MAC-assisted DSP Architecture for 50G TDM-PON Upstream Triple-Rate Reception

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Abstract: We propose and experimentally demonstrate a MAC-assisted DSP for tri-rate upstream reception of 50G PON, which greatly reduces preamble time and achieves requirements of power budget C+ class for BTB and 20km transmission. © 2024 The Author(s)

1. Introduction

With the evolution of bandwidth-consuming applications such as VR/AR, 4k/8k UHD streaming, and cloud gaming, the internet data volume has continue its exponential growth, which motivates the demand of passive optical networks (PON) towards higher data rates [1]. New PON standardization proposals are rapidly evolving and address the definition of higher speed PON (HS-PON). ITU-T has defined the 50G time-division multiplexing (TDM)-PON to be the next generation HS-PON system beyond 10G. Specifically, there are three line rates defined for the upstream transmission of 50G PON, which are 12.4416 Gbps, 24.8832 Gbps and 49.7664 Gbps.

Nevertheless, massive deployment of such 50G PON still faces multiple challenges. The first thing to consider the coexistence issue with legacy PONs and reuse the deployed optical distribution networks (ODNs). That means choosing unused wavelength bands and satisfying the current ODN power budget [2]. Similarly, the Non-Return to Zero (NRZ) modulation format is selected to meet the 50G PON power budget. And the high bit rates of 50G PON stress the physical layer constraints of the transmission: the dispersion induced penalty and the immaturity of optical and electrical components [3]. The optical interfaces parameters of the 12.4416 Gbps, 24.8832 Gbps and 49.7664 Gbps upstream transmission have been defined by ITU-T. Considering the maturity of optoelectronic devices and transceiver cost, existing optoelectronic components in combination with digital signal processing (DSP) techniques is a favorable option, such as optical transmitter (including DML/EML) and receiver components. DSP ASIC can improve the NRZ transmission performance with inter symbol interference (ISI) caused by the bandwidth limitation of the transceiver, and by the fiber chromatic dispersion (CD) [4]. In addition, ONU signals with different upstream rates and fiber transmission distances of 50G PON suffer different damage, and DSP need support upstream tri-rate dynamic burst reception. Therefore, the DSP with a single mode cannot perform differentiated compensation for different ONU signals, and needs to support the dynamic fast adaptive equalization for multi-rate ONU signals. There are some reports of DSP for 50G PON upstream transmission at single-rate or dual-rate, and show good performance. In particular, the multi-rate reception for the upstream burst-mode (BM) signals in 50G PON, has attracted lots of attentions from the industry [5-7].

In this paper, we propose a flexible MAC-assisted DSP scheme that can support the dynamic fast adaptive equalization for multi-rate ONU signal and achieve upstream tri-rate burst mode reception. We also experimentally verified the performances of the proposed MAC-assisted DSP in terms of receiver sensitivity and preamble length. The experiment results show that the proposed MAC-assisted DSP scheme achieve the good performance for BTB and 20km standard single mode fiber (SSMF) transmission.

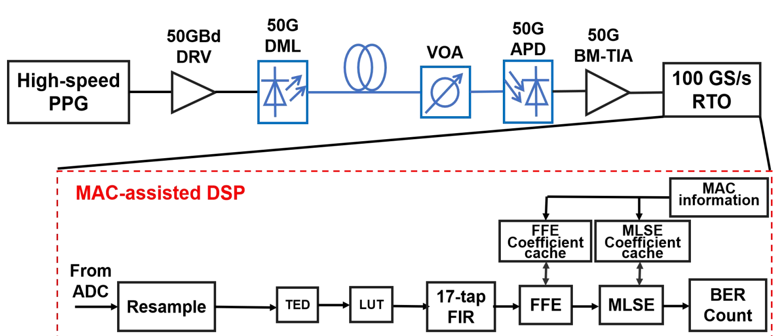

Fig. 1. Experiment setup and MAC-assisted DSP Architecture

2. MAC-assisted DSP architecture design and Experimental setup

The MAC-assisted DSP architecture is shown as Fig.1. The MAC interacts with the DSP on the upstream transmission. Because the OLT MAC knows in prior about the arriving time, the channel condition, as well as the data rate of each ONU's upstream burst signals, the DSP could utilize such information to facilitate upstream reception. In MAC assisted DSP architecture, a dedicated read and write memory (RAM) is implemented to store the FFE & MLSE coefficients, as well as the data rate information. Before each upstream burst arrives, the MAC uses the ONU ID as address to access the content of the RAM and load the corresponding coefficients to the FFE & MLSE. When channel conditions are bad, FFE and MLSE coefficients of existing ONUs are automatically updated. When an allocated transmission window is almost end, the MAC triggers a memory write using the ONU ID to update the FFE & MLSE coefficients. Using a RAM to pre-store filter coefficients can significantly shorten the FFE convergence time so the length of the preamble sequences can be reduced.

Fig. 1 shows the experimental setup for 50G PON burst-mode upstream transmission. On the transmitter side, a Keysight M8040A pulse pattern generator (PPG) is used to produce the NRZ signal with line rates of 12.4416 Gbps, 24.8832 Gbps, and 49.7664 Gbps respectively with a length 2^{24}-1 PRBS sequence. The NRZ signal is then amplified by a 50G DML driver to produce the optical signal. The output of DML is fed to a 20-km fiber span as well as a variable optical attenuator (VOA). At the Rx, the optical signal is detected by a 50G avalanche photodetector (APD) and amplified by a 50G transimpedance amplifier (TIA). The automatic gain control (AGC) loop of the TIA is disabled in this study. Instead the transimpedance gain of the TIA is controlled manually. A Tektronix DPO75902SX real-time scope (RTO) samples the electrical signal and the waveform is sent to subsequent offline DSP processing. The inset of Fig. 1 depicts the proposed MAC-assisted DSP architecture. The ADC captured signals are first resampled into 62.208 GS/s, which corresponding to 1.25 sample per symbol (SPS) for 49.7664 GBd NRZ, 2.5 SPS for 24.8832 GBd NRZ, and 5 SPS for 12.4416 GBd NRZ. For the timing error detector (TED), we adopt a Muller-Muller phase detector with a 5-tap IIR filter to estimate the amount of sampling error. Since the ONU upstream signal's clock are originated from OLT's downstream signal, no clock frequency track loop needs to be used. The timing error estimation is then used as an index of a look-up table (LUT) to obtain the coefficients for a 17-tap FIR filter, which serve as an interpolator as well as decimation filter. And we use another 17-tap adaptive FFE based on LMS for equalization. Followed by a maximum likelihood sequence estimation (MLSE) module with 2-tap post-filter (PF) and a memory length of 15 sample. There is interaction between MAC and FFT and MLSE. After equalizer, the signal is demodulated and compared with the original sequence for BER calculation.

3. Experiment Results & Analysis

To verify the performance of the proposed MAC-assisted DSP architecture, we conducted back-to-back (BTB) and 20km fiber transmission experiments using the setup shown in Fig.1. Fig. 2 (a) shows the variation of FFE equalization performance with iteration convergence time at different step-sizes for 49.7664 GBd signal without MAC-assisted DSP. We can conclude that using a larger step-size can result in faster convergence speed yet the equalizer behaves poorly in equalization performance. When the step-size is 2e-2, the FFE equalizer does not work. The Mean-Squared Error (MSE) here is the difference between the FFE output and the detected NRZ-OOK symbol after decision.

Next, there is a trade-off between speed of convergence and equalization performance and we visualize the evolution of certain FFE tap coefficients with a step-size of 6e-5 shown in Fig. 2 (b) and Fig. 2 (c). We found the FFE would be safe to switch into decision-directed LMS after approximately 8000ns without MAC-assisted DSP in

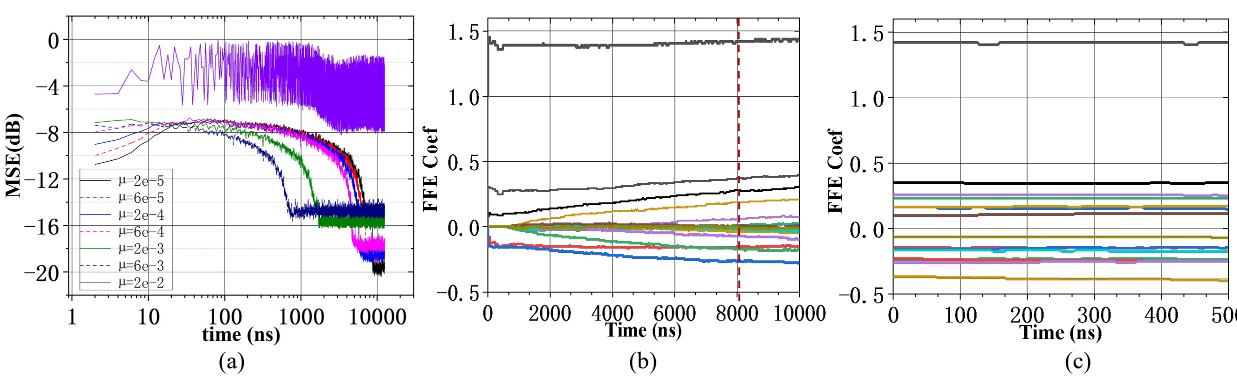

Fig. 2. (a) MSE versus FFE convergence time in different step-size parameters with the FFE with no MAC-assistance; FFE coefficient convergence curve of step-size parameter μ=6e-5 (b) with no MAC-assistance, (c) with MAC-assistance

Fig. 2 (b) and approach 0ns of FFE convergence time with MAC-assisted DSP in Fig. 2 (c). Therefore, the MAC-assisted DSP greatly reduces the system preamble time and improves the system upstream bandwidth utilization.

Fig. 3 shows the BER performance versus ROP of 49.7664 GBd, 24.8832 GBd, and 12.4416 GBd NRZ signals. We assume the FEC thresholds in this study: a 20% SD-FEC from the G.hsp (2e-2). We found MLSE is particularly helpful for the 49.7664 GBd signal as the channel is band limited for this baud rate in Fig. 3 (a). A net ROP gain of approximately 1 dB can be obtained from MLSE. For 24.8832 GBd and 12.4416 GBd NRZ signals, FFE and MLSE yield very similar ROP performance. OLT MAC knows in prior about the the data rate of each ONU's upstream burst and as a result, the MLSE block can probably be bypassed to save some power in an actual ASIC implementation for 24.8832 GBd and 12.4416 GBd NRZ signals.

For 49.7664 GBd, 24.8832 GBd, and 12.4416 GBd signals, the transmitter optical power is 6.8dBm, 5dBm amd 4dBm, respectively. Regarding back-to-back transmission, we can achieve a sensitivity of -25.5 dBm, -31 dBm, and -33.7 dBm ROP for 49.7664 GBd, 24.8832 GBd, and 12.4416 GBd signals almost without penalty comparing to the case of 20-km fiber transmission in Fig. 3 (b). We can conclude that the proposed MAC-assisted DSP achieved 50G PON upstream tri-rate burst mode reception without equalizer convergence time and achieved requirements of power budget C+ class.

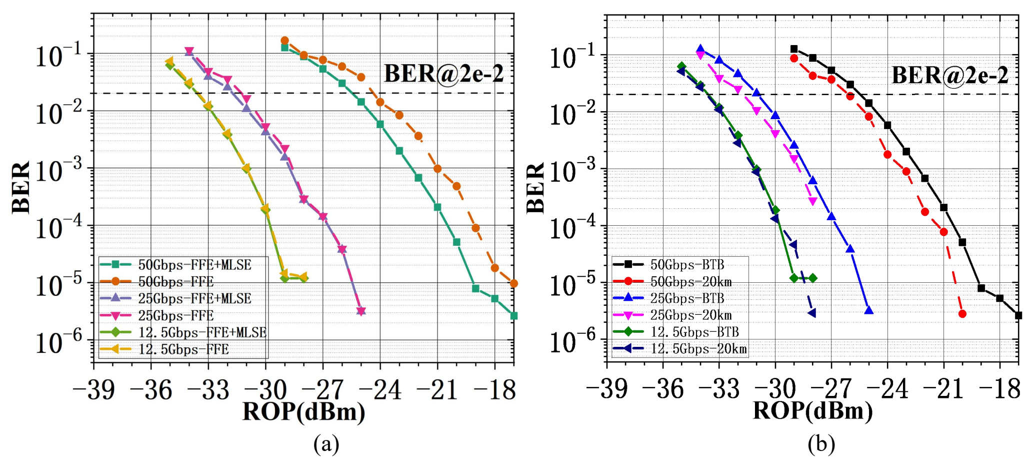

Fig. 3. (a) BER performance comparison between FFE and FFE+MLSE of MAC-assisted DSP (b) BER performance versus ROP between BTB and 20km transmission with MAC-assisted DSP

4. Conclusion

In this paper, the flexible MAC-assisted DSP architecture for 50G PON upstream tri-rate transmission is proposed and verified. Experimental results show that the proposed MAC-assisted DSP architecture can perform burst reception of the 50G PON upstream tri-rate signals. And the MAC-assisted DSP greatly shortens the equalizer convergence time, which is almost 0ns, compared to the DSP with no MAC-assistance. This work may lay the foundation for future applications of upstream multi-rate transmission of higher speed PON.

5. References

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