Mitigation of Bandwidth Requirements in 800G SWDM Systems based on Variable Rate Technique

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***Abstract*—The mitigation of TRX bandwidth requirements through variable rate technique is shown for 4λ-800G SWDM systems. Bandwidths below 38.6 GHz are demonstrated for 50 m reach using MLSE equaliser and PAM-M formats.**

Keywords—SWDM, VCSEL, MMF, Variable Rate

I. Introduction

The spread of artificial intelligence (AI) based applications is causing an unprecedented increase of computational demand in hyper-scale datacentre clusters. This reflects on the interconnections among clusters components, such as servers, GPU accelerators and high bandwidth memories, requiring higher speeds and reduced latencies. Today, datacentres mainly rely on optical connections based on vertical cavity surface emitting lasers (VCSEL) and multi-mode fibres (MMF), with transmissions up to 100 Gbps per lane. According to the IEEE P802.3db Short Reach Fiber Task Force and the IEEE P802.3dj Ethernet Task Force recommendations, 400G links are enabled by short wavelength division multiplexing (SWDM) based on four wavelengths (λs). Nevertheless, these rates will not be able to satisfy the request of throughput in the next future. Thus, progresses towards 200 Gbps per lane and 800G SWDM systems have already started. With such higher bit rates, new challenging requirements arise for VCSELs at the transmitter (TX) and transimpedance amplifiers (TIA) at the receiver (RX), as larger bandwidths and lower noise are targeted [1].

In SWDM systems based on MMF, the performance is limited by two effects: chromatic dispersion, stronger at shorter λs, and modal dispersion, stronger at longer λs. However, modal dispersion becomes more significant when longer distances are targeted, with the channel at 940 nm being the one limiting the overall SWDM reach [2]. Instead, longer reaches are achieved at 850 nm. To improve and equalise the performance on the four λs, a variable rate (VR) approach was proposed in [3] for a 4λ-400G SWDM system (850 nm, 880 nm, 910 nm and 940 nm). There, instead of transmitting 100 Gbps fixed rate (FR) on each λ, the bit rate was optimized offline for a large population of VCSEL-MMF links, resulting in higher bit rates at shorter λs and lower bit rates at longer λs. This is particularly beneficial for the 940 nm channel.

In this paper, we apply the VR technique to a four λs 800G SWDM system to mitigate bandwidth requirements, as the fabrication of wider bandwidth devices is still challenging. The analysis is carried out on different pulse amplitude modulation (PAM) formats for a target distance of 50 m. From our results, the VR technique proves to be a promising solution with two-fold advantages: mitigation of transceiver (TRX) bandwidth requirements and improvement of 800G SWDM system reach.

II. Mitigation of transceiver bandwidth

At the TX side, the limiting device is the VCSEL, while at the RX both photodiode and TIA limit the available bandwidth. In this analysis, we consider a single parameter representing the cascade of the two. The study is performed through time-domain simulations for different scenarios considering the same simulation setup as in [2], where an extensive statistical analysis was reported on a large dataset of VCSEL-MMF links. Here, we consider only OM4 fibres, as OM3 cannot guarantee useful distances at 200 Gbps. The impact of channel propagation is emulated through a single pole low pass filter (LPF), with cut-off frequency set equal to the bandwidth guaranteed by the 99% of the OM4 links of the dataset considered in [2]. At the target distance of 50 m, the cut-off frequencies of the LPF emulating the MMF channel are 54.5 GHz, 45.4 GHz, 36.6 GHz and 27.9 GHz for 850 nm, 880 nm, 910 nm and 940 nm channels, respectively. The relative intensity noise (RIN) of the VCSEL is set to -151 dB/Hz [4], while the input referred noise density (IRND) of the TIA is 15 pA/$\sqrt{Hz}$ [5]. For the analysis, we assume the enhanced forward error correction (E-FEC) code with 10.35% FEC overhead and $4 \cdot 10^{-3}$ target bit error rate (BER_T). The investigated modulation formats are PAM-4, PAM-6, implemented as in [6], and PAM-8. Feed-forward equaliser (FFE) and maximum-likelihood sequence estimation (MLSE) equaliser are considered. To further reduce the degrees of freedom in the study, we assume TX and RX bandwidths to have same value B_{TRX}.

Fig. 1(a) shows the iso-curves of distances obtained at different net bit rates and different TRX bandwidths for the 940 nm channel considering PAM-4 and MLSE equaliser. Focusing on the 50 m target distance (red line), we can see that larger bandwidths are required to transmit at higher rates. The iso-curves for all four λs at 50 m reach, still for PAM-4 and MLSE, are reported in Fig. 1(b). Since we are interested in the performance of the overall SWDM system, we can analyse the requirements on B_{TRX} with respect to the overall SWDM net throughput, computed by summing up the rates of the four λs. The resulting curve, reported in yellow in Fig. 1b (vertical axis

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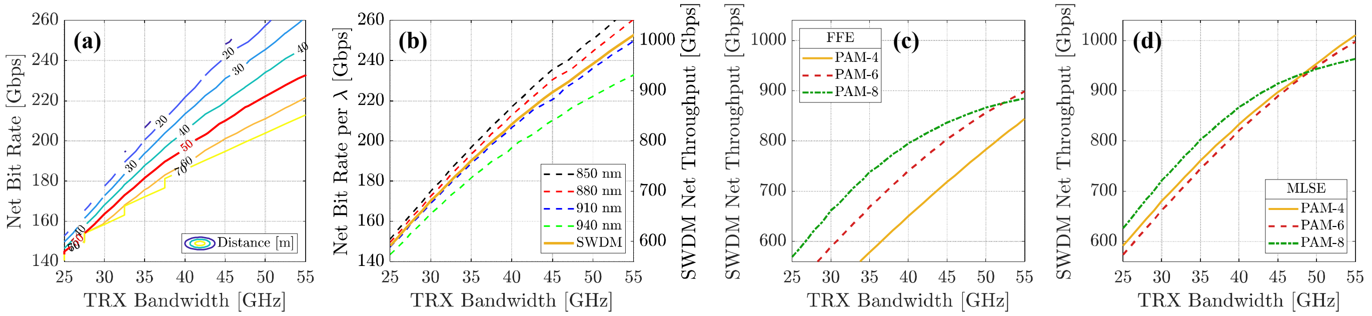

Fig. 1. (a) Achievable distances as a function of net bit rate and TRX bandwidth at 940 nm for PAM-4 and MLSE equaliser; (b) net bit rate per λ and SWDM net throughput at 50 m for PAM-4 and MLSE; SWDM net throughput as a function of TRX bandwidth at 50 m for PAM-M in case of (c) FFE and (d) MLSE equalisers.

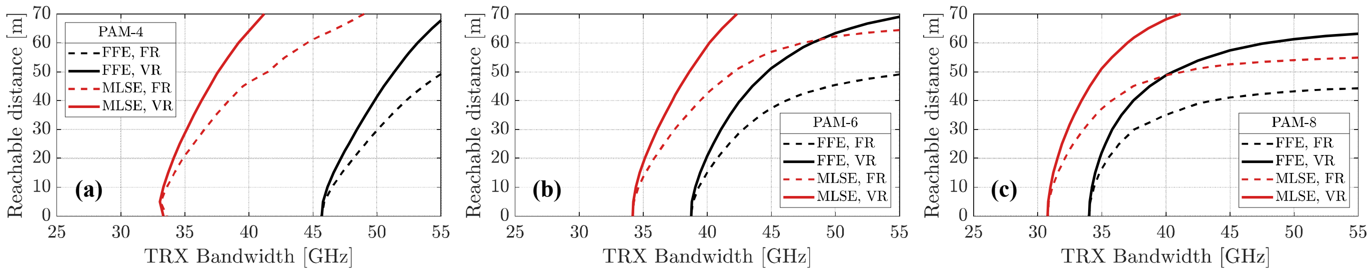

Fig. 2. Reachable distance as a function of TRX bandwidth for the FR (940 nm at 200 Gbps, dashed line) and for the VR (800G SWDM system, solid line) in case of: (a) PAM-4, (b) PAM-6 and (c) PAM-8. Results for FFE (black) and MLSE (red) equalisers are shown.

on the right), shows an intermediate behaviour in terms of TRX bandwidth requirements with respect to the four λs. Repeating the process for all cases under study, we obtain the curves in Figs. 1(c) and 1(d), respectively for FFE and MLSE equalisers. From there, PAM-8 is the less TRX bandwidth demanding format, but only up to a certain B_{TRX} value, for which the amount of noise affecting the system becomes too high. In Table I, the TRX bandwidth requirements are reported for the SWDM system operating at 800G over 50 m: $B_{TRX} \leq 38.6$ GHz are achieved using the MLSE equaliser, regardless the modulation format. According to the VR approach, we assume these TRX bandwidths on the four λs and we determine the corresponding optimized rates, reported in Table II, where we can observe an expected decreasing trend on the rates from 850 nm to 940 nm.

In Fig. 2, we compare the VR and the FR approaches in terms of reachable distance versus the TRX bandwidth for the

TABLE I - TRX bandwidth requirements at 50 m.

Scenario	PAM-4 [GHz]	PAM-6 [GHz]	PAM-8 [GHz]
VR + FFE (800G SWDM)	51.4	44.7	40.5
VR + MLSE (800G SWDM)	37.6	38.6	34.8
FR + MLSE (200 Gbps, 940 nm)	41.5	42.0	41.3

TABLE II - Variable rates of the four λs for all scenarios at 50 m.

	FFE			**MLSE**		
λ [nm]	**PAM4 [Gbps]**	**PAM6 [Gbps]**	**PAM8 [Gbps]**	**PAM4 [Gbps]**	**PAM6 [Gbps]**	**PAM8 [Gbps]**
850	207.4	210.8	215.1	207.5	207.9	208.8
880	203.7	205.9	207.3	203.9	204.0	204.8
910	198.6	198.4	197.2	198.6	198.4	198.4
940	190.3	184.9	180.4	190.0	189.7	188.0

PAM-M formats. The FR performance shows that 50 m can be reached with practical TRX bandwidths (<50 GHz) using the MLSE equaliser (B_{TRX} reported in Table I). Instead, with the VR technique a considerable decrease of required B_{TRX} is observed, especially using MLSE. Indeed, compared to FR, reductions of 9.4%, 8.1% and 15.7% are obtained for PAM-4, PAM-6 and PAM-8, respectively.

III. Conclusions

The variable rate technique, consisting in the optimization of the rate per λ, was applied to an 800G SWDM system to mitigate TRX bandwidth requirements. Together with a performance equalisation on the four λs, a significant reduction of TRX bandwidths was obtained with respect to the standard FR approach, showing that devices with $B_{TRX} \leq 38.6$ GHz can be used with MLSE equaliser in 800G links up to 50 m.

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