WDM Ring based Access Network mitigating Rayleigh Backscattering Noise

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Abstract—In this paper it is proposed and investigate a Wavelength Division Multiplexing Passive Optical Network (WDM-PON) ring providing Rayleigh backscattering (RB) noise reduction. Besides, the ring-based architecture also could reduce the RB beat noise. This is possible because RB and upstream signal are moving in opposite direction. In the proposed PON system, we have discussed and did analysis characteristics of the downstream signal using 10 Gb/s DQPSK, using optisystem software version 12. Moreover, we also investigate the upstream traffic using the 10 Gb/s OOK generated by the directly modulated reflective semiconductor optical amplifier-based optical network unit, respectively. This paper also describe the implementation strategy of our system in several well known metro network topologies including: (1) single ring. The simulation results are first presented by commercial simulation obtained using OptiSystem version 12 software. The simulation results show that the bit error rate (BER) through use of proposed wdm ring structure method is superior, especially when the received effect power is large. The eye diagram also shows that proposed wdm ring exhibits a wider opening.

Keywords—WDM-PON, CO, ONU

I. INTRODUCTION

BECAUSE of the rapid growth in the demand of broadband Multi services, passive optical network (PON) is a potential solution of the future fiber access systems [1]–[4]. Hence , Wavelength Division Multiplexed Passive Optical Networks (WDM-PONs), engaging directly modulated laser (DML) at the central office (CO) [5], [6] and reflective semiconductor optical amplifier (RSOA) for signal remodulation and reuse at each optical network unit (ONU) [7], [8] are popular system architectures of the future high-capacity and high-speed PON [9]. Hence, with colorless WDM-PON system, the Rayleigh backscattering (RB) interferometric beat noises will be generated by the downstream signal and result in impairment of network performance [10], [11]. Hence, in order to reduce the RB interferometric beat noise, various RB lessening techniques have been proposed and discussed, such as using the phase and bias-current dithering, employing wavelength-shifting technique, using advanced modulation formats, employing double laser bands source, and so on. [11]–[15]. Whereas, these projected methods would add to the complexity along with the cost of PON. Furthermore, these planned techniques were mainly used in tree-based WDM-PONs. In this paper, we propose and experimentally demonstrate the WDM-PON RING based system with the RB noise reduction. Here, we propose a new design in each RSOA is used at ONU to produce the downstream and upstream traffic moves in opposite directions. Accordingly, advanced modulation techniques are not necessary for mitigation of this RB noise. In the proposed architecture, single fiber ring configuration is used as well; each ONU will select the fiber path automatically to send out the data traffic. In this paper, this downstream 10 Gb/s DQPSK and the upstream 10 Gb/s OOK upstream signals by using RSOA-based ONU have been achieved and analyzed, respectively.

II. OPERATIONAL PRINCIPLE

Initially, a ring-based WDM-PON design with fiber-fault protection and RB noise reduction is proposed, as illustrated in Fig. 1. In the CO, the downstream and CW signals are combined via a blue
or red-band filter (BRF) and is transmitted through a WDM multiplexer and a 1X2 optical coupler and then into each ONU in counter clockwise (CCW) direction. Here, each ONU consists of 3 optical circulators (OCs), two 1-2 optical switches (SWs), an optical transceiver (TRx), a BRF, and two fiber Bragg gratings. The two FBGs are employed to reflect the consequent downstream and CW signals into the TRx to receive data and for upstream signal generation, respectively. Further, in the newly intended ONU, the TRx contains a 1.2 GHz bandwidth RSOA with a 2.5 GHz PIN receiver, respectively. Moreover, the downstream and CW signals were separated by a BRF to launch into the PIN and RSOA with that order. Hence, the RSOA will modulate the CW signal to give the upstream signal. In the signal transmission path, the upstream signal will also be reflected by the and transmit it through the CCW direction into CO. Resulting, the backscattered CW signal and its upstream signal move in two different directions. Then RB noise is mitigated. Besides, the planned ring-based WDM-PON system can also hold wavelength remodulation scheme to improve the wavelength efficiency effectively.

![Fig. 1. The schematic illustration of the planned Ring based WDM-PON.](image1)

![Fig. 2. Design of ONU](image2)

The proposed ring-based network could be one of the capable architectures for the NG (next-generation) access due to the flexible wavelength assignment. More than one wavelength can be assigned to an ONU to increase its capacity. Also the network scalability will be improved. As well, the ring-based network can present network protection. Recently, ring-based networks have been studied in Europe (EU projects) [31], [32], the U.S. [33], Japan [34], etc. In addition, the insertion loss in the proposed network can be compensated by using optical amplifiers. Fig. 2 shows a schematic illustration of the design of the ONU with flexible wavelength assignment along with
optical amplifiers to compensate the insertion loss. By using several tunable FBGs, flexible wavelength assignment along with management can be achieved.

III. PROPOSED EXPERIMENTAL SET UP

![Experimental setup in optisystem software of the planned architecture](image1)

**Fig. 3** Experimental setup in optisystem software of the planned architecture

![DQPSK transmitter configurations for MZMs in parallel](image2)

**Fig. 4** DQPSK transmitter configurations for MZMs in parallel

![DQPSK receiver configurations for MZMs in parallel](image3)

**Fig. 5** DQPSK receiver configurations for MZMs in parallel
As shown in Fig. 4, in which the main laser source is used at CO, which works as a carrier for DQPSK signal generated by phase modulators (MZM-1& MZM-2) and precoder circuit, which is transmitted over 20km standard single mode fiber (SSMF) 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 than DQPSK at the same symbol rate. As compared to OOK modulation, DQPSK provides better performance against nonlinear effects and much improved receiver sensitivity due to balanced receiver design. In single fiber WDM-PON, DQPSK also provides good resilience against RB induced noise. For the DQPSK downstream transmission, pseudo random binary sequence (PRBS) is used to generate 10 Gbit/s binary data to produce electrical stream, then signal is passed through serial to parallel conversion (S/P) and precoder. In DQPSK, precoder is essentially used to avoid iterative decoding, to reduce hardware complexity and to achieve accuracy at receiver for demodulation and detection. After the precoding, signal is split into two 5 Gbit/s streams 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, π/2, π, 3π/2) or (π/4, 3π/4, 5π/4, 7π/4). To achieve this, π and π/2 phase difference is set in the two phase modulators using in series configuration instead of phase modulators in parallel combination as was in. The carrier wave laser operates properly voltage biased LiNbO3 Mach-Zehnder modulators MZM-1 and MZM-2 for the phase modulation in DQPSK downstream signal without pulse carving and EDFA. At the DQPSK receiver, signal is split into two parts then two Mach-Zehnder delay interferometers (MZDI) are used for realizing the coherency and optical signals cancellation with delay T and phase shifts π/4 and -π/4. To produce phases in I and Q parts, 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 parts of DQPSK then bit error rate (BER) analyzer is used for analysis. Fig.4 and Fig 6 show DQPSK transmitters configuration by MZMs in parallel and proposed MZMs in series for signal generation respectively. Fig. 5 and Fig. 7 shows receivers configuration for MZMs in parallel and proposed MZMs in series for DQPSK signal reception respectively.

**TABLE 1 Design Parameters and values for RSOA**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Input Facet Reflectivity</td>
<td>99.99999999 e⁻⁰⁹⁹</td>
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<tr>
<td>Output Facet Reflectivity</td>
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<tr>
<td>Active Length</td>
<td>0.00050556 m</td>
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<tr>
<td>Taper Length</td>
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<tr>
<td>Width</td>
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<tr>
<td>Height</td>
<td>0.4 e⁻⁰⁶ m</td>
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<tr>
<td>Optical Confinement Factor</td>
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</tr>
<tr>
<td>Non Linear gain parameter</td>
<td>100 e⁻⁰²⁴ m³</td>
</tr>
</tbody>
</table>

In table 1 design parameters and their values for RSOA are shown. These parameters belong to input facet, output facet, and active region of RSOA model. These parameters are selected to give desired result. The re-modulated upstream signal was sent back to CO.
Fig. 6. DQPSK transmitter configurations for MZMs in series

Fig. 7. DQPSK receiver configurations for MZMs in series

Table 2: Parameters used for simulation

<table>
<thead>
<tr>
<th>SSMF Parameters</th>
<th>Values</th>
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<tr>
<td>Dispersion parameter</td>
<td>16.75 ps/nm/km</td>
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<tr>
<td>Dispersion slope</td>
<td>0.075ps/nm²/km</td>
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<tr>
<td>Attenuation Coefficient</td>
<td>0.2dB/km</td>
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<tr>
<td>Effective core area</td>
<td>80um²</td>
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<tr>
<td>Non Linear index coefficient</td>
<td>2.6x10⁻²⁰</td>
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<tr>
<td>Rayleigh backscattering</td>
<td>5x10⁻³/km</td>
</tr>
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</table>

IV. RESULTS AND DISCUSSION

Analyze the characteristics of the downstream signals 10 Gb/s using DQPSK and the upstream traffic 10 Gb/s using OOK

4.1 UPSTREAM ANALYSIS

Transmission performance of proposed WDM ring has been analyzed in Optisystem version 12 software. Performance analysis of channel 1550.6 nm has been investigated in upstream transmission with the help of eye diagrams and bit error rate (BER) measurements. Figure 8 shows
BER versus received optical power of OOK for the selected channel 1550.6 nm 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 channel are found nearly 4 dB. Such a power penalties are largely attributed to two basic components of RB i.e., the carrier backscattering and the signal is backscattering along with chromatic dispersion.

![BER versus Rx power OOK](image)

**Fig. 8** BER versus Rx power OOK.

![Eye diagrams of OOK](image)

**Fig. 9** Eye diagrams of OOK

### 4.2 DOWNSTREAM ANALYSIS

#### 4.2.1 Performance analysis using Serial MZM
Fig. 10 BER versus R x power DQPSK-I.

Fig. 11 BER versus R x power DQPSK-Q.
Transmission performance of proposed WDM-PON has been analyzed in Optisystem 12 software. Performance analysis of channel has been investigated in downstream transmission with the help of constellation diagrams, eye diagrams and bit error rate (BER) measurements. We have given maximum input optical power 0 dBm for DQPSK and 7 dBm for OOK modulation respectively. Constellation diagrams for DQPSK channel in Fig. 13, with good symbol sampling instants in the complex plane, indicate good transmission performance and resilience against influence of RB induced noise in downstream for proposed WDM-PON ring. Eye diagrams of DQPSK-I, DQPSK-Q are shown in Fig. 12(a), Fig. 12(b) respectively. These eye diagrams are obtained at input optical power is equal to 0 dBm. Large eye openings ensure transmission performance with RB noise-resilience in both directions of transmission of proposed WDM-PON ring. To measure transmission power penalty of downstream or upstream channels in single fiber WDM-PON ring, following method is required in all cases. In which received optical power of every channel is analyzed with respect to bit error rate (BER) in back to back (B2B) and over 20 km transmission and then at required BER i.e. $1 \times 10^{-9}$, the difference of received optical powers provides the power penalty of DQPSK-I, DQPSK-Q channel. Fig.10 shows BER versus received optical power of DQPSK-I for channel in downstream WDM-PON ring. As per required method, we compared these channels over 20 km transmission and back to back (B2B) at required $1 \times 10^{-9}$ BER, it can be observed that transmission power penalties are 2 dB. Similarly in Fig. 11, BER versus received optical power of DQPSK-Q for channel in downstream WDM-PON ring can be observed that transmission power penalties are 2.2 dB.
4.2.2 Performance analysis using Parallel MZM

Fig. 14 BER versus R x power DQPSK-I

Fig. 15 BER versus R x power DQPSK-Q.

a)
Fig. 16 Eye diagrams: (a) DQPSK-I, (b) DQPSK-Q

Fig. 17 Constellation diagrams of DQPSK (a) at 20 km (b) B2B
Figure 14 shows BER versus received optical power of DQPSK-I for the selected channel in downstream transmission. We compared those channel in back to back (B2B) and after 20 km transmission setup at BER of $10^{-9}$, transmission power penalties of the chosen channel is found 3.0 dB. Figure 15 shows BER versus received optical power of DQPSK-Q for the selected channel in downstream transmission. We compared those channel in back to back (B2B) and after 20 km transmission setup at BER of $10^{-9}$, transmission power penalties of the chosen channels is found 3.2 dB. Eye diagrams of DQPSK-I, DQPSK-Q channels are shown in Fig.16. These eye diagrams are obtained at input optical power is equal to 0 dBm . Good eye openings ensure high transmission performance in both downstream and upstream of proposed WDM-PON ring. 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 is shown as in Fig. 17 at 20 km and B2B, with good symbol sampling instants in the complex plane, indicates high transmission performance in downstream of proposed WDM-PON ring.

V. CONCLUSION

We have proposed basic design for WDM-PON ring . We also obtained experimental setup for this proposed design. We proposed and demonstrated a centralized lightwave colorless WDM-PON ring 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. 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. Here we have observed the sensitivity of DQPSK format was better compare to OOK. We have successfully designed ring based WDM PON for 4 ONU without EDFA with less BER.

REFERENCES


