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Wavelength reused bidirectional reflective coherent-PON based on cascaded SOA/RSOA ONUs

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ABSTRACT

This paper demonstrates wavelength reused bidirectional transmission for a reflective coherent passive optical network (R-Co-PON). By reusing the downstream optical signal as the upstream optical carrier, the proposed R-Co-PON enhances the optical spectral efficiency. In an experimental demonstration, the proposed R-Co-PON achieved a symmetrical bidirectional transmission rate of 12 Gb/s using a 73-km-long fiber loopback architecture. The experiments confirmed the potential applicability of the proposed system in future optical access networks, particularly those using wavelength-division multiplexing.

1. Introduction

Recently, many content-rich networks applications have considerably increased the bandwidth requirements of core networks. As the final destination of these applications is the subscriber and the traffic demand from the core network are continually growing, the access network requires breakthrough technologies to accommodate the increasingly heavy traffic flows [1]. In addition, passive optical networks (PONs) are trending toward long-reach transmission architectures supporting multiple optical network units (ONUs), which boost the transmission capacity [1–3]. Because of their low receiver sensitivity, intensity modulation, and direct detection-based PONs have limited transmission lengths and in their optical distribution network (ODN). To overcome these limitations, we require optical access networks with coherent optical transmission [4].

Coherent optical transmission is a promising candidate for future optical access network solutions. Such transmissions can operate over long distances with high receiver sensitivity and spectrally efficient higher-order modulation with phase and polarization diversity. Therefore, using coherent optical transmission in PONs, coherent PONs (CO-PONs) effectively support massive ONUs with wavelength-division multiplexing (WDM) technologies owing to their precise wavelength selectivity [4]. In particular, using orthogonal frequency-division multiple access (OFDMA), a coherent OFDMA PON can provide a flexible and efficient multiple-access function with two-dimensional time-bandwidth resource allocation [2].

Among the many Co-PON candidates, reflective Co-PONs (R-Co-PONs) have received considerable attention for their cost effectiveness and compatibility with WDM technologies [4–6]. Based on a centralized carrier distribution topology, an R-Co-PON provides high-performance optical sources for every laserless ONU [5–7]. Each ONU receives a common optical source from the optical line terminal (OLT) of the R-Co-PON, which in turn modulates the distributed optical source through reflective semiconductor optical amplifiers (RSOAs), reflective electro-absorption modulators, or semiconductor optical amplifiers with fiber loops. Because ONUs require no tunable lasers, R-Co-PONs have high scalability with WDM as the number of ONUs increases. In addition, because upstream detection uses the same optical source for the upstream optical carrier and the local oscillator (LO), the received upstream signals have no carrier frequency offsets, enabling easy application of second-level multiplexing techniques, such as OFDMA. However, most proposed R-Co-PONs require separate wavelengths for the downstream and upstream transmissions. Consequently, as the number of ONUs increases in future access networks, the required optical bandwidth becomes twice the number of available wavelength channels. As the number of channels increases, inefficient wavelength usage in limited optical bandwidths is expected in the near future.

To achieve single-wavelength transmission at the downstream and upstream, researchers have designed reuse techniques based on reflective MZM subsystem and gain-saturated SOAs [8–13]. In coherent bidirectional systems where extracted optical carriers are also used as LO sources, carrier reusing method using SOA is more efficient because of the need for high power LO. These solutions using gain-saturated SOAs have shown promise for use in WDM PONs, reducing the system complexity and enhancing the optical spectral efficiency. However, these techniques have limited usable signal bandwidth for both the

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upstream and downstream transmissions. Moreover, the limited relaxation time of the SOA reduces the usable modulation depth of the downstream signal [10]. Other proposals for wavelength reuse include SOA with an external modulator [11], cascaded SOAs [12], and RSOAs [13]. Although the additional modulators in these approaches enhance the upstream capacity, the downstream capacity remains limited by the response of the SOA. Because the upstream transmission performance is considerably sensitive to the signal suppression ratio of the downstream signal, the modulation depth of the downstream signal must be minimized to enhance the signal suppression efficiency. These two critical limitations reduce the transmission capacity for access network traffic. In our previous research, a novel method of wavelength reusing by cascaded SOA/RSOA had been proposed [14]. The method had consisted of amplified spontaneous emission (ASE) insertion and signal removing using gain saturated SOA, and which had improved the remodulation efficiency of wavelength reusing system using RSOA.

In this paper, we proposed wavelength-reused bidirectional transmission of an R-Co-PON. The proposed ONU configuration was based on our previous wavelength reuse technique with cascaded SOA/RSOA. The recovered optical carrier was used as upstream carrier and LO for downstream coherent receiving. By reusing the downstream optical signal as the upstream optical carrier, the proposed R-Co-PON achieves a symmetrical bidirectional transmission rate of 12 Gb/s using a 73-km-long fiber loopback architecture.

2. Proposed R-Co-PON with wavelength-reused ONUs

Fig. 1 shows the schematic of the proposed R-Co-PON in which the proposed wavelength-reused ONUs are constructed into a single-fiber loopback structure. The proposed scheme reuses the downstream signal as the optical carrier of the upstream transmission, enabling the use of a single optical source for each wavelength channel. In the OLT, the optical source of one wavelength channel manages multiple transceivers. The modulated downstream signals are distributed through the transmission link and broadcast to every ONU using a passive splitter.

At the ONU side, the incoming signals are filtered through a tunable optical filter. After filtering the wavelength channels of interest, the incoming signals are divided into two paths using an optical power splitter. The cascaded SOA/RSOA in the ONUs effectively suppresses the modulated downstream signals from the optical carrier. These recovered optical carriers are then used as the LO for downstream reception and as an optical carrier for upstream transmission. At the OLT side, the incoming upstream signals are de-multiplexed by an arrayed waveguide grating (AWG) and detected by self-homodyne coherent reception. The proposed system provides a second-level multiplexing over the WDM to enhance the flexibility of massive multiple access in each wavelength channel. Second-level multiplexing can be implemented by time-division multiple access (TDMA), frequency-division multiple access (FDMA), or both time and frequency division based on the OFDMA scheme. In second-level multiplexing (here implemented by OFDMA), the ONUs share the same wavelength, improving the flexibility of the ONU support in the architecture.

Fig. 2 shows the basic principle of the proposed signal suppression technique for wavelength-reused ONUs. By retaining the optical signal-to-noise ratio (OSNR) of the optical carrier, the technique suppresses the modulated downstream signals and reuses the downstream optical signals as upstream optical carriers. The proposed signal suppression technique can be divided into three steps.

First, the optical power of the incoming signal is reduced to a sufficiently low level using an optical power attenuator. The incoming optical signal (comprising the optical carrier and the modulated signal) is then attenuated to the same scale. This step maintains the same OSNR of the modulated signal and the optical carrier despite the absolute power reduction for both components.

Second, the first SOA amplifies the incoming optical signal to increase the total optical power. In this step, the small-input optical power of the SOA generates ASE. This noise degrades the OSNR in each component of the incoming signal. Therefore, the optical gain of each amplified component is accompanied by enhanced noise related to the bias current. Under the small incoming-signal condition, the amount of ASE noise depends on the bias current of the SOA. Therefore, the OSNR of the modulated signal components degrades more seriously as the total optical power increases.

Third, the noise and signals are suppressed by a deeply saturated RSOA [12,13]. In the deeply saturated SOA, the distribution of the differential gains at each optical frequency depends on the photon density distribution [15,16]. Because the power of the optical carrier component exceeds that of the modulated optical signal component, most of the RSOA gains are dissipated by the optical carrier components and the remaining gains are distributed to the modulated optical signal components and the ASE from the second step. Consequently, the optical carrier components of the output signal sufficiently regain their OSNRs for reuse as upstream optical carriers. In addition, because of the nonlinear characteristics of gain-saturated SOAs, the RSOA suppresses the noise enhanced by the SOA. After noise suppression, the modulation depth dependence of the recovered optical carrier is effectively reduced. The interference between the re-modulated upstream signal and the modulated downstream signal is also reduced, regardless of the signal bandwidth.

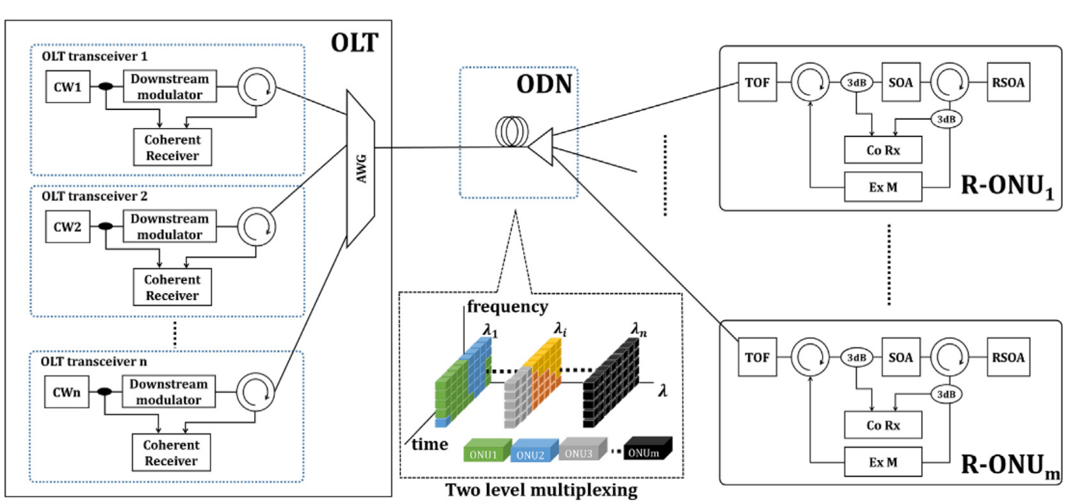

Fig. 1. Reflective coherent passive optical network (R-CO-PON) and its RONU structures.

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