The Best Modulation Format for Symmetrical Single-wavelength 50-Gb/s PON at O-band: PAM, CAP or DMT?

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Abstract: We experimentally demonstrated and compared PAM-4, CAP-16QAM and DMT-16QAM modulations in a symmetrical 50-Gb/s/λ PON based on bandwidth-limited optics over the same fiber link at O-band. The performance of power budget and dispersion are discussed.
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1. Introduction

With rapid development of cloud services, video streaming services, and 5G wireless backhaul, there occurs an urgent requirement of transmission capacity in access network segment. IEEE 802.3ca Task Force have completed 25 Gb/s and 50 Gb/s EPON standards by bonding two wavelength channels to reach its 50-Gb/s target [1]. In the ITU-T standards development organization, the standardization of single wavelength 50 Gb/s TDM PON has begun in project G. hsp [2]. To achieve a 50-Gb/s/λ PON based on IM/DD using bandwidth-limited optics, advanced modulation formats and advanced digital signal processing (DSP) are the most potential research topics. Semiconductor optical amplifiers (SOA) and stronger forward error correction (FEC) have been introduced to further increase the power budget. NRZ, PAM-4 and Duobinary are the potential modulation schemes for the high capacity PON systems due to its simpler DSP architecture and lower energy consumption. Carrier-less amplitude and phase (CAP) and discrete multi-tone (DMT) modulation schemes have strong resilience to fiber chromatic dispersion and higher spectrum efficiency [3]. For cost-effective and smooth upgrading to symmetrical 50-Gb/s/λ PON systems, the adoption of legacy low-bandwidth optics has been intensively investigated [4-6]. However, in these works, the downlink and uplink for a symmetrical PON are separately studied with different fiber links, and only PAM-4 modulation scheme is studied. Although many researchers have investigated PAM, CAP and OFDM modulation formats for metro networks, there is no reported a comprehensive comparison for 50G PON.

In this paper, we experimentally investigated and compared the performance of PAM, DMT and CAP modulation formats over the same fiber link at O-band using 10G-class optics with SOA+PIN receivers and simple DSP for the first time. The downstream and upstream performances of 50-Gb/s/λ PON with PAM, DMT and CAP modulations are intensively studied. The results show that over 26 dB power budget at HD-FEC threshold and over 29 dB at SD-FEC threshold in both downlink and uplink transmission can be achieved. Moreover, the dispersion tolerance is evaluated, and DMT-16QAM has the best dispersion tolerance performance.

2. Experimental setup

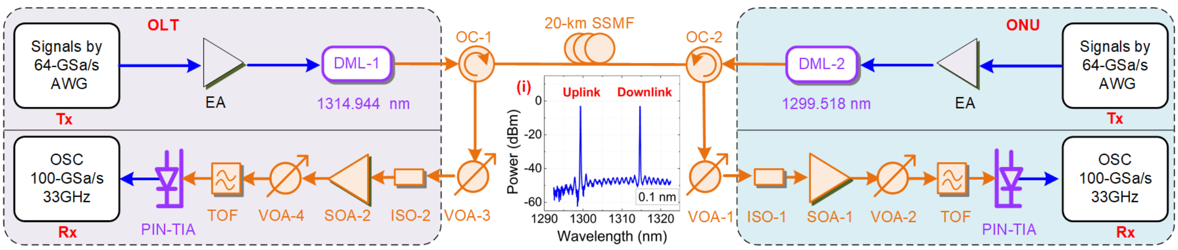


Fig.1. Experimental setup of symmetrical single-wavelength 50-Gb/s PON system over the same fiber link at O-band.

Figure 1 shows the experimental setup for the symmetrical transmission of a 50-Gb/s/λ PON based on bandwidth limited optics at O-band. The 3dB bandwidth of the downstream and upstream transceivers are 17.4 and 18.6 GHz, respectively. For both downstream and upstream links, 50 Gb/s signals with different modulations are generated from a 64 GSa/s arbitrary waveform generator (AWG) with a 3-dB analog bandwidth of 25GHz, and then amplified by a 25 GHz linear electrical amplifier (EA). The output of the EA is directly modulated by a commercial DML-1 with a power output of 9.62dBm at the central wavelength of 1314.944 nm. The downlink and uplink signals are separated by optical circulators (OC-1 and OC-2) and transmitted in the same optical fiber link. Then, the modulated optical signal transmits 20 km standard single-mode fiber (SSMF) with an average loss of 0.33 dB/km at 1310 nm. As shown in Fig. 1, a variable optical attenuator (VOA-1) is applied to account for the splitter loss. In order to support larger link loss budget, SOA-1 at the ONU is used as a preamplifier. An isolator (ISO-1) is placed between VOA-1 and SOA-1 to avoid light reflection. The VOA-2 is used to adjust the received optical power (ROP) for sensitivity measurement. The out-of-band amplified spontaneous emission (ASE) noise can be suppressed by the 1 nm pass-band TOF. After PIN-TIA, the detected signal is captured by a 33 GHz 100GSa/s digital storage oscilloscope (DSO) for offline DSP. For upstream link, another commercial DML-2 at the center wavelength of 1299.518 nm is used. The output power of the DML-2 is 9.32 dBm. In addition, the performance parameters of the devices, such as VOA-3, ISO-2, SOA-2 and VOA-4, used in the uplink are the same as the downlink. All commercially available SOAs have same device characteristics with a small-signal gain of 30 dB, noise figure of 7 dB and saturation output power of 17 dBm. The polarization dependent gain of both SOAs is less than 1 dB. The optical spectra of downlink and uplink are shown in Fig. 1(i).

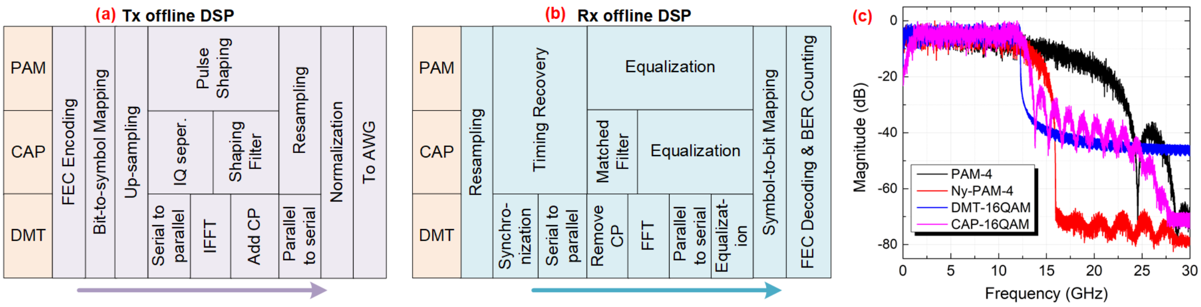


Fig. 2. (a) and (b) are the offline DSPs for PAM-4, CAP-16QAM and DMT-16QAM signals generation and recovery, respectively. (c) Spectra of 50 Gb/s signals with different modulation formats.

Figures 2 (a) and (b) show the offline DSPs for PAM-4, CAP-16QAM and DMT-16QAM signal generation and recovery, respectively. There are no pre-distortion methods such as digital pre-equalization and lookup table (LUT) at the transmitter side, and neither nonlinear equalization at receiver side to simplify the DSP process and reduce the complexity [7]. A smaller tap number of equalizers is adopt to ensure that the DSP has lower computation complexity. Fig. 2(c) shows the spectra of 50 Gb/s signals with different modulation formats. The bandwidth of PAM-4 signal without Nyquist pulse shaping is 25 GHz, and with the optimal roll-off factor 0.3 is 16.5 GHz. Furthermore, the bandwidth of CAP-16QAM and DMT-16QAM are 13.75 and 12.5 GHz, respectively. Thus, CAP and DMT modulations have higher spectrum efficiency than PAM modulation.

3. Results and discussion

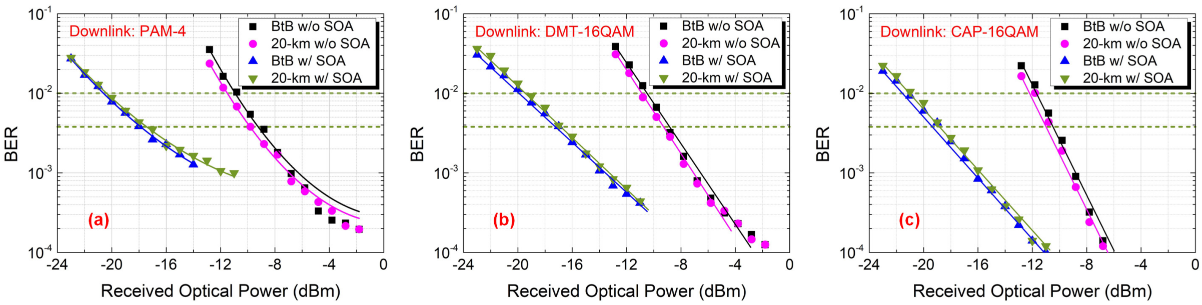


Fig. 3. BER versus ROP for 50-Gb/s PON in downlink: (a) PAM-4 and (b) DMT-16QAM and (c) CAP-16QAM.

The BER performance of 50-Gb/s PON versus ROP for downlink with PAM-4, CAP-16QAM and DMT-16QAM modulation formats after 20 km SSMF transmission are shown in Fig. 3. For PAM-4 transmission, as shown in Fig. 3(a), the receiver power without SOA at HD-FEC (3.8×10^{-3}) and SD-FEC (1×10^{-2}) threshold are -9.8dBm and -11.8dBm, respectively. Around 7.7dB and 8.7dB power budget improvement can be achieved by using SOA at HD-FEC and SD-FEC threshold. For DMT-16QAM downlink transmission, the receiver sensitivity at HD-FEC and SD-FEC threshold has about 8 dB and 8.5 dB power budget improvement after employing SOA. For CAP-16QAM downlink transmission, a power budget increase of 8.5dB and 9.2dB can be achieved at HD-FEC and SD-FEC threshold by using SOA. Therefore, DMT-16QAM and CAP-16QAM can realize error-free transmission at high receiving power, but PAM-4 has an error floor due to bandwidth limitation. There is no obvious dispersion penalty after back-to-back (BtB) and 20-km transmission. For uplink, the BER performances of 50-Gb/s PON versus ROP with PAM-4, CAP-16QAM and DMT-16QAM modulation formats for BtB and 20 km fiber transmission are tested and shown in Fig. 4. The performances of all modulation formats have around 0.5dB improvement after 20 km fiber transmission compared to BtB case.

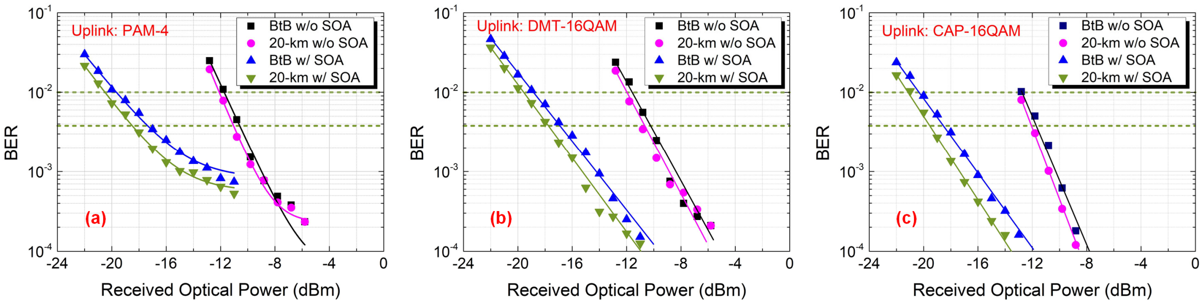
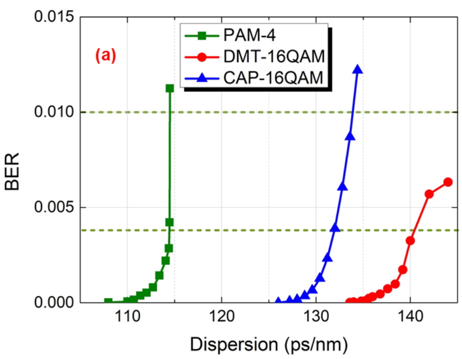


Fig. 4. BER versus ROP for 50-Gb/s PON in downlink: (a) PAM-4 and (b) DMT-16QAM and (c) CAP-16QAM.

The dispersion tolerance of the three modulation formats at O-band is shown in Fig. 5(a). At SD-FEC threshold, the accumulated dispersion of PAM-4, DMT-16QAM and CAP-16QAM is about 114 ps/nm, 141 ps/nm and 132 ps/nm respectively. Considering the highest chromatic dispersion coefficient of the ITU-T G.652 type fiber at O-band [8], all modulation formats can satisfy the accumulated dispersion of 20 km transmission in the wavelength range from 1260 nm to 1360 nm. Fig. 5(b) shows the summary of receiver sensitivity and power budget performance after 20 km transmission with the three modulation formats at HD-FEC and SD-FEC threshold. Over 26 dB power budget at HD-FEC threshold and over 29 dB at SD-FEC threshold can be achieved in both downlink and uplink transmission for all modulations. CAP-16QAM has the largest power budget.



(b) Modulation Formats		Launched Power (dBm)	Sensitivity @HD-FEC (dBm)	Power budget @ HD-FEC (dB)	Sensitivity @SD-FEC (dBm)	Power budget @ SD-FEC (dB)
DS	PAM	9.62	-17.5	27.12	-20.5	30.12
	DMT		-17	26.62	-19.5	29.12
	CAP		-18.5	28.12	-21	30.62
US	PAM	9.32	-18.5	27.82	-20.5	29.82
	DMT		-17.5	26.82	-20	29.32
	CAP		-19.5	28.82	-21	30.32

Fig. 5. (a) BER versus accumulated dispersion for three modulation formats. (b) Summary of receiver sensitivity and power budget for three modulation formats at HD-FEC and SD-FEC threshold.

4. Conclusions

In conclusion, we have experimentally demonstrated and intensively compared the first symmetrical single-wavelength 50-Gb/s PON with PAM, DMT and CAP modulation formats using 10G-class DML in the O-band assisted by SOA and DSP. DMT-16QAM has the best dispersion tolerance performance and CAP-16QAM has the largest power budget. The results show that over 26 dB power budget at HD-FEC threshold and over 29 dB at SD-FEC threshold in both downlink and uplink transmission can be achieved.

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