

# An enhanced DWBA algorithm in WDM-TDM PON networks

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**Abstract**—The main purpose of WDM-TDM PON access network is to use wavelength division multiplexing approach to increase wavelength channels in order to enhance TDM PON network bandwidth. Enhancement of bandwidth will generate more bandwidths that can be allocated to users and will result in greater quality of service. In this paper, we considered dynamic allocation method. For the conventional static allocation method, not used bandwidth which are allocated by static allocation approach is unable to be allocated to other ONUs in the service, therefore it decreases usage of upstream bandwidth. If non used bandwidths were allocated to other ONUs, users' quality of service has been improved and consequently, ONU's buffered traffic would be decreased. Thus improvement of efficiency in allocation of bandwidth, more flexible allocation approach is needed. In this study we propose the model for wavelength and bandwidth allocation in the WDM EPON network, namely Widest Bandwidth First on Earliest Available Supported Channel (WBF-EASC) model. In addition to the model analysis, the simulation result is presented and the effectiveness of the proposed model is explained.

**Keywords** — allocation, widest bandwidth, Ethernet PON, wavelength, bandwidth, dynamic bandwidth allocation

## I. INTRODUCTION

The Ethernet passive optical network (EPON) has many advantages, such as compliance with traditional Ethernet, flexibility, ability to providing a variety of services and so on. These advantages are solutions to solve the problem of user network barriers [1]. However, EPON is a single channel system in which the optical fibre potential is not fully utilized. With the emergence of new services, the bandwidth provided by EPON network is no longer sufficient to meet all the requirements of end users.

In order to transfer various applications and services that exist in the triple-play network, it is necessary to provide resources and different levels of performance so that the end-users would get a satisfactory level of service. Within a converged network, quality of service (QoS) is by far the most important consideration for implementing. QoS is a networking term that specifies a guaranteed network data performance level. QoS guarantees are important if the network capacity is insufficient, especially for real-time streaming multimedia applications such as VoIP, online games, and IP-TV, since these often require a fixed bit rate

and are delay sensitive. Accordingly, QoS could also be defined as a set of algorithms and forms which enable different priorities to be given to different applications, users, or data flows, or to guarantee a certain level of performance for data flow. In practical terms, QoS can be described as a mechanism that has to provide transmission of audio and video data with minimum delay and minimum packet loss rate. Without QoS configuration, transmission of IP voice or videoconferencing calls would be unreliable, inconsistent, and often unsatisfactory.

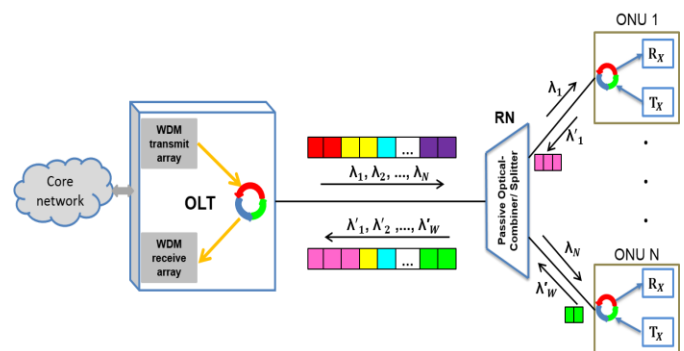


Figure 1. WDM-EPON architecture

Figure 1 illustrates the typical WDM EPON architecture. An introduction of wavelength multiplexing i.e. wavelength division multiplexing technology in EPON network is a logical step in the development of optical access networks. However, application such as high definition television, video conferencing and many others require the implementation of the quality of services in wavelength division multiplexing (WDM) networks as was the case with conventional EPON systems. It enhances available bandwidth for EPON through wavelength division multiplexing and the number of upstream wavelengths is generally less than that of optical network unit's (ONU's). Similar to EPON, dynamic bandwidth allocation algorithm is the key to implement efficient allocation of upstream bandwidth resources and to provide guaranteed network services for end users.

In [2], the author proposed three variance-based DWBA algorithms (DWBA-I, DWBA-2 and DWBA-3). In the first one of them, the OLT waits until all the Reports are received

from all ONUs. DWBA-I algorithm is completely offline algorithm in which OLT schedules until all the REPORTs are received which will result in an idle time in front of the next transmission. After that, the OLT runs a bandwidth allocation algorithm to compute bandwidth and channel for every ONU. In this case use two ways to assign transmission windows using the excess bandwidth, namely controlled excess (CE) and uncontrolled excess (UE).

In DWBA-2 and DWBA-3 upon receiving Report from  $ONU_i$ , the OLT checks whether  $B_{req}^i \leq B_{min}$ . If this condition meets, the OLT assigns  $B_{assign}^i = B_{req}^i$ , otherwise

$B_{assign}^i = B_{min}$ . Subsequently, the OLT waits until it receives all the Reports from all ONUs and collects the information about the excess bandwidth from each channel as well as the number of “highly loaded” ONUs. Each highly loaded  $ONU_i$  is allocated its share of the excess bandwidth either an uncontrolled manner, in a controlled manner, or in a fair manner. So in DWBA-2, OLT can grant the lightly loaded ONUs in advance and allow them transmit data as soon as the current transmission cycle ends so that the idle time in DWBA-I can be used to transmit. However, as the algorithm doesn't consider the varying propagation delays between ONUs and OLT, OLT would grant the requested bandwidth to the lightly loaded ONU whose propagation delay may be too large. It would also result in an idle time in front of the next transmission cycle. The function of these variants are very complexity.

Proposed “two-stage” DWA (dynamic wavelength allocation) algorithm in [4], in which the different scheduling policies are applied in each stage to schedule the grants to the used wavelength channels. In the first stage, primary thing to do is assign a bandwidth of the nearest ONUs on the supported wavelength channel. In the second stage, bandwidths of the remaining ONUs which is not assigned in the first stage are assigned on the supported wavelength channel.

In order to reduce the idle time, in [5] proposed the DWBA-HPD algorithm, OLT will grant the requested small bandwidth to the ONUs and they also have small propagation delays as soon as the REPORT is received by OLT without waiting for the REPORT of other ONUs. In the meanwhile, the ONUs with large propagation delays should wait to be granted until all the REPORTs are received by OLT.

## II. DYNAMIC BANDWIDTH ALLOCATION ALGORITHM

Transmission of different ONUs over the shared upstream channels is typically arbitrated by the optical line terminal (OLT) through the use of MPCP (multi-point control protocol, IEEE802.3ah) access protocol. The OLT gathers information from different ONUs and dynamically allocates bandwidth to ONUs using REPORT and GATE messages of MPCP. The REPORT message is used by the ONU to report its bandwidth requirements (buffer occupancy) to the OLT, which in turn

broadcasts a GATE message to that ONU, containing the appropriate transmission windows  $ONU_i$  granted.

Dynamic bandwidth assignment (DBA) in EPON has been studied greatly [2] and [3]. Reference [2] presents a comprehensive study of different DBA algorithms for EPON.

We consider a WDM/TDM EPON with N ONUs and k-wavelength channels. The transmission speed of a single wavelength is  $R_N$ . Let  $T_{cycle}$  be the grant cycle, during which all the ONU can transmit data to the OLT. TG is the guard time and  $\omega_i$  is the bandwidth weight assigned to each ONU.

The OLT receives report messages from all ONUs in n-1-th cycle, therefore at the beginning of n-th cycle, the OLT executes DBA according to the algorithm is proposed as follows.

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### Dynamic bandwidth algorithm

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#### Loop

##### for all ONUs do

OLT will check guaranteed bandwidth (GB) ONU;

##### end for

##### while all the Bandwidth are used do

OLT calculate  $B_{min}$ ;

##### if all $B_{req}^i < B_{min}$ then

OLT assign  $B_{assign}^i = B_{req}^i$

##### else

OLT assign  $B_{assign}^i = B_{dynamic}^i$

go to the end of while loop;

##### end if

##### end while

##### end loop

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$$B_i^{min} = B_{min} = \frac{(T_{cycle} - N * T_g) * R_N * k * \omega_i}{8} \quad (1)$$

If  $B_{req}^i \leq B_{min}$  ( $B_{req}^i$  -  $ONU_i$ 's requested bandwidth is less than  $B_{min}$  minimum guaranteed bandwidth), then it would be

$B_{assign}^i = B_{req}^i$  therefore GATE message will be sent to  $ONU_i$ .

On the other hand if  $B_{req}^i > B_{min}$ , when  $ONU_i$ 's requested or needed bandwidth is greater than minimum guaranteed bandwidth, lightly loaded ONUs' excess bandwidth would be calculated and send GATE messages allocating  $B_{assign}^i$  bandwidth to  $ONU_i$ .

Before allocating excess bandwidth amount of total excess bandwidth that is not used by lightly loaded ONUs should be calculated first, then the total amount of excess bandwidth requested from highly loaded ONUs should be calculated. These bandwidths will calculate by equation (2) and (3).

$$B_{excess}^{total} = \sum_{i=1}^N (B_{min} - B_{req}^i) \Big| B_{req}^i \leq B_{min} \quad (2)$$

$$B_{excess}^{require} = \sum_{i=1}^M B_{req}^{excess,i} \quad (3)$$

Excess bandwidths allocated to each highly loaded ONUs will be calculated by following equation.

$$B_{excess}^{portion,i} = \frac{B_{req}^{excess,i} * B_{excess}^{total}}{B_{excess}^{require}} \quad (4)$$

This DBA algorithm's results can be seen from table 2. Here we used a fair excess (FE) - allocation scheme that assigns portions to highly loaded ONUs according to their bandwidth demand.

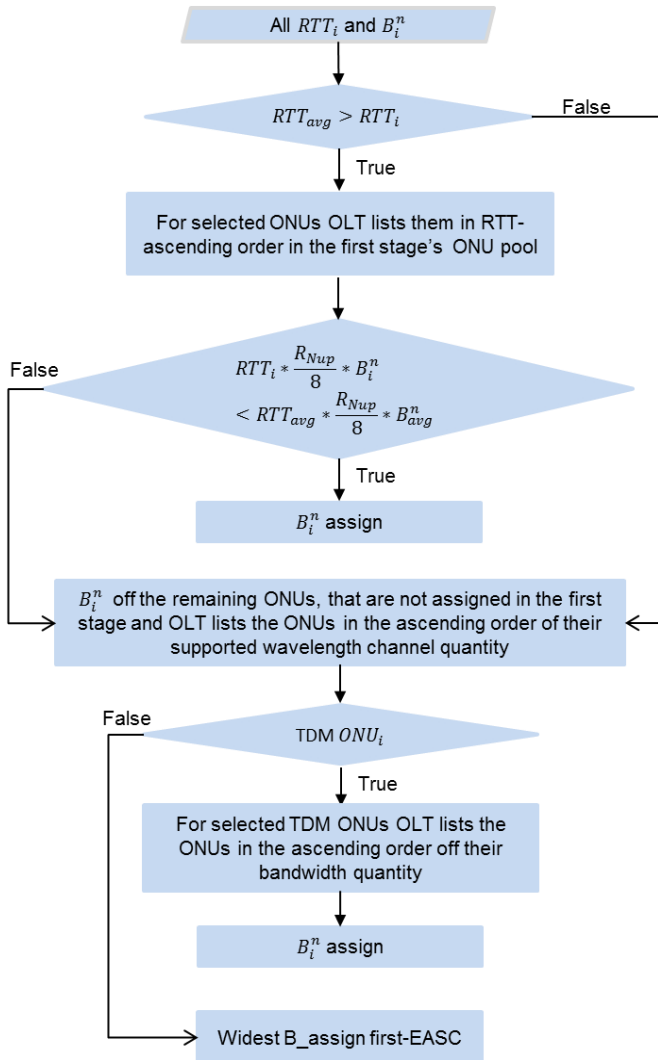


Figure 2. Flow chart of Dynamic Wavelength Assignment

### III. DYNAMIC WAVELENGTH ALLOCATION ALGORITHM

Passive optical networks (PONs) with time-division multiple access (TDMA) have been deployed for mass roll-outs of fibre-to-the-home/curb access networks. However, it has been envisioned that TDMA PONs cannot cope with the requirements of future network evolution due to the aggregated bandwidth and the allowable power budget. These limitations lead to the development of the next-generation PONs which are based on wavelength division multiplexing (WDM) [6].

Right after the DBA execution, before the GATE message transmitted to the ONUs, OLT makes a dynamic wavelength allocation (DWA) using two-stage Widest Bandwidth First on Earliest Available Support Channel (WBF-EASC) method.

In the two-stage DWA algorithm, if wide bandwidth assigned in the wavelength channel already occupied by some allocated bandwidths, it leads to ineffective upstream bandwidth channel utilization. In order to eliminate this flaw, we suggest WBF-EASC method for upstream channel assignment.

As a result of WBF-EASC method, the upstream wavelength channel utilization would be improved and the scheduling cycle time will be reduced. Consequently, the packet delay in ONU will greatly decrease, thus the quality of service will be improved.

The operation of WBF-EASC method is follows:

1.  $RTT_i$  times of all ONUs are sorted by increasing order and identify  $RTT_{avg}$  time. (RTT-Round trip time)
2. Check  $RTT_i < RTT_{avg}$ .
3. If  $RTT_i < RTT_{avg}$ , wavelength channel supported by that  $ONU_i$  will be identified.
4. Allocated bandwidths are sorted by descending order of bandwidth size.
5. Starting from widest bandwidth allocated to ONUs that are less than  $RTT_{avg}$  will be assigned to supported wavelength. If  $ONU_i$  supports at least one wavelength channel:

- $ONU_i$  that satisfied  $RTT_i^j < RTT_{avg}$  (j-wavelength channel) term must be identified. If there is more than one  $ONU_i$  that satisfies this term:
- In order to keep ISCG time low, ONU with least  $RTT_i$  amongst ONUs that supports same wavelength channels must be assigned first ( $RTT_{min} = RTT_i$ ).
- When we choose next ONU to assign on wavelength channel from other satisfactory ONUs we calculate continuing time  $T_i^j = B_{assign(\mu s)} + T_g$  and assign the ONU with least  $T_i^j$ .

6. Calculate occupied time of wavelength channel:

**TABLE 1.** SIMULATION PARAMETERS

| ONUs    | Supported wave-length channel     | RTT  |                | Assigned bandwidth |                          |
|---------|-----------------------------------|------|----------------|--------------------|--------------------------|
|         |                                   | km   | RTT ( $\mu$ s) | bytes              | Duration time ( $\mu$ s) |
| ONU1    | $\lambda 1$                       | 5    | 50             | 35000              | 280                      |
| ONU2    | $\lambda 1, \lambda 2, \lambda 3$ | 13   | 130            | 31250              | 250                      |
| ONU3    | $\lambda 1, \lambda 2, \lambda 3$ | 17   | 170            | 18000              | 144                      |
| ONU4    | $\lambda 1, \lambda 2, \lambda 3$ | 8    | 80             | 9000               | 72                       |
| ONU5    | $\lambda 1, \lambda 2, \lambda 3$ | 15   | 150            | 27000              | 216                      |
| ONU6    | $\lambda 1$                       | 15   | 150            | 38000              | 304                      |
| ONU7    | $\lambda 1, \lambda 2, \lambda 3$ | 8    | 80             | 5000               | 40                       |
| ONU8    | $\lambda 1$                       | 20   | 200            | 32500              | 260                      |
| ONU9    | $\lambda 2$                       | 7.5  | 75             | 19500              | 156                      |
| ONU10   | $\lambda 1, \lambda 2, \lambda 3$ | 12   | 120            | 66000              | 528                      |
| ONU11   | $\lambda 1, \lambda 2, \lambda 3$ | 9    | 90             | 16500              | 132                      |
| ONU12   | $\lambda 2$                       | 10   | 100            | 29000              | 232                      |
| ONU13   | $\lambda 1, \lambda 2, \lambda 3$ | 15   | 150            | 4000               | 32                       |
| ONU14   | $\lambda 1, \lambda 2, \lambda 3$ | 13   | 130            | 7000               | 56                       |
| ONU15   | $\lambda 1, \lambda 2, \lambda 3$ | 5    | 50             | 15000              | 120                      |
| ONU16   | $\lambda 2$                       | 20   | 200            | 31000              | 248                      |
| Average |                                   | 11.4 |                |                    |                          |

**TABLE 2.** THE RESULT OF FAIR-EXCESS DYNAMIC BANDWIDTH ALLOCATIONALGORITHM

| ONUs            | B_request | B_assign | B_excess | B_require |
|-----------------|-----------|----------|----------|-----------|
| ONU1            | 35000     | 35000    | 215000   | 0         |
| ONU2            | 31250     | 31250    | 218750   | 0         |
| ONU3            | 18000     | 18000    | 232000   | 0         |
| ONU4            | 9000      | 9000     | 241000   | 0         |
| ONU5            | 27000     | 12500    | 0        | 14500     |
| ONU6            | 38000     | 12500    | 0        | 25500     |
| ONU7            | 5000      | 5000     | 7500     | 0         |
| ONU8            | 32500     | 12500    | 0        | 20000     |
| ONU9            | 19500     | 12500    | 0        | 7000      |
| ONU10           | 66000     | 12500    | 0        | 53500     |
| ONU11           | 16500     | 12500    | 0        | 4000      |
| ONU12           | 29000     | 12500    | 0        | 16500     |
| ONU13           | 4000      | 4000     | 8500     | 0         |
| ONU14           | 7000      | 7000     | 5500     | 0         |
| ONU15           | 15000     | 12500    | 0        | 2500      |
| ONU16           | 31000     | 12500    | 0        | 18500     |
| B_total_require | 162000    |          |          |           |
| B_total_excess  | 928250    |          |          |           |

$$T_j^{occupied} = ISCG + T_j^{during} + T_g$$

here, ISCS – inter scheduling cycle gap

7. Next starting with ONUs that are left unassigned,  $ONU_i^j$  that supports only one wavelength will be assigned on it's supporting wavelength channel. If one wavelength channel is supported by many  $ONU_i^j$ , it will be done by the 4th section's way.

8. But when we assign ONUs that supports many wavelength channels, we assign them through the orders of bandwidth amount assigned to ONUs, not by  $RTT_i$ . Therefore it must be assigned by orders of widest bandwidth to least bandwidth ( $B_i^{assign}$ ) on earliest available supported channel. If we sort it by  $T_j^{occupied}$  time, wavelength channel with least amount of time will be Earliest Available Supported Channel (EASC).

Figure 2 shows the flow chart of dynamic bandwidth assignment explained above.

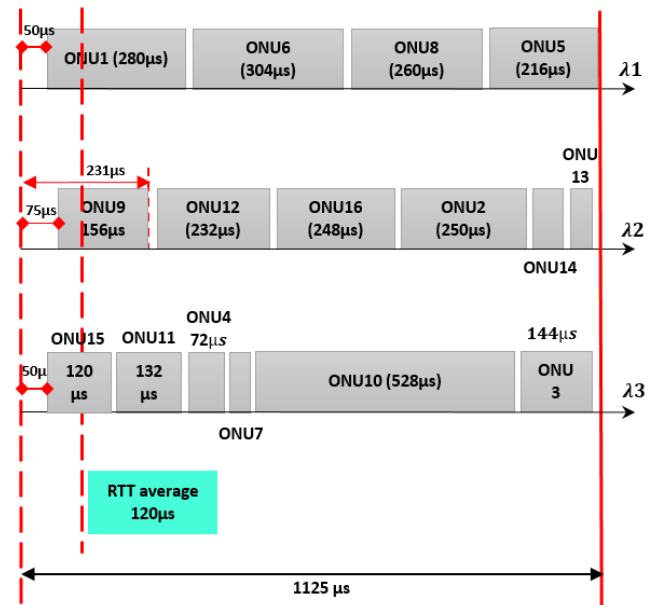
#### IV. SIMULATION AND ANALYSIS

The proposed Dynamic Bandwidth and Wavelength Allocation methods are simulated in the access network with 16 ONUs and 3 wavelength channels using Matlab program.

Table 1 reflects each ONUs' supported wavelength channels and randomly requested bandwidths as well as each ONU's RTT for the simulation purpose.

The result of DBA using the fair excess dynamic bandwidth allocation algorithm presented in section II is shown in table 2.

The result of DWA using WBF-EASC method based on data of Table 1 and 2 is shown in the Figure 3.

**Figure 3.** WBF-EASC DWA algorithm

To validate the effectiveness of proposed DWA method (i.e., WBF-EASC method), we have executed the dynamic bandwidth assignment by using “two stage” DWA algorithms that are described in reference 4 based on data of Table 1 and results are presented in Figure 4.

Bandwidth wastage depends on the amount of non-utilized slots in a scheduling time cycle. Usually, the bandwidth wastage problem appears in fixed-bandwidth-allocation scheme. In the DBA scheme, the granted window size is not fixed, and as a result, the amount of bandwidth wastage can be reduced [7].

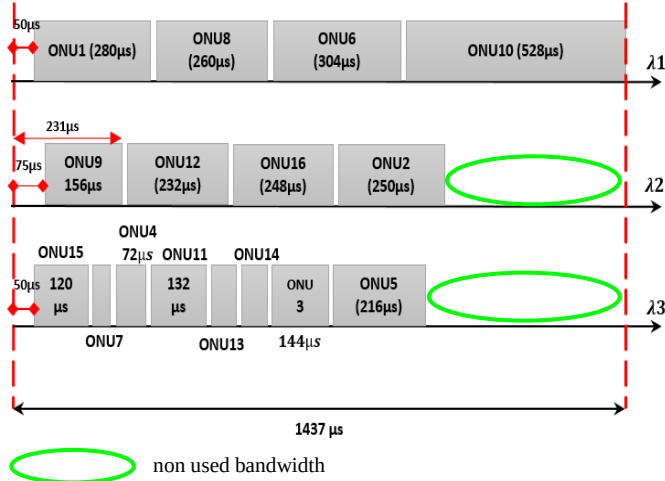


Figure 4. 2 stage DWA algorithm

Still, a marginal amount of bandwidth wastage occurs due to the guard intervals, Ethernet overheads, and idle time. The following formula is used to calculate the bandwidth wastage in a DWA scheme.

$$B_{waste} = \frac{\sum_{i=1}^N T_{idle}^i + \sum_{i=1}^N T_{EO}^i + 2NT_g}{T_{cycle}}$$

where,

$B_{waste}$  – is the wasted bandwidth

$T_{idle}$  – is the idle time

$T_{EO}^i$  – is the length of Ethernet overhead of  $ONU_i$

By optimally performing allocation of dynamic bandwidth and wavelength, we can decrease bandwidth wastage [8]. So, we applied the Widest Bandwidth First-Earliest Available Supported Channel (WBF-EASC) model to reduce bandwidth wastage. As for Figure 3, it appears that scheduling time cycle is less than using method for two stage DWA. That means the upstream wavelength channel utilization is improved and consequently, a packet delay will be decreased.

## V. CONCLUSIONS

Nowadays information technology field is developing extremely fast. According to this fact networks that meets the

needs of consumers are requiring massive amount of bandwidth. This rummages of needs in improving efficiency in the allocation of bandwidth such as allocating bandwidth equally through types of usage of consumers, make allocation more flexible and efficient.

Therefore, we analysed allocation of dynamic wavelength and bandwidth that are used in optical access network users' service, which to assign widest bandwidth assigned first and to allocate excess bandwidth fairly.

WBF EASC's main purpose is to deploy bandwidths that are pre calculated on OLT and allocated to ONUs, on the supported wavelength channel correctly and optimally. In order to do this, firstly calculate  $RTT_{avg}$  and ONU's bandwidths that are in close range within OLT and satisfying condition  $RTT_i < RTT_{avg}$  will be put on supported wavelength channel. Reason to select ONUs with less  $RTT_i$  than  $RTT_{avg}$  is to keep ISCS's value at minimum, therefore ONUs with least propagation delay will be select first.

This WBF-EASC method's main principle is working as according to algorithm shown in picture 2, but when placing ONUs' bandwidths on supported wavelength; widest bandwidths will be placed on its supported wavelength channel which satisfies EASC condition. Proposed WBF-EASC method's result is illustrated in Figure 3.

On the other hand, same data from table 1 has been calculated according to “two stage” DWA algorithm presented in Reference 4 and results are shown in Figure 4.

It can be seen that DWA algorithm used in WBF EASC method has a less cycle time than method shown in picture 4 by observing picture 3 and picture 4.

What seen from Figure 3 is that wastage bandwidth is almost non-existent. But from Figure 4 you can see  $\lambda_2$  and  $\lambda_3$  has wide amount of unused bandwidth. This unused space is losing opportunity to transfer delaying bandwidths in ONU's buffer. What seen from Figure 4 average delay time of cycle will increase which causes negative influence to the quality of service.

To conclude from this, using suggested WBF-EASC method will lessen the duration cycle time. This means the upstream wavelength channel utilization is greatly improved in case of WBF-EASC method. Consequently, packet delay in ONU will decrease and thus, the quality of service will be improved.

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