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A low-overhead switched-mode Energy saving strategy for OFDMA-PON downstream transmission

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ABSTRACT

Green networks and energy saving have become important topics of worldwide concern and attracted intensive attention from both academia and industry. As orthogonal frequency division multiplexing access passive optical network (OFDMA-PON) employs more advanced and energy-consuming digital signal processing (DSP) techniques than other PON systems, it is of critical importance to improve the energy efficiency of OFDMA-PONs. In this paper, we propose a switched-mode energy saving strategy with low overhead for OFDMA-PON downstream transmission. By embedding information in the short training sequences (STSs) of the OFDM frame preamble, the STSs serve a twofold purpose: providing time synchronization and carrying the information with regard to the destination of the frame, hence eliminating the need for extra upper-layer control or information exchange between OLT and ONU. As STS is an inherent part of the OFDM frame, the proposed scheme requires little extra overhead in transmission time and hardware cost. The ONU continues the subsequent processing only when it is the intended receiver, while the unintended ONUs drop the frame and stands by to save energy. In order to achieve a tradeoff between energy saving and delay performance, the scheme switches between single-ONU mode and team mode where either a single ONU or a team of ONUs are the targeted receivers. We verify the feasibility of proposed scheme through experiments and evaluate the performance in terms of energy saving and packet delay by simulations. The results indicate that substantial energy can be saved compared with conventional OFDMA-PON systems.

1. Introduction

Telecommunication networks and broadband access consumes huge amount of energy [1–3]. It is worth noting that around 70% of overall Internet energy consumption is consumed by access network equipment [4]. With the ever-increasing data traffic demands, energy saving in access networks have become an important issue of worldwide concern in recent years. Passive Optical Network (PON) is considered as one of the most power-efficient solutions in terms of energy consumption per transmission bit [5]. In particular, orthogonal frequency division multiplexing access PON (OFDMA-PON) has emerged as an attractive candidate for next-generation broadband optical access due to its numerous advantages such as high spectral efficiency, strong robustness to chromatic dispersion, and great flexibility in dynamic bandwidth allocation [6,7]. Several OFDMA-PON systems capable of ultra-high data rates have been reported and demonstrated [8,9].

Like other PONs, the optical line terminal (OLT) and optical network units (ONUs) are the active equipments in OFDMA-PON. With the increase of the number of subscribers, ONUs located at the user premises dominate a major portion of the overall power consumption. Furthermore, the ONUs in OFDMA-PON employ a great number of advanced and energy-consuming digital signal processing (DSP) components [10], such as the energy-intensive fast Fourier transform (FFT) module. As a result, ONU side energy saving is a challenging and critical task for OFDMA-PON.

Substantial efforts have been devoted to making PON more energy-efficient during past years. Among the existing approaches, a class of schemes based on the use of sleep/doze modes has been proposed, which turns off the transmitter and/or receiver of idle ONUs to save energy [11,12]. Lately, the sleep mode mechanism has been applied to OFDMA-PON [13]. However, such schemes induce a service disruption risk when downstream traffic arrives and require a very precise sleep control. To convey the accurate power-on/off time indication, there is an inevitable increase in MAC control cost, such as new protocol data units (PDUs)

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introduced in the three-way handshake process between OLT and ONUs [11].

Meanwhile, from the perspective of physical layer, several schemes for improving the energy efficiency of OFDMA-PON have been proposed by taking the inherent features of OFDM into account [10,15,16]. The main idea is to adaptively enable/disable processing modules according to the dynamic network load. For example, the energy-efficient OFDM transceiver proposed in [15] adaptively tunes the signal bandwidth and sampling rate, and selectively powers off individual block of parallel modules based on instant traffic load. Similarly, in [10], the authors propose a modular DSP design for both OLT and ONUs. The DSP modules are adjusted or switched-off when lower bit rates are required. While in [16], a time-domain interleaved OFDM technique is proposed to reduce the power consumption of OFDM-PONs by reducing the sampling rate and the FFT size of the ONUs. Note that such solutions pose challenges to implementation as it requires special design for the hardware architecture.

More recently, in Ref. [17], the authors propose an energy-efficient selective sampling receiver for OFDMA-PON, which only samples when the incoming data is targeted to the ONU and stays in standby during the rest of the time. Nevertheless, the energy saving comes at a cost as specially arranged orthogonal pseudorandom noise (PN) sequences need to be added in the frame head to identify the intended ONU.

In this paper, we focus on reducing the power consumption of the ONUs for OFDMA-PON downstream transmission and propose a switched-mode energy saving strategy. To the best of our knowledge, this is the first work to leverage on the short training symbols (STS), which is an inherent part of an OFDM frame, to achieve energy saving without extra cost in transmission of MAC control message or overhead in the frame head. The proposed scheme switches between two modes according to the incoming traffic status to obtain a trade-off between energy-efficiency and packet delay performance. It is shown that ~70% energy saving can be achieved on the ONU side during the downstream transmission compared to conventional OFDMA-PONs under heavy traffic load.

2. Proposed energy saving scheme

2.1. Energy-efficient receiving modes

In this paper, we propose two energy-efficient receiving modes for OFDMA-PON downstream transmission, including single-ONU mode and team mode. As shown in Fig. 1, the ONUs marked in yellow are the intended receivers.

Under single-ONU mode, each ONU is treated as an independent entity, and the frame is destined to only one particular ONU. While under team mode, the ONUs are divided into several teams. M ONUs form a team and share a common team identification number. The OLT packs downstream data destined to ONUs in the same team and form a complete OFDM frame to be transmitted. The frame is destined to all the M ONUs belonging to the intended team. The system can switch between the two modes to meet different requirements of energy saving and delay under various scenarios.

Under team mode, OFDMA is realized within a group of ONUs. The available bandwidth can be shared with dynamic bandwidth allocation among individual ONUs under the same team. Note that, when M takes the value of the total number of ONUs N, the proposed scheme is reduced to conventional OFDMA-PON. On the other hand, single-ONU mode can be seen as a special case of team mode with $M = 1$. This mode compromises the fine granularity feature in resource allocation of OFDMA and is suitable for scenarios where energy saving holds priority over bandwidth allocation flexibility. Therefore, by setting the numbers of ONUs per team, a tradeoff can be achieved between energy saving and flexibility of OFDMA.

2.2. Physical layer data frame format

The proposed frame structure with specially designed preamble used in this work is shown in Fig. 2. The preamble consists of 10 cycles of short training sequence (STS) of 16 samples and 2 identical long training sequences (LTS) of 64 samples preceded by a

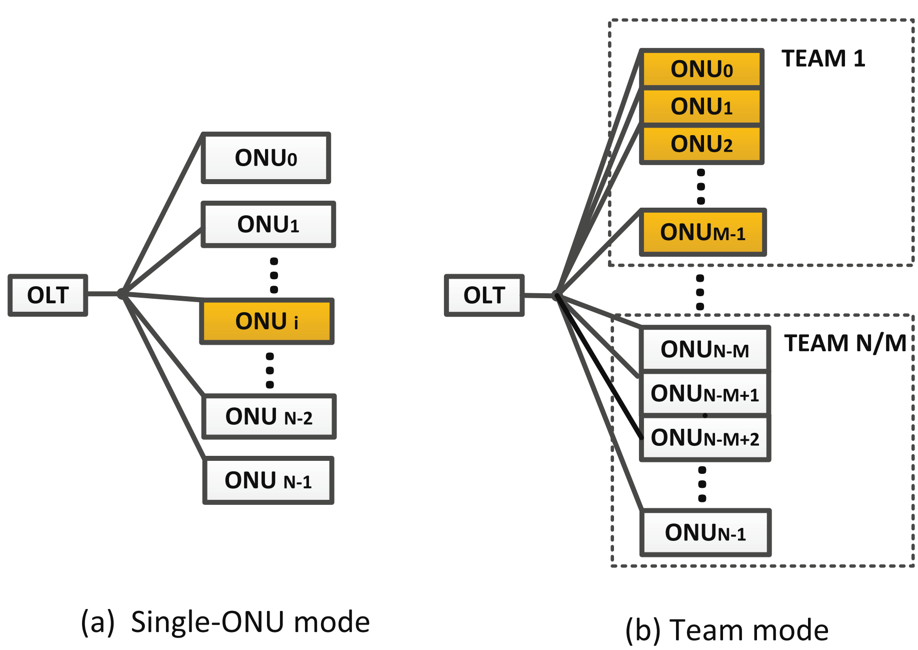

Fig. 1. Structure of two energy-efficient modes.