World's First Demonstration of Pluggable Optical Transceiver Modules for Flexible TWDM PONs

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Abstract Optical transceivers are demonstrated with error-free performance in TWDM PONs. *Integrated OLT transceiver in CFP-module transmits 10dBm power and achieves -36dBm sensitivity. Low-cost tunable SFP+ ONU transceiver can be tuned over 4 channels with 4dBm transmitted power and -26dBm sensitivity.*

Introduction

Rapid growth of internet traffic, driven by the proliferation of video services, continues to push broadband optical access networks for higher data rates and better quality of services. Currently GPON and EPON are widely deployed and 10G PONs (e.g. XG-PON and 10G EPON) are expected in next few years [1]. Beyond 10G PONs, TWDM PON has been demonstrated as a viable solution for future broadband services [2]. Such TWDM PON systems use a combination of time and wavelength division multiple access, providing an aggregated capacity of at least 40Gb/s. A new set of standards on TWDM PON will be released by ITU-T in next year, paving the way for future deployment. However, before large scale deployment, technology development and engineering solutions of TWDM PON systems and optical transceiver modules must be made commercially viable for manufactuerability and cost effectiveness. Recently, a flexible TWDM PON system was demonstrated which can support desirable features such as pay-as-you-grow, load balancing, channel protection and power saving [3]. In such a system, OLT (optical line terminal) equips with 4 channel transceivers while ONU (optical network unit) integrates a tunable laser and a tunable receiver. However, discrete transceivers were used in this flexible TWDM PON system. To the authors' knowledge, integrated transceiver modules have not been reported, and it remains a very challenging task to develop TWDM PON optical transceivers with good performance, small footprint and low power consumption.

In this paper, we demonstrate, for the first time, integrated OLT transceiver module and tunable ONU transceiver module for flexible TWDM PONs. The OLT transceiver consists of 4x10Gb/s transmitters, 4x2.5Gb/s burst mode optical receivers, optical mux/demux and integrated optical amplifiers in an enhance CFP (C Form Factor Pluggable) module. The low-cost ONU transceiver includes a tunable laser and a tunable receiver in SFP+ (Small Form Factor Pluggable) package. The average transmitted power of the OLT module is larger than 10dBm and its receiver sensitivity is better than -36dBm, while the tunable ONU achieves more than 4dBm average transmitted power and -26dBm sensitivity. With these pluggable transceiver modules, a flexible TWDM PON system is demonstrated with error-free performance and over 36dB power budget.

Optical Transceiver Module Design

For OLT transceiver module in TWDM PONs, performance and footprint is very important, so the integration of both electronics and optics is a primary task. Fig. 1 illustrates the architecture of the 4-channel OLT transceiver module. For the transmitter, there are 4 EMLs (electroabsorption modulated lasers), each modulated by a 10Gb/s data stream. The outputs of EMLs at different wavelengths are then multiplexed by a low-loss multiplexer and amplified by an L-band EDFA. At the receiver side, optical signals from ONUs in 4 different wavelength channels are first amplified by a C-band EDFA and then separated by a demux before being detected by burst-mode APD ROSAs (receiver optical subassembly). Limiting amplifiers (LA) following the ROSA further boosts the received signals. To achieve bidirectional transmission on a single fiber, a WDM (wavelength division multiplexing) filter combines/separates the upstream and downstream wavelengths. A microprocessor is also included in the transceiver module for control and monitoring purpose. It sets

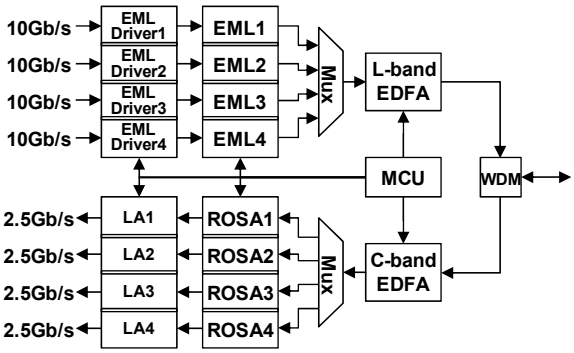


Fig. 1: OLT transceiver architecture.

the operation conditions of various optical and electronic components in the module, and performs monitoring functions such as transmitter output power control, receiver signal power measurement, and loss-of-signal alarm. Fig.3(a) shows a picture of the pluggable transceiver module in an enhanced CFP package.

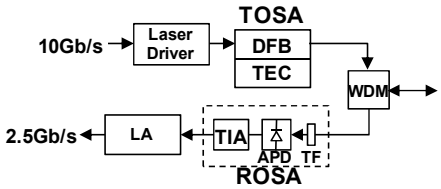
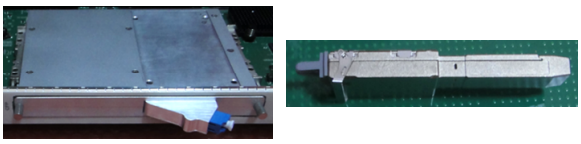


Fig.2: Tunable ONU transceiver.

On ONU side, transceiver module design is simpler but low cost is the utmost goal. Meanwhile, it still needs to achieve good performance. Hence, the trade-off between cost and performance is necessary. Fig. 2 illustrates the structure of the tunable ONU transceiver module. For transmitter, it uses a thermally tuned DFB laser directly modulated by a burst-mode laser diode driver at 2.5Gb/s. The DFB laser can emit relatively large power but can only be tuned over a few channels with 100GHz spacing and its tuning speed is about 80ms. At the receiver side, a tunable filter (TF) is packaged inside the ROSA together with an APD photodiode and a transimpedance amplifier (TIA). The tunable filter can be thermally tuned to one of the 4 downstream wavelengths in L-band, and its tuning speed is on the order of 100ms. The tunable filter provides over 25dB channel isolation to ensure good performance. Automatic gain control for APD, TIA and LA results in a large dynamic range for the downstream signal. Fig. 3(b) shows a picture of the tunable ONU transceiver module in SFP+ package.



(a) OLT transceiver (b) ONU transceiver

Fig. 3: OLT and ONU transceiver modules.

Transceiver Testing Results

Fig. 4 shows the eye diagrams of the OLT transmitter with 10dBm output power and 9dB extinction ratio. The optical spectrum of the downstream signals is plotted in Fig. 5, showing four channels on ITU grid (1608.33, 1609.19, 1610.06 and 1610.92nm). The OLT receiver sensitivity in burst mode is better than -36dBm.

Fig. 6 shows the eye diagrams of the ONU transmitter; its average transmitted power is 4dBm and extinction ratio is better than 9dB. The optical spectra of the upstream signals in different channels (with different wavelengths at 1535.82,

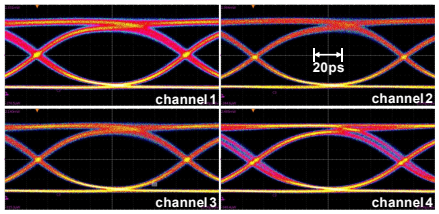


Fig.4: OLT transmitter eye diagrams.

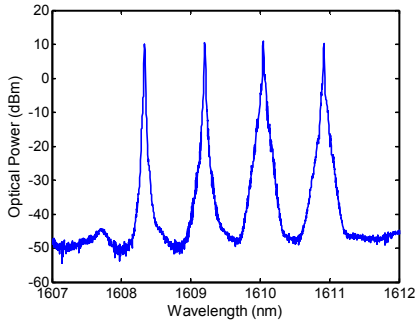


Fig.5: OLT transmitter spectrum.

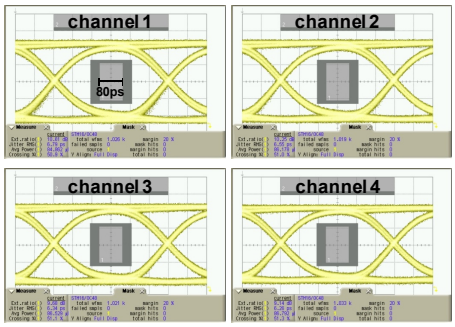


Fig.6: ONU transmitter eye diagram.

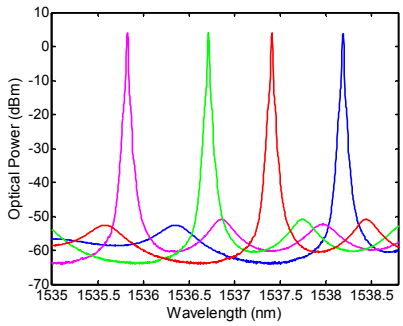


Fig.7: ONU transmitter spectra in different channels.

1536.71, 1537.41, 1538.19nm) are plotted in Fig. 7. ONU receiver sensitivity is better than -26dBm, and the receiver overload is more than 0dBm using automatic gain control.

System Demonstration

For performance verification and network throughput testing, OLT and ONU transceiver modules are plugged in the flexible TWDM PON system testbed [3]. The bit error rates for the downstream and upstream transmissions are shown in Fig. 8 for all the channels at back-to-back, after 20km and 40km single mode fiber. With these optical transceivers, 36dB power budget is achieved for both downstream and upstream.

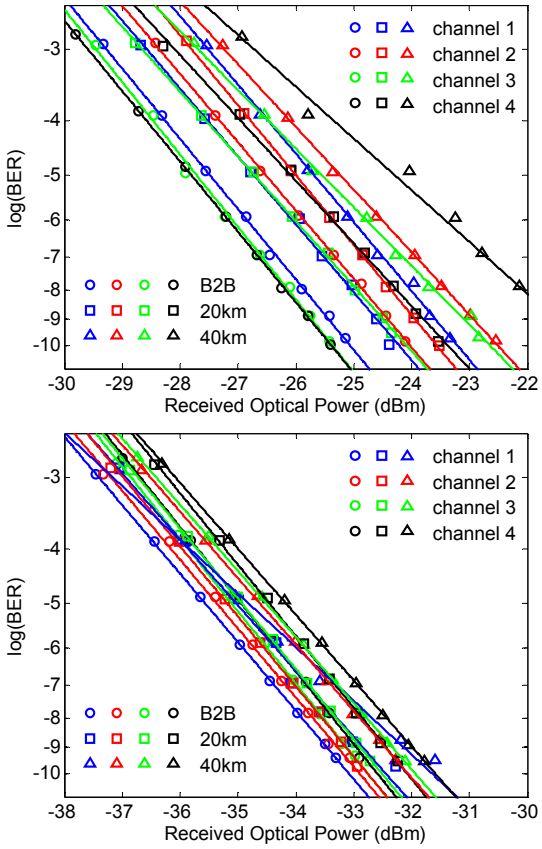


Fig. 8: Transmission performance of downstream at 10Gb/s (top) and upstream at 2.5Gb/s.

In TWDM PON system, ONU must automatically align its transceiver wavelength to the right channel. This can be done through an embedded control channel between OLT and ONU. In our system, when an ONU is powered on, it will scan the downstream wavelengths by tuning its tunable receiver. The tunable receiver can lock to a specific downstream channel by monitoring the received power through the RSSI (receiver signal strength indicator) built inside the ONU transceiver. For upstream wavelength alignment, the tunable ONU scans its transmitter wavelength, while OLT monitors the received power through RSSI reported from OLT transceiver module. Fig. 9 shows the RSSI values at OLT when ONU scans its wavelength (controlled by DAC value with roughly 4pm per step) across upstream channel 3. By finding the maximum value of RSSI, OLT can set the ONU wavelength with ONU wavelength setting command sending through the downstream. Initially during ONU activation, ONU transmitter wavelength might not be set in the middle of the channel due to the accuracy of OLT RSSI is about +/-1dB, but ONU wavelength can be guaranteed within the 1dB passband of the channel. This coarse wavelength alignment ensures upstream connection and ONU activation process. Then ONU enters normal operation phase, and the RSSI value can be recorded for each burst from the

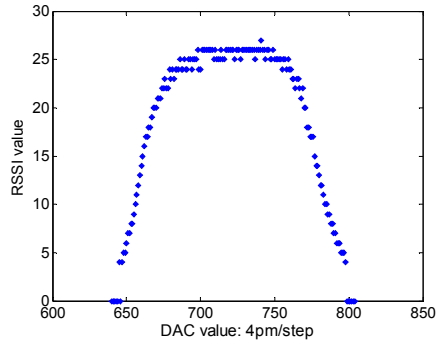


Fig. 9: Measured RSSI value from OLT transceiver when ONU wavelength is tuned across upstream channel 3.

ONU. By averaging, the RSSI accuracy can be improved significantly. Eventually, by monitoring the RSSI after a large number of averaging, the ONU wavelength can be fine tuned to the center of the upstream channel.

After the ONU wavelength alignment and activation are successful, network throughput is evaluation in our system testbed. For upstream, 5 ONUs transmit upstream signals in the same wavelength channel, and each ONU is loaded with Ethernet packets of variable length (64-1518 bytes). 2.3Gb/s aggregated throughput in a single upstream channel is achieved without any packet drop. Meanwhile, for downstream, Ethernet packets with variable length (64-1518 bytes) are transmitted by the OLT. No packet drop is observed in the downstream with the traffic load to each ONU up to 1Gb/s (limited by the gigabit Ethernet port of the ONU).

Conclusions

Integrated OLT transceiver in an enhanced CFP module and low-cost tunable ONU transceiver in SFP+ module are demonstrated for the first time in flexible TWDM PON. With integrated EDFAs, 4-channel OLT transceiver transmits 10dBm power per channel, and achieves -36dBm sensitivity in burst mode. Tunable ONU transceiver with thermal tuning can be tuned over 4 channels (100GHz spacing) in C band, and its average transmitted power is >4dBm while its receiver sensitivity is better than -26dBm. Using automatic gain control for APD, TIA and LA, the ONU receiver achieves 26dB dynamic range. With accurate RSSI detection, ONU can automatically lock to a specific downstream wavelength; at the same time, OLT can control the ONU transmitter wavelength within 1dB passband of the upstream channel. System testing demonstrates more than 36dB power budget with error free performance and zero packet drop rate.

References

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