All-optical integrated support for multicast and burst amplification in transparent optical network

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A novel scalable and integrated design that supports optical multicast and burst amplification is proposed and demonstrated experimentally. The powers of incoming signals can be tuned to optimize the results of burst amplification and replication. Experimental results also show that erbium-doped optical Fiber amplication (EDFA) transients can be suppressed to an equally low level regardless of the burst parameters. Extended structure designs are further proposed to satisfy the need of mass replication of multicast signals.

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With the potential to provide bit-rate-, format-, and protocol-independent transport for client services, transparency in optical networks has been heralded as one of the major advantages provided by wavelength division multiplexing (WDM) transmission and photonic switching systems[1]. Nevertheless, due to the all-optical transmission of traffic and the absence of optical-to-electrical-to-optical (O/E/O) conversion in the intermediate nodes, several problems emerge, including all-optical multicast and burst amplification. Multicast services (e.g., video distribution and multiple-user games) can utilize the huge amount of bandwidth provided by WDM networks; however, implementation of an all-optical multicast-capable switching node remains a challenge. To support optical multicast, data need to be cloned over optical layer based on either optical splitting[2] or multiwavelength conversion (MWC)[3]. In the first scheme, incoming optical signals are firstly split into multiple copies by an optical splitter, and then coupled onto all the outputs of the switch. In the MWC scheme, an optical signal is simultaneously replicated into multiple copies with different wavelengths through certain nonlinear effects in the MWC medium. These copies are then further routed to desired outputs of the switch. The latter method, fortunately, can avoid the excessive loss of power caused by splitters and adapt to the wavelength-based switching and routing nature of the optical network with more flexibility.

Another application of optical transparency is optical burst switching (OBS)[4], in which data bursts remain in the optical domain throughout the whole transmission period, whereas burst header packets (BHP) take care of the resource reservation beforehand. As a result, bursts can suffer from transmission impairment[5], including severe degradation induced by erbium-doped fiber amplifier (EDFA) transience, unless special techniques are adopted to suppress it, such as gain-clamping mechanisms with optical or electrical feedback control[6,7].

In this letter, we present a novel scheme to support all-optical multicast and burst amplification in one single module. Optical cloning/multicast is realized based on MWC through cross-gain modulation (XGM) effect in a semiconductor optical amplifier (SOA). The generated copies are used in turn as complementary signals to compensate for the power fluctuations of the original data bursts. With the power level balanced, EDFA transience are suppressed. Experimental results show that the power variation of the amplified bursts is less than 1 dB and data are excellently cloned with high receiver sensitivities. In addition, an extended design with two alternatives is proposed to increase the multicast capacity based on our primary module.

The scheme integrating both data cloning and burst amplification is shown in Fig. 1. The original optical burst and a control signal (continues wave (CW) light) at different wavelengths are fed into a SOA simultaneously. As a result of the XGM effect in the SOA between the bursts and the control signal, the gain experienced by the control light is reduced when the burst signal is high and, conversely, increased when the signal is low. Because of the fast-response gain in the SOA, the CW control light is converted into a complementary burst of the input burst that can be used as the cloned burst, as well as a compensation of the power variations of the original burst. Next, the original burst and its cloning (complementary) burst are launched into the EDFA together with nearly constant power to suppress EDFA transients. After wavelength demultiplexing, both the amplified burst without waveform distortion and the cloned burst originating from the CW control light are obtained. Note that the cloned bursts are inverse in waveform to the original burst. To solve this problem, we simply add control information to the BHP denoting whether or not the corresponding burst is inversed to enable the receiver to detect the signals correctly. This method is a proactive way for burst amplification because we compensate the power variations ahead of the amplification. This method also has the advantage of not being affected by the burst length or duty cycle, thereby removing the problem of response time noted in traditional feedback control mechanisms.

To enable optical multicast, we need to scale up the

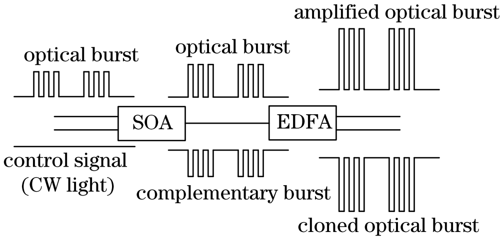

Fig. 1. Scheme for basic data cloning and burst amplification.

basic structure such that more than two copies can be made. An intuitive idea is to inject multiple control signals into SOA to perform multiwavelength conversion. However, due to the nature of the XGM process, the gain modulation in each control wavelength becomes much weaker because the XGM effect is shared by all CWs, which limits the number of copies that can be made by one such module at one time. A further step to increase the multicasting capacity is by adopting the multicasting structure shown in Fig. 2. We propose two different structures to enable the mass production of multicast signals: parallel and serial. Assume that each SOA can support one original signal and N control signals at one time under certain bias current. In the parallel model (Fig. 2(a)), the original optical burst is firstly preamplified using the basic structure at the same time a basic number of N copies are cloned. These N+1 bursts are demultiplexed into separate sets of multiple-cloning modules, where each burst is further combined with N different control signals. Therefore, a maximum total number of $(N+1)^2$ copies of bursts can be produced. However, one disadvantage of this design is the overuse of the SOA, considering the noise, cost, and integration difficulty. One way to substitute these active components is to adopt the serial model (Fig. 2(b)), with which up to $N+1$ data copies can be produced at one time. If more copies are required, we can route a portion of one of the output signals back to the input as the pump signal through a FDL loop and a GATE. The GATE module is used to control the on/off of the rerouting of the output signal into the input side. The FDL loop delays the portion of output signal from the coupler until the next timeslot. At this time, we open the GATE and begin the next clone process, during which additional copies can be made. In other words, we merely need $N+1$ time slots to generate the same amount of clones as in Fig. 2(a), with only one SOA. Another advantage of this structure is that, if output contention occurs, we can delay the production of data copy to another time slot when output or wavelength resources are available. Using this strategy, we can produce a sufficient number of bursts with different wavelengths in different time slots, which, in a way, has the potential to solve the output contention in both wavelength and time domain.

The experimental setup of the proposed scheme is shown in Fig. 3. A CW light at wavelength λ_1=1 544.94 nm (channel 1) was modulated by a 2.5 Gb/s 2^7–1 pseudo-random binary sequence and further modulated by a pulse pattern generator to generate a 250-μs-long periodic burst signal with a duty cycle of 0.5. Another CW light at wavelength λ_2=1 550.10 nm (channel 2) was used as the control signal. The light at wavelength λ_3 (channel 3) will be used later. The burst signal and the control signal were combined with a wavelength multiplexer. The average powers of the burst and the control light before the SOA were 0.85 and –3.60 dBm, respectively. The combined signals were fed into a commercial SOA (CIP SOA-NL-OEC-1550) and the bias current of the SOA was set to 150 mA, under which condition the input burst signal was sufficiently strong to saturate the gain of the SOA and optimize the XGM effect. The EDFA was placed after the SOA, and the gain of the EDFA was approximately 16.7 dB. After amplification, the signals were switched to different outputs through arrayed waveguide grating (AWG) and monitored after being detected by the optical receivers.

Figures 4(a) and (b) show the waveform of amplified bursts and the corresponding eye diagram without transient control (i.e., launching the input bursts alone directly into EDFA). Large amplitude variations (≈12 dB) and severe burst distortion can be seen in the results. In contrast, Figures 4(c) and (d) show the amplified

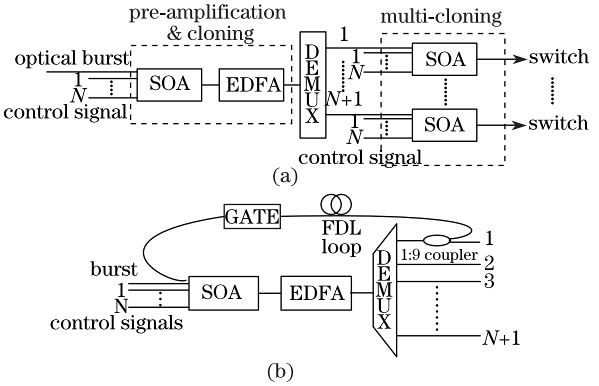

Fig. 2. Scalable multicasting structure. (a) Parallel model; (b) serial model.

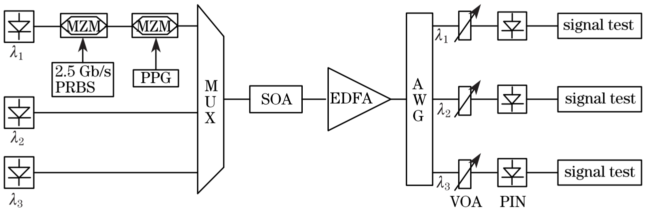

Fig. 3. Experimental setup.

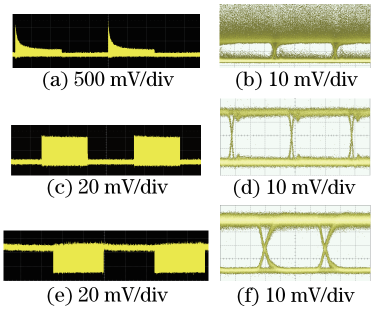
(a) 500 mV/div (b) 10 mV/div
(c) 20 mV/div (d) 10 mV/div
(e) 20 mV/div (f) 10 mV/div

Fig. 4. Waveforms and eye diagrams with one control signal (a) waveform of amplified bursts without transient control; (b) eye diagram of amplified bursts without transient control; (c) waveform of amplified bursts with transient control; (d) eye diagram of amplified bursts without transient control; (e) waveform of cloned bursts; (f) eye diagram of cloned bursts.

bursts with transient control, which manifest small amplitude variations (<1 dB) and high signal-to-noise ratio (SNR). Figures 4(e) and (f) show the cloned bursts, which also have quite small power variations and high SNR.

By changing the burst parameters in the initial experimental setup, we obtained the impacts of burst length and duty cycle on the transients (amplitude variations of the output amplified bursts), as shown in Fig. 5. Longer bursts have to endure more EDFA transients and, similarly, a longer interburst gap causes greater gain overshoot. Thus, larger burst and smaller duty cycle cause more transients. However, compared with the large variations of the transients without any control, the resulting transients were suppressed uniformly within 1 dB when our transient control technique was applied. Hence, our transient suppression results are hardly affected by certain burst parameters.

Figure 6 illustrates the impact of the control signal on the Q-factors of the received signals. High Q-factors (>6) can be achieved for both the amplified burst (AB) and the cloned burst (CB). For the AB, weak control signal (–6.59 dBm) was unable to generate sufficiently strong complementary bursts to compensate for the power variations of the signals into EDFA. Thus, the EDFA transients remained significant, whereas the strong control signal (–0.72 dBm) consumed most of the gain, which caused the insufficient amplification of AB. Therefore, an optimized injection power (–3.60 dBm) of the control signal resulted in approximately 0.5-dB improvement in Q-factors, compared with two previous cases. However, for the CB, properly low power (–8.62 dBm) of the control signal made the XGM effect in SOA more efficient and consequently caused the higher Q-factor of generated CB. This result suggests a tradeoff in determining the optimal power of the control signal.

Figure 7 shows the results when the burst signal (1.45 dBm @ λ_1=1 544.94 nm) was combined with two control signals (1.3 dBm @ λ_2=1 532.80 nm, 0.27 dBm @ λ_3=1 534.46 nm) and injected into SOA (bias current @ 254 mA) to produce three burst copies for multicasting, including one amplified original burst and two burst replicas. Note that channel 3 in the experimental setup was used here. The measured BERs are shown in Fig. 7, together with the results of burst amplification without transient control and back-to-back measurements. The burst signal without transient control had the worst BER result, and 2–4 dB sensitivity gain was achieved for the transient control technique. All three signal copies were generated with high receiver sensitivities.

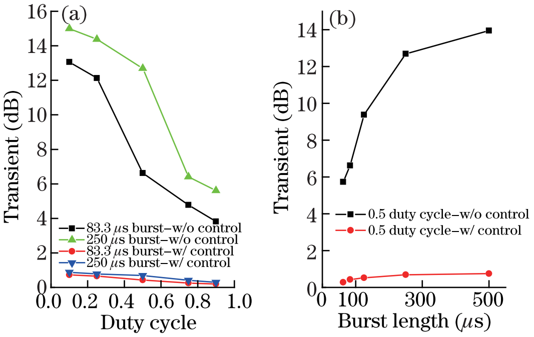

Fig. 5. Transient versus duty cycle and burst length.

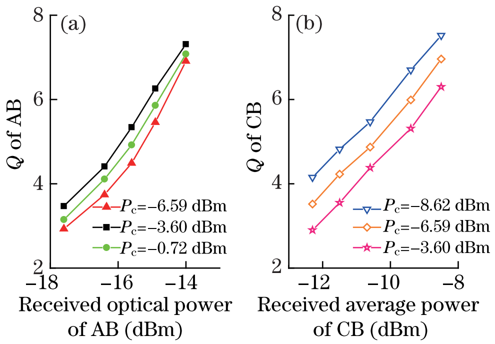

Fig. 6. Q for different powers of input control signals (P_c).

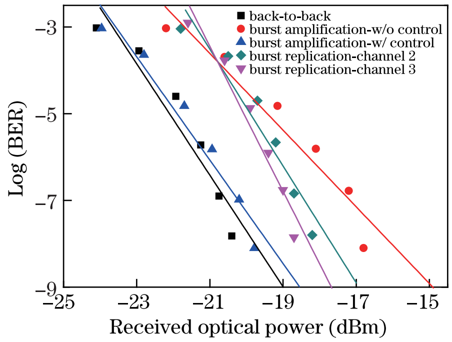

Fig. 7. Measured BERs of amplified and replicated bursts.

A novel scheme that integrates all-optical multicast and burst amplification for transparent optical network that is easy to construct and implement has been proposed. EDFA transients are suppressed significantly, and multiple burst copies with high receiver sensitivities are cloned for multicasting. With burst length and duty cycle changes, amplitude variations of received bursts can always be suppressed to within 1 dB. The optimized control power suppresses EDFA transients to minimum and produces better cloned bursts. Furthermore, two extended module designs have been presented to scale optical multicast capacity, which can potentially solve resource contention in multiple domains.

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