10 Gb/s WDM-PON Using Downstream OFDM and Upstream OOK

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Abstract

A WDM-PON architecture based on OFDM modulation is proposed and demonstrated. In this paper, 4-QAM OFDM signal at 10 Gb/s is used for downstream link. By using a SOA and a MZ-IM at the ONU side, the downstream optical signal is re-modulated for upstream OOK data at 2.5 Gb/s. Simulation results indicate that error-free operation can be achieved in a 20 km transmission for both directions. As the cost can be reduced by removing the emission part in the ONU, this WDM-PON architecture based on OFDM modulation may be viewed as an attractive candidate for next-generation PON.

Keywords: WDM-PON, OFDM, SOA

1. Introduction

In recent years, the wavelength division multiplexed passive optical networks (WDM-PONs) are considered as a promising candidate to provide broadband access for the next generation networks, since WDM-PONs have a number of excellent features including wide bandwidth, large split ratio, extended transmission reach, aggregated traffic backhauling and simplified network architecture (Gee-Kung Chang, 2009, Katsumi Iwatsuki, 2009). However, at present WDM-PONs are not regarded as a cost-effective solution, as the cost of the wavelength selective optical components and frequency-stable transmitters is still very high. So reducing the cost of WDM-PON will be the key challenge for their deployment. To make the WDM-PON system more cost effective and easily manageable, the optical network unit (ONU) should have the capability to reuse the downstream signals by re-modulating it with the upstream data (Wai Hung, 2003, Bo Liu, 2010).

Optical orthogonal frequency division multiplexing (OFDM) has emerged as an attractive candidate for future transmission systems because of its strong inherent tolerance to both chromatic dispersion and polarization mode dispersion (PMD), spectral efficiency, relatively high signal transmission capacity and natural compatibility with digital signal processing (DSP)-based implementation (Ivan B. Djordjevic, 2006). Recently, more and more architectures for PON system using OFDM have been reported and studied. In most schemes, the PON architectures including lasers in the ONU will increase the cost for implementation. In order to make the ONU "colorless", two wavelengths are used in some schemes (Po-Lung Tien, 2009) while re-modulating the downstream wavelength is used in other schemes (C. W. Chow, 2009). However, two wavelengths scheme has low spectral efficiency and re-modulation scheme has limited upstream bit rate.

In this paper, we propose a signal re-modulation scheme of 10 Gb/s downstream OFDM and 2.5 Gb/s upstream on-off keying (OOK) using a semiconductor optical amplifier (SOA) and an external modulator. By using OFDM modulation, the high rate downstream signals will be spitted into a number of low rate signals which are transmitted simultaneously over a number of subcarriers. In the ONU, the downstream optical signals are amplified by a SOA and then re-modulated by a Mach-Zehnder intensity modulator (MZ-IM) before sending back to the central office (CO). Thus, this scheme does not require any light source in the ONU and can provide sufficient power budgets for the upstream signals. For there is no emission part in the ONU in this WDM-PON architecture, this scheme can make the ONU "colorless" and reduce the cost of the system.

2. Architecture

The proposed WDM-PON architecture is shown in Figure 1. A CO consists of a distributed feedback laser diode (DFB-LD) array which offers the wavelength from λ_1 to λ_N for downlink. One intensity modulator (IM) is employed to generate up-converted OFDM intensity modulated signals for downstream transmission. In frequency domain, the modulated data streams are orthogonal to each other, thus the cross-talk between the subcarriers is eliminated. OFDM baseband signals are up-converted to a high radio frequency (RF) carrier by an electrical mixer with a RF source. Then the optical OFDM signal is transmitted from the CO to the ONUs through an arrayed waveguide grating (AWG) at the remote node (RN).

At the ONU side, part of the received optical power is fed into an OFDM demodulator to recover the downstream signals while the rest of the downstream optical signals are launched into the SOA. Then the amplified optical signal is directly modulated by the IM and sent back to the CO by a different single mode fiber (SMF) to reduce Rayleigh backscattering. Consequently, the centralized lightwave is realized because there is no additional light source in the ONU.

3. Simulation Setup and Results

To discuss the performance of the proposed WDM-PON system, we establish a model for simulation as shown in Figure 2. At the transmitter, a 10 Gb/s non-return to zero (NRZ) pseudo-random binary sequence (PRBS) downstream signal with a length of 2^{31}-1 is first coded by a 4 quadrate amplitude modulation (QAM) modulator and then mapped onto 512 frequency subcarriers by a serial to parallel converter. These subcarriers are dealt with IFFT with a size of 1024 and then inserted with a cyclic prefix (CP). The purpose of cyclic extension is to preserve the orthogonality among subcarriers even when the neighboring OFDM symbols partially overlap due to dispersion. Next, the resulting signals are serialized and then converted by a high sample rate digital to analog converter (DAC). The baseband OFDM signal is modulated with a radio frequency (RF) carrier at 7.5 GHz. Then the OFDM signal is modulated onto a wavelength at 1550nm using a MZM. The variable optical attenuator (VOA) is used to measure the receiver sensitivity of the output signal. Then the downstream signal is fed into a span of 20-km SMF. Dual-feeder fiber architecture is used to reduce Rayleigh backscattering at the CO receiver in the network.

At the ONU side, a portion of the downstream received optical power is tapped off by a 50/50 power splitter. The downstream signal will pass through an electrical bandpass filter (BPF) and then be demodulated by an OFDM demodulator. The rest of the downstream optical signal is amplified by a SOA and then re-modulated by a MZ-IM, which is driven by another 2.5 Gb/s NRZ PRBS with a length of 2^{31}–1. Then the generated upstream signal is transmitted back to the CO, via anther piece of 20 km SMF.

In the simulation, the single model fiber (SMF) has an attenuation of 0.2 dB/km, a dispersion of 16.75 ps/nm/km, a dispersion slope of 0.075 ps/nm^2/km, a nonlinearity coefficient n_2 of 2.6×l0^{-20} m^2/W, and an effective core area of 80μm^2. We have chosen a FFT of size 1024. The total number of OFDM subcarriers is 512. For a 10 Gb/s downstream signal with 4 QAM modulation, the calculated subcarrier spacing is Δf=10 Gbps/ (2×512) =9.76 MHz and the OFDM time period is T_u=1/Δf =102.4 ns. In order to minimize the overhead, we have chosen a cyclic prefix ratio G =1/64, where T_{cp}=T_s×G=1625 ps which is much higher than the maximum delay spread t_{max}=16.75ps/nm/km×20km=335 ps of the optical fiber. Thus, it compensates the fiber dispersion.

At the OLT, the data will first be modulated on a 7.5 GHz low frequency oscillator before being up-converting to high frequency by the MZM. The electrical spectra of the OFDM signal at the OLT and the ONU are shown in Figure 3(a) and 3(b). The spectrum of the optical downstream OFDM signal is shown in Figure 3(c). After an optical bandpass filter, a single side band (SSB) optical signal can be generated. Transmitting the digital signal in an optical SSB form allows for the effects of chromatic dispersion to be reduced relative to transmission in double sideband (DSB) form (Mike Sieben, 1999). So the fiber dispersion can be compensated in the electrical domain after detection. Moreover, it can save the optical bandwidth. After 20 km SMF transmission, the spectrum of the optical OFDM signal is shown in Figure 3(d).

The bit error rate (BER) performance and constellation diagrams of 10 Gb/s downstream OFDM signals are shown in Figure 4. It can be seen that after 20 km fiber transmission, the OFDM constellation is still very clear. Because the optical signal-to-noise ratio is degraded after transmission, the constellation diagram is a little worse. Thus, the received optical signal in the ONU will be a good candidate for upstream re-modulation. By comparing the BER of back-to-back with 20 km transmission, the maximum power penalty is about 1 dB at the BER of 10^{-12} for the downstream OFDM signal.

Figure 5 illustrates the measured BER curves and the corresponding eye diagrams for 2.5 Gb/s upstream signals before and after transmission. It can be clearly seen that the eye diagram is widely opened after 20 km transmission. As the downstream OFDM signal is fluctuant, we can see from the eye diagram that the ones suffer a little noise. For the upstream NRZ signal, the power penalty is about 6.5 dB at the BER of 10^{-12} between back-to-back and 20 km transmission.

4. Conclusion

In conclusion, we have proposed and demonstrated a centralized lightwave scheme for WDM PON using 10 Gb/s OFDM in downstream and 2.5 Gb/s NRZ in upstream with a SOA and a MZ-IM at the ONU. Using this scheme, downstream 4-QAM OFDM at 10 Gb/s has been transmitted over 20 km fiber. The power penalty for the 10 Gb/s downstream signal after 20 km transmission is 1 dB at a BER of 10^{-12}. For upstream link, downstream OFDM signal is re-modulated by a MZM at 2.5 Gb/s. For the upstream signal, the power penalty after 20 km transmission is about 6.5 dB at a BER of 10^{-12}. As there is no emission part in ONU, this WDM-PON architecture based on OFDM modulation may be viewed as an attractive candidate for next-generation PON.

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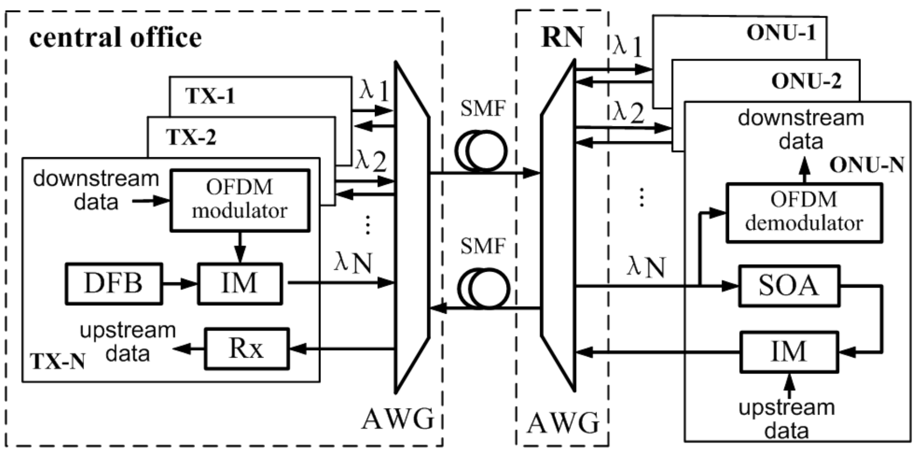

Figure 1. Proposed WDM PON system

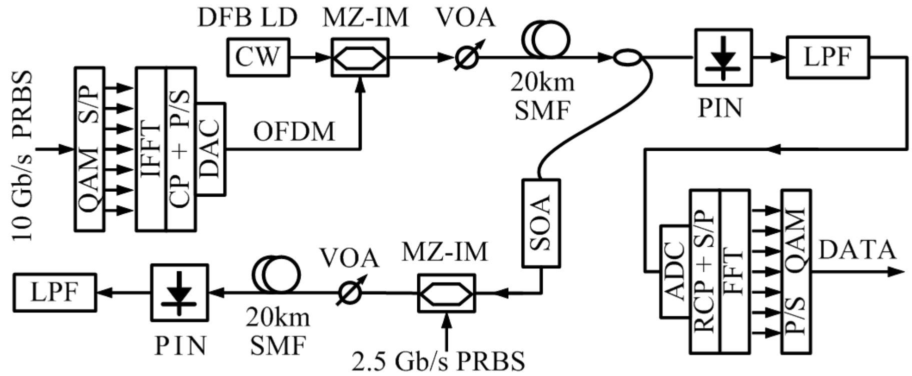

Figure 2. Simulation setup of proposed WDM-PON link

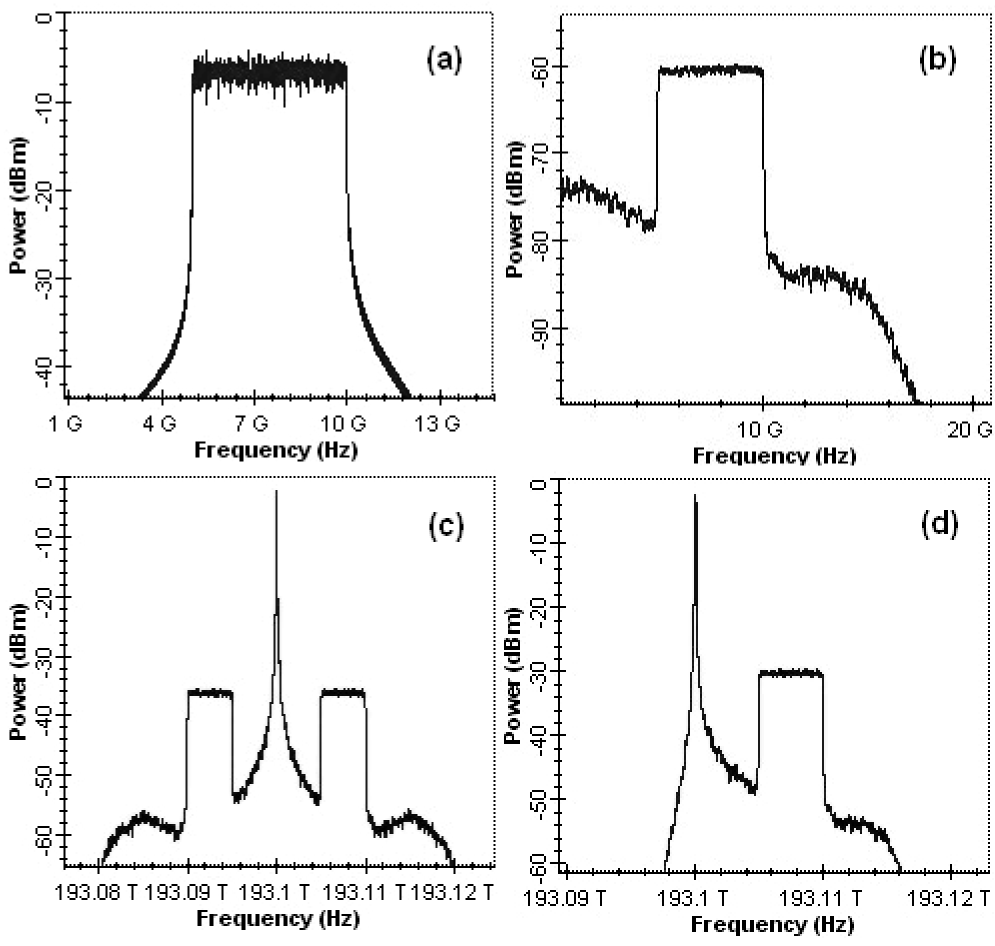

Figure 3. Electrical and optical spectrum of OFDM signal

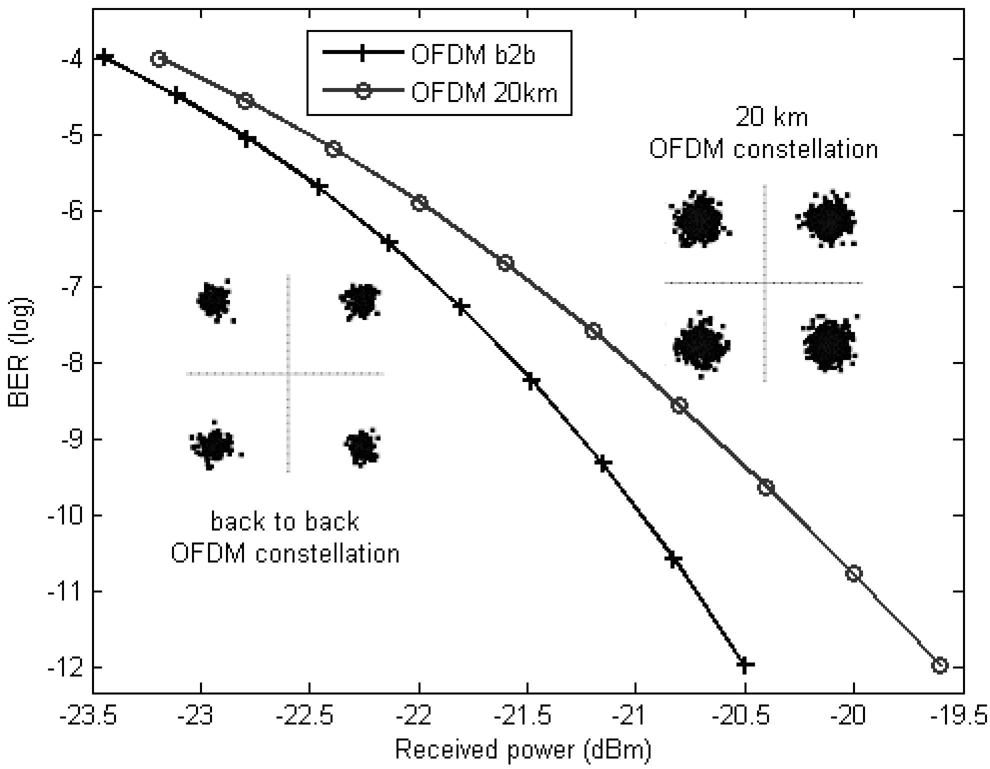

Figure 4. BER measurements of 10 Gb/s downstream OFDM

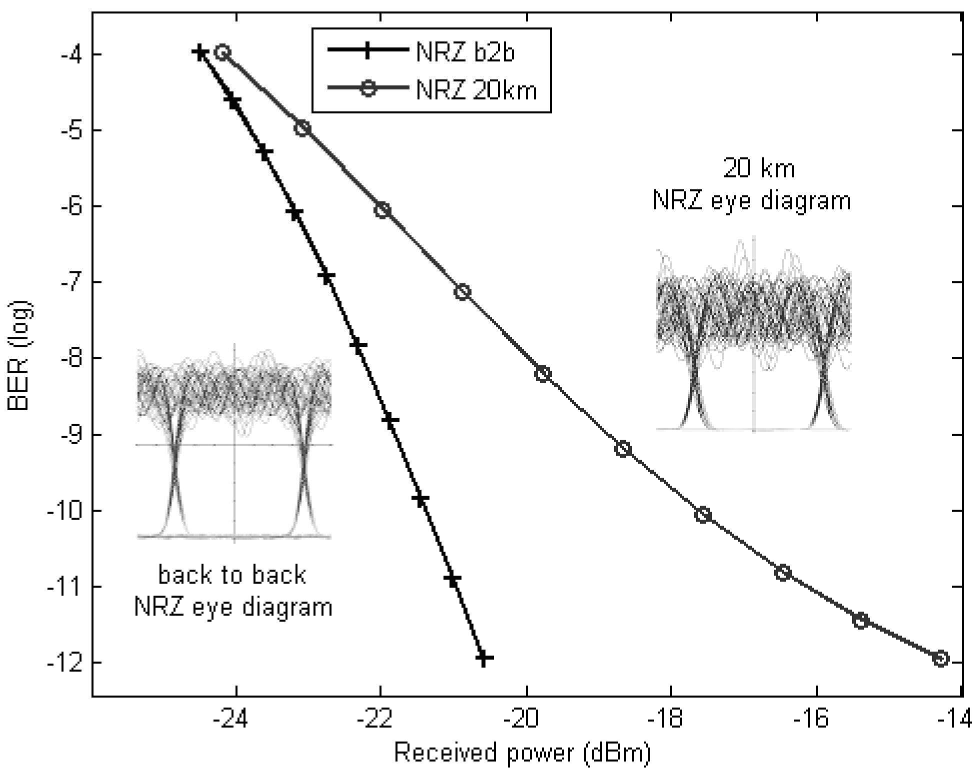

Figure 5. BER measurements of 2.5 Gb/s upstream NRZ