The Suppressing Transient Response with Shorter Burst Periods Using Standard EDFAs in Optical Burst Transmission System

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SUMMARY We investigate suppressing transient response while maintaining effective throughput by using shorter burst periods. A suitable burst period without largely degraded effective throughput is clarified through analysis, and the burst width of the largest overshoot is set to the worst case for a long-distance transmission demonstration. The suitable short burst periods enable 300-km, 12-span error-free transmission of 10Gb/s burst signal to be successfully performed independent of burst width.

keywords: *Optical TDM, burst amplification EDFA, Transient response*

1. Introduction

Optical time division multiplexing (TDM) networks has been intensively investigated for low-cost metro networks [1]. We expect that optical TDM networks will support various user requests and application requirements such as the transmission rate, number of connections, latency and flexibly.

To achieve optical TDM networks on metro networks, burst-mode optical amplification technologies for long transmission distances are necessary, especially using erbium doped optical fiber amplifiers (EDFAs) which are generally used in transport systems. However, burst-mode amplification using EDFA causes an overshoot with the transient response. The overshoot is the difference between G_{rise}, the gain of the rising part, and G_{fall}, the gain of the falling part, as shown in Fig. 1. When the overshoot is too large, transmission quality is degraded and the burst signal cannot be received [2]. Therefore, a technique is needed to suppress the overshoot.

Previous work for suppressing the overshoot includes approaches using special fiber amplifiers that have extremely fast response speeds [3] and controlling gain and signal power with fast circuits [4], but they cannot use standard EDFAs. Thus, they increase device costs as transmission distance becomes longer. Therefore, we investigate an approach for suppressing the overshoot using standard EDFAs.

It is known that the overshoot can be suppressed by shortening the interval time of burst signal because EDFAs' response speed is slow, around 10 ms [2],[5]. We focus on shortening the transmission burst period, which consists of burst width and interval time, to shorten the interval time without decreasing the number of time slots (TS) per wavelength. However, the effective throughput is degraded as the transmission burst period is shortened.

Thus, in this paper, an analysis is conducted to clarify the suitable burst period without largely degraded effective throughput. Also, a burst amplification experiment is conducted to clarify the burst width that causes the largest overshoot for checking if the suitable burst period can suppress the overshoot to enable error-free transmission independent on the burst width for a long-distance transmission demonstration. With the results, we evaluate the applicability of our approach by transmitting the burst signal of the shortened burst period over 300-km long distances and 12-span amplifications using standard EDFAs.

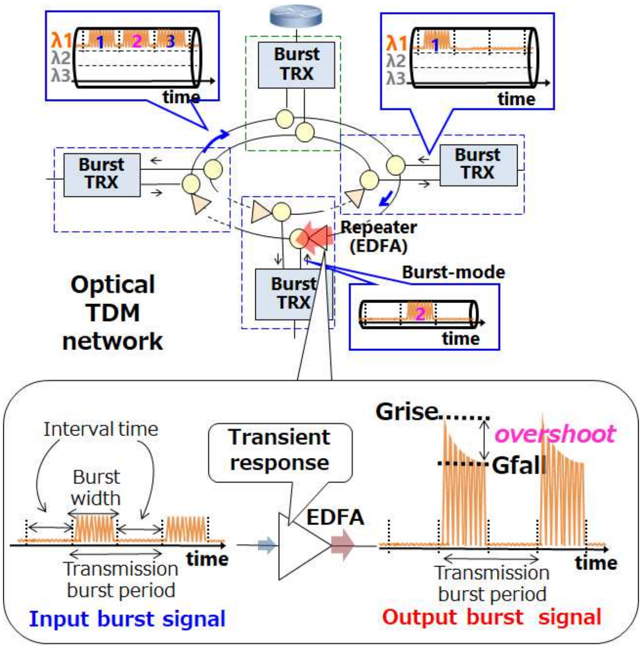

Fig. 1 State of transient response of EDFAs occurring on optical TDM network.

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2. Effective throughput analysis

First, we analyze the degradation amount of effective throughput in four transmission burst periods: 125, 62.5, 31.25, and 15.625 μs.

The degradation amount is calculated as follows. When the maximum number of TS is 8 for the burst period T [μs], the burst width per TS is $T/8$ [μs]. According to the NG-PON2 and ITU-T standards, the client signal has time excluding 98.2 ns from $T/8$ [μs]. The 98.2 ns consists of the burst gap, preamble, and delimiter time. Moreover, the client signal is compressed to 0.99 by header, overhead, and trailer and to 0.87 by forward error correction (FEC). Therefore, the effective throughput E_{thr} is expressed by Eq. (1).

$$E_{thr} = \frac{\left({}^{T}/_{8} - 98.2 \times 10^{-3}\right) \times 0.87 \times 0.99}{{}^{T}/_{8}} \qquad (1)$$

Fig. 2 shows the results of effective throughput analysis. The degradation amount of effective throughput is small when the burst period is shortened to 31.25 μs. Therefore, it is suitable to set 31.25 μs as a short burst period without largely degraded effective throughput.

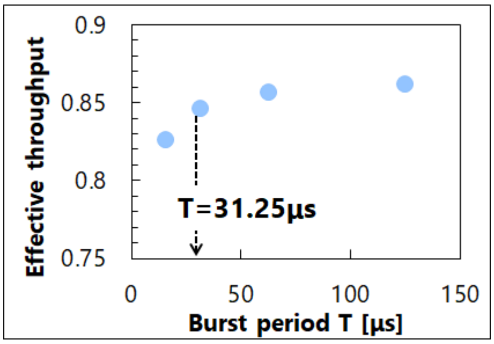


Fig. 2 Effective throughput with burst periods of 125, 62.5, 31.25, and 15.625 μs.

3. Transmission experiments

3.1 Overshoot experiment with shorter burst periods

Next, a burst amplification experiment is performed using an EDFA to evaluate how the overshoot changes when burst period T and burst width t_b are changed as shown in Tab. 1.

Table 1 Experimental conditions for burst period T, burst width t_b, interval time, and ratio of burst width to burst period t_b/T.

Burst period T(μs)	Bust width t_b(μs)	interval time (μs)	Ratio of burst width to burst period t_b/T
125	115.24	9.76	0.92192
125	86.83	38.17	0.69464
125	57.77	67.23	0.46216
125	29.15	95.85	0.2332
125	15.16	109.84	0.12128
62.5	57.85	4.65	0.93952
62.5	43.72	18.78	0.71232
62.5	29.35	33.15	0.48256
62.5	15.07	47.43	0.25536
62.5	7.73	54.77	0.1376
31.25	29.17	2.08	0.93344
31.25	21.95	9.3	0.7024
31.25	14.8	16.45	0.4736
31.25	7.58	23.67	0.24256
31.25	3.98	27.27	0.12736

Fig. 3 shows the experimental setup. The wavelength of the transmitted burst signal is 1532.68 nm. The transmitter (B-Tx) and receiver (B-Rx) are compliant with NG-PON2, the transmitted signal is modulated at 10 Gb/s on-off-keying, and the transmitter burst output power is 10 dBm. The burst received power is the average received power per burst width when the overshoot occurs. By using Variable Optical Attenuators (VOAs), the burst received power is set to -15.5 dBm, which is near the center value within a receivable range in the NG-PON2.

The loss is 25 dB per span. A span consists of the coupler (CPL) for add-drop, the fiber, and the dispersion compensation module (DCM), which are 7, 9, and 9 dB, respectively. Note that this experiment does not use optical fiber because it does not concern the nonlinear optical effect. The fiber loss and the DCM loss are emulated by fixed attenuators (ATTs).

EDFAs operate in the auto gain control (AGC) mode, and the EDFA injection current is set so that gain becomes 25 dB regardless of the burst signal waveform.

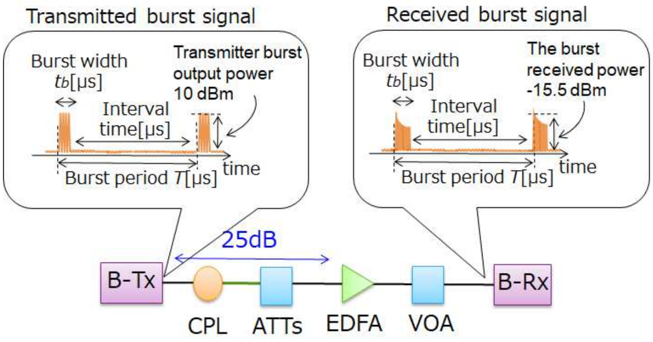


Fig. 3 Experiment setup with EDFA.

Fig. 4 shows the experimental results for the overshoot after 1-span amplification using an EDFA. The shorter the burst period, the more sufficiently the overshoot is suppressed. Here, the transmission quality is not degraded by the nonlinear optical effect and dispersion, and the noise amount is constant due to using the AGC mode. Thus, transmission quality depends on the overshoot in this experiment. Therefore, Fig. 4 shows that the overshoot becomes small and transmission quality improves as the burst period is shortened.

Next, we discuss the relationship between burst width and the overshoot. The overshoot $D(t)$ for an isolated burst pulse is determined from unsaturated gain G_0 and saturated gain G_{cw} as shown in Eq. (2) [6]. G_0 is determined by the input signal and characteristics of amplifiers. G_{cw} is gain when the continuous input signal is amplified, t is time variant, t_{sp} is the spontaneous emission time, w_0 is transition probability coefficient, and P_{in} is the EDFA input power. The overshoot becomes larger as burst width becomes wider following Eq. (2) because G_{fall} is close to G_{cw}.

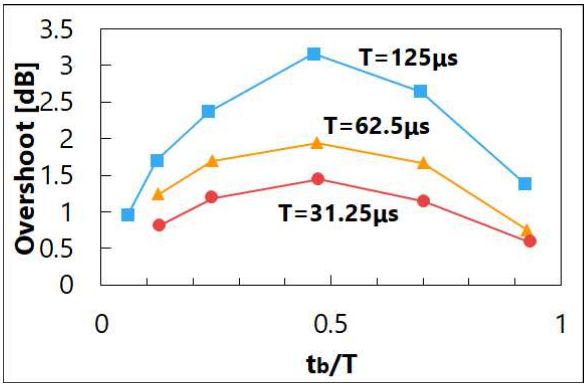
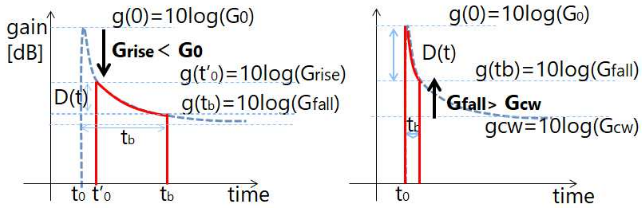


Fig. 4 Overshoot after 1-span amplification.

$$\begin{cases} D(t) = 10log\dfrac{G_{cw} + G_{dif}exp(-Wt)}{G_{cw} + G_{dif}exp(-Wt_b)} \\ G_{dif} = G_0 - G_{CW},\ \mathrm{W} = \dfrac{1}{t_{sp}} + w_0 G_0 P^{in} \end{cases} \quad (2)$$

However, Fig. 4 shows that the overshoot is the largest when the burst width occupies about half of each burst period like (burst period T, burst width t_b) = (31.25 µs, 14.8 µs), (T, t_b) = (62.5 µs, 29.35 µs), and (T, t_b) = (125 µs, 57.77 µs). The burst signal in an optical TDM network is transmitted constantly following burst periods, so the overshoot is affected by the previous burst period. The longer the burst width of the largest overshoot, the smaller the overshoot because the interval time cannot be recognized and G_{rise} becomes smaller than G_0 (Fig. 5(a)). Also, the shorter the burst width of the largest overshoot, the smaller the overshoot because G_{fall} becomes larger than G_{cw} (Fig. 5(b)).



(a)Grise<G0 as longer tb (b) Gfall>Gcw as shorter tb

Fig. 5 Images of the overshoot dependence on burst width.

3.2 Transmission demonstration with shorter burst periods

Finally, the long-reach burst-signal transmission with a shorter burst period is demonstrated.

Fig. 6 shows the demonstration setup, which is almost the same as in Fig. 3. The distance of a span is 25-km single-mode fiber (SMF) (0.36 dB/km), and the burst received power is set to -18 dBm.

The lower limit value of the burst period is 31.25 µs from the effective throughput in Fig. 2. Also, the worst condition of the overshoot is when burst width occupies about half the burst period in Fig. 4. Therefore, we measure the overshoot and transmission quality Pre-FEC bit-error rate (BER) when the burst signal of (burst period T, burst width t_b) = (31.25 µs, 14.8 µs) is transmitted on 12-span and 300-km SMF. The FEC code is RS(248,216) in the NG-PON2. The burst signals of (T, t_b)= (62.5 µs, 29.35 µs) and (T, tb)= (125 µs, 57.77 µs) are also transmitted for comparison.

As conditions for error-free transmission, the Pre-FEC BER is measured for 300 s, the number of uncorrectable blocks is 0, and the Pre-FEC BER is less 1×10^{-3} in this demonstration. As a result, the burst signal of (T, t_b) = (31.25 µs, 14.8 µs) can achieve error-free transmission that has 4.69 dB overshoot and 1.73×10^{-4} Pre-FEC BER. In contrast, the signal of (T, t_b) = (62.5 µs, 29.35 µs) cannot achieve error-free transmission because uncorrectable blocks occur that have 7.65 dB overshoot. This is because the overshoot exceeds the acceptable range. Also, the burst signal of (T, t_b) =(125 µs, 57.77 µs), which is a regular burst period, can achieve error-free transmission up to 2 spans and 50 km. However, BER cannot be measured for longer distance transmission because the overshoot is too large.

Therefore, this shows that the burst signal of the 31.25-µs burst period achieves 12-span 300-km error-free transmission independent of burst width. The 300-km transmission distance is 2.5 times longer than in previous works using optical TDM like long-reach PON systems [7] -[9].

Table 2 Experimental conditions for transmission burst signal and results of overshoot and Pre-FEC BER after 12-span burst transmission.

Conditions for transmission burst signal				After 12-span transmission	
Burst period T(μs)	Bust width t_b(μs)	interval time (μs)	Ratio of burst width to burst period t_b/T	Overshoot (dB)	Pre FEC BER
125	57.77	67.23	0.46216	n/a	Not error-free transmission
62.5	29.35	33.15	0.48256	7.69	Not error-free transmission
31.25	14.8	16.45	0.4736	4.96	1.73×10^{-4} (error-free transmission)

4. Conclusions

We evaluated an approach to suppress transient response of shortening the burst period with standard EDFAs by analyzing effective throughput and performing an optical burst transmission experiment.

The analysis and experiment showed that the signal of a 31.25-μs burst period was able to achieve 300-km and 12-span error-free transmission independent of burst width without large degradation of effective throughput.

Therefore, we showed that this approach of shortening the burst period to suppress the overshoot is applicable for optical burst transmission systems.

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