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# Channel-reuse bidirectional transmission at 10 Gb/s/λ in long-reach DWDM-PON employing self wavelength managed tunable laser

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We experimentally demonstrate a channel-reuse, bidirectional, 10 Gb/s/λ, long-reach dense wavelength-division-multiplexing passive optical network (DWDM-PON) and an optical beat noise-based automatic wavelength control method for a tunable laser used in a colorless optical network unit (ONU). A 42 km reach, channel-reuse, full-duplex, 10 Gb/s transmission on a 50 GHz DWDM grid is achieved. Transmission performance is also measured with different optical-signal-to-Rayleigh-backscattering-noise ratios (OSRBNRs) and different central wavelength shifts (WSs) between upstream signal and downstream signal in the channel-reuse system.



## 1. Introduction

The wavelength-division-multiplexing passive optical network (WDM-PON) has been regarded as a promising solution for next-generation optical access networks requiring high security, easy maintenance, great flexibility, and broad bandwidth [1–4]. Driven by ever-increasing user demands for broad-band services to support high-quality internet protocol television (IPTV), e-learning, interactive games, and future looking peer-to-peer multimedia services, it is expected that the data-rate demand will continuously grow, and that numerous access nodes will be deployed over the next few decades. Owing to the continuous growth of bandwidth-hungry new services, the WDM-PON access networks will migrate to systems with 100 Gb capacities in the near future [5–7]. In addition, developments for supporting longer reach and larger split are also expected [8,9]. As 10 Gb/s per channel will be one of the typical channel rates of WDM-PONs in the near future [10–12], the main challenge when increasing the total system capacity lies in improving the spectral efficiency. Narrow channel spacing and channel-reuse techniques are promising methods for increasing the total system capacity of such WDM-PONs.

One important issue for WDM-PONs is achieving low noise, as well as cost-effective colorless optical sources in the optical network unit (ONU). Various colorless optical sources have been proposed, including the reflective semiconductor optical amplifier (RSOA) [13,14], the semiconductor optical amplifier-reflective electro-absorption modulator (SOA-REAM) [15], and the tunable laser. The tunable laser (or tunable optical transmitter) is an attractive candidate for a colorless optical source for channel-reuse, long-reach, and high-speed transmission as the wavelength of the upstream optical carrier can be set flexibly in the ONU; this can reduce the Rayleigh backscattering noise existing in loopback mode-based wavelength-reuse system [16,17]. However, an automatic wavelength control method is required by the tunable laser-based colorless optical source to realize true colorless operation with plug-and-play features. Using the Rayleigh backscattering effect is one means of solving this problem [18]. However, the control accuracy will degrade as the length of the drop fiber increases. Accordingly, these solutions either cannot effectively provide the initial wavelength setting, or they increase the system cost.

In this paper, we propose a dense WDM-PON (DWDM-PON) scheme. This scheme is tunable laser-based, capable of channel reuse on 50 GHz DWDM grid, and bidirectional transmission at 10 Gb/s/λ. It also exhibits a long reach. Moreover, we propose an optical beat noise-based automatic wavelength control method using a downlink optical signal to manage the wavelength of the tunable laser diode (TLD). A channel-reuse, full-duplex, bidirectional, 10 Gb/s transmission on a 50 GHz DWDM grid is demonstrated using a Mach–Zehnder (MZ) modulator and a direct detection (DD) receiver with a 42 km reach. The transmission performance is also measured with different optical-signal-to-Rayleigh-backscattering-noise ratios

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(OSRBNRs) and different central wavelength shifts (WSs) between upstream signal and downstream signal in the channel-reuse system.

## 2. System architecture

Fig. 1 shows the proposed tunable laser-based, channel-reuse, bidirectional, 10 Gb/s/$\lambda$, long-reach DWDM-PON scheme. The optical line terminal (OLT) consists of n optical transceivers constituted by n on-off keying (OOK) intensity modulation (IM) transmitters and DD receivers, n three-port optical circulators (i.e., $OC_{T1}$, …, $OC_{Tn}$), and one $n \times 1$ array waveguide grating (AWG). In the remote node (RN), one $n \times 1$ AWG is used to couple $n$ ONUs. In one ONU, the uplink transmitter consists of a TLD and an external optical modulator. The downlink receiver is a DD receiver. An optical beat noise-based automatic wavelength control method using the downlink optical signal to manage the wavelength of the TLD is also designed to initialize the wavelength setting of the TLD. Part of the uplink optical carrier and part of the downlink optical signal are coupled into a photo-detector (PD) using three $2 \times 2$ optical couplers. At this stage, the optical beat noise between the uplink carrier light and the downlink optical signal is generated at the PD. The beat noise power is measured by a microwave power meter and is sent to a control unit (CU). The wavelength of the uplink optical carrier generated by the TLD is controlled by the CU to match the wavelength of the downlink optical signal.

## 3. Experiments and results

### 3.1. Automatic wavelength control method

In order to verify the feasibility of the automatic wavelength control method using the downlink optical signal, we experimentally measured the optical beat noise average powers between the downlink optical signal and the uplink optical carrier generated by a TLD in various central WS cases. Fig. 2 shows the experimental setup. A 10.3125 Gb/s pseudo-random bit sequence (PRBS) OOK optical signal is generated by a 50 GHz DWDM grid tunable optical transmitter (Finisar FTLX4213). The optical signal is then sent to one input port of a 3 dB optical coupler via an AWG, a polarization controller (PC1), and a variable optical attenuator (VOA1). Considering that the polarization state of the downlink optical signal in the WDM-PON system is random and time-varying after transmission over a long length of standard single-mode fiber (SSMF), PC1 is used to generate an optical output with a time-varying polarization state under the artificial control in our experiment. The output of a power-tunable TLD (Souther Photonics-TLS150) with a 6–16 dBm output power range is sent to another input port of the 3 dB optical coupler via a PC (i.e., PC2) and a VOA (i.e., VOA2). PC2 is used to generate a circularly polarized optical output, which ensures that the optical beat noise is generated in the PD. At this stage, the optical beat noise is generated at a PD (1 GHz optical receiver) and measured by a microwave power meter (Agilent N1911a). The noise power value is sent to a CU, which consists of a computer and control software with a general purpose interface bus (GPIB) interface. The output wavelength of the TLD is controlled by the CU using a universal serial bus (USB) interface to match the wavelength of the downlink optical signal.

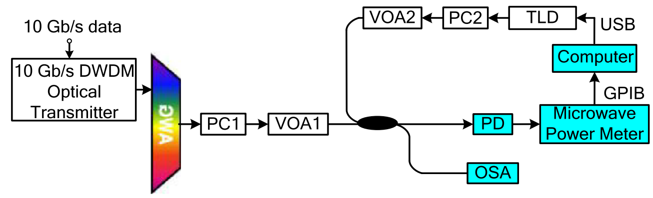


**Fig. 2.** Experimental setup of optical beat noise power test.

In our experiment, the bandwidth of the 10.3125 Gb/s OOK signal generated by the 50 GHz DWDM optical transmitter was about 10 GHz, and the linewidth of the uplink optical carrier generated by the TLD was about 1 MHz. The output optical powers of VOA1 and VOA2 were set at −18 dBm and −2 dBm, respectively, based on the actual power conditions in the proposed DWDM-PON scheme. The noise power was then measured by the microwave power meter with a frequency setting of 300 MHz. Fig. 3 shows the measured average beat noise powers with different central WSs. The results show that the average noise power was approximately −36 dBm when the central WS was more than 0.4 nm; this means that the operation wavelengths of the 50 GHz DWDM optical transmitter and the TLD were set at two adjacent 50 GHz DWDM channels. The average noise power was higher than −33 dBm when the central WS was less than 0.15 nm, and 3 dB higher than the average noise power when the central WS was more than 0.4 nm. Therefore, the CU was able to accurately determine whether the two wavelengths were identical based on the average optical beat noise power measured by the microwave power meter. Moreover, the CU was also able to set or change the central WS in one 50 GHz DWDM channel based on the measured average optical beat noise power. Additionally, considering that it requires less than 2 ms for beat noise power detection and data processing, the tuning period per single adjustment of the TLD was less than 10 ms, the stabilization time of the tunable laser was generally less than 100 ms (for example, 75 ms for the EXFO FLS-2600B tunable laser source; 100 ms for the Souther Photonics tunable laser source), thereby the total time to discover the downlink optical signal wavelength was less than 10 s, even when the number of the DWDM channel was as large as 80.

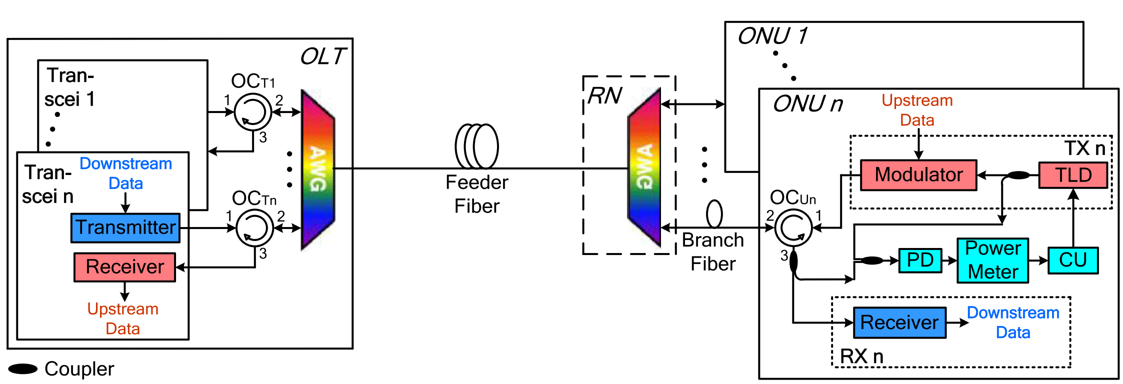


**Fig. 1.** Proposed channel-reuse long-reach DWDM-PON architecture.