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RESEARCH ARTICLE

Rayleigh backscattering noise in single-fiber loopback duplex WDM-PON architecture

Duan LIU (✉), Songnian FU, Ming TANG, Ping SHUM, Deming LIU

National Engineering Laboratory of Next Generation Internet Access System, School of Optical & Electronic Information, Huazhong University of Science and Technology, Wuhan 430074, China

Abstract This paper investigated the impact of Rayleigh backscattering (RB) noise in the proposed wavelength-division-multiplexed (WDM) single-fiber loopback access network. RB noise's impacts on the downstream and upstream service were discussed in details. It was found that the receiver sensitivity was less sensitive when the seeding-light power was below −12.6 dBm. And for the uplink RB noise, a higher reflective semiconductor optical amplifier (RSOA)'s bias current results in lower receiver sensitivity.

Keywords passive optical network (PON), reflective semiconductor optical amplifier (RSOA), Rayleigh backscattering (RB)

1 Introduction

The rapid growth of the Internet is strengthening demands for broadband services, such as telemedicine, three-dimensional (3D) gaming, video conferences and e-learning, video telephony, high-definition video, and 3D display, in access networks. To satisfy these growing demands, the wavelength-division-multiplexed passive optical network (WDM-PON) is one of the most attractive solutions. Owing to its high data rates to the customer's premises, large capacity and strong security [1–5], WDM-PON architecture is expected to naturally compatible with the existing PON access infrastructure and radio-over-fiber system without much change of optical line terminal (OLT) [6]. For WDM-PON access networks, a wavelength-independent optical network unit (ONU), which is a colorless ONU, is the key technical issue. In some WDM access networks, a WDM light source is located at the central office (CO) and each ONU includes an optical modulator [2,3]. For upstream service in these networks, a continuous wave (CW) light is distributed from the CO to each ONU, modulated, and sent back to the CO. This upstream transmission is achieved by using two fibers [1,6] or a single fiber link [7,8]. In single-fiber loopback access networks such as the architecture in Ref. [5], bidirectional transmission of the CW light and the modulated signal causes a technical issue; the signal-to-noise ratio (SNR) is degraded by the interference intensity noises generated by backreflection in the feeder fibers. And Rayleigh backscattering (RB) will degrade the transmission performance of both downstream service and upstream service. Thus, it is critical to investigate the impact of the RB noise to the transmission performance of both downstream and upstream services in the single-fiber loopback WDM-PON access networks.

In this paper, we investigate the impact of the RB noise on the proposed WDM single-fiber loopback access network system's performance. For the downstream signal transmission's carrier-RB noise, the receiver sensitivity improves as the seeding power of the RSOA increases when the seeding-light power was below −12.6 dBm. The high seeding light power before the RSOA improves the signal transmission performance by increasing the optical signal-to-noise ratio (OSNR) of the uplink signal and the modulation bandwidth of the RSOA. However, a high seeding power means a high transmission power, which will introduce a high signal-RB noise, and deteriorate the performance of the uplink signal. While for the upstream signal transmission, in order to investigate the influence of the uplink signal-RB noise, we fixed the seeding light power and changed the uplink signal power by adjusting the bias of the RSOA. A higher bias current results in lower receiver sensitivity. Although a high bias current increases the signal power and the modulation bandwidth, it also increases the uplink signal-RB noise.

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E-mail: duanliu@mail.hust.edu.cn

2 Proposed WDM-PON architecture

The proposed WDM-PON architecture is shown in Fig. 1. At the CO, the downstream point-to-point (P2P) data is modulated using the sub-harmonic modulation (SCM) scheme with the subcarrier of the laser light at a frequency of f_{SC}, and the broadcasting data is superimposed onto the optical carrier by the differential phase-shift keying (DPSK) scheme as shown in Fig. 1. After being multiplexed by an optical multiplex (MUX), all WDM channels are transmitted over 60 km optical fiber via an optical circulator. At the RN, a single interferometric filter (IF), e.g., an asymmetrical Mach-Zehnder interferometer (MZI), is used to separate the optical carrier and subcarrier as the small insets depicted in Fig. 1. Note that the free spectral range (FSR) of the MZI should be twice of the f_{SC}, and the WDM channel spacing is multiple integer times of the FSR. Therefore, the filter can transmit all optical carriers to one port and all subcarriers to the other output port. The separated subcarriers are subsequently demultiplexed into individual subcarrier pairs by a WDM multiplexer (MUX3) and then fed to each corresponding ONU for downlink detection with baseband receivers. Similarly, the optical carriers are also demultiplexed with another multiplexer (MUX4). Each optical carrier is then directly injected to a RSOA located at ONU, where the upstream data are modulated to the optical carrier. While each optical carrier carrying the DPSK modulated broadcasting signal is also fed into a DPSK demodulator for broadcasting data detection. All the uplink channels are combined again and pass through the same MUX4, MZI, and optical fiber back to the CO for upstream data detection. The proposed scheme could significantly reduce the implementation cost of the WDM-PONs for the following reasons: 1) each ONU only consists of receivers and a RSOA; 2) the IF is shared by all the downlink and uplink channels; and 3) the operating wavelengths are centrally arranged in the CO, hence, easy to manage.

It can be seen as shown in Fig. 1, in the proposed PON system, downstream P2P data is generated by modulating the laser light (λ_n as shown in Fig. 1) through the SCM scheme with an intensity Mach-Zehnder modulator (MZM). While the broadcasting data is generated and combined with the P2P data by phase modulating the

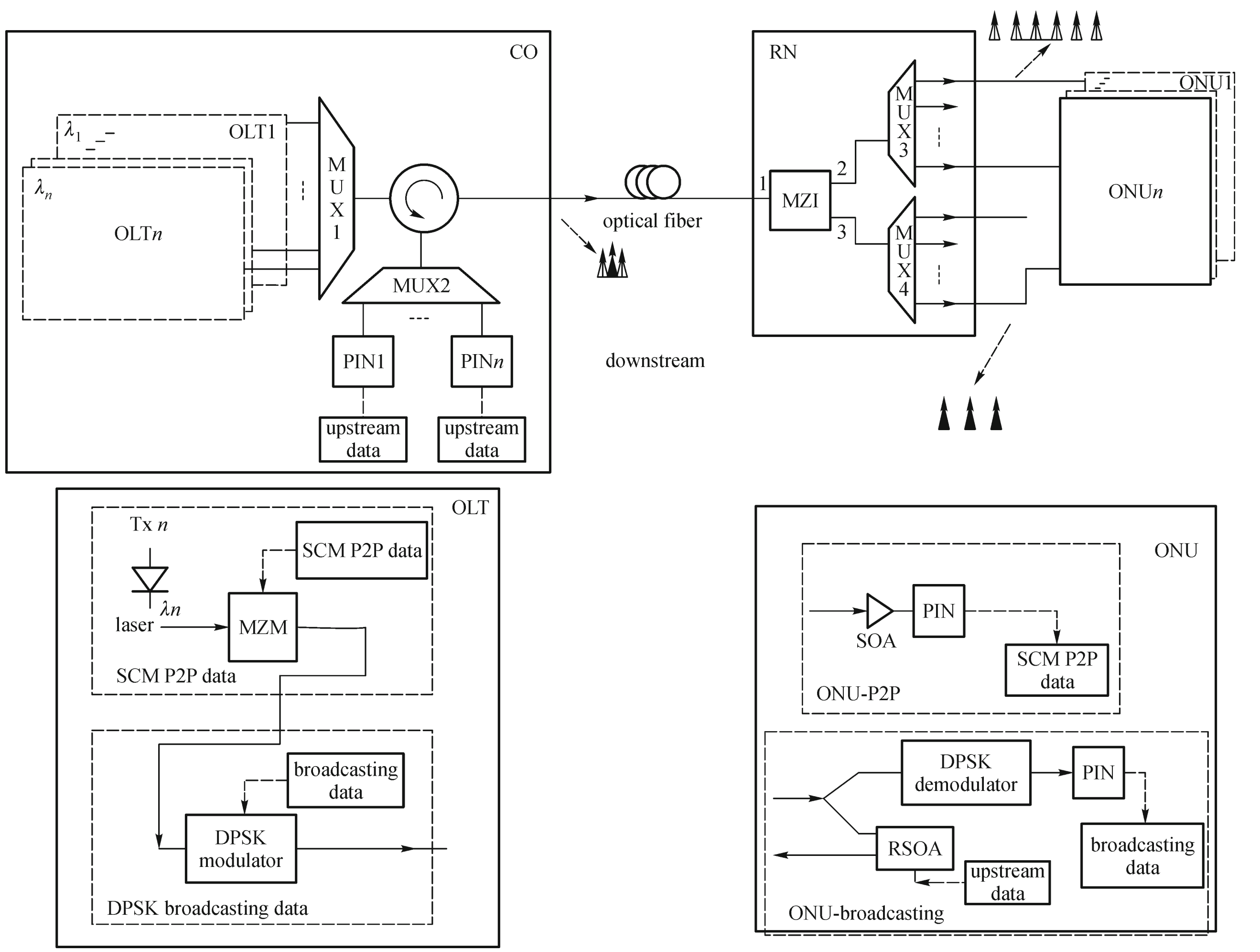

Fig. 1 Proposed WDM-PON architecture of simultaneous downstream SCM P2P data, DPSK broadcasting data and upstream data

unmodulated optical carrier using a 5 Gb/s DPSK modulator at the OLT. Therefore, the broadcasting and P2P data are packed together for each wavelength for transmission. After the laser light carrying the downstream lightwave channels with broadcast overlay and P2P data transmits through optical fibers, it is fed to the ONU side. In ONU-broadcasting, the DPSK modulated carrier is demodulated and fed to a photodetector, while the lightwave is also reflected and intensity remodulated with upstream data by a RSOA for upstream transmission. In ONU-P2P, downstream lightwave is first amplified by a traveling-wave semiconductor optical amplifier (SOA), and the laser light is then detected by the photodetetor to rebuild the downstream P2P data. The upstream lightwave transmits back through the same optical fibers and is fed into the OLT side for detection.

3 Rayleigh backscattering impact

The required seeding power of RSOA is also an important parameter for the power budget of the WDM-PON system. Figure 2 shows the relationship between the receiver sensitivity of the upstream transmission and the seeding-light power. Here, a tunable attenuator is inserted before the circulator in the OLT in Fig. 1 to adjust the seeding-light power. In our proposed system, when the seeding-light power was as low as −15 dBm, the receiver sensitivity was still as −20 dBm. The relatively low required seeding-light power and receiver optical power enhances the margin of the power budget for the whole WDM-PON system.

While, on the other hand, the receiver sensitivity was improved as the seeding power increased. This improvement was significant when the seeding-light power was below −12.6 dBm, since the higher seeding-light power, the higher OSNR of the upstream light. However, the improvement became minor when the seeding-light power was greater than −12.6 dBm due to the increase of the signal-RB noise [9] and partial saturation of RSOA. The output power of RSOA as a function of the seeding-light power is shown in Fig. 3. The output power of RSOA increases with the increase of the seeding light power, and the ROSA's gain becomes saturated with a further increase of the seeding power. As we can see from Fig. 3, the RSOA output power becomes saturated when the seeding power is over −10 dBm. The high seeding light power improves the signal transmission performance by increasing the OSNR of the uplink signal and the modulation bandwidth of the RSOA. However, a high seeding power means a high transmission power, which will introduce a high signal-RB noise, and deteriorate the performance of the uplink signal.

Besides the downlink RB noise, the uplink signal-RB noise launched into the RSOA is amplified and also deteriorates the upstream BER [9]. To investigate the influence of the uplink RB noise, we fixed the seeding light power and changed the uplink signal power by adjusting the bias of the RSOA. The receiver sensitivity of the upstream transmission is shown in Fig. 4 as a function of the bias of the RSOA. It is obvious that the maximum bias current cannot get the best receiver sensitivity. A higher bias current results in lower receiver sensitivity. Although a high bias current increases the signal power and the modulation bandwidth, it also increases the uplink RB noise. Other possible reason maybe the OSNR degradation with a further bias increase.

4 Conclusions

We have investigated the impact of RB noise in the proposed WDM single-fiber loopback access network. The downlink RB noise and uplink RB noise's impact on the system performance were discussed in details. It was found that the receiver sensitivity was less sensitive when the seeding-light power was below −12.6 dBm. And for the

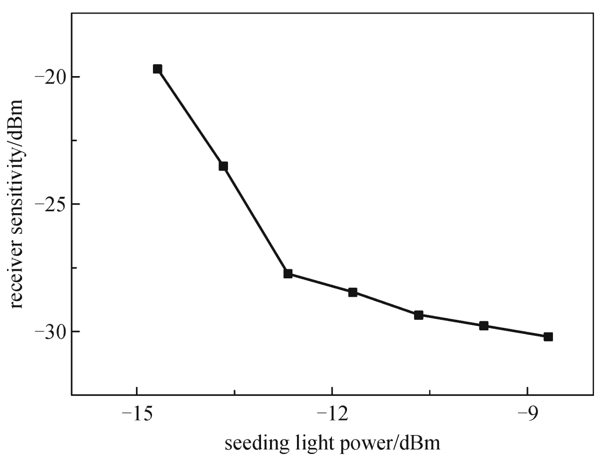

Fig. 2 Relationship between receiver sensitivity and seeding-light power

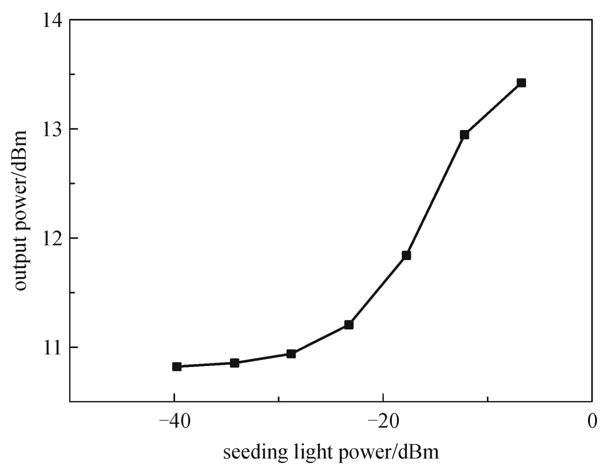

Fig. 3 Output power of RSOA versus seeding-light power

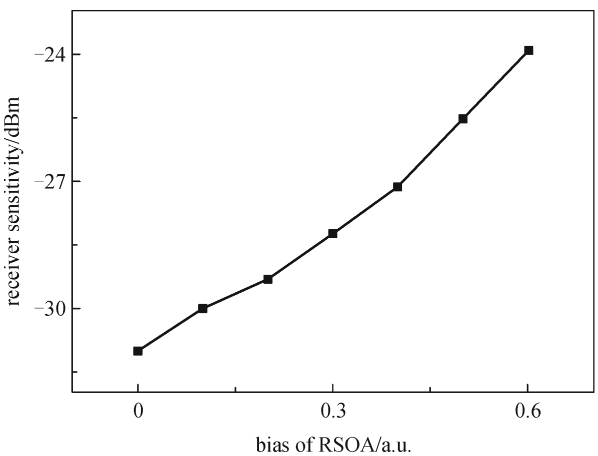

Fig. 4 Receiver sensitivity versus bias of RSOA

uplink RB noise, a higher RSOA's bias current results in lower receiver sensitivity. By using the RSOA in the ONU, the RB noise can be effectively mitigated.

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