Rate-Flexible Single-Wavelength TFDM 100G Coherent PON based on Digital Subcarrier Multiplexing Technology

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Abstract: We propose a novel rate-flexible single-wavelength 100G time-and-frequency-division multiplexing coherent PON architecture based on digital subcarrier multiplexing technology. The architecture implementation with four subcarriers is demonstrated, achieving -38-dB sensitivity after 50-km fiber transmission. © 2020 The Authors.

1. Introduction

The advance of high-speed passive optical networks (PON) has been propelled by new business and technology drivers, such as cloud services, 5G wireless transport, and high bandwidth 4K/8K video applications [1-3]. This is further evidenced by the progress in standards bodies developing next generation high speed PON standards in IEEE and ITU-T [1]. To further increase the bandwidth, coherent detection could be a promising solution for high-speed PON [2-6]. It enables high-speed data transmission with advanced modulation formats and enhances the link power budget due to the increased sensitivity [2-4]. Two types of coherent PON have been reported, including coherent time-division-multiplexing (TDM)-PON [3-5] and coherent Wavelength-Division-Multiplexing (WDM)-PON [6]. Both coherent WDM-PON and TDM-PON show great performance improvement by using coherent detection.

Different from WDM-PON, high-speed TDM-PON based on single wavelength has advantages of statistical multiplexing for bandwidth sharing and transparent signal transmission with colorless components, which not only simplify the deployment and operation, but also save the wavelength resources. WDM PON, however, can solve the restricted bandwidth sharing issue encountered in TDM-PON by allocating specified wavelengths or frequencies to some high-end subscriber. It can provide separate, low-latency and secure virtual point-to-point for some dedicate users. Taking the advantages of TDM-PON and WDM-PON would be of great interest for next generation access network to provide more flexible bandwidth allocation. For IM/DD system, TWDM-PON is an example of combing the two types of PON; however, it requires multiple wavelength, which again increases the operation complexity [7].

In this paper, we propose and demonstrate a novel rate-flexible single-wavelength TFDM 100Gb/s/λ coherent PON architecture based on digital subcarrier multiplexing technology. Only single wavelength and single transceiver are required for ONU and OLT in downstream or upstream direction. The power levelling ranges from different ONUs are also studied. Finally, the architecture implementation of 100Gb/s/λ TFDM Coherent PON is demonstrated, achieving -38.5 and -38-dBm sensitivity after 50-km fiber transmission for downstream and upstream respectively.

2. Principles and architecture

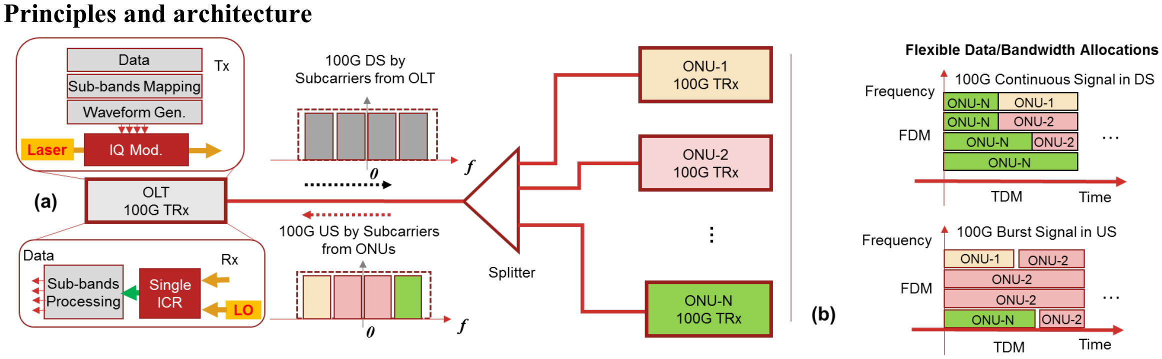

Fig. 1 The principle of TFDM coherent PON based on subcarrier multiplexing scheme: (a) the architecture; (b) one flexible data/bandwidth allocation example.

Fig. 1 shows the architecture of TFDM-Coherent PON based on digital subcarrier multiplexing technology. The architecture of 100G coherent PON with four subcarriers is shown in Fig. 1 (a). In the downstream (DS), the four subcarriers are generated and modulated on single wavelength in the OLT by using an I/Q modulator. The receivers in ONUs detect the DS multi-subcarrier signal and each sub-band can be demodulated separately. In upstream, each ONU has the capability to generate and modulate one to four subcarriers, with data rates from 25Gbps to 100Gbps. As such, the aggregated upstream signal has four subcarriers which may come from the same ONU or come from different ONUs. Only single broadband coherent receiver (ICR) is required at the OLT-side to detect the four subcarriers even they are from different ONUs. This is the major difference between IM/DD and coherent for multiple sub-carrier detection. For IM/DD, in general, multiple receiver and different wavelengths are required for different subcarriers if they are from different ONUs; otherwise, there would be strong optical beating interference (OBI) problem if single wavelength and one receiver is used [8]. The Tx and Rx setup of OLT are also shown in Fig. 1(a), and the transceiver in ONU has the same setup. Therefore, the total DS and US capacities are both 100Gbps and it is shared by multiple ONUs with hybrid TFDM scheme as shown in Fig. 1(b). The peak data rate in DS and US for each ONU can be 100Gbps, which is the same as the peak data rate achieved by TDM PON. Additionally, the bandwidth allocation of proposed TFDM coherent PON is more flexible. Two-dimensional bandwidth allocation is enabled and dedicated P2P channel can be achieved by appropriate bandwidth allocation.

3. Experimental Setup and Results

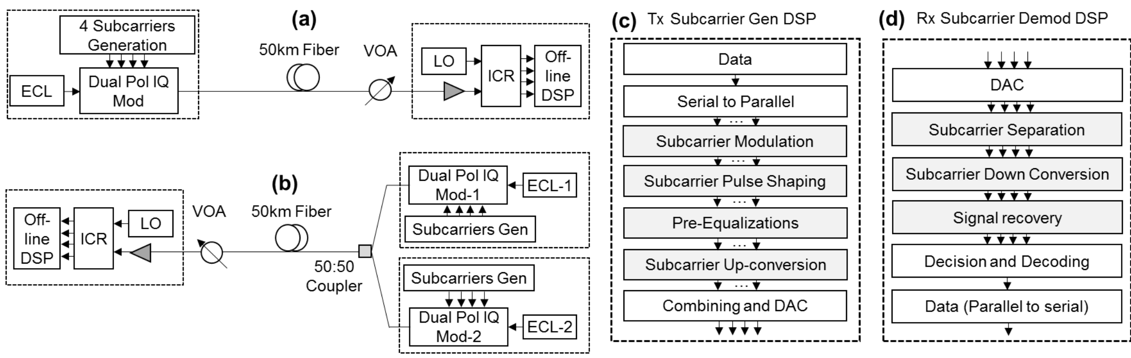

Fig. 2 Experimental setup for rate-flexible symmetrical single-wavelength coherent 100G PON based on subcarrier multiplexing scheme: (a) the 100Gb/s/λ downstream setup; (b) the 100Gb/s/λ upstream setup; (c) Tx subcarrier generation DSP; (d) Rx subcarrier demodulation DSP.

Fig.2 (a) and (b) show the experimental setup for downstream and upstream links of the symmetrical 100-Gb/s/λ TFDM coherent based on four subcarrier multiplexing scheme. For downstream, four subcarriers, Ch1, Ch2, Ch3 and Ch4, each carrying 25Gb/s PDM-QPSK, are generated by 80GSa/s arbitrary waveform generators (AWGs) and then modulated by a dual polarization (DP) I/Q modulator on single wavelength in the OLT-side. An ECL is used as the laser source with wavelength at 1549.96-nm and <100-kHz linewidth. For upstream, two independent ONUs combined by a 50:50 optical coupler are tested. Each ONU consists of an AWG, a DP-IQ modulator, and an ECL for generation and modulation of subcarriers. The two ECLs are set at the same wavelength of 1549.96-nm. After 50-km fiber transmission, a variable optical attenuator (VOA) is used for power control in BER performance test. In both downstream and upstream, the optical signals are detected by an integrated coherent receiver (ICR) after optical preamplification by using an EDFA. Another ECL is used as local oscillator (LO) at the wavelength of 1549.96-nm and less than 100-kHz linewidth. The detected signals are captured by an 80GSa/s digital storage oscilloscope (DSO) for off-line DSP. The DSP of subcarriers generation on Tx-side and demodulation on Rx-side are shown in Fig. 2 (c) and (d). For signal generation, the data is first mapped and modulated on each subcarrier. Nyquist pulse shaping is then performance with 0.1 roll-off factor to reduce the bandwidth on each subcarrier. After pre-equalization, the four 6.25GBaud subcarriers are up converted to four inter-frequencies: -15 GHz, -5 GHz, 5 GHz and 15 GHz. To support TFDM, the two ONUs generate and modulate subcarriers on different frequencies. For receiver-side DSP, the inverse processing flow is performed. Subcarriers are first filtered out, separated and then down converted to baseband. They are processed independently with several key signal recovery functions [5-6].

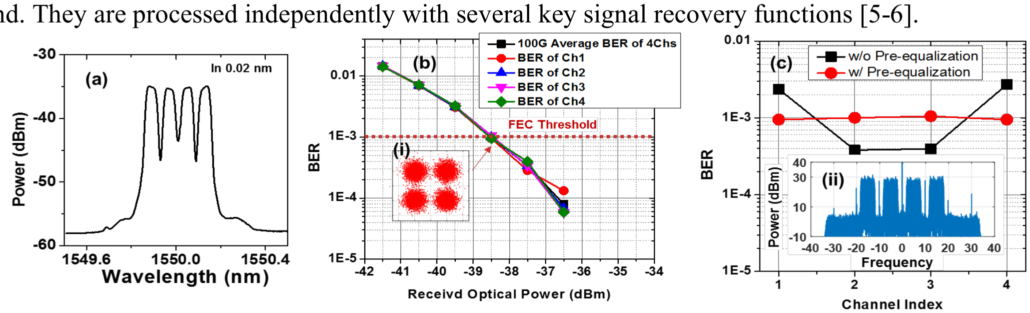

Fig. 3. Experimental results of downstream signals: (a) the optical spectrum of four subcarriers (in 0.02-nm resolution); (b) the BER performance of downstream signals; (c) the BER performance of different channels

To verify the feasibility of proposed scheme, we initially test performance in downstream. The results of downstream signal are shown in Fig. 3. The spectra of 4 subchannels, each carrying 25Gb/s are shown in Fig. 3 (a).

The BER of 100Gb/s downstream signal as a function of received optical power (with all 4 subcarriers) is shown in Fig. 3 (b). Since pre-equalization is performed in our subcarrier signal generation, four subchannels show same BER performances. The average BER performance of 100G signal with four subchannels is also plotted in Fig. 3 (b), it is seen that the required optical power at BER of 1×10^{-3} is -38.5 dBm. The constellation of Ch4 at the total received optical power at -38.5 dBm is shown as inset (i) in Fig. 3. Fig. 3 (c) show the performances of subchannels with and without pre-equalizations. Due to bandwidth limitation, the subcarriers at higher frequencies shows worse BER performance. However, after pre-equalizations, the four subcarriers have the same performance. Here the received optical power is kept at -38.5 dBm. The electrical spectrum of four subcarriers is shown as inset (ii) in Fig. 3.

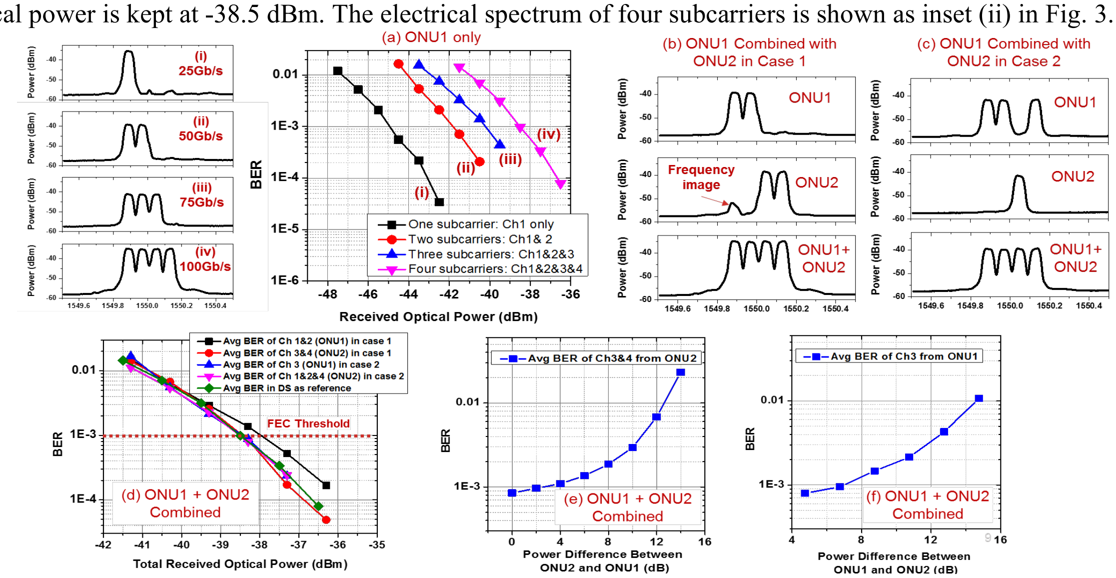

Fig. 4. The results of upstream: (a) the results with only ONU1, as inset (i)-(iv) are 1-4 subcarriers; (b) the combining case 1 with both ONU1 (Ch 1&2) and ONU2 (Ch 3&4); (c) the combining case 2 with both ONU1 (Ch 3) and ONU2 (Ch1&2&4); (d) the BER performance for different cases; (e) and (f) are power difference between ONU2 and ONU1 on signal performances. All spectra are in 0.02nm resolution.

The results of upstream signals are shown in Fig.4. The upstream case with ONU1 only is tested first with different rates from 25Gb/s to 100Gbb/s based different number of subcarriers. The BER performance of ONU1 with different number of subcarriers are shown in Fig. 4 (a), and the insets (i)-(iv) are the optical spectrum of 1 to 4 subcarriers. It is seen that compared with four subcarriers case, there is about 1.5, 3.5 and 6.5-dB sensitivity gain for 3, 2 and 1 subcarrier cases, respectively. These results are very close to theoretical sensitivity differences from 100Gb/s to 25Gb/s. The combining cases with both ONU1 and ONU2 in upstream are also studied. Here, two combining examples are studied as shown in Fig. 4 (b) and (c). In case 1, ONU1 transmits Ch 1 and 2, while ONU2 transmits Ch 3 and 4; in case 2, ONU1 transmits Ch3, while ONU2 transmits Ch 1, 2 and 4. The two ONUs are sharing bandwidth by different frequencies, while the same frequency can be shared by different ONUs in a TDM way. The BER performances of different combining cases are shown in Fig. 4 (d), and the average BER performance of DS is also shown as the reference. It is seen that the BER performances of the two combining cases are very close to the performance of DS signal, however, the Ch 1 and 2 from ONU1 in case 1 shows 0.5-dB power penalty which is due to the image frequency leakage caused by IQ imbalanced. The required power in upstream at BER of 1×10^{-3} is -38 dBm for the worst channels. The impact of power difference or power imbalance between two ONUs on BER performance is also studied, and the results are shown in Fig. 4 (e) and (f). It is desired to have equal subcarrier power after combining. In combining case 1, there is 1dB power penalty on signals from ONU2 if the power difference is offset by 8 dB; while in case 2, there would be 1 dB power penalty if the power difference is offset by 6 dB (from 4.75dB baseline). Therefore, ONU-side power levelling is desired in the proposed scheme.

4. Conclusions

We propose and demonstrate a novel rate-flexible symmetrical single-wavelength 100Gb/s/λ coherent PON architecture based on digital subcarrier multiplexing technology. The performances of downstream and upstream signals are studied. Finally, the architecture implementation of 100Gb/s/λ TFDM Coherent PON is demonstrated, achieving -38.5 and -38-dBm sensitivity after 50-km fiber transmission for downstream and upstream respectively.

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