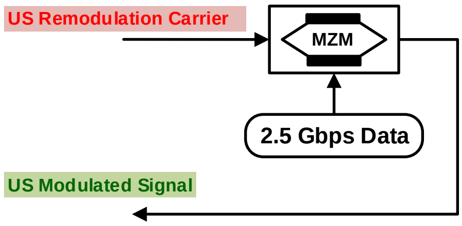


Figure 5. OOK transmitter internal structure.

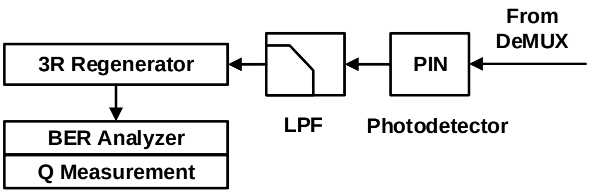
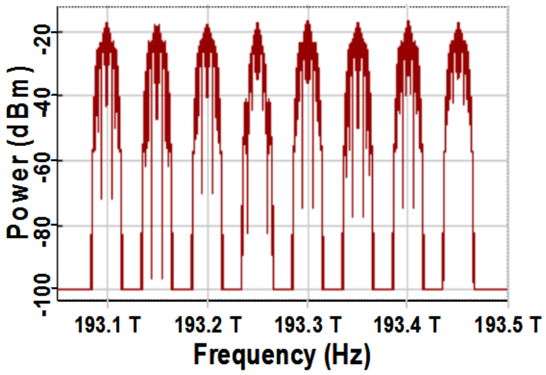


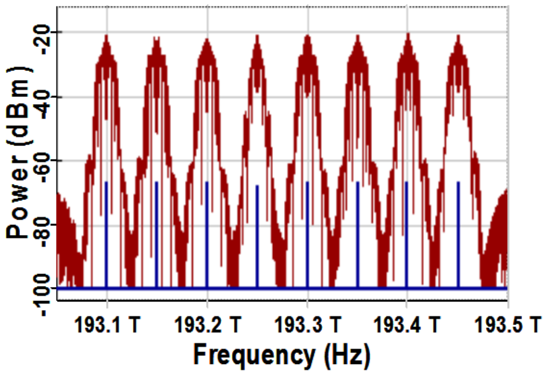
Figure 6. OOK receiver internal structure.

3. Results and analysis

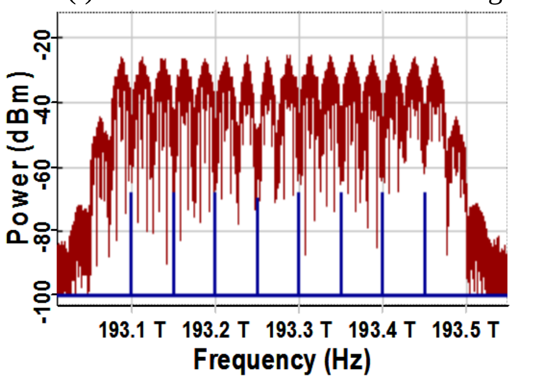
In this section, the proposed TWDM-PON architecture is verified and evaluated using simulation and the obtained results are discussed. In the OLTs, eight 50-GHz-spaced wavelengths are modulated by DPSK modulation format to be multiplexed as shown Fig. 7(i). In Fig. 7(ii), RB is illustrated (the blue signal) after transmitting the DS signals over 20 km. The RB main power (~ 70 dBm) is centered at each signal. To mitigate the RB, at the RN a MZM receives the 8 channels to suppress the carriers and generate two subcarriers for each carrier. 16 subcarriers are generated with 25 GHz spacing as shown in Fig. 7(iii). This idea has the advantages that DS signal becomes free from the RB effect and the US signals are clear from RB before retransmitting as shown in Fig. 7(iv) and without using another fiber as in Ref. [15].



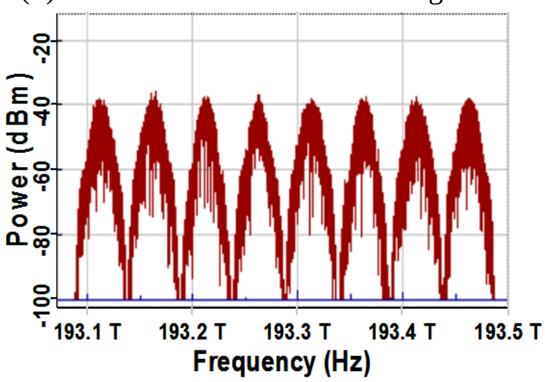
(i) 8 DS channels before transmitting



(ii) 8 DS channels after transmitting with RB



(iii) 16 subcarriers with 25 GHz spacing



(iv) 8 US channels before retransmitting.

Figure 7. Channels spectrum for each stage structure.

Figure 8 shows eye diagrams for DS and US signal. Their performances demonstrate the system feasibility and Q- factor. It is obvious that the Q- factor for both channels are greater than 7.0 which corresponds to bit-error-rate (BER) of ~10^{-13}.

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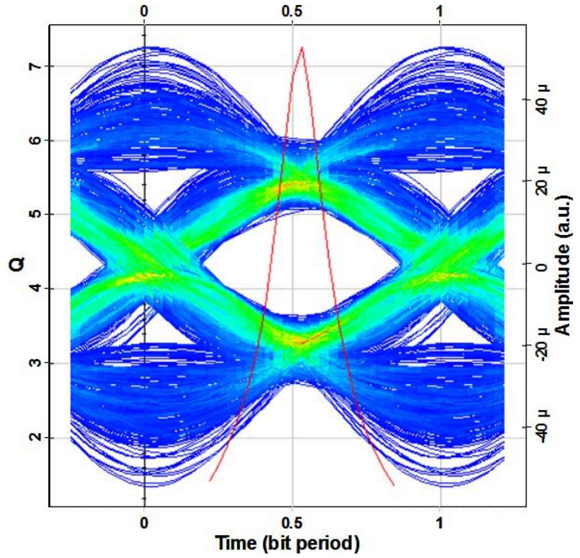
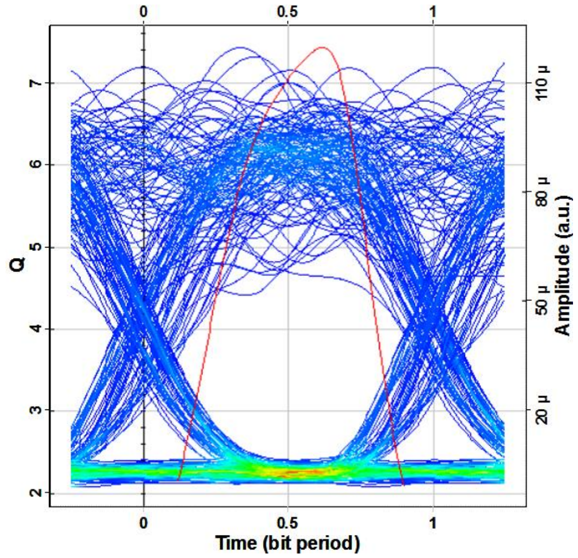


(i) DS eye diagram



(ii) US eye diagram.

Figure 8. Eye diagrams for DS and US signal.

4. Conclusion

A bidirectional TWDM-PON scheme is proposed and evaluated to mitigate the RB interferometric noise. This is accomplished by using only one MZM at RN. A successful transmission with 160 Gb/s DS and 20 Gb/s US optical channels using WDM technique is achieved. Each optical channel is splitted into 8 time slots to achieve TWDM. This scheme is capable of serving 64 users over 20 km bidirectional SMF with BER about 10^{-13}.

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