Colorless ONU implementation for WDM-PON using direct-detection optical OFDM*

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(Received 28 November 2012)

A novel architecture for the colorless optical network unit (ONU) is proposed and experimentally demonstrated with direct-detection optical orthogonal frequency division multiplexing (DDO-OFDM). In this architecture, polarization-division multiplexing is used to reduce the cost at ONU. In optical line terminal (OLT), quadrature amplitude modulation (QAM) intensity-modulated OFDM signal with *x*-polarization at 10 Gbit/s is transmitted as downstream. At each ONU, the optical OFDM signal is demodulated with direct detection, and *y*-polarization signal is modulated for upstream on-off keying (OOK) data at 5 Gbit/s. Simulation results show that the power penalty is negligible for both optical OFDM downstream and the on-off keying upstream signals after over 50 km single-mode fiber (SMF) transmission.

Document code: A **Article ID:** 1673-1905(2013)02-0135-4
DOI 10.1007/s11801-013-2407-x

Recently, the huge bandwidth is required to support the rapid growth in demand of internet protocol (IP) telephony, high definition television (HDTV), internet protocol television (IPTV) and on-line gaming. Because of the requirement of huge capacity and bandwidth by end-users in fiber access networks, the cost of bandwidth service should be considered. The possible method is to simplify the fiber access architecture to accomplish the cost-effective access traffic[1,2].

Optical network unit (ONU) is a major component of wavelength division multiplexing passive optical network (WDM-PON). It is important to study the implementation of ONU in WDM-PON, because access network is very sensitive to the economy[3-5]. The light source in the ONU should be a fixed wavelength laser, and it brings about an important issue, which is WDM-PON system needs to prepare the different wavelengths for ONUs. Therefore, colorless ONU technology is adopted, because we hope to achieve flexible rationing of the WDM-PON wavelength, especially requiring that ONU wavelength can be set or automatically adapted. As colorless ONU does not need to manage ONU wavelength, each ONU is indiscriminate, and its maintenance is very convenient.

In this paper, we propose a novel colorless ONU using polarization-division multiplexing for both downlink and uplink traffic to achieve 10 Gbit/s and 5 Gbit/s data rates, respectively. The downstream is transmitted in direct-detection optical orthogonal frequency division multiplexing (DDO-OFDM) format with *x* polarization, while each upstream is in on-off keying (OOK) with *y* polarization. The 50 km single-mode fiber (SMF) transmission is achieved by using this method.

By using the resistance of optical OFDM to chromatic dispersion and polarization mode dispersion, a novel passive and colorless ONU architecture is proposed. The schematic diagram of the architecture is shown in Fig.1.

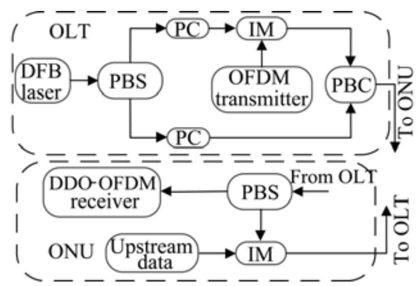

Fig.1 OLT and ONU architecture with polarization-diversion DDO-OFDM scheme

The method uses polarization multiplexing in the op-

* This work has been supported by the Open Fund of State Key Laboratory of Advanced Optical Communication Systems and Networks (No. 2011GZKF031109), and the Natural Science Foundation of Shandong Province (No. ZR2010FM043).
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tical line terminal. Optical carrier generated by the distributed-feedback (DFB) lasers is divided into x and y polarizations by polarization beam splitter (PBS). The x polarization signal is modulated by an intensity modulator (IM) in OFDM scheme, while the y polarization signal is not modulated. The two polarization signals combine using polarization beam combiner (PBC), and then transfer to the ONU. First, the two polarization signals are separated by PBS in ONU, and the x polarization signal is sent to direct-detection optical OFDM receiver for downlink data reception. The y polarization signal is transmitted to the OLT after intensity modulation.

In order to reduce the cost of the ONU, the direct-detection optical OFDM modulation is utilized in the downstream link transmission. The schematic diagram of DDO-OFDM is shown in Fig.2.

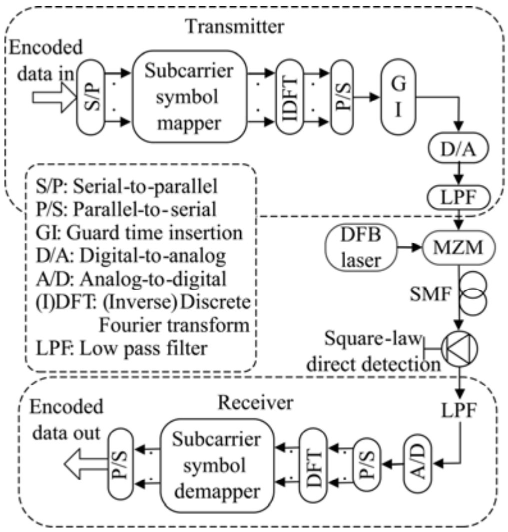


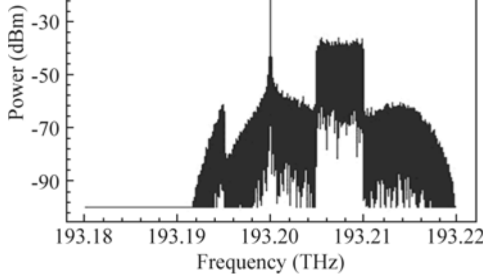
Fig.2 Schematic diagram for DDO-OFDM

At the transmitter, the input serial data bits are first converted into many parallel data pipes (serial-to-parallel conversion, S/P), and each is mapped onto the corresponding information symbols for the subcarriers within one OFDM symbol. After inverse discrete Fourier transform (IDFT) operation, the parallel-to-serial (P/S) conversion inserting guard interval and windowing are performed, and the digital time domain signal is obtained. After digital-to-analog (D/A) conversion and time-frequency coding, the signal is converted into real-time waveform. The guard interval is inserted to prevent intersymbol-interference (ISI) due to channel dispersion[6-9]. After D/A converter, the electrical OFDM signal is converted into the optical domain using the Mach–Zehnder modulator (MZM)[8,10]. The received optical signal is directly detected and converted to the OFDM signal by the photodetector (PD). The OFDM signal is sampled with an analog-to-digital (A/D) converter, transformed with S/P, and demodulated by performing discrete Fourier transform (DFT) and baseband signal processing to recover the data[11,12].

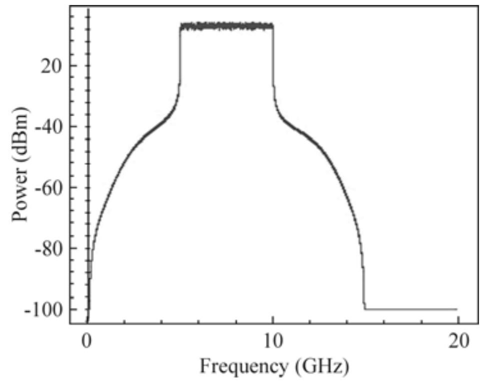
For upstream link, the y polarization optical signal is modulated by an IM. A common on-off keying (OOK) can be used in upstream link, which modulates the user data to the optical domain for transmission and proceeds the detection decision in the OLT side. In order to increase the transmission distance, optical OFDM modulation can be applied to upstream modulation for producing coherent detection optical OFDM signals, and the coherent detection methods are used for detection in the OLT side[13,14]. So the complexity is increased in the OLT side, but coherent gain is obtained, which significantly reduces the requirements of the upstream optical signal sensitivity, and is conductive for achieving the long-distance transmission.

Taking full advantage of the characteristics of the OFDM, a method of passive colorless ONU is given combined with polarization multiplexing. Using this scheme, the construction cost of the ONU can be effectively reduced, and the unified design of different ONUs can be achieved. While in OLT, OFDM access is realized by using different ONUs to which different OFDM subcarriers are allocated, and it makes up for the insufficient flexibility of simplifying the WDM-PON.

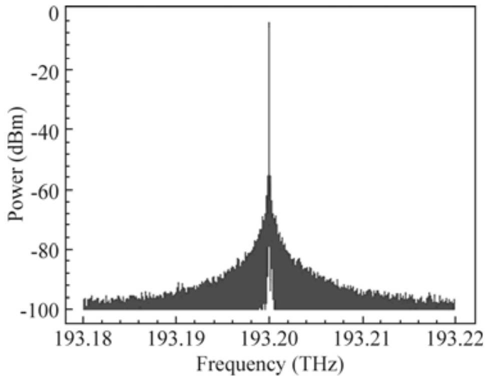
Simulation is employed to investigate the performance of the ONU design to WDM-PON. The rate of downstream with DDO-OFDM can reach up to 10 Gbit/s, and the 5 Gbit/s upstream is achieved by OOK. The commonly used parameters are applied for the simulation as 50 km span distance, the fiber chromatic dispersion of 16.75 ps/(nm·km), 0.2 dB/km loss, the differential group delay of 0.2 ps/km and the nonlinear coefficient of 2.6×10^{-20} m^2/W. The linewidths of transmitted lasers are assumed to be 100 kHz. 8 WDM channels are spaced at 100 GHz. The OFDM parameters are OFDM symbol period of 102 ns and 512 subcarriers. The guard interval is set as one-fourth of the observation period, and 4 quadrature amplitude modulation (QAM) encoding is used for each subcarrier. The bandwidth of each DDO- OFDM signal is 15 GHz.



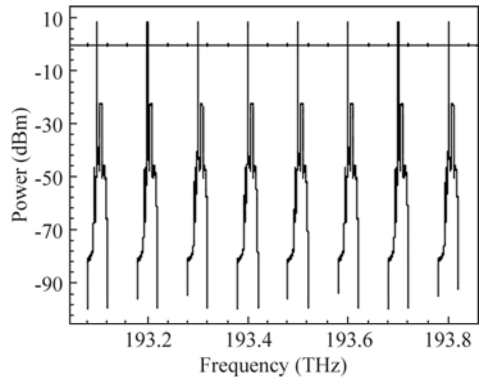
(a)



(b)



(c)



(d)

Fig.3 (a) Electrical spectrum of the OFDM signal; (b) Optical spectrum of modulated *x*-polarization signal; (c) Optical spectrum of unmodulated *y*-polarization signal; (d) Optical spectrum of WDM DDO-OFDM signal

Fig.3(a) shows electrical spectrum of the 4-QAM OFDM signal. After the electrical OFDM signal is converted into that in the optical domain by MZM, optical spectra of *x*- and *y*-polarization signals are different as shown in Fig.3(b) and (c). 8 wavelength channels are combined into a composite WDM signal, as illustrated in Fig.3(d). The BER performance curves and the constellation diagrams after back-to-back (B2B), 50 km and 100 km downlink propagations are given in Fig.4, respectively. Fig.5 illustrates the BER curve and eye diagram for upstream signal after 50 km transmission.

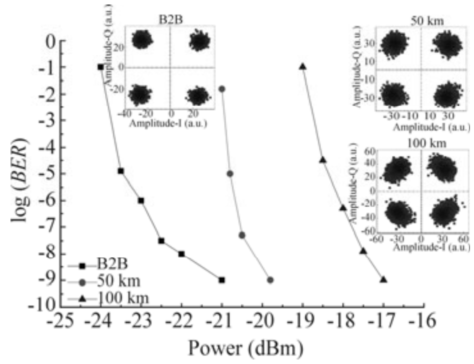


Fig.4 BER performance and constellation diagrams for downlink signal after back-to-back, 50 km and 100 km transmissions

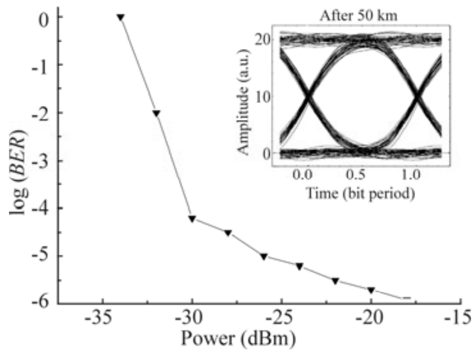


Fig.5 BER performance and eye diagram (inset) for upstream signal after 50 km transmission

Compared with previous formats, the proposed ONU implementation using direct-detection optical OFDM and polarization multiplexing can obtain higher spectral efficiency and tolerate larger fiber dispersion. The downstream signal with 10 Gbit/s intensity-modulated 4-QAM OFDM and upstream with 5 Gbit/s OOK signal are demonstrated in 50 km SMF by simulation experiment. Because optical OFDM is an effective modulation format for the next-generation optical network, this realization scheme of ONU can provide significant improvement on the reliability and flexibility of WDM-PON.

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