Rayleigh Backscattering Circumvention in Ring-Based Access Network Using RSOA-ONU

C. W. Chow, *Member, IEEE*, C. H. Yeh, *Member, IEEE*, Y. F. Wu, *Student Member, IEEE*, Y. H. Lin, F. Y. Shih, *Student Member, IEEE*, and S. Chi

***Abstract*—We propose and demonstrate a Rayleigh backscattering (RB) interferometric beat noise circumvention architecture for the ring-based wavelength-division-multiplexed (WDM) access networks. RB can be significantly avoided since the RB and the upstream signal are traveling in opposite directions. We also analyze the performance of the proposed scheme for upgrading to 40 Gb/s and the influence of wavelength-drift at the remote node (RN).**

***Index Terms*—Carrier distribution, Rayleigh backscattering (RB), wavelength-division multiplexed (WDM).**

I. Introduction

WAVELENGTH division multiplexed (WDM) is promising solution to increase the network capacity in the future [1]. Using reflective semiconductor optical amplifier (RSOA) based colorless optical networking units (ONUs) can be a cost-effective and low power consumption approach. But one drawback of using reflective ONUs is the Rayleigh backscattering (RB) interferometric beat noise generated at the receiver (Rx) in the central office (CO) [2]. RB noise can be mitigated by using advanced modulation formats [3], or using phase [4] or bias-current dithering [5]. Wavelength shifting away from the wavelength of the distributed continuous-wave (CW) optical carrier [6], [7] and using upstream return-to-zero (RZ) signal [8] can also be employed. However, they either required complicated modulations or dithering to broaden the upstream signal. A comprehensive overview of the methods for RB mitigation is given in [9]. Recently, ring-based networks have been studied in Europe [10], [11], the United States [12] and Japan [13], and are regarded as one of the promising architectures for the next generation access due to the flexible wavelength assignment and protection propose.

In this work, we propose and demonstrate a RB circumvention architecture for the ring-based WDM access network. The proposed network uses a pair of optical circulators (OC) and fiber gratings for wavelength add/drop in the remote node (RN).

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C. W. Chow, Y. F. Wu, Y. H. Lin, F. Y. Shih, and S. Chi are with the Department of Photonics, Institute of Electro-Optical Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan (e-mail: cwchow@faculty.nctu.edu.tw).

C. H. Yeh is with the Information and Communications Research Laboratories, Industrial Technology Research Institute (ITRI), Hsinchu 31040, Taiwan.

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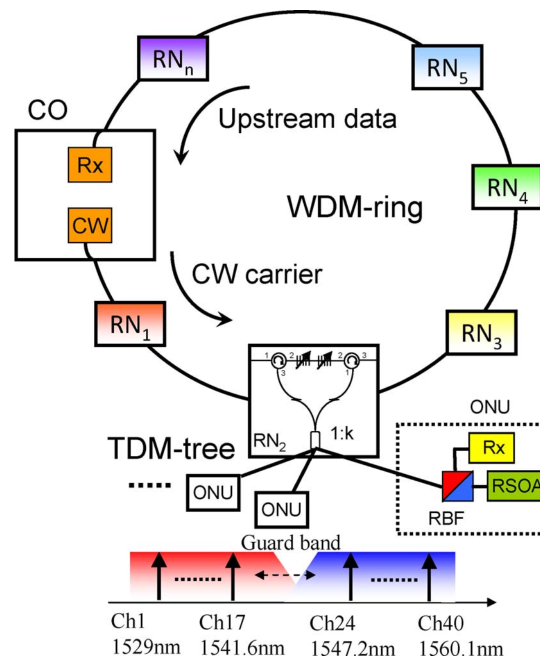

Fig. 1. Architecture of the proposed network. RN: remote node. CO: Central office. ONU: Optical networking unit.

The insertion loss could be less than using $N \times N$ arrayed waveguide grating (AWG) or $N \times N$ fiber splitter than in [10]. Besides, advanced modulations are not required in the proposed scheme. As the upstream signal and the CW carrier generated RB are traveling in two different directions, RB can be effectively avoided.

II. Network Architecture

Fig. 1 shows the proposed ring-based WDM access network. The CW optical carrier sent from the CO is traveling in the counterclockwise (CCW) direction. At the RN, wavelengths will be dropped according to the wavelength selection by the tunable fiber Bragg gratings (FBGs).

The dropped CW and the downstream signal will be distributed to different ONUs in the tree-based network. A red-blue filter (RBF) at each ONU separated the CW and downstream signals. The CW will be modulated to produce the upstream signal. It will be send back to the CO also in the CCW direction. Inset of Fig. 1 shows the wavelength plan, which has 40 channels at 100 GHz channel spacing. The red and blue sides consist of the 17 downstream and 17 upstream channels respectively. The two sides are separated by a guard band of 6 channels. We also believe that the proposed scheme can also support wavelength remodulation schemes, such as using differential phase

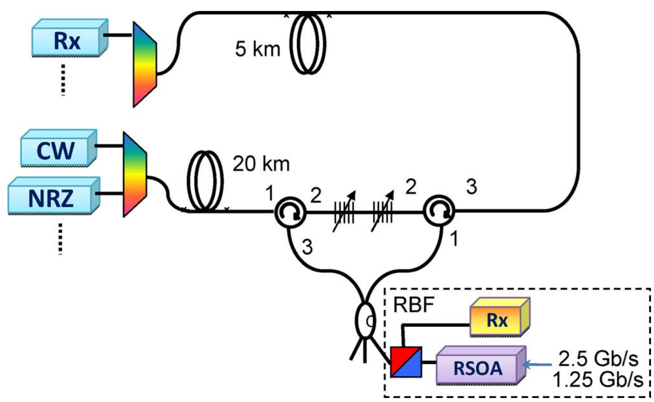

Fig. 2. Experimental setup of the proposed ring-based WDM-PON.

shift keying as downstream signal and nonreturn-to-zero (NRZ) as upstream signal [14] or using orthogonal frequency division multiplexing (OFDM) as downstream signal and NRZ as upstream signal [15].

III. Experiment

Fig. 2 shows the experimental setup of the proposed ring-based WDM-TDM access network. At the CO, a CW carrier (wavelength $= 1550.4$ nm) and the downstream NRZ (wavelength $= 1540.8$ nm) signal were launched into the ring. The NRZ signal was generated by using a Mach–Zehnder modulator (MZM) driven at 10 Gb/s, pseudorandom binary sequence (PRBS) of $2^{31} - 1$. The CW and the NRZ signals were propagating through 20 km standard single mode fiber (SSMF) before reaching the RN. They were launched to the FBGs via the left-sided OC. Only the target wavelengths of 1550.4 nm and 1540.8 nm were reflected by the FBGs, and other wavelengths transmitted through the FBGs. The reflected wavelengths were launched into the ONU via port 3 of the left OC. A red-blue filter separated the downstream signal and the CW carrier. The CW carrier was modulated at the RSOA by using 2.5 Gb/s and 1.25 Gb/s NRZ, PRBS of $2^{31} - 1$. The RSOA had a small signal gain of 23 dB, saturated output power of 5 dBm, polarization dependent gain of < 1 dB, and noise figure of 7 dB. Its modulation speed was about 2 GHz. It was dc-based at 50 mA. The FBG had a reflection bandwidth $(-0.5 \text{ dB}) > 50$ GHz. The transmission channel rejection was about 30 dB. The insertion losses for the reflection and transmission channels were 0.5 dB and 0.1 dB respectively. The polarization dependent loss was < 0.1 dB. The length of the drop fiber was 300 m.

The upstream signal was then sent back to the RN. Only the upstream signal sent to the right-sided OC was reflected by the FBG and then combined with the other wavelength channels. Finally, the upstream signal is received at the Rx in the CO after propagating through another 5 km of SSMF.

IV. Results and Discussion

Bit-error rate (BER) measurements were performed at 2.5 Gb/s and 1.25 Gb/s for the upstream signal and 10 Gb/s for the downstream signal, as shown in Fig. 3. We also tested the split-ratio of the TDM access network by using different types of splitters. Changing the split-ratios from back-to-back (B2B)

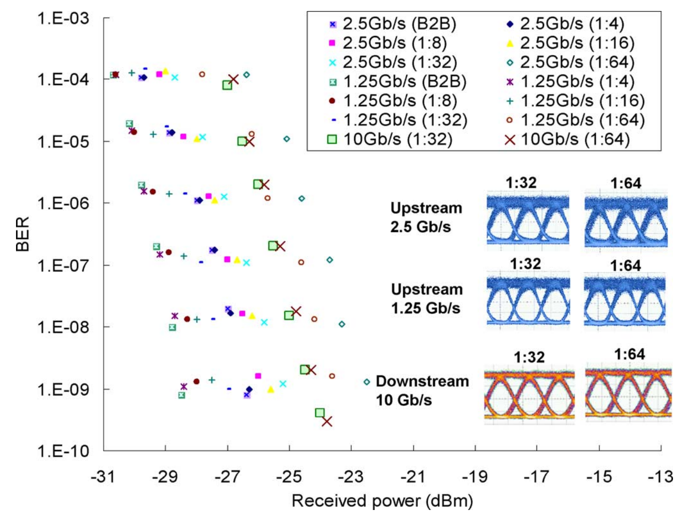

Fig. 3. Downstream and upstream BER measurements for the proposed networks at different bit rates and TDM split-ratios.

to 64 also changes the input powers to the RSOA. This changes the signal to amplified spontaneous emission (ASE) ratio, and hence causes power penalty as shown in Fig. 3. When the split-ratio is increased to 64, much higher power penalties are observed. Hence, the proposed ring-based hybrid WDM-TDM access network can be operated at about 64 split-ratios. Clear eye-opening can be achieved in both upstream and downstream signals at split-ratio of 64. As the upstream signal and the CW carrier generated RB are traveling in two different directions, RB can be effectively avoided.

Then we estimate the loss budget introduced to the distributed CW carrier. By considering the insertion losses of the fiber is 4 dB (20 km $\times$ 0.2 dB/km), reflection by the FBG is 0.5 dB, the OC is 1 dB (0.5 dB for each transmission), and the fiber splitter is 16 dB (for the split-ratio of 32), the loss budget of the CW carrier is about 21.5 dB. Then the signal is amplified by the RSOA to produce the upstream signal with output power of 2 dBm. By using the similar calculation, the upstream signal loss budget is about 18.5 dB. The number of wavelengths supported in the WDM access network determines the number of RNs. We can calculate that each transmitted wavelength channel will experience an insertion loss of 1.1 dB at each RN, hence, although four wavelengths were used in the experiment (Fig. 2), higher number of wavelength channels can be supported in the network.

For upgrading the network, network operators usually consider only replacing the equipments at ONU and *CO*, but not the optical fiber. We also consider the scenario of upgrading the proposed network form 1.25 Gb/s up to 40 Gb/s. In this case, the reflection bandwidth of the FBG in the RN should be considered carefully. Numerical analysis using VPI Transmission Maker V7.5 was performed. The simulation setup was based on the experiment as described in Fig. 2. The NRZ signal was generated using a MZM. It has a wavelength of 1550.4 nm, input power 0 dBm and extinction ratio of 20 dB. The optical fiber has a dispersion parameter of 17 ps/nm/km. The signal was measured by a PIN photodiode (PD) with 3rd ordered Bessel-shaped electrical bandwidth of 70% of the bit rate. The MZM, OC, FBG and PD used were based on the VPI built-in models. The Q-value is

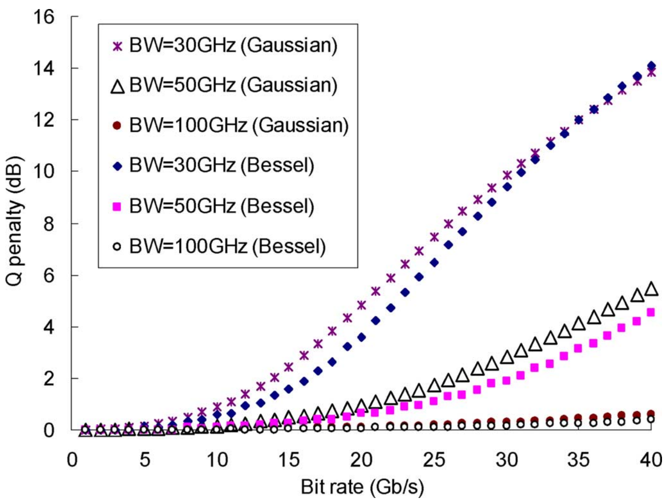

Fig. 4. Simulated Q-penalty when using different FBG bandwidths (BW) and at different bit rates.

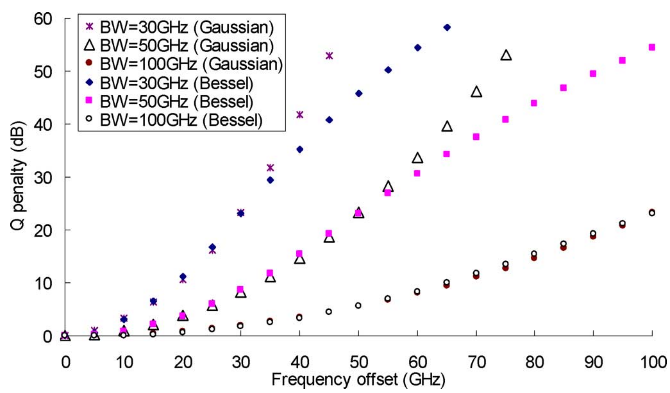

Fig. 5. Simulated Q-penalty when using different FBG bandwidths (BW) and at different frequency offsets at bit rate of 2.5 Gb/s.

calculated using the built-in function of the VPI. Fig. 4 shows the simulated Q-penalty when using different FBG bandwidths and at different bit rates. The FBGs under test are 1st order Gaussian or 1st order Bessel shaped with different bandwidths. We can observe that at the present bit rate of 2.5 Gb/s upstream and 10 Gb/s downstream signals, negligible power penalty is introduced by all the FBGs under test. However, when the bit rate increases to 40 Gb/s, 100 GHz bandwidth FBG is required. Hence larger bandwidth FBGs should be deployed for the potential upgrade of the network.

As the reflection band of the FBG will drift due to temperature or pressure changes, we also simulated the Q-penalty using different FBG bandwidths at different frequency offsets at the bit rate of 2.5 Gb/s. The results are shown in Fig. 5. We can also observe that the Gaussian-shaped FBG introduces higher power penalty in the filtering process. This is because the Gaussian-shaped FBG has a faster roll-off; hence the frequency offset will introduce higher loss to the signal. When using 50 GHz, Gaussian-shaped FBG, the 2-dB penalty window is at frequency offset of 15 GHz. As wavelength-shift introduces power penalty to the signal, athermal FBG can be used in the RN [16].

V. Conclusion

We proposed and demonstrated a RB circumvention architecture for the ring-based WDM access network. RB can be significantly avoided in the proposed architecture since the RB and the upstream signal were traveling in opposite directions. Experimental results showed that the proposed network can be operated at > 64 split-ratio. We also analyzed by means of simulations the performance of the proposed scheme for upgrading to 40 Gb/s and the influence of wavelength-shift at the RN.

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