64/32/16QAM-OFDM using Direct-Detection for 40G-OFDMA-PON Downstream

Dayou Qian, Shu-Hao Fan, Neda Cvijetic, Junqiang Hu, Ting Wang
NEC Laboratories America, Inc., 4 Independence Way, Princeton, NJ 08540
dqian@nec-labs.com

Abstract: A 43.6Gb/s downstream OFDMA-PON is demonstrated using optical single-side band 64/32/16QAMOFDM signals and direct-detection receiver through 20km SSMF. Only one photodiode/OFDM receiver is required at the ONU, thereby significantly reducing system implementation complexity and cost.

OCIS codes: (060.2330) Fiber optics communications; (130.6750) Systems

1. Introduction

Driven by both exponentially growing demand for broadband services and FSAN standardization activities, the transport capacity of next-generation optical access networks will migrate to 40-Gb/s per channel in the near future [1]. However, unlike long haul networks whose the distance-bandwidth product is large enough to leverage high implementation cost, access networks (<100km) must maintain low hardware and operation costs to remain attractive and practical. It is well known that in 40-Gb/s optical links, fiber dispersion can severely limit transmission distance. Orthogonal Frequency Division Multiplexing (OFDM) has recently emerged as a very promising modulation format for high-speed optical transmission due to both high resistance to fiber dispersion (both CD and PMD) and high spectral efficiency [2-4]. By thus eliminating the need for dispersion compensation and reducing the transmission bandwidth, OFDM can significantly increase flexibility of access passive optical networks (PON) while reducing implementation cost. 40G and 100G [5] downstream OFDMA-PON has been reported in the previous work. Limited by the DAC bandwidth and spectrum efficiency at that time, the Polarization-Multiplexing (POLMUX) OFDM signal and direct-detection has be proposed so that the required DAC bandwidth is reduced to half of the total bandwidth of the OFDM signal. However, in order to recover the signals from two orthogonal polarizations, one polarization beam slitter, two 20GHz photo-diodes and two ADC are used at the ONU receiver. Additionally, MIMO processing is needed which would also add more DSP complexity. As the rapidly increasing of the DAC sampling rate/bandwidth as well as the spectrum efficiency from higher order modulation format [6], a simple single-side band (SSB) OFDM with a real single photodiode direct-detection becomes possible for 40G+ OFDMA-PON.

We propose and experimentally demonstrate a simple OFDMA-PON architecture for downstream that benefits from all these technical development by exploiting SSB-OFDM with direct-detection to realize 40-Gb/s transmission over 20 km SSMF plus 15dB attenuation (equal to 1:32 splitter). In the proposed approach, one 10.9/8.7/7.3GHz SSB-OFDM signal is generated by an I/Q modulator and combined with another CW laser as the optical carrier at the central office (CO), direct-detected by one photodiode at the ONU. The 64/32/16-QAM modulation formats are used respectively, enabling total 43.6-Gb/s transmission.

2. Experimental Setup

Fig.1 depicts the experimental setup for OFDMA-PON downstream with single photodiode direct detection. At the optical line terminal (OLT) transmitter, 43.6-Gb/s OFDM baseband I/Q signals were generated offline and output continuously by one Tektronix arbitrary waveform generators, AWG7122B with two channels at sampling rates of 12 Gsymbols/s. For the 64QAM-OFDM baseband I/Q signals, the FFT size N = 330, for the 32QAM-OFDM baseband I/Q signals, N=276, while for 16QAM-OFDM baseband I/Q signals, N=220, with 200 data-bearing subcarriers in all the cases. Because of the short transmission distance, no cyclic prefix was added. A training frame was added every 64 data frames for channel estimation and frame synchronization. An external cavity laser (ECL1) with wavelength of 1550.28nm and 100kHz line-width was employed as the CW optical source, and was used to drive an I/Q modulator. The I/Q modulator was modulated by the OFDM baseband I/Q signals. The optical spectra (0.01nm resolution) after I/Q modulator was shown in Fig 1 (a). Additional details about OFDM signal generation can be found in [5-7]. To generate the optical carrier for direct-detection, another external cavity laser (ECL2) with wavelength 10GHz shifted away from ECL1 was employed, and was combined with the SSB-OFDM signal using a polarization maintaining coupler (PM coupler) as shown in Fig 1 (b). An EDFA was used to generate the final SSB-OFDM signal. The resulting OFDM signal was next transmitted through 20 km fiber and one 15 dB attenuator (equal to a 1:32 splitter) to the optical network unit (ONU) receiver. All fiber used is standard SMF-28 fiber with 17 ps/nm/km dispersion and an insertion loss of 0.2 dB/km at 1550 nm. The downstream transmitted power was 7.9dBm.

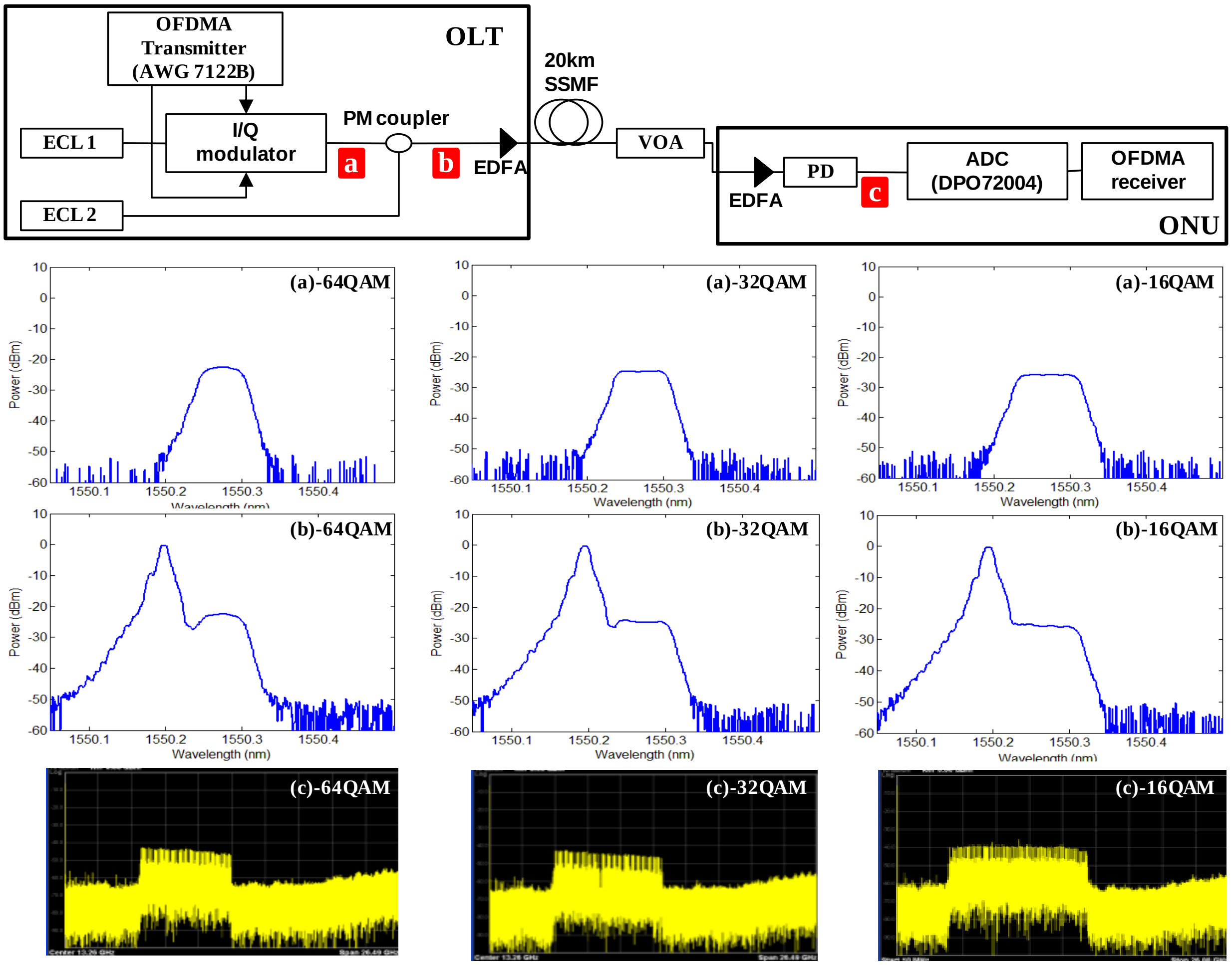

Fig. 1. Experimental Setup for 43.2Gbps-16QAM-OFDM-PON with 20km SSMF plus 15dB attenuator:
(a) Optical 64/32/16QAM SSB OFDM;
(b) Optical 64/32/16QAM SSB OFDM with optical carrier;
(c) Received electrical 64/32/16QAM OFDM signal.

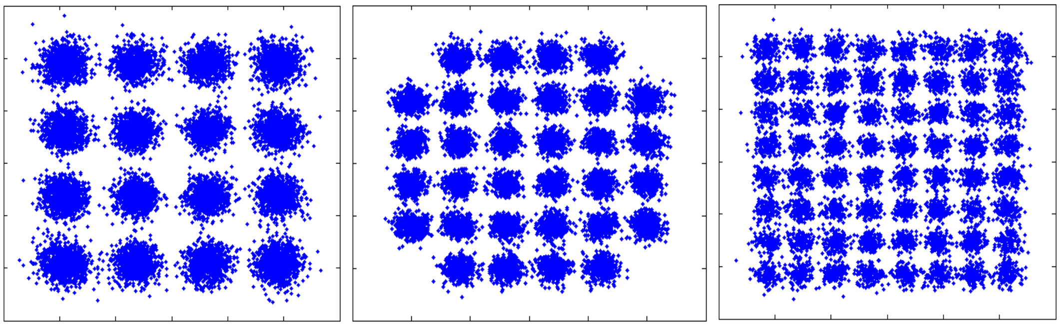

Fig. 2. 16/32/64QAM constellation after 20km SSMF

At the receiver (ONU), the received power was adjusted between -6dBm and -19dBm by a VOA, accounting for a 4-5dB attenuation from 20km fiber and 9~22dB attenuator loss. In order to compensate the path loss, another EDFA was placed before the photodiode so that the input power for the photodiode was set to 8dBm. The SSB-OFDM signal was photo-detected by one 20GHz linear PIN photodiode. The received RF OFDM signals were sampled by a Tektronix real-time oscilloscope (DPO70002) at 50Gsample/s, with all subsequent DSP done off-line. The OFDM receiver consists of a digital IQ-demux, followed by an FFT and channel estimation/equalization.

The total overhead in the experiment is divided as follows: 7% was used for FEC coding, 1.56% for preambles. It is noted that, while the total transmission rate before coding was 43.6-Gb/s, the post-coding data rate is 40-Gb/s.

3. Experimental Results

Fig. 2 shows the constellation for 64/32/16QAM OFDM signals. Obviously, the phase noise tolerance is reduced for higher order modulation formats. Fig. 3 plots the experimental BER values versus received power for optical back-to-back and after 20km SMF; each BER measurement is based on 10_6 evaluated bits. After 20 km SSMF, the FEC limit BER = 2×10^{-3} was achieved with received power -13.9dBm, -9.4dBm and -6.7dBm for different modulation formats. Moreover, as revealed by a comparison of the back-to-back and 20km transmission curves, the fiber dispersion penalty is negligible for 16QAM OFDM signals. There is about 0.5dB and 1.5dB penalty for 32/64QAM OFDM signals which may need further study.

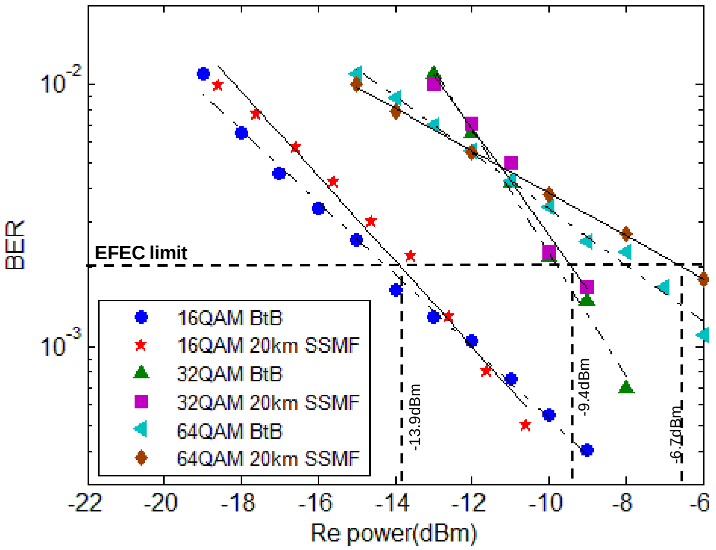

Fig. 3. BER v.s. Receive power

4. Conclusions

We have proposed and experimentally demonstrated a simple single- 43.6Gb/s PON architecture using 64/32/16QAM-SSB-OFDM signals and direct detection. Superior performance was exhibited after 20 km SSMF transmission plus a 1:32 split (15 dB extra attenuation). The novel approach required only a single set of photodiode/ADC and OFDM receiver at the ONU side. As such, the introduced architecture may be viewed as a highly attractive candidate for the practical implementation of next-generation PON (NGPON2).

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