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Study of dual-polarization OQAM-OFDM PON with direct detection*

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An offset quadrature amplitude modulation orthogonal frequency-division multiplexing (OQAM-OFDM) passive optical network (PON) architecture with direct detection is brought up to increase the transmission range and improve the system performance. In optical line terminal (OLT), OQAM-OFDM signals at 40 Gbit/s are transmitted as downstream. At each optical network unit (ONU), the optical OQAM-OFDM signal is demodulated with direct detection. The results show that the transmission distance can exceed 20 km with negligible penalty under the experimental conditions.

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Orthogonal frequency division multiplexing (OFDM) has become quite popular in wired, wireless and optical communications[1,2], mainly because of its immunity to the frequency selectivity of the channels, which allows a significant increase in the transmission rate. In recent years, the OFDM based on offset quadrature amplitude modulation (OQAM) has attracted increased interest in wireless applications, due to its enhanced flexibility, higher spectral efficiency and improved spectral containment compared with conventional OFDM[3,4].

OFDM has emerged as an attractive candidate for future optical transmission systems because of its strong inherent tolerance to chromatic dispersion and polarization mode dispersion (PMD), spectral efficiency, relatively high signal transmission capacity and natural compatibility with digital signal processor (DSP)-based implementation[5-9]. When OFDM modulation is applied to a passive optical network (PON), it provides an opportunity of having an increase in bandwidth together with an affordable cost, which shows the promising potential for many research works[10]. In order to further improve the spectral efficiency of optical communication systems, OQAM-OFDM has been proposed in coherent optical communications[10-12]. Recently, studies on OQAM-OFDM have achieved great successes to provide excellent solution for the high-speed and long-haul transmission[12-14].

In this paper, we propose a novel OQAM-OFDM PON architecture for the application in cost-efficient access networks. OQAM-OFDM is selected as the downlink modulation format in both polarizations to provide signal spectrum with high side-lobe suppression ratio, which is designed to effectively reduce the electrical sub-band frequency interference in the receiver. The transmission distance is expected to exceed 20 km at the bit rate of 40 Gbit/s for downlink transmission. Compared with conventional OFDM PON, the numerical simulation of the OQAM-OFDM PON scheme is proposed.

The proposed dual-polarization OQAM-OFDM PON scheme is depicted in Fig.1. Fig.1(a) shows the architecture of optical line terminal (OLT). The method uses polarization multiplexing in an OLT. Optical carrier generated by the distributed feedback (DFB) laser is divided into *x*-polarization and *y*-polarization by a polarization beam splitter (PBS). The polarization controller (PC) is installed to align the input signal polarization with the local laser polarization. Both polarization signals are respectively fed into two single polarization in-phase/quadrature (I/Q) modulators, and modulated in OQAM-OFDM scheme. The optical OQAM-OFDM signals from both polarizations are then combined by a polarization beam combiner (PBC). After a multiplexer (MUX), the *N* channels combined downstream is sent to the optical network unit (ONU).

The ONU architecture is shown in Fig.1(b). After fiber transmission, a demultiplexer (DeMUX) is used to sepa-

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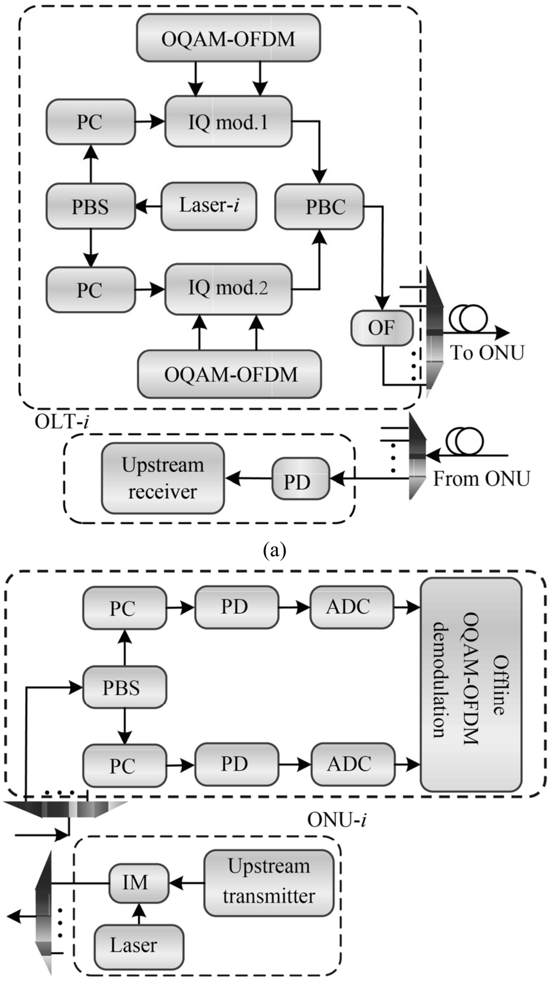
rate the *N* channels which are delivered to different ONUs. In the ONU, the downstream signals firstly pass through PBS and PC. An avalanche photodiode (PD) is used as an optical detector. The optical receiver employs a direct-detection scheme. The electronic OQAM-OFDM signals are then sampled with an analog-to-digital converter (ADC), and the demodulation is performed using offline signal processing. In the upstream direction, each ONU modulates the data over the assigned subcarrier set by intensity modulators (IM), whereas all the other subcarriers belonging to other ONUs are set to zero. Frames from each ONU combine into one upstream by a coupler at the remote node, and then it is transmitted to the OLT via the single-mode fiber (SMF).



(a)

(b)

Fig.1 (a) OLT and (b) ONU architecture for dual-polarization OQAM-OFDM PON

The schematic diagram for OQAM-OFDM is shown in Fig.2. At the transmitter, the complex input symbols are written as

$$x_k(n) = a_k(n) + \mathrm{j}b_k(n), \tag{1}$$

where $a_k(n)$ and $b_k(n)$ are the real and imaginary parts of the *n*th symbol on subcarrier *k*, respectively. The in-phase and quadrature components are staggered in time domain by *T*/2, where *T* is the symbol period. Then, the symbols pass through a bank of transmission filters and are modulated using *N* subcarrier modulators whose carrier frequencies are 1/*T*-spaced apart. The OFDM-OQAM modulated signal is

$$s(t) = \sum_{k=0}^{N-1}\sum_{n=-\infty}^{\infty}\Big[a_k(n)h(t-nT) + \mathrm{j}b_k(n)h(t-n/T-T/2)\Big]\exp\Big[\mathrm{j}k(2\pi t/T+\pi/2)\Big], \tag{2}$$

where *h*(*t*) is the impulse response of the prototype filter. After that, the OFDM-OQAM modulated signal *s*(*t*) is modulated to radio frequency (RF) band and transmitted.

At the receiver, after demodulation from RF band, the received signal *r*(*t*) is demodulated using *N* subcarrier demodulators and passed to a bank of matched filters. Following that, the filtered signals are sampled with period *T*, and the output symbols are

$$\hat{x}_k(n) = \hat{a}_k(n) + \mathrm{j}\hat{b}_k(n), \tag{3}$$

where $\hat{a}_k(n)$ and $\hat{b}_k(n)$ are the real and imaginary parts of the *n*th received symbol on subcarrier *k*, respectively. If the prototype filter satisfies the perfect reconstruction condition, the output at the receiver equals the input at the transmitter, i.e.,

$$x_k(n) = \hat{x}_k(n). \tag{4}$$

The proposed dual-polarization OQAM-OFDM PON scheme is simulated by OptiWave. In the OLT, the continuous wave is generated by a DFB laser at 1 552.52 nm. The OQAM-OFDM system is produced through MATLAB programming for the signal with aggregate rate of 2.5 Gbit/s, sub-carrier number of *N*=2 048, RF carrier frequency of 10 GHz and oversampling factor of 2. The applied modulation format is OQAM-OFDM. The prototype pulse shaping function in OQAM is set to be square root raised cosine filter with the length of *L*=4*N*. The optical OQAM-OFDM signals from both polarizations are combined by a PBC. Because the system employs both polarizations, it is able to carry 5 Gbit/s independent data streams in per wavelength channel. The wavelength multiplexers are used to combine eight distinct wavelength channels into a composite channel, which results in a 40 Gbit/s downlink transmission. Optical signals are then boosted to 15 dBm before launching into the 20 km standard SMF. After transmission, the optical signal is firstly demultiplexed into eight 5 Gbit/s streams, where each of them is separated by a PBS and demodulated using the direct detection. In ONU, 2.5 Gbit/s upstream is achieved by on-off keying (OOK).

Based on our results, we compare the bit error rate (*BER*) performances of OQAM-OFDM scheme with those of binary phase-shift keying (BPSK) and conventional OFDM. The *BER* curves of three schemes are explored in Fig.3. The OQAM-OFDM scheme can offer the

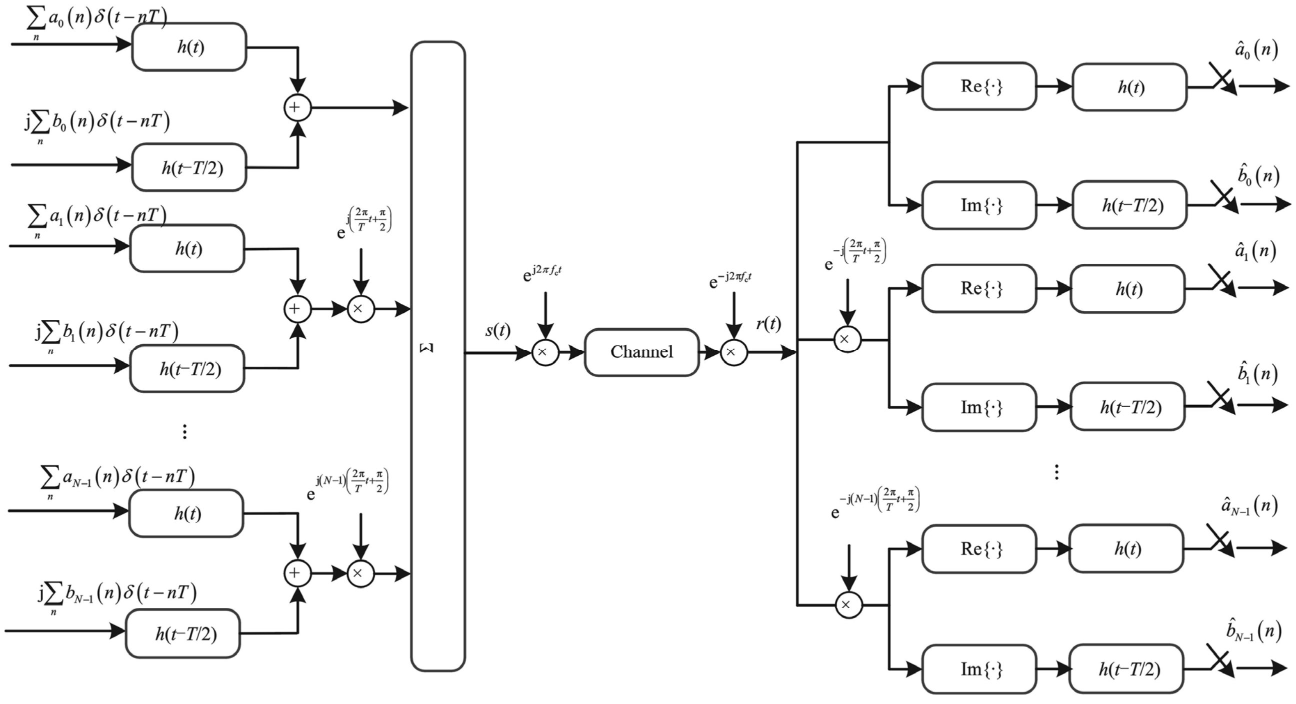


Fig2. Schematic diagram for OQAM-OFDM

potentials of up to 2 dB improvement at a total channel *BER* of 10^{-3} compared with the conventional OFDM counterpart for 20 km downlink transmission. The improvement of the OQAM-OFDM scheme compared with BPSK system and OFDM system increases as the transmitted power increases. This is due to the fact that although the subcarrier functions of OFDM are perfectly time limited, they are suffered from spectral leakage in the frequency domain and inter-carrier interference (ICI) results under non-ideal conditions. Moreover, the inclusion of the cyclic prefix (CP) entails a waste in transmitted power as well as in spectral efficiency. The OQAM-OFDM scheme allows the pulses to be well localized in both the time and the frequency domains, thus increasing the system's robustness to frequency offsets, limiting the power radiation and providing the better spectral containment in bandwidth sensitive applications.

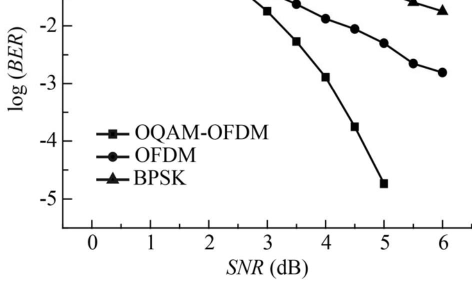
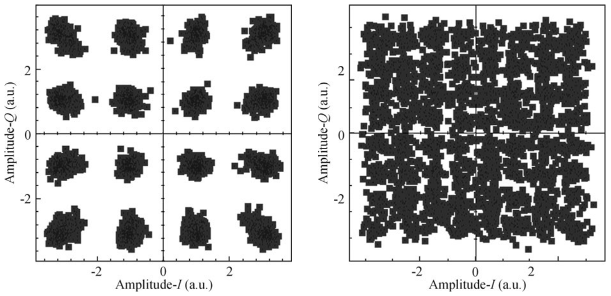
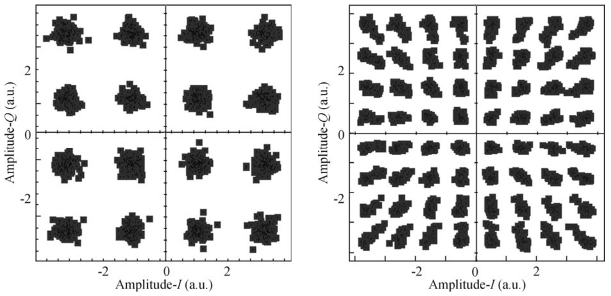


Fig.3 BER performances of BPSK, OFDM and OQAM-OFDM for 20 km downlink transmission

The constellation diagrams of conventional OFDM and OQAM-OFDM downlink with different mapping rules are shown in Fig.4. It can be seen from Fig.4 that the OQAM-OFDM schemes with both 16-QAM and 64-QAM offer much better performance than the conventional OFDM. The ability to combine with high-order modulation for OQAM-OFDM is significantly better than conventional OFDM.



(a) Conventional OFDM



(b) OQAM-OFDM

Fig.4 Constellation diagrams of 16-QAM and 64-QAM for conventional OFDM and OQAM-OFDM downlink

In this paper, we propose an OQAM-OFDM PON scheme with direct detection, and it is demonstrated that the OQAM-OFDM modulation for PON can be advantageously combined with polarization division multiplexed to still double the spectral efficiency. In this scheme, the downstream 40 Gbit/s OQAM-OFDM signals are transmitted over 20 km SMF successfully. By comparing different modulation schemes in downlink transmission, we conclude that our OQAM-OFDM outperforms conventional OFDM by more than 2 dB at *BER* of 10^{-3}, and expediently combines with high-order modulation to achieve high performance.

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