Contemporary Engineering Sciences, Vol. 7, 2014, no. 23, 1303 - 1311
HIKARI Ltd, www.m-hikari.com
http://dx.doi.org/10.12988/ces.2014.49161

Energy Efficient Dynamic Wavelength and Bandwidth Allocation for TWDM PON

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Abstract

This paper proposes a new dynamic bandwidth and bandwidth allocation (DWBA) algorithm for energy saving in time and wavelength division multiplexing passive optical networks (TWDM PONs). Decreasing the number of active upstream wavelengths, the proposed algorithm not only saves power but also provides good efficiency for TWDM PON systems. Using simulations, we evaluate performance of the proposed algorithm under self-similar traffic.

Keywords: TWDM, PON, DWBA, power saving

1 Introduction

Time and wavelength division multiplexing passive optical network (TWDM PON) is a solution for next generation PON stage 2 (NG-PON2) that supports 40 Gbps in the upstream and 10 up to 40 Gbps in the downstream [1]. A TWDM PON consists of an optical line termination (OLT) and a number of optical network units (ONUs). Also multiple wavelengths are used in both upstream and downstream directions. In the downstream direction, broadcasting is used to transmit packets from an OLT to ONUs. In the upstream direction, the OLT performs a dynamic wavelength and bandwidth allocation (DWBA) to dynamically assign an upstream wavelength and to dynamically allocate a non-overlapping transmission slot to each ONU.

Access networks consume about 80% of the energy consumed in the Internet

[2]. A TWDM PON system has potential for saving energy since it uses multiple wavelengths and many ONUs. Most of DWBA algorithms of TWDM PON systems are focused on quality-of service (QoS) such as a mean delay and a pack loss rate [3][4][5]. The energy consumption is proportional to the number of active wavelengths in a TWDM PON system. To save energy, DWBA algorithms must reduce the number of active wavelengths. Energy saving DWBA algorithm was introduced in [2]. However, the TWDM PON system of [2] is based on EPON (Ethernet PON). The TWDM PON technology [1][6] is different from the EPON technology in many points.

Energy saving DWBA algorithm was introduced in [2]. However, the TWDM PON system of [2] is based on EPON (Ethernet PON). The TWDM PON technology [1][6] is different from the EPON technology in many points. One of the most significant differences is the QoS. The service amount of a queue is constrained by a service class and a service weight in the TWDM PON recommendations [1][6]. The number of wavelengths is determined by the fraction of the total request size and the bandwidth of a wavelength in [2]. Since a service class and a service weight are not considered in the calculation of the number of wavelengths, the algorithm of [2] cannot be directly used in the TWDM PON system that is compliant to the TWDM PON recommendations.

In this paper, we propose two DWBA algorithms for a TWDM PON system which is compliant to the TWDM PON recommendations. The first algorithm is a DWBA for QoS (DAQ) whose object is to obtain high QoS by fully using the wavelengths. The second algorithm is a DWBA for power saving (DAP) whose aim is to decrease the active wavelengths to save power. Then we evaluate and show that the DAP saves power compared to the DAQ using simulations.

2 Power Saving DWBA

A TWDM PON system consists of a single OLT and N ONUs. The OLT has four transmitters and four receivers. Four downstream wavelengths and four upstream wavelengths are used in the system. Each ONU has a single tunable transmitter and a single tunable receiver. An ONU dynamically uses one of the upstream wavelengths and one of the downstream wavelengths.

To support QoS, three service classes are used in the system. In the TWDM PON technology, a service class is known as a transmission container (T-CONT) type. Each ONU has three queues for T-CONT types 2, 3 and 4, respectively. Since a static bandwidth allocation is used for the T-CONT type 1, we do not consider the T-CONT type 1 in this paper. A packet arrived from a user side to an ONU is saved one of the queues based on its T-CONT type. Each queue has a unique Allocation Identifier (AllocID).

Every operation of TWDM PON is synchronized with a frame duration (FD) which is fixed at 125 μs. Each queue reports its queue length as a request to the

OLT. The OLT saves the requests to perform a DWBA for an upcoming FD. The OLT performs a DWBA in every FD to assign an upstream wavelength and grant a transmission slot to each queue. The total sum of the transmission slots is constrained by the duration of an FD.

In this paper, we assume that an ONU does not change its upstream wavelength during an FD. When a transmitter changes its wavelength, it requires a switching time in which no packet can be transmitted. The switching time decreases the bandwidth utilization. Another side effect is that a transmission overhead increases. When an ONU starts a new transmission, it needs a guard time which is included in the transmission overhead. If an ONU changes its upstream wavelength, a new guard time has to be inserted. For simplicity, we assume that an ONU uses only one upstream wavelength in an FD.

For the purpose of comparison, we first develop a new DWBA algorithm for QoS (DAQ) whose sole aim is to support high QoS such as a low mean delay. Then we introduce a new DWBA algorithm for power saving (DAP) whose object is to decrease power consumption.

2.1 DWBA Algorithm for QoS

In [5], a DWBA algorithm is developed for a TWDM PON system with a single T-CONT type. The main object of the DWBA algorithm of [5] is QoS. To get high QoS, an ONU selects an upstream wavelength which has the largest remaining bandwidth in [5]. Extending the DWBA algorithm of [5], we develop a DAQ algorithm for the TWDM PON system with multiple T-CONT types.

Let queue(j) be a queue having AllocID j. Suppose request(j) and grant(j) are the request and the grant of queue(j), respectively. The queue(j) has two parameters S(j) and A(j): S(j) is the service interval in unit of FD and A(j) is the maximum service bytes that can be allocated during S(j). The queue(j) has two counters T(j) and V(j). The counter T(j) is decreased by 1 in each FD and then recharged to S(j) when it has expired. The counter V(j) denotes the remaining service bytes during S(j) and is decreased by the grant amount grant(j). The counter V(j) is reset to A(j) when the counter T(j) has expired.

Let W(i) be the upstream wavelength of ONU i where W(i) = 1,…,4. If an upstream wavelength of ONU i is 4, we write as W(i) = 4. If no upstream wavelength is assigned to ONU i, then we write as W(i) = 0. Assume F(k) is the remaining bandwidth of an upstream wavelength k. At the beginning of each FD, F(k) is charged to its maximum value. The bandwidth F(k) is decreased by the grant amount during a DWBA process.

The first stage of the DAQ is the allocation of the upstream wavelength. Since ONU i uses a single upstream wavelength during an FD, all queues of ONU i have to use the same upstream wavelength during an FD. Suppose queue(j) is a queue of ONU i and grant(j) has not been allocated. If the upstream wavelength of ONU i has been allocated, i.e., W(i) > 0, queue(j) has to use the upstream wavelength

W(i). If the upstream wavelength of ONU i has not been assigned, i.e., W(i) = 0, the OLT assigns a tentative wavelength, C, to ONU i. The tentative wavelength C is given by the index of the maximum of F(k), k=1,…,4. For instance, F(2) is the largest one then we have C = 2. The tentative wavelength C will be finally allocated to ONU i only when grant(j) > 0. That is W(i) = C only if grant(j) > 0. Otherwise, W(i) = 0.

The second stage of the DAQ is the allocation of bandwidth. The grant(j) is calculated by

$$\text{grant}(j) = \min(\text{request}(j), V(j), F(k)) \quad (1)$$

where k = W(i) if W(i) > 0, otherwise k = C. If grant(j) > 0 and W(i) = 0, then the tentative wavelength C is allocated to ONU i, i.e., W(i) = C. If grant(j) = 0 and W(i) = 0, we have W(i) = 0. At the end of the calculation, each of request(j), V(j) and F(k) is decreased by the amount of grant(j).

For the service fairness among ONUs, the DAQ algorithm changes the starting ONU number in a round robin manner. For example, if the DAQ started from ONU 4 at the previous FD, the DAQ starts from ONU 5 at the current FD. The DAQ algorithm uses a static priority among T-CONT types. First, the DAQ algorithm is performed for the queues of T-CONT type 2. Then the algorithm is executed for the queues of T-CONT type 3 with the remaining resources. Finally the algorithm is processed for the queues of T-CONT type 4 with the remaining resources.

2.2 DWBA Algorithm for Power Saving

Since the DAQ prefers the wavelength having the largest remaining bandwidth, the upstream wavelengths are fully used in general. Since the power consumption is proportional to the number of active upstream wavelengths, the DAQ is not efficient for energy saving. We propose a DAP algorithm whose main purpose is power saving in this subsection. To save energy, the DAP decreases the number of active upstream wavelengths.

The DAP uses the same parameters and counters of the DAQ. The proposed DAP algorithm comprises of three stages. The first stage of the DAP is the calculation of an estimated number of upstream wavelengths, E. Suppose queue(j) is a queue of ONU i and grant(j) has not been allocated. Let G(j) be the minimum of request(j) and V(j). That is G(j) = min(request(j), V(j)). Then grant(j) must be less than or equal to G(j). Then the estimated number E is given by

$$E = \lceil \Sigma_j G(j)/M \rceil \quad (2)$$

where the variable M is the maximum of F(k) and the maximum of E is 4.

The second stage of the DAP is the allocation of the upstream wavelength which is similar to that of the DAQ. The number of upstream wavelengths is limited by E. If the upstream wavelength of ONU i has been allocated, i.e., W(i) > 0, queue(j) uses the upstream wavelength W(i). If the upstream wavelength of ONU i has not been assigned, i.e., W(i) = 0, the OLT assigns a tentative wavelength, C, to ONU i. The tentative wavelength C is given by the index of the maximum of F(k), k=1,…,E. The tentative wavelength C will be finally allocated to ONU i only when grant(j) > 0. That means W(i) = C only if grant(j) > 0. Otherwise, W(i) = 0.

The third stage is the bandwidth allocation. The grant(j) is calculated by

$$grant(j) = \min(G(j), F(k)) \quad (3)$$

where k = W(i) if W(i) > 0, otherwise k = C. If grant(j) > 0 and W(i) = 0, then the tentative wavelength C is allocated to ONU i, i.e., W(i) = C. If grant(j) = 0 and W(i) = 0, we have W(i) = 0. At the end of the calculation, each of request(j), V(j) and F(k) is decreased by the amount of grant(j).

Fig. 1 shows the pseudo code of the second and third stages of the DAP for the T-CONT type 2. In Fig. 1, the variable R means the starting ONU number that the DAP operation begins. The variable R changes in a round robin manner. The pseudo codes for the other T-CONT types are similar to that of the T-CONT type 2. First, the DAP algorithm is performed for the queues of T-CONT type 2. Then the DAP is executed for the queues of T-CONT type 3 with the remaining resources. Finally the DAP is processed for the queues of T-CONT type 4 with the remaining resources.

```
i = stop = R;
while(1){
  // wavelength allocation
  j = AllocID of a queue of T-CONT type 2 of ONU i;
  G(j) = min(request(j), V(j));
  k = W(i);
  if (W(i) = 0) {
     C = index of max{F(n), n=1,…,E};
     k = C;
  }

  // bandwidth allocation
  if (G(j) > 0) {
     grant(j) = min(G(j), F(k));
     V(j) = V(j) - grant(j);
     request(j) = request(j) - grant(j);
     F(k) = F(k) - grant(j);
     if (grant(j) > 0 and W(i) = 0) {
        W(i) = C;
     }
   }

   i++;
   if (i = N) i = 0;
   if (i = stop) break;
}
```

Fig. 1. Pseudo code of the second and third stages of DAP for T-CONT type 2

3 Performance Evaluation

In this section, we compare performance of DAQ and DAP. We consider a TWDM PON with 4 upstream wavelengths and 32 ONUs. The bandwidth of each upstream wavelength is 2.5 Gbps. The maximum input rate from users to an ONU is 400 Mbps. The distance between the OLT and an ONU is 20 Km. The size of each queue of each ONU is 1 Mbytes. For queue(j) of the T-CONT type 2, we have A(j) = 15,624, S(j) = 5, which is equivalent to 200 Mbps. For each queue(j) of the T-CONT types 3 and 4, we set A(j) = 31,248, and S(j) = 10, which is equivalent to 200 Mbps. The initial value of F(k) is 38,880 bytes for all k.

We use the self-similar traffic model in which the input traffic of an ONU is generated by a number of Pareto distributed on-off processes. The shape parameters of the on and off intervals are given by 1.2 and 1.4, respectively. The packet size follows the tri-modal distribution that the packet sizes are 64, 500 and 1500 bytes with the fractions of 60%, 20% and 20%, respectively as in [7]. The load fractions of T-CONT types 2, 3, and 4 of each ONU are 1/3, 1/3, and 1/3, respectively. The input loads of ONUs are balanced so that each ONU has an identical input load. The simulation time of each plot point lasts until the number of packets transmitted by ONUs to the OLT exceeds 10^9 for each algorithm. Increasing the load of each ONU from 0.1 to 0.99, we simulate and evaluate performance of DAQ and DAP algorithms.

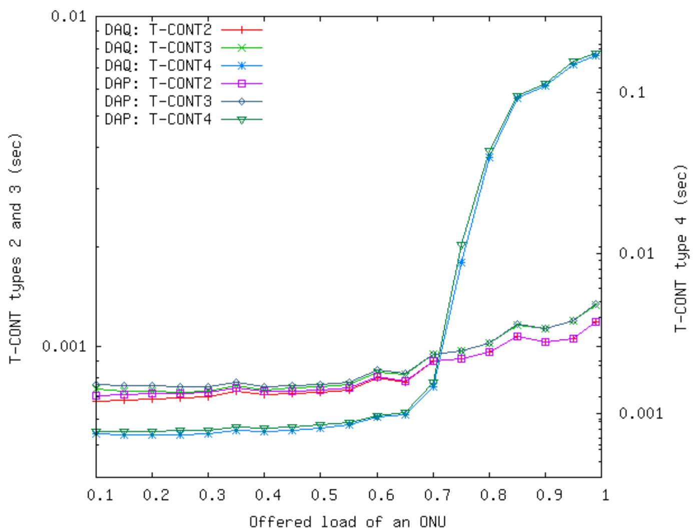

Fig. 2. Mean delay of DAQ and DAP

Fig. 2 shows the mean delays of both algorithms. As we can see from Fig. 2, the DAQ is better than the DAP in the mean delay especially when traffic is light. The reason is that the DAQ fully uses all wavelengths to get high QoS while the DAP tries to decrease the number of active wavelengths to save power. When traffic is heavy, the DAP cannot help but use all wavelengths since the requests are large. This makes two algorithms have almost identical performance when traffic is heavy. Fig. 3 shows the packet delay variance of both algorithms. As we can observe from Fig. 3, the DAQ is better than the DAP when traffic is light. Also, we can see that the DAQ is better than the DAP in the packet loss rate in Fig. 4.

Fig. 5 illustrates the average number of active upstream wavelengths of both algorithms. From Fig. 5, we can see that the DAP algorithm decreases the active wavelengths when traffic is light. Therefore, the DAP decreases the power consumption owing to the active upstream wavelengths.

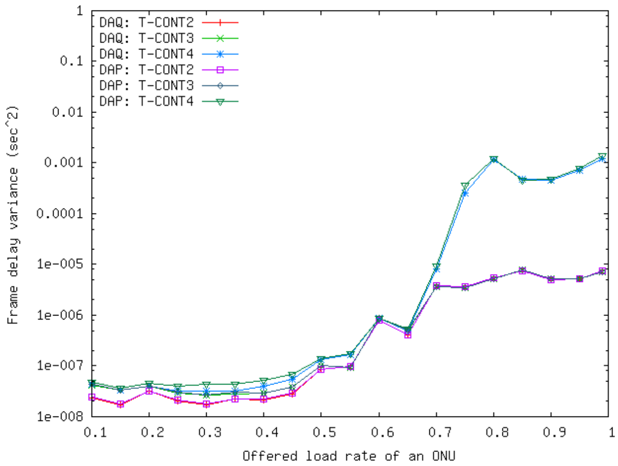

Fig. 3. Packet delay variance of DAQ and DAP

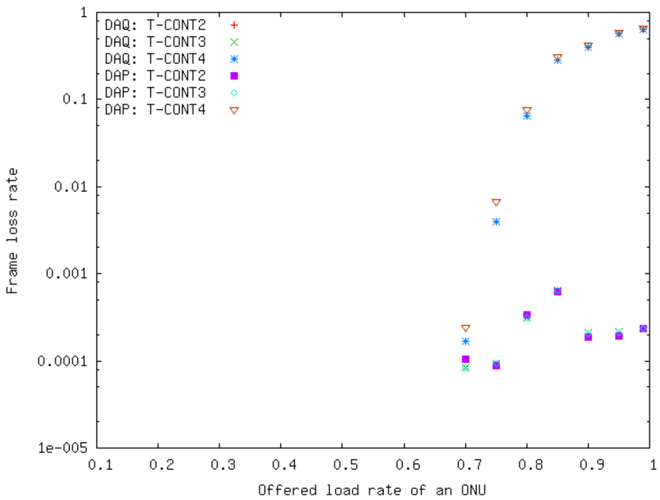

Fig. 4. Packet loss rate of DAQ and DAP

4 Conclusions

We proposed two DWBA algorithms for TWDM PONs. The DAQ fully uses all upstream wavelengths to provide high QoS. The DAP reduces the number of active upstream wavelengths to save power. Using simulations, we evaluated performance of both algorithms and showed that the DAP saves power compared to the DAQ.

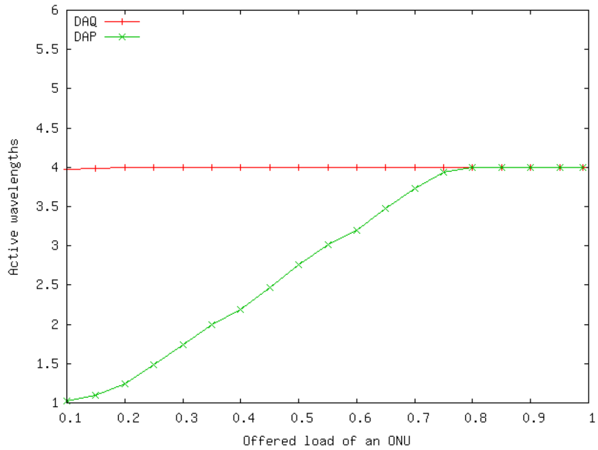

Fig. 5. Average number of active upstream wavelengths

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Received: August 16, 2014