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Experimental demonstration of an improved EPON architecture using OFDMA for bandwidth scalable LAN emulation

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ABSTRACT

We propose and demonstrate an improved Ethernet passive optical network (EPON) architecture supporting bandwidth-scalable physical layer local area network (LAN) emulation. Due to the use of orthogonal frequency division multiple access (OFDMA) technology for the LAN traffic transmission, there is no need to change the existing EPON architecture. Only one receiver at each optical network unit (ONU) is required to detect both LAN traffic and EPON downstream traffic, which makes the proposed system simple and cost-effective. Moreover, flexible assignment of LAN traffic bandwidth is realized by allocating different number of subcarriers or using different modulation formats. The 250 Mb/s 4-quadrature amplitude modulation (4-QAM) and 500 Mb/s 16-QAM OFDM LAN traffic are successfully emulated with the EPON traffic in our experiment.

1. Introduction

Ethernet passive optical network (EPON) has been widely accepted by many operators in the world for the development of optical access networks, and it is a future-proof solution for handling exponentially increasing data traffic such as Video Conferencing, Interactive Gaming, and Remote Education, etc [1]. Due to the widespread deployment of EPON, the demand for efficient point-to-point (P2P) communications among optical network units (ONUs) within EPON has shown rapid growth. For instance, different campuses or buildings in a university or an enterprise covered by the same EPON desire to establish a private local area network (LAN) to perform high-quality interactive video/audio, and other broadband applications. Moreover, in the field of large scale E-science, collaborative teams of scientists will also desire to share a large amount of data among scientific equipments located at different sites [2].

By adopting the multi-point control protocol (MPCP) in EPON according to IEEE 802.3ah, point-to-point emulation (P2PE) and shared-medium emulation (SME) can be implemented to realize inter-communications among ONUs [3,4]. Typically, MPCP requires high-layer bridges/routers at an optical line terminal (OLT) to reflect the data frames back to ONUs which results in wastage of up/downstream transmission bandwidth, longer LAN traffic delays, and higher processing complexity at the OLT. Several studies have already been performed to tackle these issues [5–8]. For example, a dynamic wavelength reflector is used in Ref. [5] to develop optical-layer LAN communications among different PONs at 10 Gb/s. Spectrally slicing and novel arrayed waveguide grating (AWG) wiring connections are used in Ref. [6] to build all-optical P2P connections between ONUs in wavelength division multiplexing (WDM) PON system. And an optical spectral-amplitude-coding (SAC) network has been proposed for high-speed IP routing and LAN emulation in Ref. [7]. Moreover, a star coupler-based PON using optical carrier sense multiple access with collision detection (CSMA/CD) is reported in Ref. [8] for local networking. All these schemes could support efficient and all-optical LAN emulation, but they use different types of PON architectures and protocols and may be not suitable for EPON system. However, there are some schemes which are proposed to implement efficient LAN emulation directly in the physical layer of EPON [9–12]. Additional reflective fiber Bragg gratings (FBGs) are placed close to the star coupler to directly reflect 155 Mb/s on-off keying (OOK) LAN traffic back in Refs. [9,10], these schemes suffer from high splitting loss as the optical LAN signal traverses through the power splitter twice. As an alternative, the schemes connecting each ONU to an M × N star coupler via two distribution fibers for separately transporting up/downstream traffic and 1 Gb/s [11] and 155 Mb/s [12] OOK LAN traffic with the employment of an optical switch (OSW) and FBGs are demonstrated. Nevertheless, these schemes mentioned above need

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the changes of the existing EPON architecture. In addition, the flexibility and scalability of the LAN traffic bandwidth allocation is limited in these schemes.

To address these limitations, in this paper, we propose an improved EPON (complying with IEEE802.3ah standard with 1000BASE-PX20 physical interfaces) system with simplified ONUs to provide efficient and bandwidth-scalable LAN capabilities among the customers, without changing the existing EPON architecture. In our system, orthogonal frequency division multiple access (OFDMA) is employed for LAN traffic transmission, thus the bandwidth of the LAN traffic could be flexibly adjusted by allocating different number of subcarriers or using different modulation formats. Moreover, due to the use of frequency division multiplexing (FDM) technology for the LAN traffic and EPON traffic, only one receiver is needed at each ONU, and the LAN traffic will not waste up/downstream transmission bandwidth. In this way, our scheme can provide more efficient and flexible LAN emulation while cost less. Furthermore, some low cost lasers, such as vertical cavity surface emitting lasers (VCSELs) [13] and reflective semiconductor optical amplifiers (RSOAs) [14], can be also potentially used in reality to transmit the LAN orthogonal frequency division multiplexing (OFDM) signals.

2. Operation principle of the proposed network

The proposed EPON architecture is shown in Fig. 1a. The OLT consists of an upstream receiver, a LAN traffic receiver and a downstream transmitter. λ_U = 1310 nm and λ_D = 1490 nm represent the wavelengths for the upstream and downstream traffic, respectively. The composite upstream traffic and LAN traffic are separated by a coarse wavelength division multiplexing (CWDM) filter. The detected LAN traffic is electrically combined with downstream traffic for delivery to the ONUs. An example of the optical spectrum allocation for the up/downlink is shown in Fig. 1a. At each ONU, there are a CWDM filter, a LAN traffic transmitter, an upstream transmitter and a downstream/LAN traffic receiver. An additional wavelength λ_{LAN} = 1520 nm is used for the LAN transmission, and is modulated by LAN OFDM signals. Due to the employment of this additional wavelength, OFDMA protocol could be used for the LAN traffic transmission, and several ONUs could be active for the LAN transmissions at a particular time. Moreover, the LAN traffic will not occupy the bandwidth of the up/downstream. Meanwhile, only one receiver is required to simultaneously detect the LAN traffic and downstream data at each ONU.

Fig. 1b displays the dynamic bandwidth allocation diagram of the LAN traffic. It clearly shows that the overall bandwidth of the LAN traffic in the proposed system can be divided into orthogonal OFDM subcarriers and time slots according to the OFDMA protocol. By allocating different time slots to each ONU or changing the modulation parameters of the OFDM LAN signals (such as the number of OFDM subcarriers and the modulation formats on these subcarriers) at the transmitter of each ONU, the bandwidth of the LAN traffic can be flexibly adjusted. For example, if a broadband light source is employed for the LAN traffic to reduce the optical beat interference [15], multi-ONUs occupying different subcarriers can transmit their LAN traffic simultaneously in a given time slot.

3. Experimental setup

The experimental setup of the proposed system and the details at the ONU_2 are shown in Fig. 2, and the blue dash line illustrates the P2P communication between the ONU_1 and ONU_2. By using an arbitrary waveform generator (AWG, Agilent N8241A), the OFDM LAN traffic data is generated with 256 orthogonal frequency subcarriers. Due to the bandwidth limitation of the used AWG, 4 or 16-quadrature amplitude modulation (QAM) at a total bit rate of 250 Mb/s or 500 Mb/s is used on each subcarrier with a pseudo random binary sequence (PRBS) word length of 2^{15}–1 in the experiment. In order to combine the LAN traffic and downstream at the OLT using FDM technology, this LAN traffic data is upconverted to a radio-frequency (RF) carrier at 6 GHz from a vector signal generator (VSG, Agilent E8267D), and then used to directly modulate a 1550 nm (instead of 1520 nm for demonstration purpose) distributed feedback (DFB) laser biased at −60.42 mA. Meanwhile, a lightwave is intensity modulated by a 1.25 Gb/s PRBS upstream signal with a word length of 2^{15}–1. For demonstration purposes, the lasers operating at 1530 nm for the upstream traffic and 1545.8 nm for the downstream traffic are used, instead of 1310 nm and 1490 nm. Subsequently, the combined optical upstream traffic and LAN traffic are launched into 22.8 km standard single-mode fiber (SSMF).

At the OLT side, the optical LAN traffic and upstream traffic are separately detected by two photodetectors (PDs) after a CWDM filter. The baseband upstream traffic is sampled by a digital storage oscilloscope (Agilent DSO91304A, DSO) with 13 GHz analog bandwidth, and then demodulated by a digital signal processing (DSP) receiver which includes filtering, reshaping and decision threshold functions. In the mean time, by using a lowpass filter (LPF) and an electrical combiner, the received LAN traffic is electrically combined with 1.25 Gb/s downstream. After an electrical amplifier (AMP), the composite signals are then modulated onto a 1545.8 nm lightwave at an intensity modulator (IM) biased at its quadrature point. Similarly, a DSP receiver is used to separate and demodulate the downstream and OFDM LAN traffic. At each ONU, only one PD is required to simultaneously detect the OFDM LAN traffic and downstream, and the LAN traffic will not occupy any up/downstream transmission bandwidth. Fig. 3 shows the electrical spectra of the composite signals of LAN and EPON traffic, as well as the separated OFDM LAN signals at the ONU_2.

4. Experimental results and discussion

Both 4-QAM and 16-QAM are used as LAN traffic emulator in our experiment. Fig. 4 shows bit-error-rate (BER) curves of the

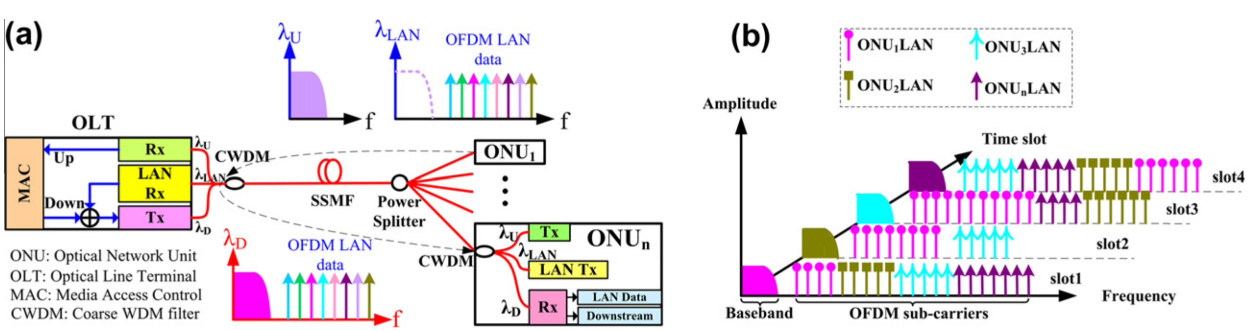

Fig. 1. (a) The proposed EPON architecture. (b) The bandwidth allocation diagram of upstream and LAN traffic.