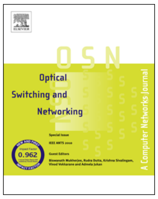
Optical Switching and Networking 18 (2015) 169–179

Contents lists available at ScienceDirect

Optical Switching and Networking

journal homepage: www.elsevier.com/locate/osn



Energy efficient dynamic bandwidth allocation for Ethernet passive optical networks: Overview, challenges, and solutions[☆]

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ARTICLE INFO

Article history:
Received 3 June 2013
Received in revised form
1 May 2014
Accepted 6 May 2014
Available online 14 May 2014

Keywords:
Dynamic bandwidth allocation
Energy efficiency
EPON
Optical access

ABSTRACT

Energy efficiency and green communications have become well-established themes for next-generation communications systems, with specific regard to reducing carbon footprint, lowering environmental impact, and minimizing operational expenditures. Apart from conforming to the required societal green agenda, there are also many practical and financial advantages to creating solutions that exhibit such benefits. Extending the advantages of energy efficiency to access networks is paramount as it is the major contributor of energy consumption in the Internet. Among the various factors of energy consumption in access networks, optical network units (ONUs) at the customer's premises consume the bulk of energy: ONUs consume about 60–70% of the energy consumed in current fiber-to-the-home networks. In this paper, we propose a dynamic bandwidth allocation (DBA) algorithm for Ethernet passive optical networks (EPONs). The DBA algorithm exploits the sleep mode functionality, in which the optical network unit (ONU) is put into sleep according to the traffic load of the ONU. We explore the DBA paradigm for two kinds of ONUs: legacy (with large sleep overheads) and next generation (with small sleep overheads). We also extend the DBA algorithm with a variety of grant sizing (bandwidth allocation) schemes. The DBA algorithm achieves significant power savings in comparison to traditional power-ignore DBAs.

1. Introduction

Expected global energy demand is growing faster than 2% per annum [1], and will most likely become unattainable in the years to come. Among others, one of the factors leading to the upsurge in the energy needs of society is the continuous colossal growth in the information and communication technology (ICT) sector, particularly the Internet. Today, the ICT and the Internet are the important constituent factors of power consumption; and they account for approximately 5% and 1% respectively of the total electrical power consumption in developed economies [2]. However, the contribution of the ICT and the Internet will continue to become more crucial in the coming years because of today's always-online behavior of users and the continual emergence of bandwidth absorbing applications. It is estimated that a substantial increase of electric power of 20 TWh per annum is required, and this is approximately 8–10% of the total generated power for the ICT [3]. Such a high increase in energy consumption not only poses a serious threat of the

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[☆] A short summarized version of this paper was presented at the IEEE Advanced Networks and Telecom Systems (ANTS) 2012 Conference in Bangalore, India, in December 2012.

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http://dx.doi.org/10.1016/j.osn.2014.05.006
1573-4277/

scarcity of energy but also increases the consumption of hydrocarbon fuels leading to the emissions of greenhouse gases, which have serious environmental impacts. This has forced the scientific community to solicit the measures of energy efficiency, and now green communication is a well-nurtured theme.

Out of the total Internet power consumption, access networks consume about 80–90% of the power, and an optical network unit (ONU), installed at a customer's premises, accounts for about 60–70% of the energy consumed in current fiber-to-the-home (FTTH) networks. Thus, designing energy-efficient access networks can reduce the appalling requirements of energy production and its environmental connotations, and can lead to significant economic dividends. Passive optical networks (PONs) are presently considered as a promising technology to deliver high data rates to users, and are inherently more energy efficient than their previous counterparts (e.g., ADSL and VDSL) [4]. Ethernet PON (EPON), which is an important candidate of PONs, has been widely deployed in Japan and Korea, and is the focus of this paper.

Many efforts have been made to minimize the power consumption of ONUs. An actively considered solution is the implementation of low power modes, in which some ONU functionalities are powered down if they are temporally not used [5]. An important example of a low power mode is sleep mode [6,7].

In paper [8], we proposed the sleep mode aware (SMA) dynamic bandwidth allocation (DBA) algorithm that slots the activity period of every ONU, only during which an ONU needs to wake up to transmit and receive packets. In this paper, we extend the evaluation for two kinds of ONUs: ONUs with latest technology use, referred as next generation (NG-ONUs), and ONUs that are already deployed, referred as legacy (L-ONUs). NG-ONUs can use the latest innovations in receiver and transmitter designs and will have minimal overheads (few microseconds). On the other hand, L-ONUs will suffer from large sleep overheads (few milliseconds). The challenges in designing DBA algorithm for both kinds of ONUs are different. NG-ONUs require frame-by-frame (or cycle-by-cycle) sleep control whereas L-ONUs require longer sleep time. Depending upon the network load, the proposed solution achieves energy savings of about 70–80% for NG-ONUs and of about 30–70% for L-ONUs.

The remainder of this paper is organized as follows. We discuss the overview and the requirements of sleep mode in EPON in Section 2. In Section 3, we introduce the energy efficient DBA algorithm. Section 4 gives the simulation results and finally Section 5 concludes the paper.

2. Overview of low power mode in EPONs

In this section, we give an overview of EPON (Section 2.1), present benefits and requirements of sleep mode (Section 2.2) in EPON, discuss various low power modes (Section 2.3), outline the architectural challenges in the implementation of sleep mode (Section 2.4), and then describe the energy efficient DBA algorithms (Section 2.5).

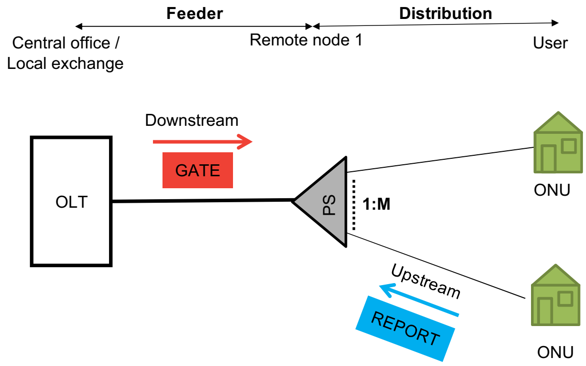

Fig. 1. A typical architecture of a TDM-PON, like EPON.

2.1. EPON

An EPON is a point-to-multipoint fiber optical network with only passive elements in the optical distribution network (ODN), i.e., between an optical line terminal (OLT) at the central office (CO) and the ONU (Fig. 1). The most typical EPON architecture is based on a tree topology, with the OLT as the root of the tree and the ONUs as the leaves, connected over a passive power splitter. Sometimes, even a two-stage of splitting may be used. The distance between the OLT and each ONU typically ranges between 10 and 20 km. The upstream (ONUs to OLT) and downstream (OLT to ONU) transmission channels are separated by using wavelength division multiplexing (WDM). Typically, a 1550 nm wavelength is used for downstream transmission and a 1310 nm wavelength is used for upstream transmission.

In the upstream direction, an EPON is a multipoint-to-point network, in which multiple ONUs transmit data to the OLT through the 1:M passive combiner. Since all ONUs share the same upstream transmission medium, an EPON employs a medium access control (MAC) protocol, called multi-point control protocol (MPCP), to arbitrate the access to the shared medium in order to avoid data collisions in the upstream direction. The ONU sends REPORT messages requesting bandwidth based on its queue size, and the OLT sends back a GATE message to the ONU informing the allocated bandwidth. Several DBA algorithms have been proposed for facilitating this bandwidth access, and Interleaved Polling with Adaptive Cycle Time (IPACT) [9] is the most important example, in which the polling of each ONU is interleaved, i.e., the next ONU is polled before the transmission from the previous one has arrived at the OLT.

In the downstream direction, an EPON is a point-to-multipoint network, in which the OLT broadcasts data to each ONU on a first come first serve (FCFS) basis through the 1:M power splitter. Each ONU extracts the data destined for it based on its MAC address. Due to this FCFS transmission, an ONU has to continuously probe the packets destined to it, and this leaves no opportunity to sleep. Therefore, new DBA algorithms are required that can impart sleep efficiency in EPONs.