Field and Laboratory Demonstration of 48nm Optical Transport with Real-Time 32T (80×400G) over G.652 Fiber Distances up to 640km

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Abstract: We report first successful field trial and laboratory demonstration of 48nm extended C band transport. Error-free transmission of 32Tb/s (80×400Gb/s) is achieved over 640km G.652 link in laboratory and 42km G.652 link in field.

OCIS codes: (060.4510) Optical communications; (060.1660) Coherent communications; (060.4250) Networks

1. Introduction

Upgrading optical networks to higher capacity has been driven by fast advancing in internet services and applications such as cloud computing, high-definition video, big data analysis and so on. It imposes critical challenges to operators to seek solutions in an efficient and timely manner to meet the fast increase in bandwidth demanded by customers. Operators need a high-capacity solution immediately to address growing service demands with limited fiber resources; they cannot wait till new optical layer is built or new technologies such as spatial division multiplexing (SDM) [1] become matured. Even though high spectral efficiency (SE) coherent transmission with high-order modulation formats such as 32QAM, 64QAM and 128QAM [2-4] has been recognized as an efficient and timely solution to expand the transmission capacity in deployed fibers, drastically decreasing in reach distance limits the usage of high order modulation in operator's metro and long haul networks. Therefore, extending the amplification bandwidth beyond conventional C band (32nm bandwidth) provides an exploring dimension to increase the transmission capacity. Several solutions have been proposed to achieve wide-band amplification beyond the C band, such as C+L band [5] and S+C+L band [6] amplification schemes. However, implementation of multi-band amplification in coherent systems requires more sophisticated gain control algorithm to manage system degradation such as the stimulated Raman scattering (SRS) effects and increases the cost and technical difficulties. Tier-1 operators lean to extend the conventional C band to a wider bandwidth using a single amplifier unit to meet immediate demand on high capacity.

In this paper, a newly designed erbium-doped fiber amplifier (EDFA) that extends the amplification bandwidth from the conventional C band (32nm bandwidth) to a super C band (48nm bandwidth), is used to extend the transmission capacity of 400-Gb/s PDM-16QAM wavelength division multiplexing (WDM) systems. With the super C-band amplification system, we achieved, for the first time, a real-time 32Tb/s transmission over a 640km SSFM (G.652) link with eighty 400-Gb/s PDM-16QAM channels at a grid of 75 GHz (5.33 bit/s/Hz SE). Moreover, a successful field trial for the super C-band transmission is performed in a Teir-1 operator's network in India.

2. Experimental configuration and setup

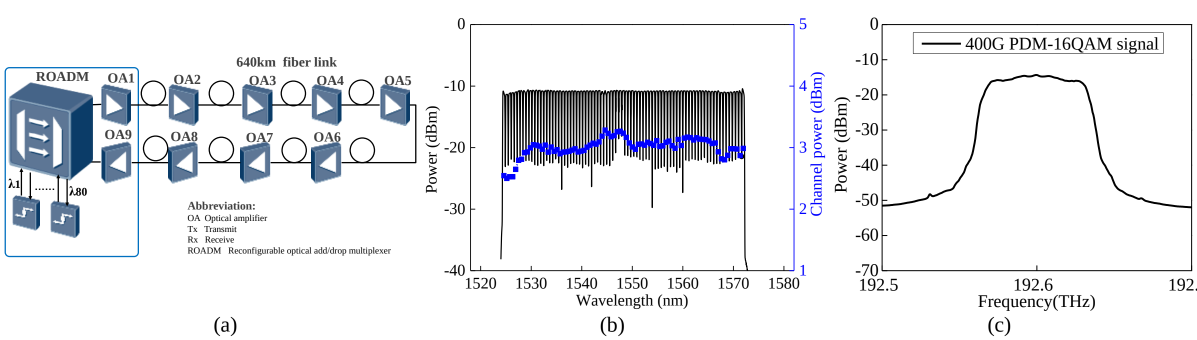

Fig. 1: (a) Experimental set up for the 32Tb/s transmission; (b) Measured spectrum over the 48nm super C band and optical power per channel at the output of the fifth optical amplifier; (c) Measured optical spectrum for the 400-Gb/s PDM-16QAM signal.

Fig. 1(a) depicts the transmission link which is made of eight 80km standard single-mode fiber (SSMF, G.652) spans. Eighty 400-Gb/s PDM-16QAM channels at a grid of 75 GHz are generated by real-time coherent transceivers and multiplexed into the fiber link. At the output of the link, the channels under test are de-multiplexed and detected by real-time coherent receivers. The bit-error rates before and after FEC correction are reported from the ASIC DSP processor. The coherent transceivers used in the transmission are equipped with advanced ASIC DSP processor that enables reconfigurable modulation formats, flexible bit rates and high capacity FEC. Fig. 1(c) shows the optical spectrum measured for the 400Gb/s PDM-16QAM signal. The 3-dB bandwidth of the 400Gb/s PDM-16QAM signal is about 69 GHz, which allows a robustness to filtering effects in 75-GHz grid WDM transmission systems. The in-line amplifiers featured with super C-band amplification technique offer a much wider amplification bandwidth of 48 nm ranging from 1524nm to 1572nm, comparing to the conventional C-band amplification (32-nm bandwidth). Fig. 1(b) shows the optical spectrum measured and the optical power per channel at the output of the fifth optical amplifier (320km transmission distance), where a flatness of better than 1.0 dB over 48-nm bandwidth is achieved. The superior gain flatness is obtained by the equalization of higher fiber loss for shorter-wavelength channels.

3. Results and discussion

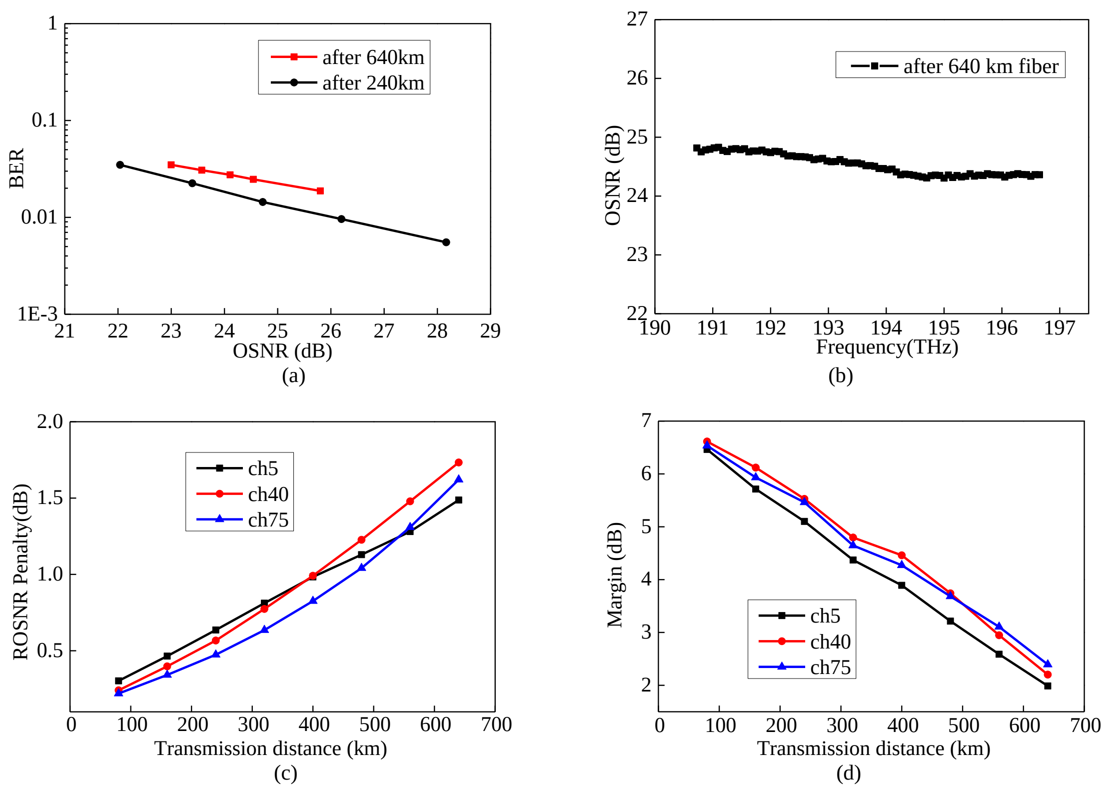

Fig. 2: (a) BER versus OSNR for transmissions over 240km and 640km distance; (b) Measured OSNR spectrum over the 48nm super C bandwidth; (c) Measured required OSNR (ROSNR) penalty versus transmission distance for selected channels; (d) Measured OSNR margin vs transmission length for selected channels.

Fig. 2(a) shows the measured pre-FEC BER as a function of optical signal noise ratio (OSNR) for 240km and 640km transmission distances, respectively, where the testing channel is at a wavelength of 1547.62 nm. For the transmission distance of 240km and 640km, the ROSNR measured at pre-FEC threshold is obtained at 22.2 dB and 22.7 dB, respectively. The 400Gb/s PDM-16QAM transceiver supports channel-matched shaping (CMS) technology and therefore provides higher channel distortion resilience and longer transmission distance at the same spectral efficiency (5.33bit/s/Hz) while comparing to the 400Gb/s transceiver reported in [7]. The CMS technology is a combination of shaping, compression, compensation, and error correction technologies that sense and deal with different types of transmission cost in an actual optical network.

The management of OSNR tiltness is a major challenge for wide-band amplification systems. The OSNR tiltness is caused by the wavelength-dependence of the fiber attenuation, the SRS spectral gain profile (larger loss for short wavelengths) and the noise figure spectrum. Significant OSNR tiltness causes non-uniform performance crossing the channels. To enhance the OSNR flatness over the 48nm bandwidth, a joint optimization algorithm for signal launch power and amplifier gain profile is performed. The built-in OSNR monitor is used to optimize the signal input power to reduce the gain titlness. The gain profile of the newly designed broad-bandwidth erbium-doped fiber and the gain flattening filter are furthermore optimized to achieve an overall flat gain profile. Fig. 2(b) shows the measured OSNR for 80 WDM channels after the 640km link. It clearly shows that the super-C amplification system provides an OSNR value of more than 24.3 dB over the entire 48 nm transmission bandwidth with a non-uniformity of about 0.5 dB. The OSNR performance guarantees enough margin for all the channels to achieve error-free transmission performance.

Fig. 2(c) plots the required OSNR penalty (relative to back-to-back transmission) as a function of the transmission distance. Three channels at 1547.62 nm (ch-40), 1526.92 nm (ch-5) and 1568.88 nm (ch-75), representing respectively the channels at the middle and two edges of the super C-band, are selected for performance comparison. For transmission distance ranging from 80km to 640km, the performance difference among the three channels is smaller than 0.3dB. Fig. 2(d) shows the measured OSNR margin as a function of the transmission length for the selected three channels. The launched power per channel for each fiber span is set at ~3dBm. For the transmission distance of 640km, a difference of ~0.5dB in OSNR margin is observed between ch-5 and ch-75. This small performance difference is determined by the link OSNR spectrum and the OSNR penalty as characterized in Fig.2 (b) and (c), respectively.

A field trial is performed in a Tier-1 operator's network in India, with WDM Mesh connectivity. The super C-band amplification system is employed to achieve the 48-nm transmission bandwidth. The 400Gb/s PDM-16QAM WDM channels are transmitted over a live 42km SSFM (G.652) link between two core sites. A pre-FEC BER of below 1e-2 is obtained for the worst channel allocated at the edge of super C band, which is much lower than the pre-FEC BER threshold. No post FEC bit error is recorded in a measurement time duration of 24 hours for all the channels under test. Based on this trial performance, we analyze and evaluate the capacity of one stack of operator's network which has over 85 links with different transmission distances. Considering a 50% increase in the number of channels and 75% links upgraded from 200Gb/s (4bit/s/Hz SE) to 400Gb/s (5.33bit/s/Hz SE) channel transmission, the super C-band system can increase the total network capacity by 87.5% comparing to the conventional C-band systems.

4. Conclusions

To the best of our knowledge, we report first time the high-capacity real-time WDM transmission utilizing 48nm super C band amplification systems. 32Tb/s transmission over 640km is achieved with real-time 400-Gb/s PDM-16QAM coherent transceivers. The successful field trail of the super C band transmission has been performed in an operator's metro network. In this work, the super C band amplification extends the total spectral bandwidth by 50% (32 nm to 48 nm), comparing to conventional C band. Therefore, the 80×400-Gb/s PDM-16QAM WDM transmission over super-C band achieves an equivalent capacity to 80×400-Gb/s PDM-64QAM transmission over conventional C band but with a much longer transmission distance.

5. References

[1] D. Soma et al. "10.16-Peta-b/s dense SDM/WDM transmission over 6-mode 19-core fiber across the C+L band," J. Lightw. Technol., **36**,

[2] R. Elschner et al., "Improving Achievable Information Rates of 64-GBd PDM-64QAM by Nonlinear Transmitter Predistortion," OFC 2018, M1C.2

[3] A. Matsushita et al., "Single-carrier 48-GBaud PDM-256QAM transmission over unrepeated 100km pure-silica-core fiber using commercially available μITLA and LN-IQ-modulator," OFC 2018, M1C.1

[4] G. Khanna et al., "400G single carrier transmission in 50 GHz grid enabled by adaptive digital pre-distortion," OFC 2016, M1C.2

[5] Y. Yu, et al., " 400 x 377.6 Gb/s C+L Band Seamless Transmission over 200km with Raman Amplifier Using PDM-256QAM," ECOC 2018,

[6] F. Hamaoka et al., "Ultra-Wideband WDM Transmission in S-, C-, and L-Bands Using Signal Power Optimization Scheme," J. Lightw. Technol., 37, 1764-1771(2019).

[7] Zhou, Yu Rong, et al. "Field trial of 400G single-carrier ultra-efficient 1.2 Tb/s superchannel over 250km," IEEE Photon. Technol. Lett., 29,17,1451-1454(2017).