WDM-OFDM-PON System with Clipping Pre-distortion and RSOA

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Abstract. A low cost WDM-OFDM-PON system with clipping pre-distortion and RSOA for colorless ONU is proposed. On the basis of theoretical research, the transmission performance of the back-to-back and after 25km transmission is simulated and analyzed. The results show that proposed system can guarantee the transmission performance with colorless ONUs and recover the signal after 25km transmission.

Introduction

With the development of high-bandwidth services, such as IPTV and video-on-demand, next generation passive optical network (NG-PON) has been regarded as a promising technology in order to meet access bandwidth requirement. Orthogonal frequency division multiplexing (OFDM) has been successfully employed into numerous digital standards for broad-range of applications such as digital audio/video broadcasting and wireline/wireless communication systems. Recently, using optical OFDM modulation in PONs has attracted much attention. The main purpose of combining OFDM and PON is to exploit the superior physical layer performance of optical OFDM to satisfy the evolution requirements of PON access networks [1, 2].

Compared with long-haul backbone optical networks, access networks are very cost-sensitive. Passive optical network (PON) is a promising candidate to meet the bandwidth demand and the cost effectiveness. Optical carrier distribution with a colorless optical networking unit (ONU) is one of the cost-effective implementations of the WDM-PON. The reflective semiconductor optical amplifier (RSOA)-based ONU is important for the WDM-PON owing to its compact size and low power consumption [1-4]. Although the cost of OFDM-PON is lower than WDM-PON system, it needs different lasers for each ONU. This impedes the commercialization of the OFDM-PON in optical access networks. As one of the most critical and urgent problems, colorless ONU has always been a hot topic. Compared with equipping extra laser for upstream transmission, it is more attractive to reuse the downstream signal for upstream transmission. However, existing colorless ONU schemes usually suffers from either upstream capacity limitation or high cost, and could not fully satisfy the requirements of high-speed WDM-OFDM-PON systems. To reduce the cost, it can be achieved by employing colorless ONUs in OFDM-PON system to cut down the number of the lasers. Colorless ONUs is one of the important problems that should be resolved in OFDM-PON system [3].

In this paper, a WDM-OFDM-PON system with clipping pre-distortion and RSOA is proposed. The OFDM signal can be transmitted without distortion. It improves the signal quality of the transmitter and implemented colorless of the ONUs by using RSOA. The paper is organized as follows. Firstly, we present a general configuration of the OFDM-PON. Then the proposed WDM-OFDM-PON is shown and the performance of the system is analyzed. In the end, we conclude the paper.

Principle of OFDM-PON

Figure 1 is the schematic diagram of OFDM-PON. For downstream transmission in OFDM-PON, the OFDM frame is first modulated to optical signal in optical line terminal (OLT). Then the downstream from OLT is fed into the single mode fiber (SMF), split into n part by a 1: n splitter at the remote node.
(RN), and broadcast to all of the ONUs. For upstream transmission, each ONU maps its data to its assigned OFDM subcarriers, and performs OFDM modulation to generate a complete frame. Frames from each ONU combine into one upstream by a coupler at the RN, then transmits to the OLT via the SMF.

Figure 1. Schematic diagram of OFDM-PON.

At the OFDM transmitter, binary input data is converted from a high-speed serial signal to a relative low-speed parallel signal firstly and coded as the QAM symbol. Then the symbols are input into an inverse fast Fourier transform (IFFT) and after IFFT the orthogonal signals are generated.

WDM-OFDM-PON with Colorless ONUs

System Design

Colorless ONU in WDM-OFDM-PON system is the ONU without special upstream lasers for upstreaming optical carrier [5]. In OFDM system, different sub-carriers are used to different ONUs. To implement colorless ONU, the main idea is to separate downstream signal with modulator or filter. A part of signal is used as the downstream signal for downstreaming transmission, the other part of signal is used as the upstreaming signal processed by modulator to substitute the optical carrier of the ONU, or directly processing the downstream signal to use as the upstreaming optical carrier [6]. In this way it does not need lasers for corresponding ONU, and only OLT needs configure lasers. The cost of the system is lower and the system structure is much simpler. So the colorless ONU for WDM-OFDM-PON is implemented.

Figure 2. Proposed WDM-OFDM-PON system with colorless ONUs.

The main idea to implement colorless the ONU can be divided into two steps. First, the OFDM signal of transmitter in ONU and OLT is clipping predistorted to make the high peak OFDM signal transmitting without distortion. In this way the quality of the signal in transmitter can be improved.
Second the E/O in ONU is substituted to RSOA. RSOA can amplify, erase, and modulate. It can carry signals at the same time amplify the ONU-end signal, and has a low cost, portable, fast dynamic response and low insertion loss. RSOA has good performance of optical modulation, wavelength conversion, optical detection and signal regeneration in optical systems, and meet the requirements of passive optical networks transceivers. In OLT, the OFDM signal processed by clipping predistortion is upconverted to RF OFDM signal, then modulated by downstream optical laser to generate optical OFDM signal. Then the signal is transmitted over fibre channel to each ONU through optical splitter. In ONU, the signal is divided into two parts. One part is completed the downstream transmission, the other part is sent to RSOA. The RSOA receives the optical OFDM signal and erases it to get the pure optical carrier as the upstream carrier. In this way, upstream laser can be substituted by RSOA. The upstream baseband OFDM signal after upconverted to RF OFDM signal is sent to RSOA to modulate to get optical OFDM signal. Then the signal transmits through splitter over fiber to OLT. The upstream transmission completes by photodetector, downconverter and receiver. In the whole system, there is no need to configure lasers for optical carrier in ONUs, just a RSOA can implement colorless WDM-OFDM-PON to lower the cost of the ONU. At the same time in OLT clipping predistortion can ensure the system performance.

Performance Results

We use joint simulation to analyze the performance of the proposed WDM-OFDM-PON system. The clipping predistorted OFDM signal is generated by Matlab. The cyclic prefix is added to OFDM signal with length of 1/64. The IFFT length is 256. The times of the joint clipping is 6. 16QAM modulation is employed and the downstream signal rate is 10Gb/s. Then the OFDM signal is input to WDM-PON system simulated by OptiSystem. The attenuation factor of the fiber is 0.2dB/km and the fiber is 25km. The upstream signal is 5Gb/s NRZ. The input power of the RSOA is 0dBm.

To compare the system transmission performance between the proposed system and the original system, we simulate the SER (symbol error rate) and BER of the OFDM-PON. Power margin is generally used to measure power. The expression of power margin is shown as Eq. 1:

$$P_{Md} = P_{td} + G_{EDFA} - P_{sd} - L_{Down}, \quad P_{Mu} = P_{tu} + G_{EDFA} - P_{su} - L_{Up}.$$  \hspace{1cm} (1)

$P_{Md}, P_{Mu}$ represent the power margin of the downstream and upstream signal, and $P_{td}, P_{tu}$ represent the output power of the downstream and upstream OFDM signal. $G_{EDFA}$ represents the gain of the EDFA and $P_{sd}, P_{su}$ represent the sensitivity of the downstream and upstream receivers. $L_{Up}$ and $L_{Down}$ mean the power loss of the up and down links. According to the Chinese access network standard, when the distance exceeds 10km, there is no impact to system performance only the signal power margin should guarantee to more than 3dB.

The transmission performance of the back-to-back and after 25km transmission system is analyzed. The results of the relation between downstream OFDM signal’s SER and received power is shown as Fig 4. Generally the receiver sensibility requirement is about $10^{-3}$ for optical fiber communication system. When SER equals $10^{-3}$, the received power is -22.5dBm after 25km transmission and -24dBm of the back-to-back in the proposed system. The power penalty is 1.5dBm. The power penalty is due to the transmission loss and the dispersion caused by optical devices such as splitter and interference of the signal. Whether the power penalty is within the permitted rang can compare the power margin which be computed by Eq. 1 is greater than 3dB. When the power penalty is 1.5dB, the power margin of the system is about 7dB. It is greater than 3dB and meets the requirement of the system performance. In original system, the received power of downstream OFDM signal after 25km transmission is -22dBm. It is 0.5dBm greater than the proposed system. The SER in proposed system is obviously lower than original system with same received power. So the bit error rate performance in the proposed system is better than the original system.
The simulation results of received power and BER for downstream OFDM signal in back-to-back and after 25km transmission is shown as Fig. 5. When BER equals $10^{-12}$, the received power is -19.6dBm after 25km transmission and -20.5dBm in back-to-back. The maximum power penalty is 0.9dB and meets the system performance requirement. The BER after 25km transmission in proposed system is obviously greater than back-to-back with same received power. The downstream BER in both transmission mode is low and the quality of the signal is high. It can be used to input RSOA as the upstream carrier. The received power of downstream OFDM signal in original system after 25km transmission is about -18.6dBm, and it is 1dBm greater than the proposed system. The BER in proposed system is obviously lower than original system with same received power. It can be seen from above analysis that the proposed system can implement colorless ONU with improved downstream transmission performance.

The simulation results of SER with different SNR for downstream OFDM signal is shown as Figure 6. The performance of back-to-back is better than after 25km transmission. When SER equals $10^{-3}$, the SNR of the receiver for downstream signal is 3.3dB in back-to-back and 4.2dB after 25km transmission. The difference of the system required SNR is 0.9dB for two transmission mode. It is able to satisfy the system requirements and does not have great influence on system performance.

The transmission performance of WDM-OFDM-PON system for upstream signal with NRZ is shown as Figure 6. When BER equals $10^{-12}$, the received power is about -20.5dBm in back-to-back and -14.2dBm after 25km transmission. The maximum power penalty of upstream NRZ signal is about 6.3dB after 25km transmission. When BER equals $10^{-4}$, the received power is about -24.5dBm in back-to-back and -24.2dBm after 25km transmission. The minimum power penalty of upstream NRZ signal is about 0.3dB after 25km transmission. The BER and power penalty of the system...
transmission is within the bearable range, and the effect on the transmission performance is acceptable.

Summary
A WDM-OFDM-PON system with clipping pre-distortion and RSOA for colorless ONUs is proposed. The simulation results show that the transmission performance of the proposed system improves significantly than original system. The proposed system can guarantee the transmission performance with colorless ONUs and well recover the signal after 25km transmission. The quality of the upstream optical carrier is improved through better downstream signal in ONUs. So the WDM-OFDM-PON system will not cause system performance degradation because the quality of the signal, to realize the colorless.

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