Multi-Rate 25/12.5/10-Gb/s Burst-Mode Upstream Transmission Based on a 10G Burst-Mode ROSA with Digital Equalization Achieving 20dB Dynamic Range and sub-100ns Recovery Time

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Abstract *We experimentally demonstrate multi-rate burst-mode transmission at 25, 12.5 and 10Gb/s using a 10GHz-class burst-mode receiver optical sub-assembly (ROSA), respectively achieving receiver sensitivities of -27.7, -31, and -32.1dBm after 20-km SSMF transmission at 1E-2 BER, all with 20-dB dynamic range and 92-ns burst recovery time.*

Introduction

For upstream transmission in the ITU-T 50G-PON standards currently being developed, multiple data rates, such as 50 Gb/s, 25 Gb/s, 12.5 Gb/s and 10Gb/s, are desired to be supported[1]. 25 Gb/s burst-mode upstream transmission was recently demonstrated by using 25G APD[2,3], 10G APD/TIA/AGC ROSA[4], and 25 Gb/s burst-mode ROSA based on PIN/TIA/AGC [5]. In Refs [2] and [3], automatic gain control (AGC) was not implemented so the dynamic range was limited to ~8 dB. In Ref. [4], a commercially available 10G APD/TIA/AGC ROSA was used to enable a large dynamic range of over 20 dB, but stress test with unequal burst powers was not conducted. In Ref. [5], it was found that the transient time response and burst-mode receiver performance depend on the power difference between two adjacent bursts. In order to determine the guard time (Tg) and preamble time (Tp) specifications for 50G-PON upstream transmission, it was suggested to study the performance of DSP-assisted burst-mode receiver with the consideration of unequal burst powers.

Here, we report the use of a 10GHz-class burst-mode ROSA[9] for multi-rate reception of 25 Gb/s, 12.5 Gb/s and 10 Gb/s signals under the condition of unequal burst powers, and further study the achievable dynamic range and burst recovery time. With receiver-side digital signal processing (DSP), fast burst synchronization and recovery are realized with a large dynamic range of 20 dB and a short preamble time (T_p) of 92 ns, showing the promise of this type of cost-effective ROSA for practical 50G-PON upstream applications.

Experimental setup

Figure 1 shows the experimental setup for multi-rate 25/12.5/10-Gb/s burst-mode upstream transmission with a commercial 10G bust-mode ROSA (MACOM-02238) based on APD/TIA/AGC. Inset (a) is a screen capture showing the transmitted optical signal spectrum. Inset (b) is a photo of the 10G burst-mode ROSA (on an evaluation board) used in the experiment. We first generated periodic NRZ signal bursts with a spacing of 40 μs, by using an arbitrary waveform generator (AWG). Each

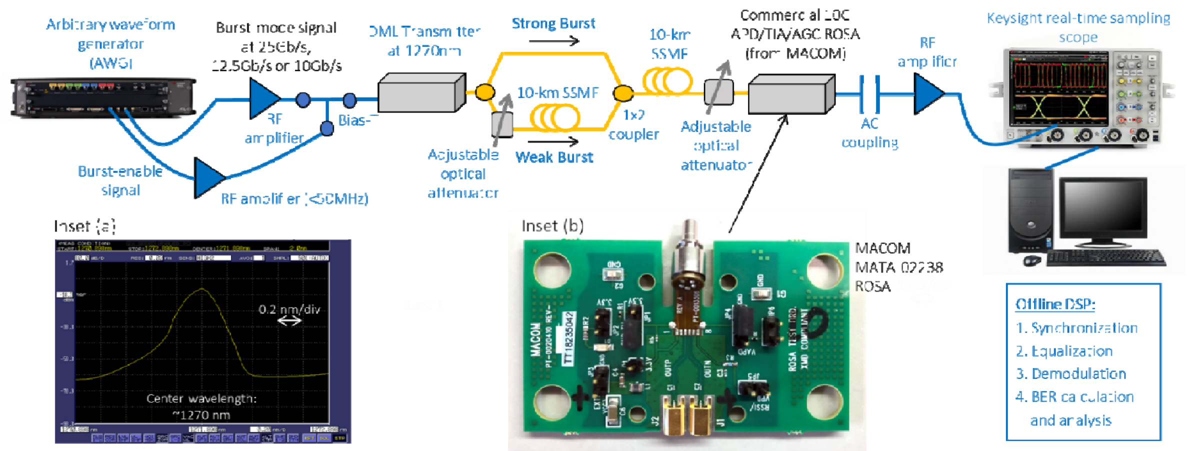

Fig. 1: Experimental setup for multi-rate 25/12.5/10-Gb/s burst-mode upstream transmission with a commercial 10G bust-mode ROSA based on APD/TIA/AGC. Inset (a): screen capture showing the transmitted optical signal spectrum. Inset (b): photo of the 10G burst-mode ROSA (on an evaluation board) used in the experiment.

burst had a duration of 9.95 μs. It contained a preamble that was 92 ns in duration, followed by payload data bits, which were taken from a PRBS 2^{20}-1 sequence. The preamble consisted of a known upstream physical synchronization block (PSBu) for synchronization purpose, similar to the PSBu used in 10G-PON. The upstream signal was amplified by a high-bandwidth RF amplifier, and the burst-enable signal was amplified by a low-bandwidth RF amplifier. These two RF signals were combined by a bias-T. The combined RF signal was then used to drive a DML with a center wavelength of ~1270 nm to generate an upstream optical signal with a power of 5 dBm per burst. The extinction ratio of the transmitted optical signal is set at 7 dB by varying the amplitude of the upstream data. The signal was then split by a 1×2 coupler into two paths. The 1st path was directly connected to an input port of a second 1×2 coupler, while the 2nd path was delayed by 50 μs by a 10-km SSMF, before being connected to the other input port of the second 1×2 coupler. The signal bursts passing through the 1st path and the 2nd path are referred to here as Strong Burst and Weak Burst, respectively. Due to the extra fiber loss and the use of an adjustable optical attenuator, the power of the Weak Burst is 10 dB lower than that of the Strong Burst, as shown in Fig. 2(a). The transmitted optical signal waveform was measured by a DC-coupled O/E converter (from Keysight).

The combined burst signals were then launched into another 10-km SSMF. After fiber transmission, another adjustable optical attenuator with a built-in optical power monitor was used to vary the optical signal power for receiver sensitivity measurements. The optical signal was detected by the 10G burst-mode ROSA. As AC-coupled burst-mode transmission was shown to offer several advantages such as high performance and low power consumption[6,7], we chose to use AC coupled burst-mode reception. The RF signal from the burst-mode ROSA was AC-coupled to an 80-GSamples/s analog-to-digital converter (ADC), which was embedded in a Keysight real-time sampling scope. The signal waveform received by the burst-mode ROSA is shown in Fig. 2(b). Evidently, the AGC of the ROSA reduces the power difference between the Strong Burst and the Weak Burst from 10 dB to <1 dB. The guard time between these two bursts is only 50 ns and it takes only 40 ns for the ROSA to produce NRZ signal with full swing, as shown in Fig. 2(c). This configuration emulates real-world upstream transmission of multiple upstream bursts with different powers.

Evidently, the received waveforms were well-conditioned with a burst settling time of shorter than 50 ns. Offline DSP was performed on the sampled waveforms. Receiver-side burst synchronization based on the cross correlation between the received signal and the known PSBu was conducted to find beginning of each burst. At the same time, equalization (EQ) based on a 32-tap feed-forward equalizer (FFE) was also performed. After equalization, the payload signal was demodulated and compared with the original payload to calculate the BER and its evolution with time.

Experimental results

We conducted measurements for three data rates, 25 Gb/s, 12.5 Gb/s and 10 Gb/s. At 25 Gb/s, a 32-tap FFE equalizer is used to compensate the limited bandwidth of the 10G ROSA. Figure 3 shows the measured raw BER for optical transmission over 0 and 20km SSMF as a function of the ROP per burst. Receiver sensitivities are measured at raw BER values of 1E-2 and 2.4E-2, respectively, which correspond to the BER thresholds of the hard-decision (HD) and soft-decision (SD) LDPC decoders that are being considered by the ITU-T 50G-PON standard group[8]. These key results are summarized in Table 1.

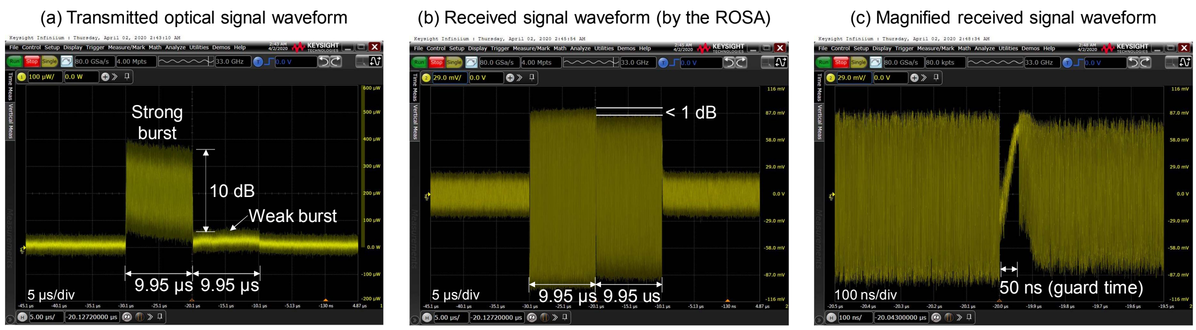

Fig. 2: (a) Screen capture showing the transmitted optical signal waveform, (b) screen capture showing the received signal produced by the burst-mode ROSA, and (c) screen capture showing a magnified version of the received signal waveform.

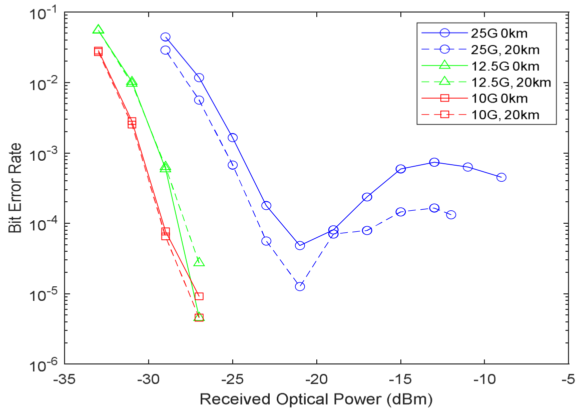

Fig. 3: Measured raw BER as a function of the ROP per burst at 25 Gb/s, 12.5 Gb/s and 10 Gb/s.

Tab. 1: Measured receiver sensitivities for three data rates.

	Receiver sensitivity at BER=1E-2 (2.4E-2)	
	L=0 km	L= 20 km
10 Gb/s	-32.1 (-33) dBm	-32.1 (-33) dBm
12.5 Gb/s	-31 (-32) dBm	-31 (-32) dBm
25 Gb/s	-26.9 (-28) dBm	-27.7 (-28.8) dBm

From the results shown in Table 1, we have the following observations:

1. With receiver-side EQ, the 10G burst-mode ROSA is capable of receiving 25, 12.5 and 10 Gb/s signals with reasonably good receiver sensitivities, both for 0-km transmission and 20-km transmission. With the DML power of 5 dBm, a link budget of 31.9 dB can be achieved for all these cases.
2. The dispersion penalty is negligible at 10 Gb/s and 12.5 Gb/s, while it becomes ~-0.8 dB at 25 Gb/s, which is reasonable considering the signal wavelength used.
3. Increasing the data rate from 10 Gb/s to 12.5 Gb/s and 25 Gb/s causes sensitivity penalties of 1.1 dB and 4.6 dB at BER=1E-2 after 20-km transmission, respectively.
4. Increasing the BER threshold to 2.4E-2 (via SD-LDPC) increases the link budget to 33 dB for all these cases.

It is important for the upstream burst-mode receiver to have a large dynamic range of over 15 dB to accommodate the differential optical path loss[6] in the optical distribution network (ODN). When the ROP is between -26.9 dBm and -6 dBm, the BER values in all the cases are below the HD-LDPC threshold of 1E-2. This indicates that the burst-mode ROSA is suitable to support a large dynamic range of over 20 dB.

It is also important to achieve fast burst recovery in order to reduce T_p and thus increase the transmission throughput. Fig. 4 shows representative recovered 25-Gb/s NRZ symbols of a weak burst at a ROP of -21 dBm. With the use of burst-mode EQ, stable burst synchronization and recovery can be realized after a short preamble time (T_p) of only 92 ns.

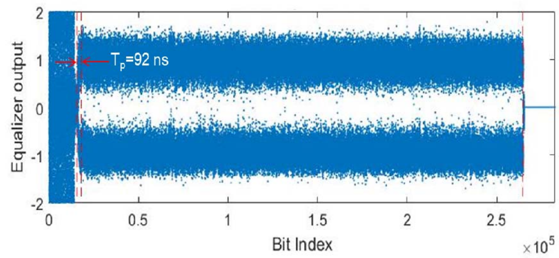

Fig. 4: Recovered 25-Gb/s symbols in the weak burst.

Conclusions

Using a 10GHz-class burst-mode ROSA with receiver-side DSP, we have demonstrated the feasibility of multi-rate burst-mode upstream transmission at 25 Gb/s, 12.5 Gb/s and 10 Gb/s for 50G-PON, respectively achieving receiver sensitivities of -27.7 dBm, -31 dBm, and -32.1 dBm after transmission over 20-km SSMF at a raw BER of 1E-2. The DSP-assisted burst-mode receiver enables fast burst synchronization and recovery with a preamble time (T_p) of 92 ns and a guard time (T_g) of only 50 ns, as well as a large dynamic range of over 20 dB, showing the promise of this type of cost-effective ROSA for practical 50G-PON upstream applications.

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