Novel DBA algorithm for Energy Efficiency in TWDM-PONs

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Abstract Time and wavelength division multiplexed passive optical networks (TWDM-PONs) have been widely accepted as a next generation optical access (NGOA) solution. We propose a novel dynamic bandwidth allocation (DBA) algorithm for energy efficiency in TWDM-PONs.

Introduction

Next generation optical access (NGOA) networks are required to replace aging access networks to provide higher data rates to users. An important candidate that has been widely envisioned as an NGOA solution is time and wavelength division multiplexed passive optical network (TWDM-PON). TWDM-PON provides a higher data rate and has potential to save significant amount of energy, emphatically important with current access networks (including customer's premises equipment) consuming about 80 % of the energy consumed in the Internet. In this paper, we focus on the data link approaches to save energy in TWDM-PONs: both in the optical line terminal (OLT) and optical network units (ONUs).

TWDM-PON

In 2011, full service access network (FSAN) has initiated an effort to investigate NGOA architectures, and adopted TWDM-PON as the future NGOA architecture[1]. TWDM-PON stacks four XG-PONs using WDM, and increases upstream and downstream capacity (Fig. 1).

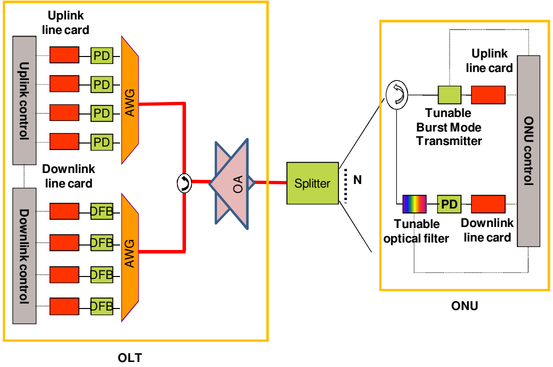


Fig. 1: Architecture of a stacked TWDM-PON. Abbreviations used in the figure: DFB=distributed feedback laser, PD =photodiodes, AWG = arrayed waveguide grating, OA = Optical amplifiers

Energy saving algorithms

TWDM-PON opens up interesting vistas to save energy, both at OLTs and ONUs. The wavelengths at the OLT can be used at high utilization by turning off idle ones, and ONUs can exploit sleep modes[2] due to a bursty and slotted transmission in TDM. Nevertheless, it requires a dynamic bandwidth allocation (DBA) algorithm to minimize the performance degradation due to possible enlarged delays. To minimize the complexity of scheduling, we use a disjoint upstream and downstream scheduling algorithm. We proposed the sleep mode aware[2] (SMA) algorithm to exploit sleep modes, particularly for EPON or for static TWDM-PONs (where a group of ONUs specifically uses a wavelength pair for upstream and downstream, and this cannot be rearranged, for example with a changing traffic demand). In this paper, we propose the hybrid SMA (HSMA) algorithm, which extends the concept of SMA in flexible TWDM-PONs.

Hybrid Sleep Awareness Algorithm:

HSMA adopts two phase scheduling: wavelength minimization and assignment (WMA) and time slot assignment (TSA). WMA tackles variability in traffic over a period of time, whereas TSA distributes bandwidth among ONUs on a per cycle basis.

WMA: In WMA, the number of wavelengths and the users on a wavelength are determined after a fixed time T. T can be fixed based on the choice of an operator and the variability in the traffic use: if T is large (12 hours), then WMA is on a day-night basis, and a small T (2 ms) tackles a more rapid variation in traffic. Note that a smaller T follows traffic more precisely and will harness better energy efficiency gains. Conversely, it induces penalties of large tuning times (TTs) that an ONU suffers as a result of hopping on to a different wavelength. Thus, it is important to ensure the fair selection of the ONUs that will hop on during a next frame (or WMA).

We use the number of wavelengths (N_w) according to the load as $N_w = \left\lceil \sum_{i=1}^{N} B_i \Big/ T.\lambda_d \right\rceil$,where B_i is the sum of requested data (in bits) of ONU i over a period of T, N is the number of ONUs and λ_d is the data rate (bits/second) of each wavelength. After deciding the number of wavelengths, another challenge is the ONUs' assignment on wavelengths that maintains evenly loaded wavelengths, while being fair to the ONUs. The ONUs are assigned on the wavelengths in a round robin manner. In a time frame *n,* the round is initiated by the ONU with id *n* modulo *N* (Fig. 2*)*. This is done to ensure uniform distribution of wavelength switching (or tuning times) among ONUs. An ONU is assigned to a wavelength if the normalized load of the ONU is smaller than twice the remaining capacity (where the remaining capacity is the difference between the normalized $\sum_{i=1}^{N} B_i \Big/ T.\lambda_d.N_w$ and the already assigned capacity) on the wavelength; otherwise it is deferred to the subsequent wavelength. After assignment of ONUs on a wavelength, the normalized load of other (remaining) wavelengths is updated according to the under- or over-utilization of the wavelength.

Fig. 2 shows that in a frame n, four wavelengths are used, and the round starts with ONU 1. In the next frame, due to a lower load, one wavelength is switched off, and the ONU assignment starts with ONU 2. Note that using a minimal number of wavelengths still satisfying the requirements of all ONUs is a bin-packing problem, which ideally requires complex heuristics (NP-hard) to optimally assign ONUs to wavelengths. In addition, the heuristics may cause some ONUs (lightly loaded) to switch more than the others causing fairness problems. Our proposed algorithm maintains simplicity and fairness; however, it may lead to more loaded wavelengths increasing delays (still less than the state-of-the-art earliest finish time (EFT) algorithm, Fig. 5).

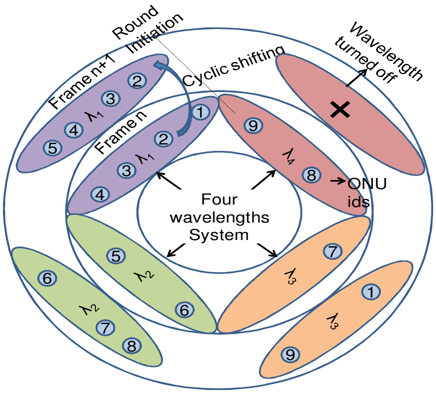


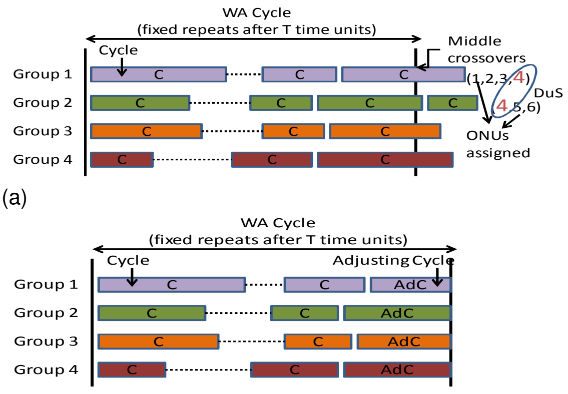
Fig. 2: Wavelength assignment and grouping in the proposed algorithm.

TSA: Within a WMA frame, the various ONUs' groups (the ONUs on a same wavelength) are assigned TDMA cycles using the SMA with up- and downstream centric (UDC)[2] algorithm. SMA-UDC proposes to transmit the up- and downstream traffic of an ONU at the same time for maximal energy efficiency[2] (sleep period). This entails that the ONUs be grouped identically in the up- and downstream direction: segmenting TWDM-PON into logical TDMA PONs, where a group of ONUs uses the same up- and downstream wavelength. However, due to a different load profile, the grouping of ONUs (according to WMA methods) in up- and downstream direction may be different. As a result, whichever grouping (based on down- or upstream) induces a lower peak-normalized load on a wavelength is chosen for both the directions. Note that a contrary approach can be to select the grouping according to higher wavelength utilizations: reaping higher energy efficiency at the risk of enlarging delays.

Another challenge is to keep the TDMA cycle assignments within a WMA frame. Given the varying lengths of TDMA cycles and a fixed T (Fig. 3), this is not guaranteed per se. Unchecked TDMA cycles may cross the time epoch of wavelength assignments (Fig. 3), and may lead to problems of duplicated scheduling (DuS) as an ONU may get assigned to two wavelengths at the same time: one in the cycle (C) of the previous frame, and the other in the cycle of a new frame. For example, ONU 4 may be scheduled in two wavelengths at the same time (Fig. 3). To solve this problem, we introduce adjusting cycles (AdC). Whenever, the remaining scheduling length R_l of the frame becomes shorter than the maximum cycle length C_{max}, the OLT distributes R_l among all ONUs in the ratio of their requested windows (REPORTs). Should the REPORT from an ONU not arrive at the time of the start of an AdC, the previous requested window is adopted (exploiting the fact that traffic is bursty and traffic requests from an ONU repeat for some cycles). In addition, in the AdC, the ONUs are informed of their next grouping and the up- and downstream wavelengths they need to use.

Advantages of the proposed scheme with conventional approaches

To the best of our knowledge, this is the first paper which combines the energy efficiency due to sleep modes at ONUs and the energy savings due to shutting down idle transceivers at the OLTs. Moreover, it decouples the wavelength assignment from TDMA assignment and removes complexity in scheduling, leading to a lower processing requirement. The joint time and wavelength scheduling (JTWS) has been proposed in[3]. However, JTWS approaches like EFT are only concerned with minimizing delays and lead to unlimited wavelength switching at ONUs leading to large delays due to TT at ONUs; the TT can be as large as 10 ms.



(a)

(b)

Fig. 3: The problem of middle crossovers and duplicated scheduling (DuS) in (a) and solution by introducing the concept of AdC in (b).

Simulation Results

In OPNET, we study the performance of HSMA by conducting a simulation of a TWDM-PON with 512 ONUs, and four wavelengths in each direction. We assumed a maximum ONU load of 100 Mbps, downstream and upstream line rate of 10 Gbps and 2.5 Gbps, maximum OLT to ONU distance of 20 km, maximum cycle time of 2 ms, ONU buffer of 1 MB, T as 0.1s, TT of ONUs as 1 ms, ONU power as 80% of the total (OLT+ONU) power, power in sleep mode as 15% of the active ONU power, and guard time between adjacent ONU slots as 1 µs. We generated traffic as in[2]. The up- and downstream normalized load is considered to vary symmetrically. In results, only upstream delay (the highest of the two) is plotted.

The energy consumption and capacity usage are shown in Fig. 4. The energy consumption is reduced to an average of 31% compared to the case when there is no saving at the OLT or ONUs. At very small loads, the sleep mode periods are worse as cycle times are short, leading to frequent ONU wake ups.

We compare the delay performance of HSMA with EFT, with and without WM (wavelength minimization). We use all 4 wavelengths for “without WM” scenarios. Further note that, in EFT, ONU grouping is not required as the users are not assigned on a wavelength per frame but per cycle. In addition, EFT-WM also suffers from middle crossovers and thus AdC is used for them. Delay performance is shown in Fig. 5. The delay oscillates because the normalized load oscillates due to the addition and deletion of wavelengths. For example, when network load is 0.2, only one wavelength is used and the normalized load is 0.8. However, as soon as the load crosses 0.25, most of the time 2 wavelengths are used, leading to a normalized load of 0.5. Hence, though network load always increases, normalized load oscillates, leading to an oscillating delay performance. Moreover, the delay performance of HSMA without WM and with WM is improved compared to EFT counterparts due to an excessive wavelength switching in EFT.

Lastly, the delay performance is shown with the variation in T and TT at the normalized load of 0.4 (Fig. 6). As TT increases, delay increases. However, increasing T has two different effects. First, as T increases, degradation due to TTs minimizes and secondly the network response to burstiness of traffic decreases. Due to these two counter effects, the optimal value of T is found as 0.1 s.

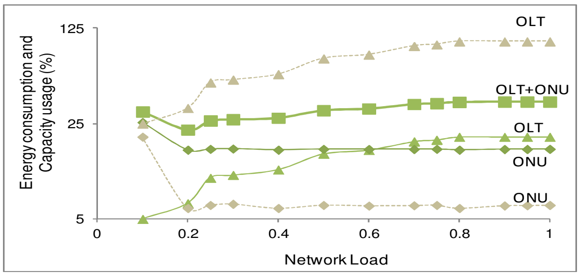


Fig. 4: Energy consumption (solid lines) and capacity usage (dashed lines) in HSMA

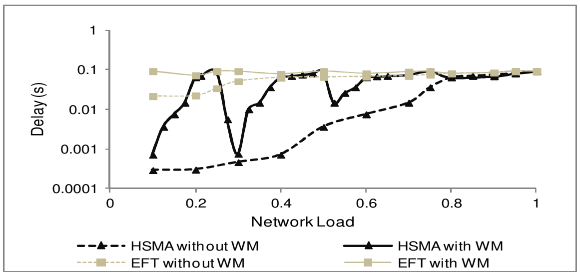


Fig. 5: Delay with and without WM in HSMA and EFT

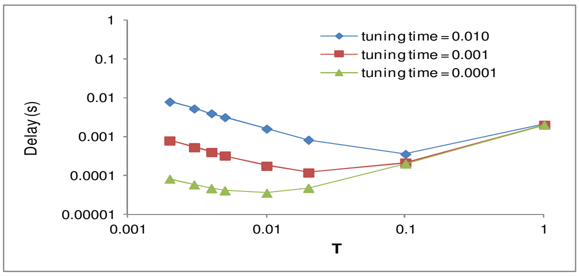


Fig. 6: Delay with a variation in TT and T.

Conclusions

We proposed the HSMA algorithm which combines the energy efficiency due to sleep modes and the load dependent use of transceivers at the OLT. Due to this, the average energy consumption is reduced to 31%. In addition, the delay is reduced in HSMA compared to conventional algorithms like EFT.

References

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[2] A. Dixit et al., Optics express, 20 (26) (2012).
[3] K. Kanonakis et al., JSAC 28 (6) (2010).