DML based long reach TWDM-PON

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Abstract: In this paper, we present a review of our recent research results in the area of symmetric 40-Gb/s, long reach time and wavelength division multiplexed passive optical network (TWDM-PON) employing directly modulated lasers (DML).
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1. Introduction

Time and wavelength division multiplexed passive optical network (TWDM-PON) was selected by Full Service Access Network (FSAN) as the primary architecture for next generation PON stage 2 (NG-PON2) in Apr. 2012. Afterwards, the detailed parameters of the system were standardized in ITU-T recommendations G989.1 and G989.2. A lot of system proposals and experimental demonstrations have been reported, e.g. Huawei demonstrated the first 40/10-Gb/s TWDM-PON system with the optical line terminal (OLT) transceivers assembled in CFP-module and optical network unit (ONU) transceivers in SFP+ module with 36-dB loss budget [1], which is almost ready to be commercialized. But for symmetric 40-Gb/s system, the supporting technology is still under research. In another aspect, a PON system with long-reach ability and high loss budget is preferred to enable the consolidation of central offices. A lot of challenges exist in long-reach, symmetric 40-Gb/s TWDM-PON configuration, one of the key issues is the choice of upstream transmitter. The basic requirements for upstream transmitter include the wavelength tenability, a wide modulation bandwidth, the ability to support long distance transmission and be cost-effective as well. During long distance fiber transmission, chromatic dispersion is a significant impairment factor, which will severely distort the signal if not well controlled. Therefore, although directly modulated laser (DML) is much cheaper, external modulation was more generally used in high data rate, long reach PON systems because of its lower chirp parameter and higher tolerance to fiber dispersion. If direct modulation is used, then dispersion management is required, either by using advanced modulation format to obtain a narrower signal bandwidth [2], or using electrical dispersion compensation for signal recovery [3]. As for loss budget improvement, repeater in the remote node was commonly used, which requires the remote node to be reconstructed [4]. In another work, a truly passive long reach 10-GPON is realized using external modulation combined with coherent detection [5].

We propose to use DML as both upstream and downstream transmitters to achieve a long reach, high loss budget symmetric 40-Gb/s TWDM-PON [6]. The chirp management is realized by optical filtering or fixed-value dispersion compensation in OLT, which could support any transmission distances within 100-km. Also, the DML is proved to be robust to fiber nonlinearity, enabling a high launch power in downstream link. As a result, by using DML combined with terminal amplifiers, we realized a symmetric 40-Gb/s TWDM-PON with 53-dB loss budget, supporting 100-km fiber transmission and 1024 splits [7]. Note that the system involves only OOK format and direct detection techniques, relaxing the requirement on complex modulation format and coherent digital receiver.

2. Performance evaluation of DML

Compared with external modulation, DML transmitters offer many advantages including small footprint, high output power, low driving voltage, and low power consumption. Also, the output wavelength can be thermally tuned in a small range of ~3 nm by varying its working temperature, which is sufficient for 4 wavelength stacked TWDM-PONs. However, DML was considered to be unsuitable for long distance transmission due to the strong chirp, which interacts with chromatic dispersion in fiber and distort the signal during fiber transmission. Only if the propagation penalties are suppressed, DML seems the most convenient way to meet the twin constraints of low-cost and high performance for the access network. For high dispersion tolerance, a suitable optical filter is necessary to perform frequency to amplitude modulation conversion to increase the extinction-ratio (ER). The idea of employing optical filters for chirp management is by no means new, and the corresponding product is named as chirp managed laser (CML). However, we experimentally observed that filtering in the receiving end also works, which makes the DML based upstream solution more attractive, especially for upstream direction. We proposed to employ a single delay interferometer (DI) in the OLT side, which performs as a periodical notch filter that can be shared by all channels. Fig.1 shows the optical spectra and eye diagrams of the original and reshaped signals of both directions after 100-km fiber transmission. The transmission character of the DI is also depicted. In the following experimental demonstration part, we'll show the detailed performances of the DML and DI based transmitters. Besides, dispersion compensation using dispersion compensating fiber (DCF) or tunable dispersion compensator (TDC) is another way to recover the distorted signal, where different dispersion values should be set to compensate the dispersion of different transmission distances. However, a PON system includes tens or hundreds of branches, where the distance from OLT to each branch various. Adjusting the dispersion values for each branch seems impossible. We tried to set the dispersion compensator on a fixed value to recover the distorted signal and the measured eye diagrams of signal under different negative dispersion values in BtB case are shown in Fig. 2. We can see that the eye diagram still open even when the dispersion value is -2020ps/nm, verifying that the directly-modulated signal has a high tolerance to negative dispersion. Considering that the negative dispersion accumulated during 100-km transmission is ~1700 ps/nm, so we can set the dispersion compensation value at -1700ps/nm to cover any distances within 100 km. The sensitivities under different transmission distance cases were also measured, and the results are shown in Fig. 3. Note that the results refer to upstream link, where the TDC is placed in the OLT side and the dispersion compensation value was fixed at -1800 ps/nm. The best sensitivity of ~-42 dBm is achieved when the distance is 100 km. Although the sensitivities for shorter distances are worse, but as the fiber loss is also lower, the splitting ratio is not limited.

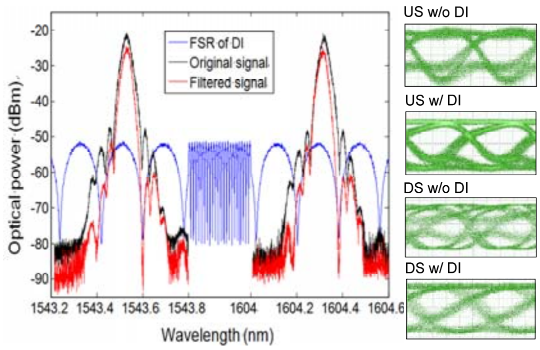

Fig. 1 Optical spectra and eye diagrams of Signal using DI based chirp management solution

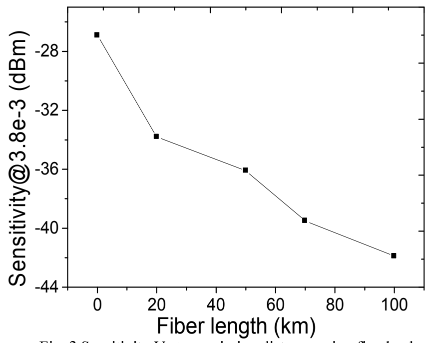

Fig. 3 Sensitivity Vs transmission distance using fixed value dispersion compensation (-1800ps/nm)

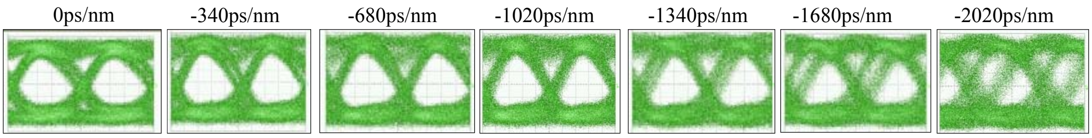

Fig.2 Eye diagrams of signal under different post-compensation values

On the other side, high loss budget is a big challenge for long reach PON systems. The loss budget of a system is determined by two factors: launch power and receiving sensitivity. For the upstream link, the sensitivity can be improved by employing EDFA as pre-amplifiers in OLT. However, for the downstream link, EDFA in the ONU for pre-amplifying is unacceptable because of its large size and high cost. Employing semiconductor optical amplifiers (SOA) in the ONUs to improve the link loss budget has been considered as a beneficial solution due to their large gain bandwidth and their capability to be integrated. Another solution is increasing the downstream launching power, but high power induced signal distortion due to nonlinear effects in fiber such as stimulated Brillouin scattering (SBS) and self-phase modulation (SPM) limits the maximal launching power. We experimentally evaluated the nonlinear tolerance of several commonly used transmitters, including MZM, EML, DML and CML [8]. Based on our experimental results, DML and CML showed higher tolerance to fiber dispersion and nonlinearity, which is particularly suitable for long reach PONs.

3. System demonstrations

Fig. 4 depicts the network configuration of the proposed repeater-less long reach TWDM-PON using DML as transmitters in both OLT and ONUs. A single DI is applied as a bi-pass and periodical notch filter to suppress the frequency chirp for all DS and US channels. For the DS direction, four DMLs combined with a DI act as a CML array but with much lower cost. A high power L-band erbium-doped fiber amplifier (EDFA) is used in OLT to improve the DS loss budget, and the downstream sensitivity is improved by using an SOA in each ONU as pre-amplifier. For upstream link, a C-band hybrid Raman/EDFA in OLT is used to improve the receiver sensitivity for all upstream signals, achieving similar or even superior performance compared with coherent receivers but with much lower complexity. All the components used in this configuration are commercially available with mass production capability.

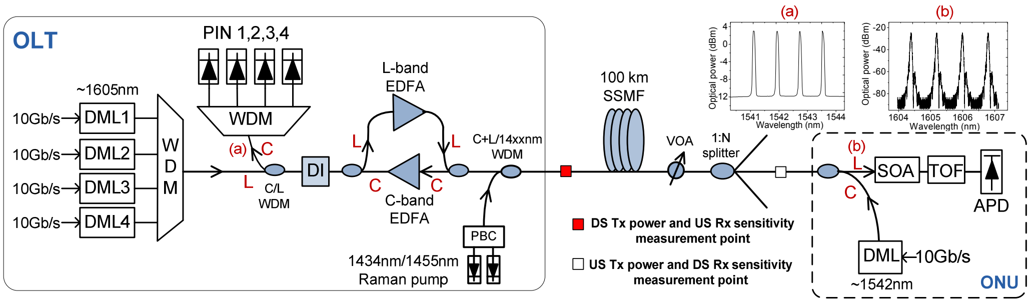

Fig.4 Experimental setup

We measured the sensitivities of both directions after 100-km transmission. By using the hybrid Raman/EDFA, -46 dBm sensitivity can be achieved in upstream direction. Considering the 10-dBm launching power of DML, the US loss budget is 56 dB. For the downstream link, the maximal launching power is 18 dBm/ch, and the sensitivity is -35.2 dBm, corresponding to 53.2-dB loss budget. Table 1 shows the detailed US and DS loss budget, where the loss of all other passive components has already been excluded. We also varied the fiber length from 40 km to 100 km with a step of 20 km and the measured sensitivities are shown in Fig. 5. We can see the sensitivities of both DS and US signals are almost independent with the transmission distances, verifying that the proposed TWDM-PON is suitable for ONUs located at different transmission distances.

Tab.1 Loss budget evaluation

	DS		US	
	1 Ch	4 Chs	1 Ch	4 Chs
Tx power (dBm)	20.7	**18**	10	10
Rx sensitivity (dBm)	-35.2	-35.2	-46	-45.8
Fiber loss (dB)	20	20	20	20
Splitter loss (dB)	30	30	30	30
Total loss (dB)	50	50	50	50
Link budget (dB)	**55.9**	**53.2**	**56**	**55.8**
Margin (dB)	5.9	3.2	6	5.8

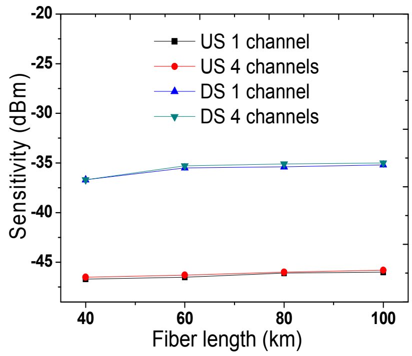

Fig.5 Sensitivities under different transmission distances

Conclusion

We investigated the feasibility of using DML as transmitters in long reach PON systems, concerning the chirp management solution, nonlinearity tolerance etc. A long-reach symmetric 40-Gb/s TWDM-PON with 53 dB loss budget was demonstrated, supporting 100-km fiber transmission and more than 1000 users. Based on the results presented in this paper, DML based long reach PON appear as a strong technology candidate capable of meeting the requirement of NG-PON2 in a simple and cost-effective manner.

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