High Capacity 400Gb/s Real-time Transmissions over AllWave ULL Fibres by 400ZR/ZR+ Pluggable Modules

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Abstract *We investigate the capability of 400ZR/ZR+ DWDM transmissions over G.652 fibres for DCI, metro/regional network. Real-time transmissions of 400Gb/s signals over 151km and 1010km fibre with capacity of >24Tb/s using 400ZR/ZR+ pluggable modules are demonstrated, respectively.*

Introduction

To meet the rapidly growing internet traffic demand, the data centre operators, cloud providers and telecom network carriers are continually increasing the bandwidth of their networks. The 100G and 200G interfaces have already widely been deployed, 400G and beyond are now adopted to meet the bandwidth demand and to reduce the cost per bit. The OIF have standardized 400ZR pluggable coherent transceiver modules for data centre interconnects (DCI) with a reach up to 120km [1], and 400ZR+ with longer reach and flexible date rates have also been proposed/developed by the industry. These pluggable coherent transceiver modules can not only be used for DCI, but also can be used to support 400G links in IP/WDM core networks [2]. They allow “IP over WDM” to become real and cost-effective. For example, BT has recently reported that significant cost saving can be obtained by adopting 400ZR/ZR+ for core-networks [2]. However, the capability of the 400ZR/ZR+ DWDM transmissions over G.652 fibres has not been reported.

In this work, we investigate the capability of 400ZR/ZR+ DWDM signals transmissions over G.652 AllWave® ULL fibres for DCI, metro/regional network applications. Using 400ZR pluggable transceiver modules, real-time transmission of 26 Tb/s over 151km fibre is demonstrated. This is achieved by transmitting sixty-five 400Gb/s channels with 75GHz frequency grid over a 151km amplified link in full C-band (1528.77nm -1567.13nm), and it has average Q^2 margin of 1.7dB. This reach is much longer than that targeted by 400ZR standard interoperability agreement (IA) [1] thanks to ultra-low loss of AllWave ULL fibre. In addition, we study the performance trade-offs with Q^2 margin and power consumption of 400ZR module when the chromatic dispersion (CD) of the link is large than the IA specification. For 400ZR+ pluggable modules, 24Tb/s (60x400Gb/s) capacity is transmitted over 1010km AllWave ULL fibre with 101km span length. This means the 400ZR+ can be deployed in much longer distance for metro/long-haul network.

26 Tb/s 400ZR transmission over 151km fibre

400ZR pluggable transceiver module is based on coherent technology utilising DP-16QAM modulation and it aims to deliver low cost 400Gb/s Ethernet links for edge DCI application with an amplified DWDM link targeting distance of 80~120km [1]. To ensure the power consumption, fit within smaller-sized-form module thermal limits [3], the 400ZR utilises concatenated forward-error-correction (C-FEC), which has overhead ~ 14.8% and can correct a bit-error-ratio (BER) of ~ 1.08×10^{-2} (Q^2-factor =7.22dB) to lower than 10^{-15}. Fig.1 (a) shows the experimental set-up for 400ZR DWDM transmission link. The transmitters consist of one loading and one measurement path. For the measurement path, three 400Gb/s channels from commercially available 400ZR pluggable coherent modules with a baud-rate of 59.84Gb/s are set to adjacent channels with 75GHz spacing and then combined. The loading path is composed of a broadband ASE source notch-filtered by a 50GHz-channelized wavelength selective switch (WSS) filter for a bandwidth window of ~250 GHz. It should be noted that the ASE sources as loading channels have been

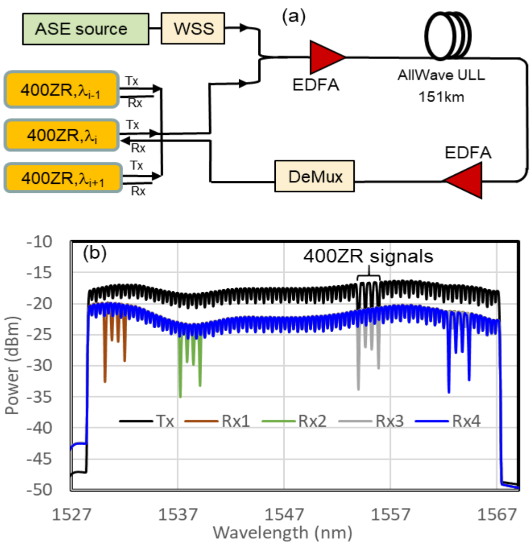

Fig. 1: Fig.2, (a)Experimental set-up for 400ZR 151km transmission; (b)Recorded transmitted spectrum and received spectra.

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used in the long-haul DWDM transmission experiments[4-5] and the accuracy and effectiveness of this approach has systematically been studied [5]. The combined DWDM channels are boosted by an EDFA and then sent to the transmission fibre link with equal launch power.

The transmission link has a 151 km length using G.652 AllWave® ULL fibre [6] which has Aeff of 83μm² and average attenuation of 0.170dB/km at 1550nm. The CD and CD slope are 16.27 ps/(nm.km) and 0.084ps/(nm².km) at 1550nm respectively. The 151km span loss including splicing and connectors is 26.1dB. A 2nd EDFA is used to amplify the DWDM signals before sending to a demultiplexer (DeMux). The selected channel from DecMux is then sent back to 400ZR receiver. The optical transmitter spectrum of the combined measurement and loading channels before launching into transmission line and receiver's spectrum after 2nd EDFA is plotted in Fig. 1 (b), where the received spectra plot four spectra from the receiver (marked as Rx1-Rx4) when the 400G measurement channels are translated to 4 different locations across C-band during the measurement, showing uniform loading of the 400ZR signal channels.

To test the 400 Gb/s transmission performance as a function of required OSNR on a 75 GHz grid, we place the group of three 400Gb/s channels at short, middle and long wavelength ranges. We adjust the launch power and measure the real-time BER of the middle channel (at wavelength 1529.94nm, 1545.32nm and 1566.52nm). We study the Q^2-margin (deduced from the measured BER) and Fig. 2(a)

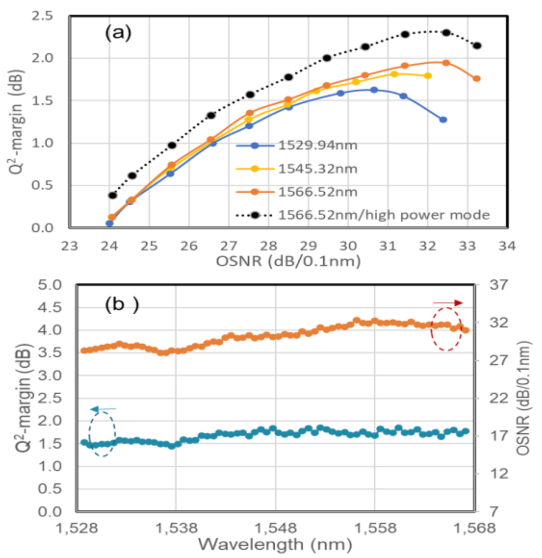

Fig. 2: (a) Q^2 -margin as a function of OSNR for three channels after 151km (solid lines for low power mode, dot-line for high power mode), (b) Measured Q^2- margin and received OSNR of all 65 channels after 151km.

shows the Q^2-margin from the measured real-time BER value as a function of OSNR after 151km transmission. The optimal OSNR is around 31~32 dB/0.1nm for middle and long wavelength channels, and 30.5 dB for the short-wavelength channel, respectively. It should be noted that the accumulated CD in 151km AllWave ULL fibre link ranges from 2192ps/nm at 1528.77nm to 2677ps/nm at 1567.13nm. In order to achieve low power consumption, the CD compensation (CDC) is limited to be 2400ps/nm in 400ZR IA specification [1], we therefore study the 400Gb/s transmission performance of the long wavelength (1566.52nm) channel with two power-consumption modes. At 'low power mode' (solid line in Fig.2 (a)), it meets OIF IA standard CD; at 'high power mode', it can compensate the CD large than the IA specs. When operating in low power mode, the total average power consumption of the module is 16.29W which gives about 4W/100Gbps power consumption aligned with the prediction in [7]. When setting in 'high power mode', the total power consumption is increased to 17.07W and Q^2-margin is increased about 0.37dB at optimal operation regime (dotline in Fig.2 (a)), which is mainly improved by the increase of internal bit-width of CDC. It should be noted that although the accumulated CD for 1566.52nm channel after 151km transmission exceeds the IA specs (2400ps/nm), there is still no noticeable CD penalty when operating in low power mode, this is because this small residual CD (~256ps/nm) is compensated by the PMD adaptive equalizer followed by CDC. It can be seen from this study the Q^2 can be improved by about 0.37dB with expense of additional 0.78W power when operating in high-power mode. The powerful DSP makes the 400ZR module for use in long reach with various types of fibre environment (e.g., G.654E) at sacrifice of small power consumption.

To test the transmission performance as a function of the wavelength, we determine the Q^2-margin from the measured real-time BER of the middle channel among three consecutive 75 GHz spaced channels as they are moved from 1528.77 nm to 1567.13 nm. Fig. 2 (b) shows the measured OSNR and Q^2-margin vs. wavelength channel. The average OSNR across 65 channels is 30.2 dB/0.1nm and Q^2 margin between 1.45dB and 1.85 dB across 38.4nm bandwidth. It has average Q^2-margin of 1.7dB, which is sufficient for real practical applications.

400ZR+ transmission of 1010km fibre link

The 400ZR+ will support variable multiple data rates of 100 to 400 Gb/s using higher coding-gain FEC capable of supporting longer reach for DCI

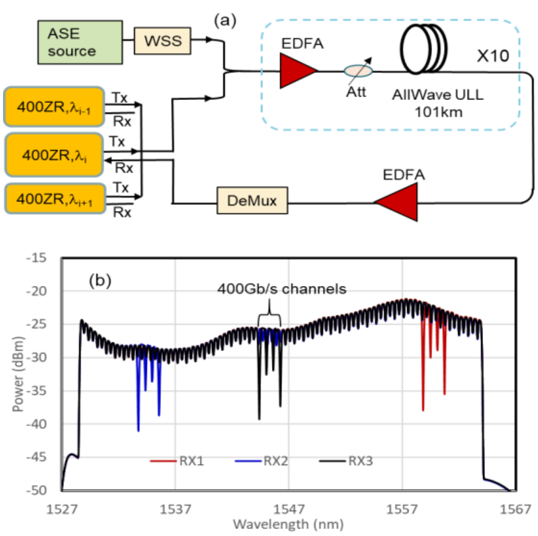

Fig.3: (a) Experimental set up for 400ZR+ over 10x101km transmission, (b) Received optical spectrum with different measurement wavelengths.

and metro/regional networks. Fig.3 (a) shows the straight-line experimental set-up for 400ZR+ DWDM transmission. The set-up of the transmitters is the same as that described in Fig.1 (a), consisting of one measurement path and one loading path. The 400ZR+ uses O-FEC which can correct a bit-error-ratio (BER) of ~ 1.89×10^{-2} (Q^2-factor =6.35dB) to lower than 10^{-15}. The transmission link consists of ten 101km AllWave ULL fibre spans as shown in Fig.3 (a). The average span loss is about 17.6dB including splices and connectors losses, which is compensated by EDFAs, and adjustable attenuator (Att) is used to adjust the total signal power into the span. Fig.3(b) shows the examples of received spectra recorded after the 11th EDFA when the three 400ZR+ measurement channels move to short, middle

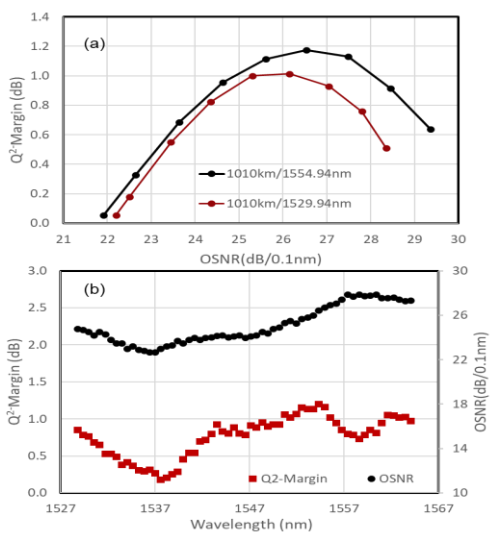

Fig.4: Q^2- margin as a function of OSNR for 1529.94nm and 1554.94nm channels after 1010km transmission, (b) Measured Q^2 margin and OSNR of all 400ZR+ channels.

and long wavelength ranges, showing equal power uniform loading of three consecutive 400Gb/s channels during the measurements. To test the 400ZR+ transmission performance, we place the group of three 400 Gb/s channels at two different wavelengths and adjust the launch power of three channels together and measure the Q^2-margin of the middle channel (at 1529.94nm and 1554.94nm). As shown in Fig.4 (a), the optimal OSNR is around 26~26.5dB/0.1nm. The Q^2 margin is about 1.0~1.2dB after 1010 km transmission at optimal operation. To test the transmission performance as a function of the wavelength channels, we determine the Q^2 margin from the measured real-time BER of the middle channel among three consecutive 75 GHz spaced channels as they are moved from 1528.77 nm to 1564.07 nm. Fig. 4 (b) shows the measured OSNR and Q^2-margin as a function wavelength channels. The average OSNR across 60 channels is 25.0 dB/0.1nm with a variation of 5.2dB, and the large variation of the OSNR is due to imperfect GFF in 11 cascaded EDFAs. The average Q^2- margin is 0.76dB with a variation of 1.02dB. The low Q^2-margin at wavelength around of 1538nm is due to low OSNR, which is caused by large variation of signal power after 1010km transmission, however the slightly lower Q^2-margin around 1558nm, where OSNR is relatively high, is due to nonlinear penalty. The overall transmission performance in term of Q^2-margin or capacity can be further improved by optimizing the GFF in the cascaded EDFAs or deploying a dynamic gain equalizer (DGE) at the middle of the 1010km link.

Conclusions

We have investigated the capability of 400ZR/ZR+ DWDM transmissions over G.652 fibres. Real-time transmission of 26 Tb/s (65x400Gb/s with 75 GHz frequency grid) over 151km AllWave® ULL fibre is achieved by using 400ZR pluggable transceiver modules. In addition, we have studied the performance trade-offs with Q^2 margin and power consumption of 400ZR module when the CD of link is large than the IA specification. The Q^2 margin can be increased about 0.37dB with expense of 0.78dB power consumption at high power mode, which makes the 400ZR very flexible for use in long reach with various types of fibre environment. For 400ZR+ pluggable modules, 24Tb/s (60x400Gb/s) capacity is transmitted over 1010km AllWave ULL fibre with 101km span length. The transmission performance for 400ZR+ DWDM system can be further improved by optimizing the GFF design in EDFAs in the link or including a DGE in the middle of link.

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