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On the efficiency and fairness of dynamic wavelength and bandwidth allocation algorithms for scheduling multi-type ONUs in NG-EPON

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ABSTRACT

In the Next Generation Ethernet Passive Optical Network (NG-EPON), Optical Network Units (ONUs) can work on multiple wavelengths simultaneously to achieve higher peak rates. There are three types of ONUs (25G, 50G and 100G ONUs) sharing all the 100 Gb/s bandwidth. Each type of ONUs has a total bandwidth constraint due to ONUs' working wavelength capabilities. In this paper, we investigate the fairness and efficiency of dynamic wavelength and bandwidth allocation (DWBA) algorithms for scheduling multi-type ONUs while considering their bandwidth capacity constraints. Proposed DWBA algorithms can achieve high efficiency, excellent fairness as well as good wavelength load balancing.

1. Introduction

To meet the continuously increasing bandwidth demand of optical access networks, the IEEE initializes the 802.3ca task force to study the Next Generation Ethernet Passive Optical Network (NG-EPON) [1]. NG-EPON can provide up to 100 Gb/s access data rate by stacking four 25 Gb/s wavelength channels. Meanwhile, in order to promote peak data rates, Optical Network Units (ONUs) are enabled to bundle multiple wavelength channels and transmit data on multiple wavelength channels simultaneously [2]. Distinguished by the capable wavelength amounts, there are three types of ONUs, namely 25G ONUs, 50G ONUs and 100G ONUs [3]. Specifically, 25G ONUs, 50G ONUs and 100G ONUs are equipped with 1, 2 and 4 fixed transceivers respectively as shown in Fig. 1(a). The coexistence of multi-type ONUs brings challenges to many PON functionalities such as dynamic wavelength and bandwidth allocation (DWBA) in the Optical Line Terminal (OLT). In the conventional EPONs, including 1G-EPON [4] and 10G-EPON [5], ONUs only work on one wavelength in the upstream and the wavelength allocation is not considered. However, in the NG-EPON, ONUs work on multiple wavelengths and the wavelength capabilities of each type of ONUs are different. DWBA needs to take charge of bandwidth allocation as well as wavelength allocation under such complicated conditions. When allocating bandwidth for each ONU, DWBA must consider the bandwidth capacity constraint for each type of ONUs. Specifically, 25G ONUs work on wavelength λ_1, 50G ONUs work on wavelength λ_1 and λ_2, and 100G ONUs work on wavelength λ_1, λ_2, λ_3 and λ_4. Accordingly, the total bandwidth of 25G ONUs should not exceed 25 Gb/s, the total bandwidth of 25G and 50G ONUs should not exceed 50 Gb/s, and the total bandwidth of all the ONUs should not exceed 100 Gb/s. DWBA allocation should meet these bandwidth capacity constraints. Meanwhile, the bandwidth utilization as well as fairness should also be taken into account. As shown in Fig. 1(b), allocating each ONU with small bandwidth could meet the capacity constraints while the bandwidth utilization is pretty small, which causes huge bandwidth waste. If we enlarge the bandwidth allocated to each ONU, the bandwidth utilization can be improved and the capacity constraints are still satisfied. However, unfair bandwidth distribution could cause bandwidth monopoly by some ONUs. For example, 100G ONUs monopolize the overwhelming bandwidth while 25G ONUs and 50G ONUs are starving. Such bandwidth allocation greatly impairs the fairness among all the ONUs. Therefore, DWBA in NG-EPON should allocate wavelength and bandwidth to these multi-type ONUs efficiently and fairly within the bandwidth capacity constraints, which is challenging and worthy of study.

There exist many bandwidth allocation algorithms for EPONs, which can be classified by different dimensions (grant scheduling framework, grant sizing policy and grant scheduling policy) [6]. Among them there are many algorithms allocating bandwidth fairly between ONUs, and most of them originate from [7,8]. However, these DBA algorithms are designed for 1G-EPON and 10G-EPON, which have only one wavelength and only one type of ONUs (in terms of working wavelength amount). As for the multi-wavelength NG-EPON, there are several literature about DWBA algorithms in recent years. Literature [9,10] investigates a next-generation wavelength-agile PON where a flexible number of wavelengths can be assigned to one ONU. All the ONUs have the same flexibility of wavelength amount. A water-filling DWBA is proposed to reduce the delay by allocating ONU's bandwidth to each capable wavelengths like filling water into depression

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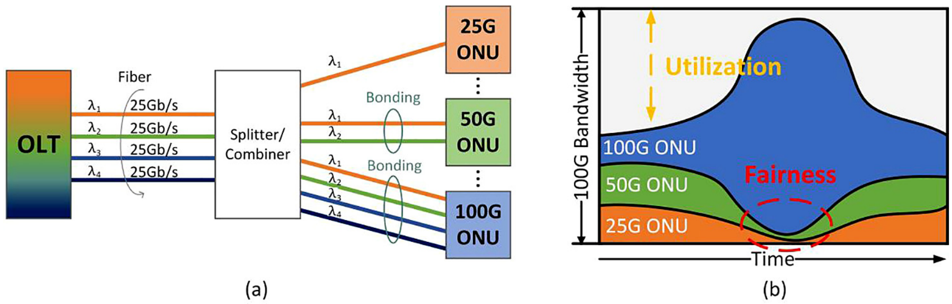

Fig. 1. (a) NG-EPON with multi-type ONUs; (b) problem of utilization and fairness in NG-EPON bandwidth allocation for multi-type ONUs.

storages. Literature [11] studies the DWBA algorithm for NG-EPON ONUs with four wavelengths. Different from [9,10], literature [11] allocates ONU's bandwidth in the earliest available wavelength each time. Such first-fit single wavelength allocation reduces occurrences of guard time, thus reducing the delay. Literature [12] studies the problem of frame reordering caused by parallel transmission in NG-EPON and proposes a DWBA algorithm to reduce the number of ONUs suffering frame reordering. All the NG-EPON DWBA algorithms mentioned above only consider scheduling single type of ONUs with uniform wavelength capability. Due to channel bonding, there can be several types of ONUs with different wavelength capabilities coexisting in single NG-EPON system. We first studied the problem of scheduling NG-EPON multi-type ONUs with different wavelength capabilities. A fair and flexible DWBA algorithm for scheduling NG-EPON multi-type ONUs is proposed in [13]. In this work, we extend our research on the problem of scheduling multi-type ONUs in NG-EPON. We mathematically model the problem of scheduling multi-type ONUs in NG-EPON and design DWBA algorithms by carefully considering efficiency, fairness and load balancing. We decompose the DWBA into bandwidth allocation step and wavelength allocation step. Several bandwidth allocation algorithms and wavelength allocation schemes are proposed. We conduct simulation experiments to evaluate the performances (in terms of throughput and packet delay) of proposed DWBA algorithms.

The rest of the study is organized as follows. In Section II, we mathematically model the problem of scheduling multi-type ONUs in NG-EPON. In Section III, we decompose DWBA into bandwidth allocation and wavelength allocation. We propose two fair and efficient bandwidth allocation algorithms and three wavelength allocation schemes. In Section IV, we conduct simulation experiments for numerical study. Section V concludes this work.

2. Mathematical model

Generally, there are two major kinds of ONU scheduling mode, i.e., online and offline scheduling. Online scheduling makes wavelength and bandwidth decision for an ONU instantly after receiving its bandwidth request. Offline scheduling makes wavelength and bandwidth decision after all the ONUs' bandwidth requests are collected. Compared with online scheduling, offline scheduling that schedules ONUs based on global bandwidth request information can make a more comprehensive, fair and efficient bandwidth allocation decision. Therefore, we consider offline scheduling in this study.

Similar to that in 10G-EPON, the bandwidth negotiation in NG-EPON is implemented in a request-and-grant way. ONUs report their bandwidth request to the OLT by sending REPORT messages. Considering that an ONU may be allocated with multiple transmission timeslots on different wavelengths, the REPORT message is sent at the end of transmission timeslot with the latest finishing time. After collecting REPORT messages from all the ONUs, the DWBA allocates wavelength and bandwidth to each ONU and send GATE messages containing transmission start time and granted bandwidth size on each wavelength to all the ONUs. When DWBA makes wavelength and bandwidth allocation decision for multi-type ONUs, three important criteria need to be considered. The first one is bandwidth utilization or efficiency, which needs to be maximized as possible. The second one is fairness among all the ONUs. ONUs should share the total bandwidth in a fair manner. Heavy-loaded ONUs should not monopoly all the bandwidth while light-loaded ONUs are starving. The third consideration is the load balancing between wavelengths. In order to achieve smaller cycle size and reduce average packet delay, the bandwidth distribution among all the wavelengths should be as even as possible.

In this work, a NG-EPON system serving N ONUs with W wavelengths is considered. Each wavelength works at the rate of C. ONUs are equipped with transceivers working on some of the W wavelengths. A symbol $O_{i,w}$ is used for representing ONU's wavelength capability. $O_{i,w} = 1$ means ONU i is able to work on wavelength w. $O_{i,w} = 0$ means ONU i isn't able to work on wavelength w. The ONUs' types reflect on the different combinations of $O_{i,w}$. The work of DWBA is scheduling data transmissions for these multi-type ONUs, including transmission wavelengths and bandwidth allocated to each wavelength. In order to differentiate ONUs with different Service Level Agreements (SLA), a weight ϕ_i representing ONU's bandwidth right is introduced. Assuming each ONU requests for bandwidth R_i, DWBA needs to decide the bandwidth allocated to each wavelength according to R_i. We use a non-negative variable $B_{i,w}$ to represent bandwidth allocated to ONU i on wavelength w. The problem of scheduling multi-type ONUs in NG-EPON can be described as follows:

1) ***Given***
- W: set of wavelengths $\{\lambda_1, \lambda_2, ..., \lambda_w\}$.
- C: line rate of each wavelength.
- N: set of ONUs.
- L: maximum cycle length.
- $O_{i,w}$: a binary value representing whether ONU i can work on wavelength w, 1 for yes, 0 for no.
- R_i: bandwidth request of ONU i.
- ϕ_i: bandwidth allocation weight of ONU i, depending on SLA.

2) ***Variables***
- $B_{i,w}$: bandwidth allocated on wavelength w for ONU i.

3) ***Objectives***

Maximize bandwidth utilization:

$$\text{Maximum} \sum_{i,w} B_{i,w} {*} O_{i,w} \tag{1}$$

Maximize weighted-based fairness:

$$\text{Maximum} \frac{\left(\sum \frac{\sum_{w} B_{i,w} * O_{i,w}}{\phi_i} \right)^2}{N \sum \left(\frac{\sum_{w} B_{i,w} * O_{i,w}}{\phi_i} \right)^2} \tag{2}$$