Demonstration of Point-to-Multipoint 100G Coherent PON to Support Broadband Access and B5G/6G Mobile X-haul

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Abstract: We experimentally demonstrate a rate-flexible point-to-multipoint 100G coherent PON with downlink and uplink using digital subcarrier multiplexing to simultaneously support up to 64 nodes for fixed broadband and W-band mmWave wireless access. © 2022 The Author(s).

1. Introduction

Point-to-point (PTP) intensity modulated/direct detection (IM/DD) systems have been deployed for 4G/5G mobile x-haul [1]. In order to meet the demand of increasing wireless data and massive interconnections such as cloud service and ultra-HD resolution in B5G/6G era, it requires the next-generation optical network to have higher capacity, be simpler, cost-efficient, and more flexible [2]. Point-to-multipoint (PTMP) passive optical networks (PON) with coherent detection are considered to be a potential solution for the fixed and mobile access network [3-6].

Digital subcarrier multiplexing (SCM) slices a wavelength into multiple subchannels. It not only can be addressed to different end nodes in a PTMP architecture but will also be adapted to deployed legacy PTP applications. Recently, several research works have discussed the application of subcarrier multiplexing in PTMP architecture and coherent PON [3-6]. Figure 1 shows the optical access network for future fixed and B5G/6G mobile services. In the fronthaul, the PTMP coherent architecture uses a single high-speed transceiver at the distributed unit (DU) side to send/receive independent data streams to/from multiple low-speed transceivers at different active antenna unit (AAUs) and optical network unit (ONU). For the downlink, subcarriers are multiplexed digitally at the DU side and then sent by a high-bandwidth coherent transmitter. The multi-carrier signal is split through a power splitter and routed to each node in the link. For the uplink, the signals from all the nodes are multiplexed by an optical combiner. The multi-carrier signal in the downlink/uplink is coherently detected and moved to the baseband by the LO with a corresponding center frequency. In comparison with current schemes, this PTMP coherent architecture is cost-efficient and makes the fronthaul network more open and flexible. Actually, to our knowledge, there is almost no coherent PON demonstration using PTMP architecture to simultaneously support fiber broadband and mmWave wireless access.

In this paper, we proposed a symmetrical PTMP 100G coherent PON to simultaneously support fiber broadband and W-band mmWave wireless access based on digital SCM. We set 4 subcarriers in signal, and the system can support up to 64 nodes both in downlink and uplink communication. The results show that over 40dB/42dB power budget at SD-FEC threshold in fiber downstream/upstream transmission can be achieved, and over 34dB/47dB power budget in mmWave downstream/upstream (50G) transmission can be achieved.

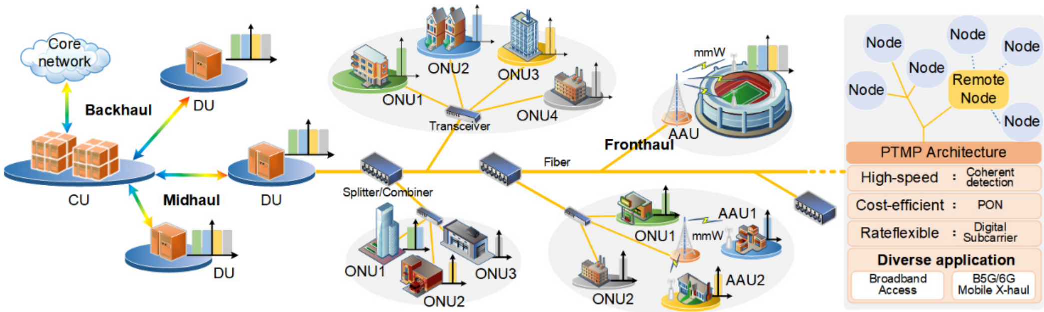

Fig. 1. PTMP optical transport networks for fixed and mobile x-haul services enabled by SCM coherent PON.

2. Experiment setup

Figures 2 (a) and (b) show the experimental setup for downstream and upstream of the rate-flexible PTMP 100G coherent PON based on digital SCM. For the downlink, four subcarriers, each carrying 25Gb/s 16QAM, are generated by a 92GSa/s arbitrary waveform generator (AWG) with a-3dB analog bandwidth of 32GHz, and then modulated by an I/Q modulator on a single wavelength at optical line terminal (OLT) side. An ECL is used as the laser source with a wavelength at 1549.315 nm. The optical signal is amplified by an erbium doped fiber amplifier (EDFA) with 9 dBm optical power, and transmitted over10 km single-mode fiber (SSMF) with an average loss of 0.33 dB/km at 1310 nm. Then, the optical signal is divided into two paths by a 1:2 splitter and then through a 1:4 splitter with 7dB loss firstly, and divided by a 1:8 splitter with 10.32 dB loss after 5-km SSMF transmission secondly, and transmitted over 3-km SSMF finally. For the downstream link, we set one fiber-wired ONU1 and one mmWave-wireless ONU2 at W-band to simulate the broadband access and B5G/6G mobile x-haul. At ONU1, one polarization controller (PC) is applied to stabilize the polarization state of signals, one variable optical attenuator (VOA) and EDFA is used for power control in BER performance test. Another ECL is used as a local oscillator (LO) at the wavelength of 1549.315 nm. Finally, the optical signals are detected by an integrated coherent receiver (ICR), and captured by a digital storage oscilloscope (DSO) for off-line DSP. At ONU2, the optical signal and laser source from another ECL with 92.5GHz frequency space are coupled by an optic coupler (OC). Then, the mmWave signals at 92.5GHz are generated from photomixing by a photodetector diode (PD), and amplified by a W-band low noise amplifier (LNA) and transmitted by the antenna. After 6 m wireless transmission, the receive signals are mixed to an intermediate frequency (IF) signal at 13 GHz, and amplified by an electrical amplifier (EA) and captured by a DSO for off-line DSP.

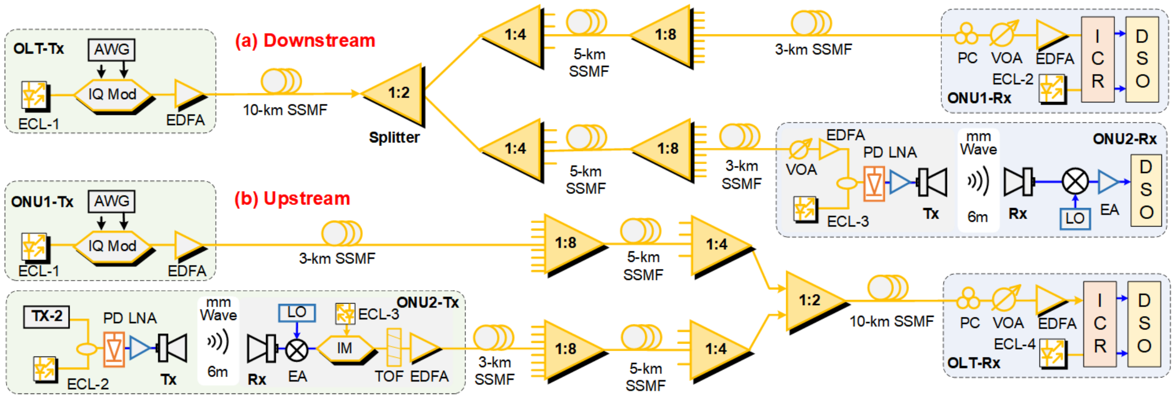

Fig. 2. Experimental setup of rate-flexible PTMP 100G fiber-wireless coherent PON system: (a) downstream; (b) upstream.

As shown in Fig. 2(b), the uplink architecture is similar to the downlink: ONU1 Tx-side is the same as OLT Tx-side, and the OLT Rx-side is the same as ONU1 Rx-side. In ONU2, the received IF signals are modulated to an optical carrier by an intensity modulator (IM) and filtered out to obtained sideband optical signals by tunable optical filter (TOF), then the signals are fed into the fiber and transmitted to the OLT side. The subcarriers generation on Tx-side and demodulation on Rx-side are processed in off-line DSP. For signal generation, the data is first mapped and to Nyquist pulse shaping with a 0.1 roll-off factor, then modulated on four inter-frequencies (-10.303GHz, -3.4343GHz, 3.4343GHz, 10.303GHz). For Rx-DSP, the subcarriers are first filtered respectively, then down-converted to baseband and processed independently with signal recovery functions. In this demonstration, the maximum rate of each subcarrier can reach 25Gb/s. Each ONU and OLT can generate up to 4 subcarriers and receive up to 4 subcarriers. Moreover, the ONU can select the number of subcarriers as required in downstream link. For the upstream link, each ONU has the capability to generate and modulate one to four subcarriers. Therefore, we design 5 different combinations to demonstrate rate-flexible transmission in this architecture.

3. Results and discussions

We initially test the BER performance for downlink transmission. In practical application, the ONU can flexibly select the number of subcarriers according to the requirements. The result of different subcarriers and all subcarriers of downstream is shown in Fig 3. Due to the bandwidth limitation, the subcarriers at higher frequencies shows worse BER performance, as shown in Fig. 3 (a). In order to balance the performance of the four subcarriers, the pre-loading is performed in the generation process of subcarriers. The electrical spectrum of four subcarriers with pre-loading is shown as inset (i) in Fig 3(a). For fiber broadband access, the BER performance of 100G signal and four 25G signals in ONU1 is plotted in Fig. 3 (b), and the constellation of SC1 at the total received optical power (ROP) at -31 dBm is shown as inset (ii). It can be observed that the ROP of 100G signal at BER of 1×10^{-2} is -31dBm and the broadband access power budget can be calculated as 40dB. For mmWave wireless access, Fig. 3 (c) shows the BER performance of 100G signal and four 25G signals in ONU2, and the constellation of SC1 at ROP at -25 dBm is shown as inset (iii). The ROP of 100G signal at BER of 1×10^{-2} is -25dBm. The power budget of mmWave mobile x-haul is 34dB.

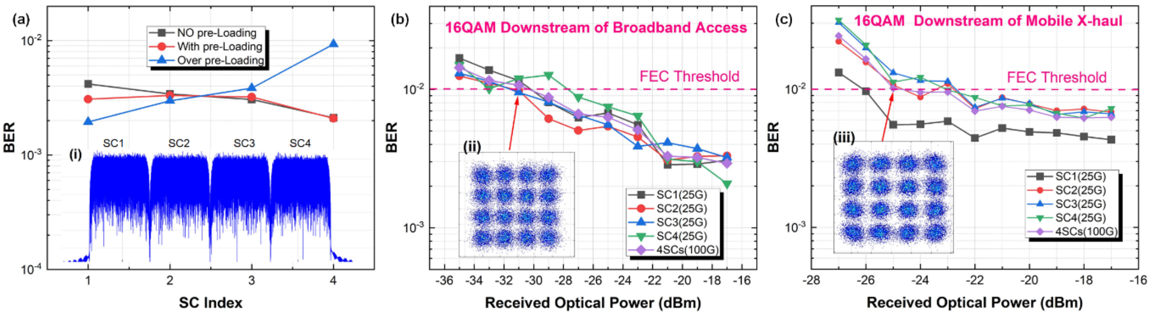

Fig. 3. Experimental results of downstream signals: (a) the BER performance with different power loading cases; (b) the BER performance of fiber broadband access in ONU1; (c) the BER performance of mmWave wireless access in ONU2.

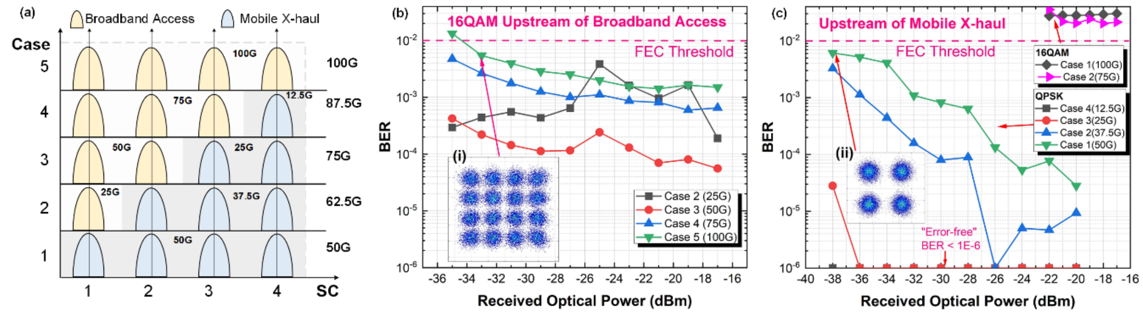

Fig. 4. Experiments results of upstream signals: (a) 5 cases for upstream signals; (b) the BER performance of fiber broadband access from ONU1; (c) the BER performance of mmWave wireless access from ONU2.

The upstream link is based on frequency division multiplexing (FDM), ONU1 and ONU2 are separately built and individually measured. There are five combinations of uplink signals from ONU1 and ONU2 depending on the number of subcarriers, as shown in Fig. 4 (a). For the upstream fiber transmission, as shown in Fig. 4(b), the required power of 100G fiber upstream signal at BER of 1×10^{-2} is -33 dBm in the worst case (case 5), and the constellation of SC1 at the ROP at -33 dBm is shown as inset (i). The BER performance of 3, 2, and 1 subcarrier cases have some degree of improvement compared with 4 subcarriers case, due to the required bandwidth gradually decreasing. For the mmWave wireless upstream, two cases (case 1 and case 2) in the 16QAM modulated signals could not reach the FEC threshold. The high-frequency attenuation is more serious in wireless transmission. For a more comprehensive evaluation of the system, QPSK format is considered, and the rate of wireless upstream signal is up to 50G. The total uplink flexible rate ranges from 50G to 100G for fixed and mobile access. Fig. 4(c) shows the BER performance of QPSK upstream signals in 4 cases and 16QAM upstream signals in 2 cases. The BER is almost error-free in case 3 and case 4. The BER performance of wireless signals is affected by the number of subcarriers, similar to the cases in fiber. The required optical power of QPSK wireless upstream signal at BER of 1×10^{-3} is -38dBm in the worst case (case 1), and the constellation of SC1 at the ROP at -38 dBm is shown as inset (ii). Finally, the power budget of upstream can at least reach 42 dB (100G fiber-wired) and 47 dB (50G mmWave-wireless).

4. Conclusions

We demonstrate a rate-flexible PTMP 100G coherent PON with downlink and uplink using digital subcarrier multiplexing to simultaneously support fixed broadband and W-band mmWave wireless access. The architecture implementation with four 25G subcarriers and up to four 25G (fiber-wired) /12.5G (mmWave-wireless) subcarriers for downstream and upstream, respectively. PTMP 100G coherent PON can achieve rate-flexible transmission and increased network capacity with a good trade-off between system complexity and cost-efficiency, which can be applied to next-generation optical networks or wireless access applications in the future B5G/6G era.

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