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Using Wavelength Splitting at the Remote Node to Mitigate Rayleigh Backscattering for Optical Wired and Wireless Access Networks

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Abstract: We demonstrate an optical wired and wireless access network using wavelength-splitting (WS) at remote-node. A pair of CW carriers is generated from each laser source for wired and wireless applications respectively for effective Rayleigh-backscattering mitigation.

OCIS codes: (060.2330) Fiber optics communications, (060.4510) Optical communications

1. Introduction

Although wired optical access networks (e.g. passive optical networks (PONs)) require extensive deployment of optical fiber, they can provide high bandwidth, secure and reliable network services. On the other hand, wireless access networks require less fiber deployment and provide high mobility network services. The integration of the wired optical and wireless access network can provide a single and low cost platform for both fixed and mobile users [1]. In the future, high radio-frequency (RF) carriers are needed to carrier high data rate signals in wireless networks. But the relatively high atmospheric attenuation in the high frequency band means that the area covered by each wireless base station should be small. Thus, a large number of base stations are required to provide sufficient network coverage. Because of this, networks using radio-over-fiber (RoF) distribution with remote antenna units (RAUs) could extend the signal distribution and reduce the number of base stations by using lower cost RAUs [2].

Dense wavelength division multiplexing (DWDM) can be used to further reduce the cost in these wired and wireless access networks, since different optical networking units (ONUs) and RAUs, each working at different wavelengths, can share the same optical amplifiers and backhaul fiber in the networks. In these DWDM wired and wireless access networks, one great challenge is the transmitter (Tx) at the ONU/RAU must be wavelength-precisely aligned to a pre-assigned DWDM wavelength channel. Colorless ONU/RAU can be used to reduce the inventory cost and simplify the wavelength management. The upstream signals from different ONU/RAUs will be generated from the continuous wave (CW) carriers distributed from the head-end office (HE) [3]. Although the carrier-distributed DWDM wired and wireless networks have many attractive features, a key issue that needs to be addressed is how to reduce the impairments caused by the optical beat noise generated by the optical back-reflections and Rayleigh backscattering (RB) of the optical carrier at the upstream receiver (Rx) at the HE. Here, we propose and demonstrate, for the first time, an optical wired and wireless access network using wavelength splitting (WS) at the remote-node (RN). A pair of CW carriers is generated from each laser source for wired and wireless applications respectively with effective RB suppression.

2. Architecture of the Wired/Wireless Access Network and RB Contributions

For a typical carrier-distributed network [4], there are two dominant contributions to the RB noise, which interfere with the upstream signal at the Rx. The first contribution, Carrier-RB, is generated by the backscatter of the CW carrier being delivered to the ONU. The second contribution, Signal-RB, is generated by the modulated upstream signal at the output of the ONU. Backscattered light from this upstream signal re-enters the ONU, where it is re-modulated and sent towards the upstream Rx. The Carrier-RB has the same spectrum as the CW carrier, while the Signal-RB is modulated twice by the ONU, hence having a broader spectrum.

Fig. 1 shows the proposed optical wired and wireless network with RB mitigation using WS, with the corresponding schematic optical spectra. For efficient RB noise mitigation, we have to minimize the spectral overlap between the upstream signal and both types of RB. This ensures that the majority of the frequency components of the electrical beat noise will fall outside the bandwidth of the Rx.

The CW carrier at optical frequency f_0 (Fig. 1(a)) (wavelength = 1549.5 nm, optical power = 7 dBm) produced at the HE will be modulated by a Mach-Zehnder modulator (MZM) (40 Gb/s, $LiNbO_3$-based) at the RN, which is electrically driven at Δf (25 GHz). The Carrier-RB noise will be produced by the distributed CW carrier. The Carrier-RB has the similar optical spectrum as the CW carrier (Fig. 1(b)). The MZM at the RN will produce two optical sidebands which is 50 GHz apart with suppression of the center wavelength (Fig. 1(c)). At the RN, erbium doped fiber amplifiers (EDFAs) (saturation power = 23 dBm, noise figure = 5 dB) are used to compensate the transmission losses. Then, each sideband is filtered by a 50-GHz channel spacing arrayed waveguide grating (AWG_3), producing a pair of optical carriers ($f_0+\Delta f$, $f_0-\Delta f$) for the ONU and the RAU respectively (Fig. 1(d), (e)). It is worth to mention that only a single MZM at the RN is needed to produce the WS for all the DWDM channels.

Polarization-insensitive MZM [5] can be used for practical networks. In this architecture, AWG_1 and AWG_3 are aligned to $f_0+\Delta f$, while AWG_2 is aligned to f_0. The two optical carriers ($f_0+\Delta f$, $f_0-\Delta f$) will be modulated at the ONU/RAU, forming the upstream signals for PON and wireless connection respectively (Fig. 1(f)). Semiconductor optical amplifiers (SOAs) are used in the ONU/RAU to compensate the loss of the distributed carriers. A fixed optical attenuator of -15 dB is placed in front of the ONU/RAU to emulate a 32 split-ratio in standard PON. The ONU/RAU is constructed by an EAM and a SOA. The SOA has a saturation power of 18 dBm with polarization dependent gain of 1 dB.

The upstream signals will bypass the MZM in the RN by using the two optical circulators (OCs) configuration, and detected by the Rx at head-end office. The upstream data will also be backscattered by the 25 km single mode fiber (SMF) towards the RN, where it will be wavelength split by the MZM, forming the Signal-RB (Fig. 1(g)). They will be filtered out by the AWG_3 without entering the ONU/RAU. Due to the back-reflection of the AWG_3 and the limited isolation of the OC, the Signal-RB will be reflected towards the head-end Rx. Owing to the modulation by the MZM at the RN, the spectral components of the Carrier-RB and Signal-RB will be different from the upstream data signal. As shown in the schematic optical spectra of Fig. 1(h) at the head-end before AWG_1, the Carrier-RB is at frequency f_0, while the double-modulated Signal-RB has the frequency components of f_0 and $f_0\pm2\Delta f$. This shows that in principle there is no spectral overlap between the upstream data and both types of RB, suppressing the RB noise. Besides, the frequency components of RB will be highly attenuated by the AWG_1 to further enhance the RB tolerance. The head-end Rx is optically pre-amplified (consists of an EDFA (saturation power = 21 dBm), optical filter (Gaussian-shaped, 3-dB bandwidth = 50 Ghz) and a PIN).

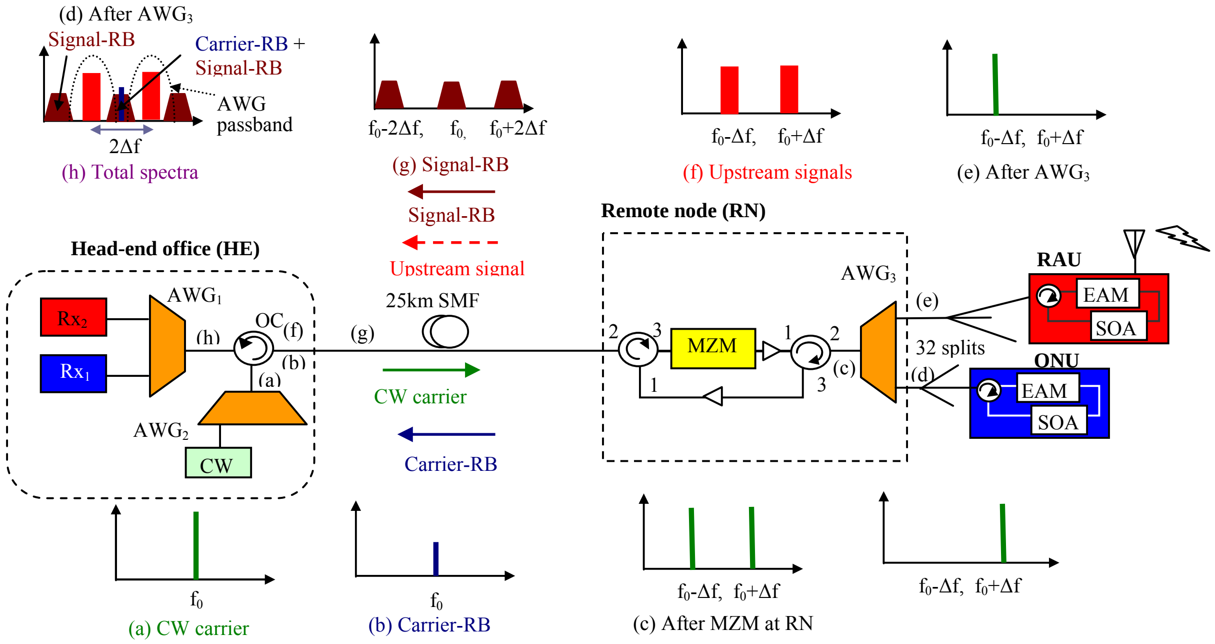

Fig. 1. Architecture of wired and wireless network using wavelength splitting, with different schematic optical spectra at different locations. AWG: arrayed waveguide grating, OC: optical circulator, SMF: single mode fiber, MZM: Mach-Zehnder modulator, EAM: electroabsorption modulator, SOA: semiconductor optical amplifier.

3. Results and Discussion

Fig. 2 shows the experimental optical spectra produced by a 40 Gb/s $LiNbO_3$ based MZM at the RN. It was electrical given at 25 GHz sinusoidal signal produced by a synthesizer. We can observe that two optical sidebands are produced with center carrier suppression. The curve $f_0+\Delta f$ shown in Fig. 2 shows one of the filtered sideband, which can be used for PON application. First, we evaluated the RB tolerance of the proposed scheme. By using the techniques described in [4], we can separately analyze the Carrier-RB and Signal-RB performances. WS signal $f_0+\Delta f$ (encoded by 10 Gb/s non-return-to-zero (NRZ) data) was selected and compared with the conventional NRZ signal without WS. Fig. 3 shows the Rx power penalties at a bit error rate (BER) of 10^{-9} for different signals as a function of optical signal to Rayleigh noise ratios (OSRNRs). The OSRNR is defined as the ratio of the upstream signal power to the RB power measured prior to the head-end AWG_1. For conventional NRZ signal, the required OSRNR is equal to 25 dB (at 1-dB penalty), showing that NRZ power should be >25 dB than the RB power in order to have < 1 dB penalty. The WS scheme significantly improves the required OSRNR by ~13 dB in both RB cases. This is due to the reduction of the spectral overlap by wavelength shifting the upstream signal away from the center wavelength by 25 GHz. We can observe that the results also agree with our previous simulation analysis using our developed modeling [3] by wavelength shifting the upstream signal 20 GHz. This implies that wavelength shifting of 20 GHz could be good enough for effective RB suppression.

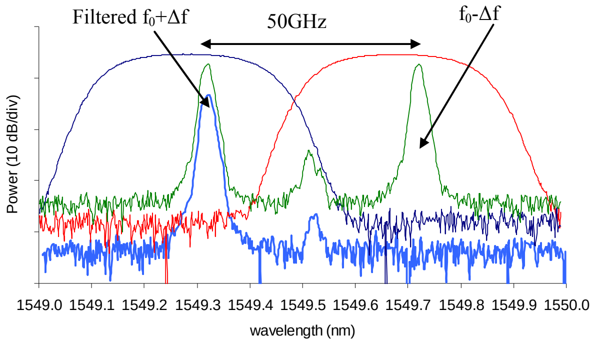

Fig. 2. Measured optical spectra of the f_0-Δf, f_0+Δf generated by MZM.

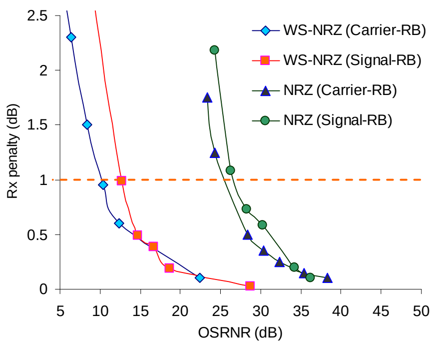

Fig. 3. RB performance at different OSRNRs of wavelength splitting (WS) scheme and conventional NRZ signal.

Then we evaluated the transmission performances of the upstream signals by encoding the NRZ (for PON application) and orthogonal frequency division multiplexing - quadrature amplitude modulation (OFDM-QAM) (for wireless application) in the proposed carrier distribution network without and with using WS. 10 Gb/s pseudorandom binary sequence (PRBS) 2^{31}-1 NRZ data and 16-QAM OFDM signal were applied to the EAM respectively. A baseband digital signal processing was used to produce the 16-QAM OFDM signal. An arbitrary waveform generator with 4-GHz sampling rate was then used to convert the digital-to-analog data, which was then applied to the EAM. The OFDM signal consisted of 16 subcarriers. Each subcarrier was in 16-QAM format. The OFDM signal was RF up-converted, occupying ~1 GHz of RF spectrum (from 62.5 MHz to 1,125 MHz). Owing to 16-QAM format is used, the total data rate of the OFDM signal was 4 Gb/s, with data pattern consisted of 8,192 OFDM symbols. The cyclic prefix was 1/32 symbol time. The detail OFDM signal generation was described in [6]. The BER performance of the OFDM signal was calculated from the measured error vector magnitude (EVM) [7]. Fig. 4 and Fig. 5 show the BER performances of the NRZ and OFDM signals in the carrier distributed network with and without WS, with the corresponding eye-diagrams and constellation diagrams. Error-floors at 10^{-9} and 10^{-8} were observed in Fig. 4 and Fig. 5 respectively when WS was not implemented. Results show that the proposed scheme can significantly mitigate the RB noises in a carrier distributed network.

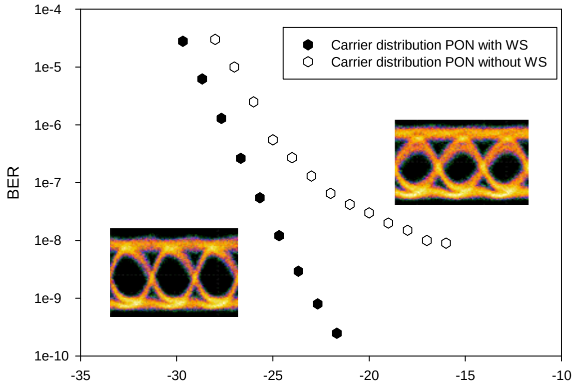

Fig. 4. BER of NRZ signals in the carrier distributed network with and without WS. Insets: corresponding eye-diagrams.

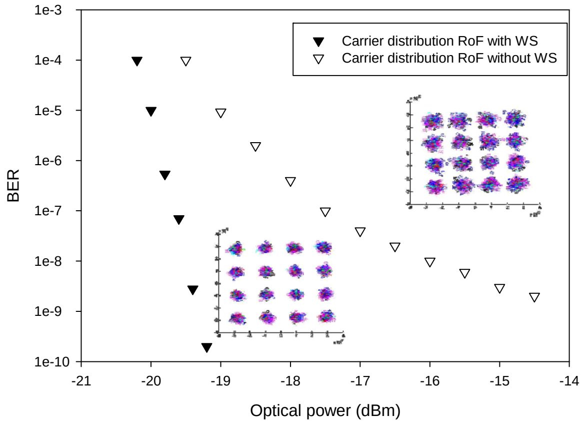

Fig. 5. BER of OFDM-QAM signals in the carrier distributed network with and without WS. Insets: corresponding constellation diagrams

4. Conclusion

We demonstrated a WS wired and wireless access network using colorless ONU/RAU. A pair of CW carriers was generated from each laser for wired/wireless applications. Only a MZM was needed for WS to all the DWDM channels. OSRNR improvement of ~13dB was observed in both RB analysis (Carrier-RB and Signal-RB). Upstream NRZ and OFDM signals were measured in this loop-back network, showing the RB noise is significantly suppressed.

5. References

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