First Demonstration of MWDM-Based 400G-LR4 over 10-km SSMF Supporting 400GE and OTN Dual Rates

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Abstract: We report the first demonstration of cost-effective 400G-LR4 optical module based on O-band MWDM, achieving error-free transmission of both 400GE and OTN rates over 10-km SSMF with an optical link budget of over 6.7 dB. © 2023 The Author(s)

1. Introduction

Computing force network (CFN) is rapidly development, which is pushing forward the upgrade of fundamental network. IP router and optical transport network (OTN) equipment are both evolving from 100G to 400G to meet the high-capacity transmission requirement of CFN among data centers [1-2]. 400G Ethernet and OTN optical module is the key part of 400G system, which has been widely investigated by industry and academic area [3-4]. 400GBASE-FR8/LR8 optical modules based on 50G-per-lane with 8 lasers have been matured and deployed. 100G-per-lane 400G optical module is more attractive to further reduce the system cost and power consumption. The traditional wavelength schedule of four-lane optical module is based on coarse wavelength division multiplexing (CWDM) or local area network (LAN)-WDM, such as CWDM4, 100GBASE LR4, etc. However, the maximum transmission distances of 100G-per-lane 400GBASE-FR4 and 400GBASE-LR4-6 optical module based on CWDM are 2 km and 6 km, respectively. It cannot satisfy the transmission requirements of 10-km, which is limited by chromatic dispersion for the longest wavelength of 4-channel CWDM centered at 1331 nm. The method for generation of 100G-per-lane 400G optical signals by using 4-channel LAN-WDM around zero-dispersion region of G.652.D fiber may introduce four wave mixing (FWM) impairment, which is under study for 10-km application [5]. Moreover, the cost of LAN-WDM laser is higher than that of CWDM laser due to narrower wavelength spacing. Medium WDM (MWDM) has been proposed and is under standardization in ITU-T SG15 named G.owdm2, which can be obtained by shifting the design parameters of the CWDM laser at blue side and red side, respectively [6]. In this way, each CWDM channel can be divided into two MWDM channels, achieving 12-channel around O-band.

In this paper, we propose and demonstrate 100G-per-lane 400G optical module with Ethernet and OTN dual-rate over 10-km based on MWDM in O-Band. By using any four channels of 6-channel MWDM from 1265 nm to 1317 nm, the maximum chromatic dispersion is only 13 ps/nm, which can satisfy the requirement of TDECQ after10-km transmission. With sufficiently channel spacing and uneven channel allocation of MWDM, the FWM risk could be effectively reduced. We performed prototype of 100G-per-lane 400G optical module by picking up CWDM lasers which satisfy the MWDM channel schedule. With 10-km G.652 fiber in the worst cases of positive and negative dispersions, the experimental results show that the worst-case receiving sensitivities of the 100G-per-lane 400GE and 400G OTN optical module are -9.1 dBm and -8.2 dBm, respectively. There is about 0.9-dB receiving penalty when the optical module is sped up from the 400GE rate to 400G OTN rate. The corresponding optical link budgets of these 400GE and 400G OTN optical modules are calculated to be over 7.6 dB and 6.7 dB, respectively, which can fulfill the requirement of IEEE 802.3 standard within the optical link budget of 6.3 dB. To the best of our knowledge, this is the first demonstration of 100G-per-lane 400G optical module with Ethernet and OTN dual-rate over 10-km.

2. Architecture and Principle

The point-to-point 10-km system architecture of the proposed 100G-per-lane 400G PAM-4 MWDM optical module is shown in Fig. 1(a). The key parts of the proposed 400G PAM-4 MWDM optical module consists of four MWDM lasers, 1×4 thin-film filter (TFF)-based MWDM multiplexer/demultiplexer, PAM4 DSP, PIN, TEC, etc. Here, MWDM lasers can be obtained by adjusting the optical grate of the CWDM laser with 3.5-nm away from the central wavelength of CWDM symmetrically and the spectral response of TFF-based MWDM multiplexer/demultiplexer is correspondingly performed. The central wavelengths of CWDM and MWDM schemes are shown in Tab.1. The other parts can reuse that of existing 100G/400G PAM-4 optical modules.

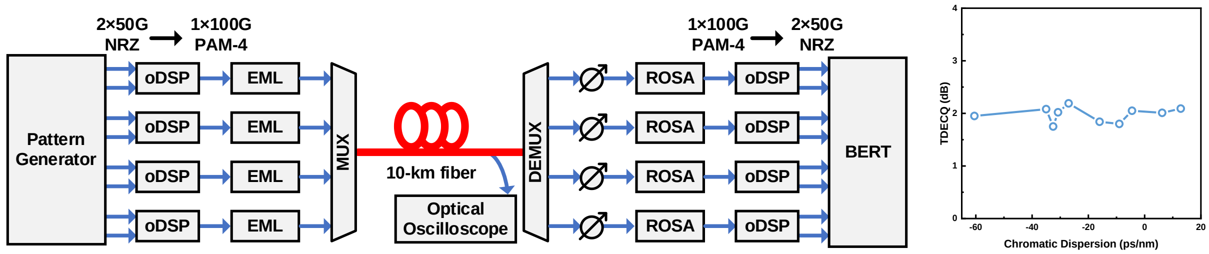

Fig. 1 (a) The point-to-point 10-km system architecture of the proposed 100G-per-lane 400G PAM-4 MWDM optical module; (b) TDECQ versus chromatic dispersion.

Tab. 1. Central wavelengths of CWDM and MWDM channels.

CWDM Channel (nm)	MWDM Channel (nm)		CWDM Channel (nm)	MWDM Channel (nm)	
Centre / Range	Centre	Range	Centre / Range	Centre	Range
1271	1267.5	1265~1270	1331	1327.5	1325~1330
1264.5~1277.5	1274.5	1272~1277	1324.5~1337.5	1334.5	1332~1337
1291	1287.5	1285~1290	1351	1347.5	1345~1350
1284.5~1297.5	1294.5	1292~1297	1344.5~1357.5	1354.5	1352~1357
1311	1307.5	1305~1310	1371	1367.5	1365~1370
1304.5~1317.5	1314.5	1312~1317	1364.5~1377.5	1374.5	1372~1377

The relationship between TDECQ and chromatic dispersion for 100G-per-lane PAM-4 MWDM externally modulated laser (EML) transmitters is shown in Fig. 1(b). It can be seen that the maximum value of TDECQ is about 2.1 dB as the chromatic dispersion is between -61 ps/nm and 13 ps/nm. The corresponding wavelengths of MWDM lasers are located from 1265 nm to 1317 nm. Considering the maximum TDECQ of 100G-per-lane PAM-4 over 10-km defined by IEEE 100GBASE-LR1 is 3.4 dB, any four channels of 6-channel MWDM from 1265 nm to 1317 nm can satisfy the requirement of TDECQ after10-km transmission, which can be regarded as candidate wavelengths for 100G-per-lane 400G PAM-4 application.

With low chromatic dispersion around zero-dispersion wavelength of the G.652.D fiber, the impact of FWM impairments is also studied. Table 1 shows that the channel spacings between adjacent channels of MWDM are 7 nm and 13 nm alternatively. With the help of the sufficiently channel spacing and uneven channel allocation, the FWM penalty for the link performance of MWDM could be effectively suppressed.

3. Experimental results

Corresponding experimental tests to evaluate the transmission performances of the 100G-per-lane 400G optical module are carried out according to the setup shown in Fig. 1(a). At the transmitter side, four wavelength channels with central wavelengths of 1268.78 nm, 1272.78 nm, 1289.48 nm and 1294.93 nm are firstly generated, respectively, which satisfy the wavelength schedule of MWDM channels. For each channel, two independent 53.25-Gbit/s pseudo-random-binary-sequence (PRBS) non-return-zero (NRZ) signals generated by a bit-error-rate tester (BERT, EXFO BA4000) are combined to produce an electrical 106.5-Gbit/s PAM-4 signal. Then the PAM-4 signal is sent into an EML to produce the optical PAM-4 signal. After multiplexed by cascaded TFFs, the 4-channel MWDM signals are fed into the fiber-optic transmission link. The optical spectrum of the launched MWDM signal is shown in Fig. 2(a), as well as the received optical spectral after 10-km positive-dispersion fiber (PDF) and 10-km negative-dispersion fiber (NDF). The zero-dispersion wavelength of the PDF is 1300 nm, while that of the NDF is 1324 nm. We can see that there is no significant distortion or undesired harmonics introduced by FWM in Fig. 2(a), which mainly owes to the uneven-spacing wavelength configuration in the MWDM scheme. At the receiver side, the MWDM signal is demultiplexed by another TFF-based WDM demultiplexer and each wavelength channel is detected by a receiver optical subassembly (ROSA). Figure 2(b) shows the response of the TFFs-based MWDM multiplexer/demultiplexer. Finally, the output electrical signal of the ROSA is sent back to the BERT for the BER measurement.

The experimental 106.5-Gbit/s PAM-4 eye diagrams for the corresponding signals are captured by an optical oscilloscope (Keysight N1092) assisted by a clock data recovery module (CDR, Keysight N1078) and have been depicted in Figs. 3(a-c). Clear eye diagrams of the 106.5-Gbit/s PAM-4 signals can be observed at back-to-back

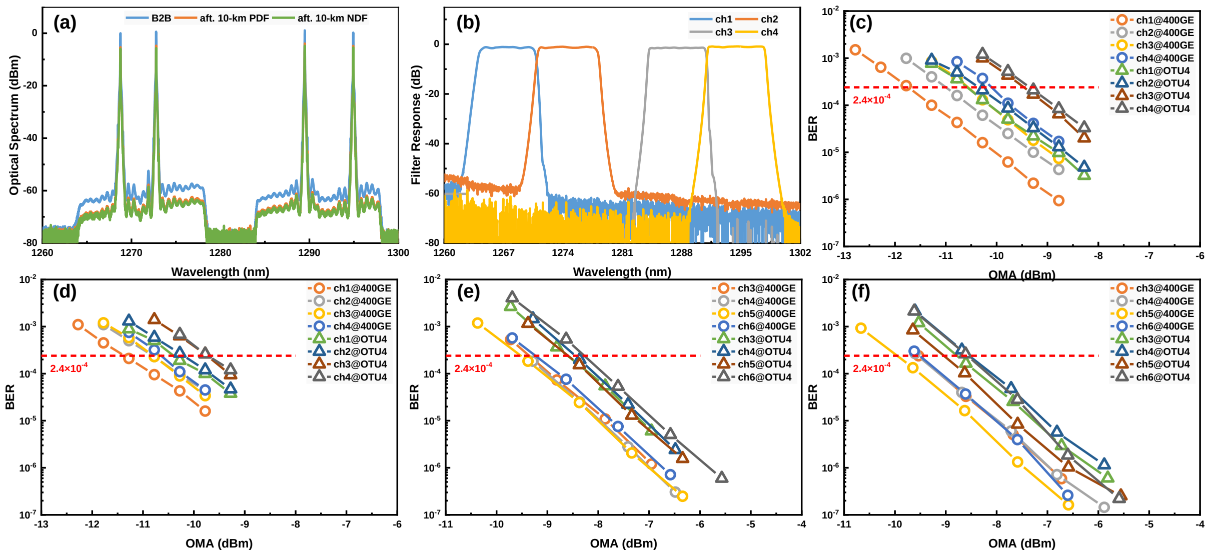

Fig. 2 (a) Optical spectrum of the launched MWDM signal and the received MWDM signal after 10-km PDF or NDF fiber; (b) the response of TFF-based MWDM multiplexer/demultiplexer; BER curves versus OMA for 1268.78 nm, 1272.78 nm, 1289.48 nm and 1294.93 nm after 10-km (c) PDF and (d) NDF transmission, for 1287.20 nm, 1295.16 nm, 1307.84 nm, and 1314.20 nm after 10-km (e) PDF and (f) NDF transmission.

(B2B) and after 10-km PDF/NDF transmission for all the four wavelength channels. The ERs are all beyond 4 dB. Figures 2(c-d) show the measured BER curves versus optical modulation amplitude (OMA) of the PAM-4 signals at B2B and after 10-km PDF/NDF transmission. To further verify the feasibility of 400GE rate applied in other MWDM wavelength regions, the BERs of another 4 channels with central wavelengths of respectively 1287.20 nm, 1295.16 nm, 1307.84 nm, and 1314.20 nm are evaluated and shown in Figs. 2(e-f). Meanwhile, the performance of OTU4 rate is also investigated and compared with the case of 400GE rate as shown in Figs. 2(c-f). For simplicity, all the six wavelength channels mentioned above are labeled from short to long as respectively ch1, ch2, ch3, ch4, ch5 and ch6 in Fig. 2. At the 7%-overhead forward error-correction (FEC) threshold of 2.4×10^{-2}, the worst-case receiving sensitivities of the 100G-per-lane 400GE and 400G OTN optical module after 10-km transmission are -9.1 dBm and -8.2 dBm, respectively. With 2.6-dBm transmitting OMA and below 2-dB multiplexer insertion loss, the corresponding optical link budgets are calculated to be over 7.6 dB and 6.7 dB, respectively, demonstrating the feasibility of 100G-per-lane 400G optical module with Ethernet and OTN dual-rate over 10-km.

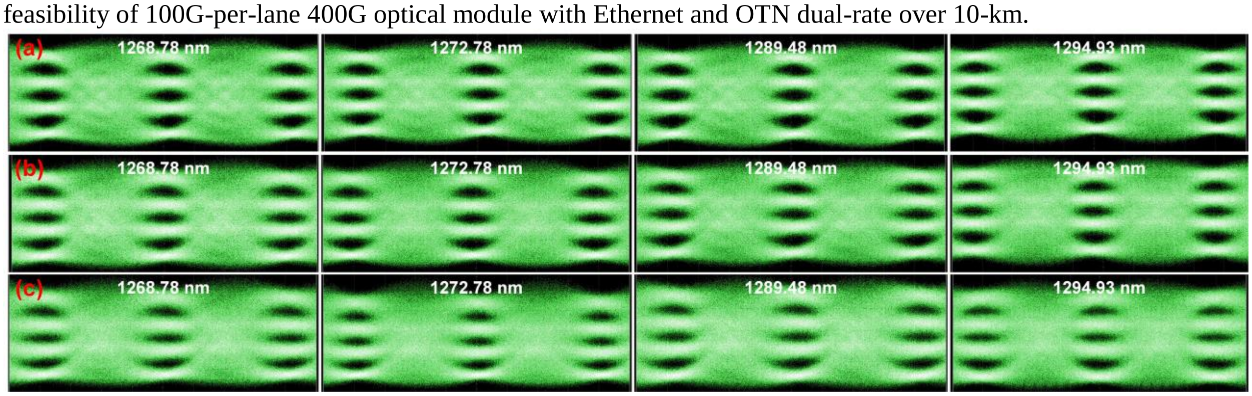

Fig. 3 Experimental 106.5-Gbit/s PAM-4 eye diagrams (a) at B2B, after 10-km (b) PDF and (c) NDF transmission.

4. Conclusion

Error-free transmission of 100G-per-lane 400G Ethernet and OTN dual-rate signals over 10-km with an optical link budget of over 6.7 dB has been experimentally demonstrated for the first time, showing the feasibility of using MWDM in the O-band to support 100G-per-lane 400G Ethernet and OTN with high cost-effectiveness.

5. References

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