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Efficient bandwidth management algorithm for NG-EPON

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Abstract: Next generation ethernet passive optical network (NG-EPON) is a promising technology to cater huge bandwidth and efficient distribution demands of the future Internet services. IEEE working group has been doing efforts for the standardization of NG-EPON. Four wavelength channels of 25Gbps each are supported by NG-EPON for the transmission of optical network unit (ONU) traffic towards optical line terminal (OLT). Dynamic wavelength and bandwidth allocation (DWBA) algorithms are needed for the efficient arbitration of bandwidth resources between subscribers. In this paper, we have proposed a DWBA algorithm named as efficient bandwidth management algorithm (EBMA) for NG-EPON. EBMA has been designed to manage the diversified traffic requirements of different ONUs. EBMA performance is evaluated comparatively with modified IPACT (M-IPACT) and first fit (FF-DWBA) algorithms. EBMA for NG-EPON proves to be better on the basis of packet delay, packet drop ratio and grant utilization. Simulation results showed improved performance of EBMA in comparison with M-IPACT and FF-DWBA algorithms.

Key words: NG-EPON, dynamic wavelength and bandwidth allocation (DWBA), packet delay, packet drop ratio, grant utilization

1. Introduction

Demand of heavy and fast data services is increasing exponentially every day. Trends are showing that the amount of data being transmitted by an access network is continuously rising-up and would reach thousands of exabyte in upcoming future [1]. Demand of high bandwidth is crafting the space for commercial implementation of passive optical networks (PON). Higher data transmission capability and cost efficiency are key PON benefits [2]. Ethernet PON (EPON) is a known and capable solution for access networks that can handle the higher bandwidth demand of users. EPON is the technology that combines the features of ethernet with high data capacity of PON [3]. EPON is the easiest technology to setup, as there is no conversion required for connecting the Ethernet based networks. EPON is further categorized as; time division multiplexed [4] (TDM)-EPON, wavelength division multiplexed [5] (WDM)-EPON and hybrid (TWDM)-EPON. TDM-EPON uses single wavelength for both directions and provide a cost effective solution. WDM-EPON provides dedicated wavelength channels to each optical network unit (ONU) for both directions. TWDM-EPON combines TDM-EPON and WDM-EPON to form a flexible design architecture [6]. In TWDM-EPON, we have an arrayed waveguide grating (AWG) situated at optical line terminal (OLT). AWG allocates a wavelength channel to a coupler (splitter), which then further transmits TDM slots. Traffic from multiple ONUs is forwarded by coupler (combiner) in upstream and then by AWG for delivery to the central office [7].

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1G-EPON is currently a progressive access technology, but could not meet future requirements of bandwidth because of capacity limitations. EPON must evolve to cope with bandwidth demands of high data rates. Subscribers of business and residential access networks are increasing every day. High speed internet connectivity is needed by everyone. Very high data rates are needed by the subscribers because of bandwidth intensive applications like 3D gaming, HD video services, parallel video streams, concurrent online sessions etc. An IEEE group is working for the exploration of NG-EPON, that could accommodate the rapid increase in bandwidth requirements of future access network subscribers.[8].

NG-EPON is the technology that can manage to provide the enormous bandwidth and channel capacity distribution. NG-EPON can provide powerful capabilities that would help ISPs to meet the unprecedented requirements being provided through their networks. NG-EPON could broader covered/engaged area and enhance data transferring speed [9]. It could also provide reliable and preventive communication as compared to legacy EPON. NG-EPON can allow convergence of multiple services network onto a single optical distribution network (ODN). NG-EPON would enable the introduction of new and efficient architectures that could be adjusted in depth to meet the changing and emerging demands of the subscribers. NG EPON would be able to provide communication rate of 40Gbps and/or 100Gbps in downstream direction and 100Gbps in upstream direction. NG-EPON enables new business opportunities for ISPs, because of its capability to deliver 10Gbps/25Gbps and more to a single subscriber [10]. The existing EPON could be upgraded to next generation EPON by substituting central office (OLT) and subscribers (ONUs) as depicted in Figure 1.

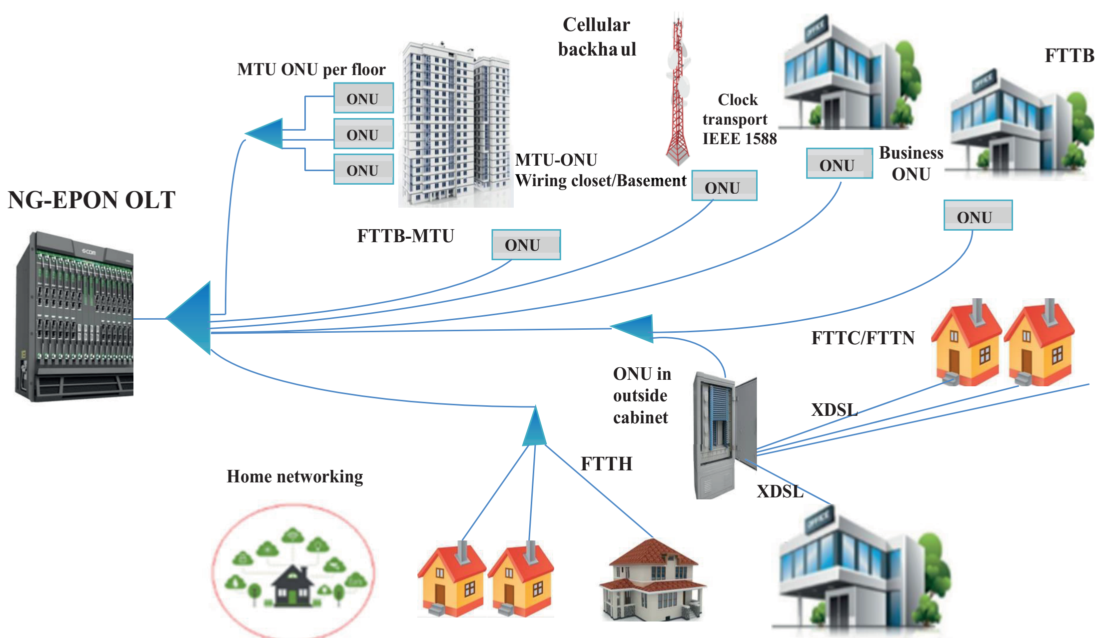

Figure 1. Next generation EPON.

Multiplexing technique selected for NG-EPON is TWDM [11].This decision has been made by FSAN group and IEEE, on the basis of cost effectiveness, power and overall system performance parameters. NG-EPON supports a minimum of single wavelength channel that can grow up to 4 wavelengths (1 to 4) in a pay-as-you-grow model on each fiber. Devices upgradation, assurance of security due to broadcasting nature, eavesdropping and efficient bandwidth utilization are the different problems for NG-EPON that should be addressed [12]. A phenomenon named as DWBA is implemented at the OLT for dynamic bandwidth distribution between ONUs for upstream transmission [13]. DWBA helps to arbitrate traffic to avoid conflicts between end users (ONUs).

Bandwidth management problem on multiple wavelength channels could be addressed by 3 different proposed design classifications; multi-scheduling (MSD)-EPON, single scheduling (SSD)-EPON and wavelength-agile (WA)-EPON[14]. In MSD-EPON, a single wavelength channel is granted by OLT to an ONU. One ONU could send data on a single wavelength at one instance of time, so that different ONUs could send their traffic on different channels simultaneously. Allocation of time slots to an ONU depends on DWBA implemented at the OLT. In SSD-EPON, all the available wavelength channels are assigned to one ONU at single instance of time. One ONU is granted the permission to transmit data traffic towards OLT in one time window. Allocation of time slots to an ONU depends on DWBA implemented at the OLT. WA-EPON provides more flexibility of wavelength channel allocation and sharing, as more than one wavelength could be allocated to any ONU at different demanding hours. WA-EPON could manage the temporary network traffic floods of some ONUs by assigning larger timing window on multiple wavelength channels to minimize the transferring time. The objective of this paper is to design, develop and implement new DWBA algorithm for wavelength-agile (WA) design architecture of next generation-EPON, to provide bandwidth management and utilization in an efficient manner. The main contributions of this paper are as follows: - We have proposed architecture for NG-EPON that provides support for handling different traffic requirements of the subscribers. - We designed and implemented DWBA algorithm for Wavelength-Agile NG-EPON design architecture. - Our proposed DWBA algorithm is designed on the basis of future requirements of consumers. - The performance of our proposed bandwidth management algorithm is evaluated with existing solutions on the basis of packet-delay, completion-time, packet-drop-ratio and grant-utilization. The rest of paper is organized as follows: Section II introduces multiple design oriented architectures of NG EPON. Section III discusses different existing algorithms that could handle DWBA problem in NG-EPON. In Section IV, we will propose new DWBA algorithm that can provide better utilization of bandwidth resources for NG-EPON. In Section V, the performance evaluation and analysis of our proposed algorithm would be done comparatively with some existing DWBA algorithms. In Section VI, we would conclude our work.

2. Bandwidth allocation based design architectures for NG-EPON

In EPON, downstream wavelength channels are accessed by the OLT for data transmission. To transmit data OLT does not require any arbitration mechanism. For upstream transmission, OLT grants the channel access to different ONUs. OLT permits ONUs to transfer their respective data to the OLT. On the basis of OLT arbitration for wavelength channels access, NG-EPON could be implemented into following different design classifications.

MSD-EPON

OLT grants one wavelength to one ONU at a single time in MSD-EPON. An ONU could transmit its buffered data on one wavelength at one instance of time. Multiple ONUs could transfer data simultaneously on different channels. Working principle of MSD-EPON is shown in Figure 2. DWBA implemented at the central office equipment would be responsible for the allocation of transmission window to a specific ONU. MSD-EPON seems to be similar to TWDM-EPON. Already designed DWBA schemes for hybrid (TWDM)-EPON can be utilized for MSD-EPON by making appropriate parametric adjustments [15].

SSD-EPON

OLT provides access of all wavelength channels to an ONU at a single instance in SSD-EPON. ONU could transfer its accumulated data on all wavelengths at one instance of time. Working principle of SSD-EPON is shown in Figure 3. DWBA implemented at the central office equipment would be responsible for the allocation of transmission window to a specific ONU. SSD-EPON likely seems to be a replica of TDM-EPON. Already designed bandwidth management algorithms for TDM-EPON can be utilized for SSD-EPON by making suitable parameter based adjustments.

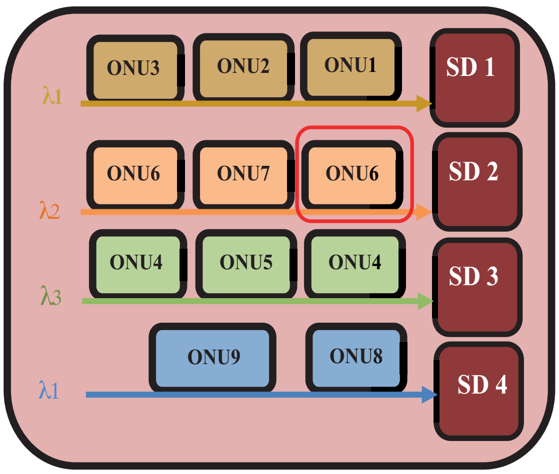

Figure 2. MSD-EPON design architecture.

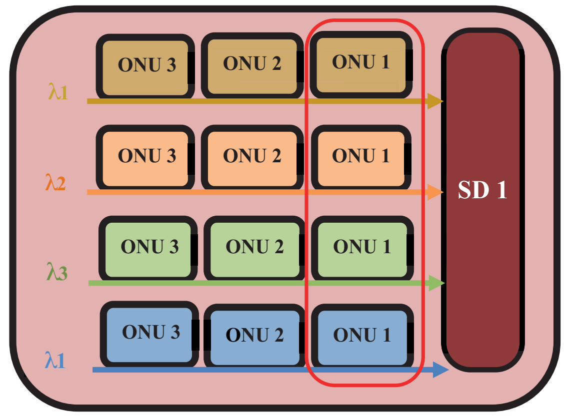

Figure 3. SSD-EPON design architecture.

WA-EPON

WA-PON is a combination of MSD and SSD EPONs. In WA-EPON, OLT can grant single wavelength and/or multiple wavelengths simultaneously to different ONUs based on their requirements. If an ONU wants to transmit on multiple wavelengths, it should have tunable lasers. In WA-EPON, OLT grants access to an ONU of multiple wavelength channels for transferring its queued data. To effectively schedule transmission, an arbitrator is needed to prevent collision in the upstream direction. Working principle of WA-EPON could also be understood from Figure 4. WA-EPON is a more flexible architecture to meet the varying needs of subscribers. The existing DWBA techniques could not be used for WA-EPON design architecture.

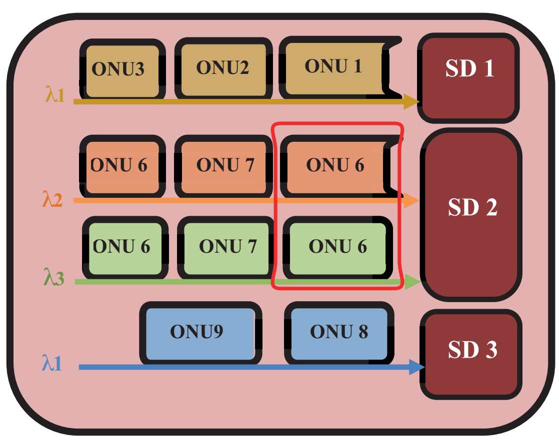

Figure 4. WA-EPON design architecture.

A comparative analysis between 3 different DWBA based (design) architectures for next generation EPON is shown in Table. In next section, we will discuss different existing bandwidth distribution/allocation algorithms for EPON.

Table . Comparison of NG-EPON design architectures.

Parameters	**MSD-EPON**	**SSD-EPON**	WA-EPON
Basic principle	1 ONU transmit on different wavelength 1-1 at a time	1 ONU transmit on all wavelength 1-all	1 ONU transmit on one/multiple wavelengths 1-1 or 1-many
Multiplexing technique	Similar as TWDM	Similar as TDM	Similar as TWDM but quite flexible
Status	Existing DBA of TWDM EPON could be used for MSD-PON by making appropriate parametric adjustments	Existing DBA of TDM-PON could be used for SSD-PON by making appropriate parametric adjustments	Existing or already developed DWBA schemes could not be used for WA-EPON
Algorithms	EFT	IPACT	FF-DWBA

3. Different existing DBA algorithms

DBA is a method through which we can assign bandwidth on demand and fairly between different subscribers of a network. When the traffic on a link increases and bandwidth requirement changes quickly with time, there is a need of DBA. DBA in EPON is a decision oriented phenomenon used for bandwidth distribution and allocation. It is implemented at the OLT and is used for the allocation of bandwidth to multiple users. The major purpose of DBA is to reduce idle slots of upstream wavelength channels [16]. Already developed TDM-EPON DBAs can be utilized for SSD-EPON through suitable parameter configurations according to characteristics and constraints of NG-EPON. Fixed bandwidth allocation (FBA) is a DBA for TDM-EPON. FBA offers an ONU fixed time slots for its communication window in the upstream direction. FBA is easy to execute, without overhead of bandwidth management and arbitration. It consumes upstream wavelength with low competence without considering the rapid changes in traffic [17]. Interleaved polling with adaptive cycle time (IPACT) [18]; a TDM based DBA which could be utilized for SSD-EPON. In IPACT, we are provided with a resource management mechanism for bandwidth management using queue-state technique. IPACT poll requests and issues time slices based transmission in RR (round-robin) fashion. Using IPACT, ONUs having higher traffic loads can easily monopolize channels for larger amount of time and thus causes other ONUs to suffer in terms of delay. IPACT with grant estimation is another DBA for TDM EPON. IPACT-GE predicts the amount of packets reached at ONU-side between 2 consecutive polling cycles. OLT determines the transmission size of each ONU, by estimating frame size along with the size of transmission window requested in previous cycle [19]. DBA problem in WDM-EPON is to manage upstream data transmission on different wavelengths supported by ONUs and is also known as dynamic wavelength allocation (DWA). Effective DWA algorithms are needed for the allocation of upstream data transmission. There are two approaches for the management of DWA problem: online and offline scheduling [20]. Best fit (BF) is a DWA for WDM-EPON. BF allocates the best wavelength to each ONU in order to improve network performance in terms of packet delay and data traffic loss [21]. Online next available supported channel (NASC) is a DWBA for WDM-EPON. In online NASC, OLT schedules upstream communication of ONUs on the first available supported wavelength channel after obtaining the consequent REPORT message. If the wavelength is not free, ONU has to wait until the wavelength becomes free. In NASC, there is no need to wait for all REPORT messages to be received at the OLT [22].

The working principle of MSD EPON is similar to TWDM-EPON. DWBA algorithms designed for TWDM-EPON can be utilized by MSD-EPON through appropriate parametric adjustments (like heavy data rate support, large coverage area up to 100 km, channel capacity of 10Gbps and/or 25Gbps per wavelength channel etc.) according to prescribed factors of NG-EPON. Existing DWBA schemes for [23] hybrid-EPON which can be used for MSD-EPON are as follows: static-wavelength-dynamic-time (SWDT) is a DWBA scheme, that assign the wavelengths statically to ONUs. Upstream channels are allocated by catering the bandwidth requests of subscriber ONUs [24]. Dynamic-Wavelength-Dynamic-Time (DWDT) is a DWBA scheme, which assigns wavelengths and time-slots to end-users in a dynamic manner. In DWDT, we manage and maintain the log of all wavelengths for dynamic assignment to ONUs according to their requests [25]. Some QoS based DWBA algorithms for TWDM-EPON have also been designed. DBA-I and DBA-II are 2 similar DWBA algorithms. DBA-I is used for the intra-ONU adaptive fairness scheduling. DBA-II is used for both inter-ONU and intra-ONU scheduling. DBA-III uses 2 wavelengths in parallel, 1 for low and 1 for high data rate transmissions on different channels [26]. Earliest-finish-time (EFT) is an online DWBA designed for scheduling upstream wavelength channels. The requests of ONUs are scheduled on the wavelength that would be free earliest. Scheduling is imminently executed to assign transmission window to ONUs when reports arrive at OLT. Additional data could not be transferred on the same wavelength channels. Transmission of designated traffic on the earliest available wavelength ensures an early completion time between channels [27]. EFT assigns earliest channel to ONUs whose last communication finishes early as compare to the rest of other channels. Earliest finishing time with void filling (EFT-VF) is also a DWBA for MSD-EPON. It is a modified scheme that provides improvement as compared to EFT and also minimizes the waiting time in contrast with EFT. A scheduling void is the interval of time between two succeeding communication, when the given wavelength turn out as free. Void filling part of the DWBA scheme is used to fill these voids by scheduling the transmission of an ONU during the available time. When the channel becomes free, the scheduling void must be long enough to enable the communication [28].

Water filling (WF) DWBA algorithm has been proposed for WA-EPON [29]. In WF-DWBA, bandwidth is assigned to an ONU in such a way that its requirement is fulfilled. The utilization of wavelength channels is converged in equivalence. Channels are arranged on the basis of utilization in WF algorithm. At first instance a grant is allocated on the channel which is minimal utilized, so that it could be matched with the second minimal used wavelength. In case, the variance between 2 consecutive wavelengths is greater than next required bandwidth, the allocation would be done at merely first wavelength. In WF-DWBA, an ONU is allocated bandwidth grants on several wavelengths subject to required bandwidth and difference between finish timing of wavelengths in last instance of distribution. In some situations WF-DWBA acts in a similar manner as just like the modified version of the IPACT (modified-IPACT). The modified IPACT is the implementation of legacy IPACT [18], by considering all the four wavelengths as a single wavelength channel.

Recently, first fit (FF) DWBA [30] has also been proposed for WA-EPON that provides better performance as compared to WF-DWBA. FF-DWBA is proposed to allocate a grant on a single wavelength channel; a channel whose availability is earliest as compared to all the other channels. Main idea of the FF-DWBA is to manage the availability of channels all the time. According to FF-DWBA, allocation of bandwidth grants on fewer channels is better in terms of efficiency as compared to the concept of leveling the channel resources on all available channels. ONUs are given grant in parallel in FF-DWBA; thus provides improved fairness and reduces the network latency as compared to WF-DWBA. New DWBA algorithm for NG-EPON is proposed in the next section. Our new algorithm is designed to meet the needs of future access WA-EPON.

4. Neoteric efficient bandwidth management algorithm for NG-EPON

In NG-EPON architecture there are 4 wavelengths available for upstream direction. The channels are shared by ONUs on the basis of time division multiplexing. MPCP is the underlying protocol used for arbitration of upstream channels. Report-gate mechanism is used to control the requests and allocation process of the channels to multiple ONUs on their demand. DWBA is an important functionality in NG-EPON that closely arbitrates the upstream transmission between different ONUs on multiple available bandwidth channels. DWBA is responsible for the allocation of channels and timeslots to different ONUs. There are different new trends observed in network user traffic behavior in access networks. Residential and business users have different requirements on different busy hours; it means that different ONUs have different bandwidth requirements at different timings of the day. Secondly, the distribution of traffic is really twisted; real scenarios suggest that only few percentile of subscribers use 50% of their allocated bandwidth. So, we have to design NG-EPON with a complex situation where heavy flow and mice flow can coexist in our network. We have proposed a DWBA named as efficient bandwidth management algorithm (EBMA) by keeping in view the 2 different types of users in our future network. We have segregated our ONUs into 2 types; Heavy Loaded (HL) ONUs and Light Loaded (LL) ONUs. ONUs that consumes 10% to 20% of data traffic are categorized as LL ONUs. ONUs that consumes more than 50% of data traffic are categorized as HL ONUs. In our architecture, half of our ONUs would be LL and remaining half of ONUs would be HL. Our proposed EBMA is for WA-EPON design architecture of NG-EPON. NG-EPON architecture for which we have proposed EBMA-DWBA is shown in Figure 5.

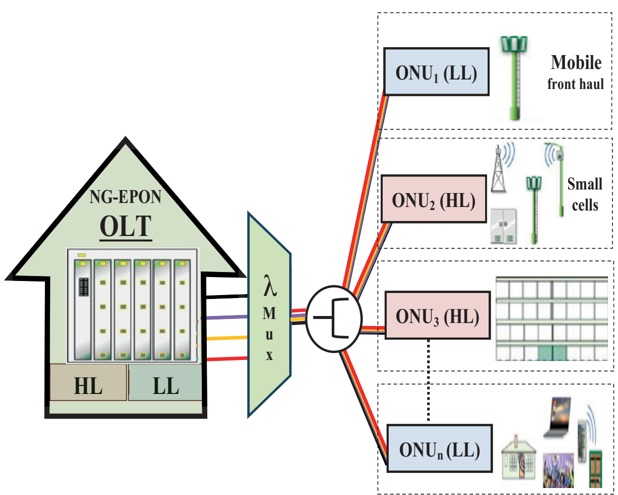

Figure 5. NG-EPON architecture for our proposed EBMA.

For EBMA implementation, OLT side would be capable of segregating the ONUs requests into HL pool and LL pool. The requests of HL ONUs would be placed in HL pool and requests of LL ONUs would be placed in LL pool. The subscribers paying more for heavy bandwidth requirement belongs to HL group and subscribers paying lesser belong to LL group. Four wavelength channels are available in our NG-EPON architecture. Three

Efficient bandwidth management algorithm Mode-1 for heavy loaded ONUs

```
Process start // EBMA Mode-1 (HL ONUs)
Receive RPTs from HL ONUs in pool (P_HL)
List_HL()
{
List_HL = Arrange the ONUs in the ascending order of PT; }
}
While (P_HL!=Null)
{
If(wavelength free)
List_HL();
Else
{
Wait for the availability of wavelength;
List_HL();
}
Allocation:
Allocate free wavelength to two top most ONUs in the List_HL;
If (ONUs left in List_HL)
{
If (Wavelength free)
goto Allocation;
Else
{
Wait for the availability of wavelength;
goto Allocation;
}
} // End of current List_HL
} // End of While loop
All HL ONUs completed transmission & no RPTs left
Process ends
```

wavelengths are dedicatedly assigned for HL ONUs grant (HL pool) and 1 wavelength is assigned for LL ONUs grant (LL pool). EBMA is comprised of 2 modes. Mode-1 is for the HL ONUs and Mode-2 for LL ONUs.

All the report messages for HL ONUs are gathered in the HL pool. Mode-1 would be used for the bandwidth allocation of HL ONUs. We arrange HL ONUs in ascending order on the basis of their processing times (PT). ONU with minimum PT would come at top and ONU with maximum PT would come at the end of list. We use a function List_HL to make the arrangement of ONUs for allocation. Then the availability of the wavelength channel would be checked. If wavelength channel is available, the top 2 ONUs would be assigned requested slots on a single wavelength channel. After scheduling the transmission of ONUs, again check wavelength availability; if the wavelength is available then pick up 2 ONUs from the List_HL whose PT is less than other and schedules them on the available wavelength. If no wavelength is available, then wait for the wavelength to become free.

Efficient bandwidth management algorithm Mode-2 for light loaded ONUs

```
1. Process start //EBMA Mode-2 (LL ONUs)
2. Receive RPTs from LL ONUs in pool (P_LL)
3. List(){
4. {
5. List_LL = Arrange the ONUs in an ODD and EVEN manner of their PT,
             ONU with ODD PT would come first in arrangement;
6. }
7. If( wavelength available)
8. Allocate slots to ONU according to the List_LL;
9. Else
10. {
11. Wait for the availability of Wavelength;
12. Allocate slots to ONUs according to the List_LL ;
13. }
14. Again receive PRTs from LL ONUs ;
15. While(P_LL!= null)
16. {
17. If(Half reports of LL ONUs received at P_LL)
18. {
19. List ();
20. If(Wavelength available)
21. Allocate slots to ONUs according to the List_LL;
22. Else
23. {
24. Wait for the availability of Wavelength;
25. Allocate the slots to the ONU according to the List_LL;
26. }
27. }
28. Else
29. Wait till half RPTs are received;
30. } // End of While loop
31. All ONUs completed their transmission and no RPTs left in pool;
32. Process ends
```

Schedule transmission of ONUs on the available wavelength when it becomes free. Repeat this allocation until all requests in the list_HL are served. Again list_HL function would executed on report messages received in the pool (P_HL). After the formation of list_HL and availability of the wavelength, allocation of wavelength channel would be performed as mentioned above. HL ONUs allocation is performed in an online manner. In Mode-1, two ONUs are allocated on a single channel at one instance of time. An ONU would be assigned a single wavelength channel at one time; this would help to remove the frame resequencing problem in NG-EPON. Once an ONU complete its transmission on allocated wavelength channel, then that wavelength would be allocated to the next ONU. The pseudo-code of Mode-1 for our proposed EBMA is given above.

All the report messages for LL ONUs are gathered in LL pool. Mode-2 would be used for the bandwidth allocation of LL ONUs. Report messages of all the LL ONUs are first received in pool (P_LL). Then list_LL function would be executed on ONUs request to generate the list for light loaded ONUs (list_LL). To generate list_LL, ONUs would be arranged in odd-even manner on the basis of their processing times (PT). ONUs with odd processing time would be at the top of list and ONUs with even processing time would be at the bottom of list. After the generation of list_LL, the wavelength availability is checked. When wavelength becomes available, slots are allocated to LL ONUs on the basis of generated list_LL. After the completion of first cycle for LL ONUs, we would again check the status of report messages in P_LL. If the number of report messages are less than half of the total number of LL ONUs, we should wait for report messages to be received in P_LL. When reports of half number of ONUs are received in P_LL, we would execute list_LL function again to generate the sorted list for LL ONUs. After the generation of list_LL and availability of wavelength channel, we would allocate time slots to ONUs in list_LL. Minimum half number of report messages should be in pool for the execution of Mode-2 algorithm and allocation of time slots to LL ONUs. Mode-2 continues to execute in the same manner till all LL ONUs complete their job transmission towards OLT. Mode-2 of our EBMA is executed in a partial offline manner. The pseudo-code of Mode-2 for our proposed EBMA is given above.
The time complexity of FF-DWBA is $O(NlogN)$, N is the number of ONUs that should be assigned a wavelength channel. W is the number of wavelengths we have to allocate different ONUs according to their demands. As a worst case, the time complexity of FF-DWBA would reaches $O(N \times N)$. We have computed time complexity of our EBMA-DWBA,as we know that we have W-1 wavelengths for HL ONUs and 1 wavelength for LL ONUs. We have total N ONUs in our NG-EPON architecture. N/2 ONUs are designated as HL ONUs and N/2 ONUs would be LL ONUs. So, time complexity of EBMA is computed to be $O[N/2 \times (W\text{-}1)+N/2]$. This complexity of our EBMA-DWBA could be improved to $O[((N/2)\log(W\text{-}1))+(N/2)]$. It can be seen that computational complexity of our EBMA-DWBA is proved to better as compared to FF-DWBA.

5. Performance evaluation

The performance of different existing DWBA algorithms in comparison with our proposed EBMA is evaluated by performing discrete event simulation. We have conducted a C++ based discrete event simulation. We have conducted simulation for NG-EPON model having 4 wavelengths for upstream direction. The capability of each wavelength is considered to be 25Gbps for our NG-EPON model. The model for NG-EPON is comprised of tree shaped network arrangement having 64 ONUS (N = 64). We have divided our network in 2 ONU segregations having dissimilar data requirements. Group 1 is comprised of the residential subscribers having low traffic requirements and other group is comprised of the business and corporate subscribers having higher traffic requirements. The data requirement generated by the business and corporate subscribers is assumed to be 10 times higher than the residential subscribers. This difference in traffic requirements between the 2 groups is maintained at different offered loads of our network. The ratio of data generated by ONUs in a unit time at the available number of wavelengths to the actual number of available ONUs is referred as average offered load in the NG-EPON (i.e. (4 × 25)Gb/64). Our network load is normalized and it varies uniformly at different offered network loads. The size of buffer for each ONU is considered as 10 MB. In between multiple grants, a fixed guard time is set which is taken as 2 micro-sec. Ethernet frame size distribution ranges from 64 to 1518 bytes. ONU RTTs are uniformly allocated between a range 80 to 120 micro-sec.

One wavelength has been assigned for light loaded (LL) ONUs network traffic and 3 wavelengths for heavy loaded (HL) ONUs network traffic for our EBMA simulation. ONUs for residential subscribers are considered to be LL ONUs and ONUs for the business and corporate subscribers are considered to be HL ONUs. We compared our proposed EBMA with 2 existing algorithms (i.e., First Fit (FF-DWBA) & modified IPACT (M-IPACT-DWBA)). We have compared algorithms on the basis of average delay, average completion time, grant utilization and packet drop ratio. There are different types of delays that collectively form the overall average packet delay in NG-EPON architecture; gate-to-report delay, schedule-to-gate delay and report-to-schedule delay. In our proposed EBMA, we allocate two ONUs a single wavelength at one single time which causes the reduction of report-to-schedule delay. Similarly for LL ONUs, we allocate the time slots to ONUs when half of the reports are received at pool. This factor also reduces the overall delay of LL ONUs. Figure 6 shows that EBMA performs better as compared to M-IPACT and FF-DWBA on the basis of the average packet delay. EBMA gives lower average packet delay at all offered loads. Comparative difference between EBMA and existing algorithms on the basis of average delay is higher at low network loads. At higher network loads, gap in terms of average delay between EBMA and existing algorithms decreases. In Figure 7, comparison on the basis of completion time is shown. Our proposed EBMA performs better in terms of completion time comparatively. EBMA shows more improvement in terms of average completion time at low network loads as compared to M-IPACT and FF-DWBA algorithms.

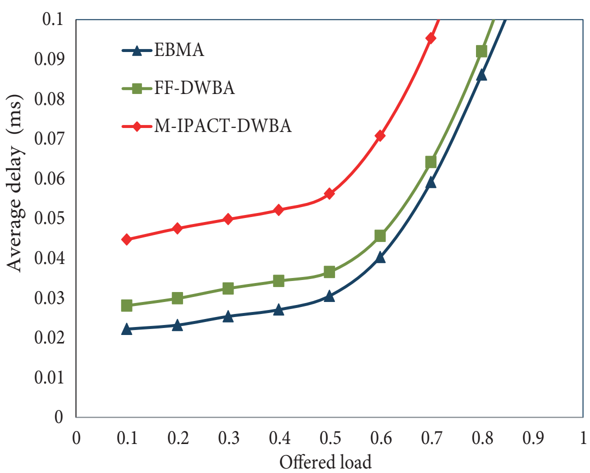

Figure 6. Average packet delay comparison of M-IPACT, FF-DWBA and proposed EBMA.

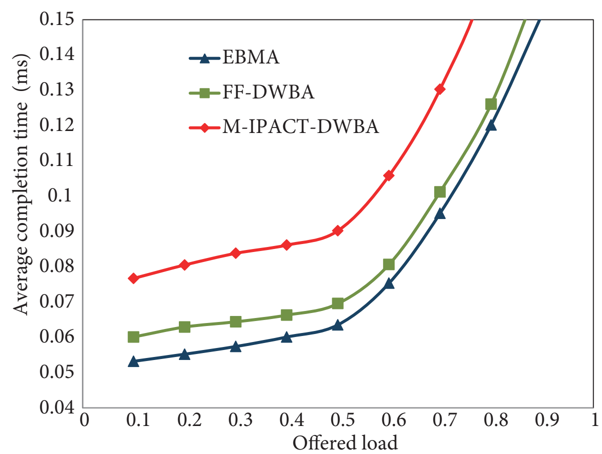

Figure 7. Average completion time of M-IPACT, FF-DWBA and proposed EBMA.

To evaluate performance of EBMA further, comparison on the basis of packet drop ratio (PDR) is shown in Figure 8. EBMA also performs better in terms of packet drop ratio as compared to FF-DWBA and M-IPACT-DWBA. PDR ensures that our EBMA do not require to have larger buffers/queues for the storage of data ONUs. Each ONU would get a fair chance of transmitting their data towards the OLT. We have taken an appropriate buffer size for each ONU. If ONUs have to wait more for transmitting their data, they would require lager buffers. EBMA shows improved fairness as compared to FF and M-IPACT, thus EBMA performs better in terms of PDR. The performance of EBMA on the basis of grant utilization is shown in Figure 9. It can be analyzed that EBMA performs better in terms of channel utilization as compared to FF-DWBA and M-IPACT-DWBA.

We have also comparatively analyzed EBMA-DWBA with earliest finish time (EFT) in terms of average packet delay (APD) and average completion time (ACT). Figure 10 shows the comparison of EBMA with EFT on the basis of APD. EBMA performs better than EFT in terms of average delay at all offered loads. Improvement in performance of EBMA is greater than EFT at higher network loads. In Figure 11, comparison on the basis of average completion time between EBMA and EFT is shown. Our proposed EBMA also performs better than EFT in terms of completion time comparatively at all offered loads. EBMA shows greater improvement in results on the basis of completion time than EFT at higher network loads.

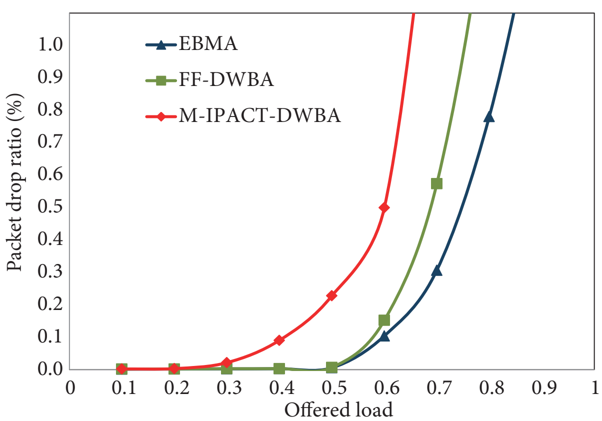

Figure 8. Packet drop ratio of M-IPACT, FF-DWBA and proposed EBMA.

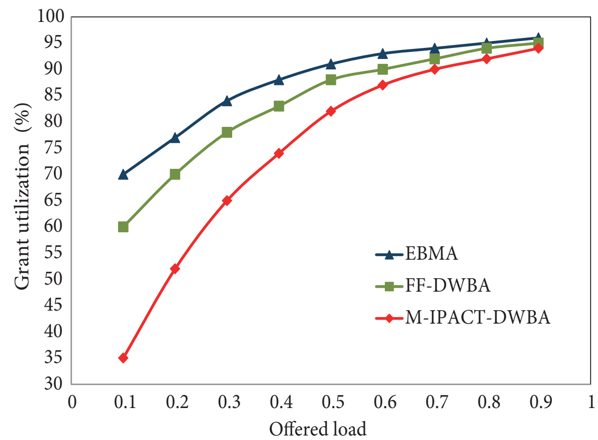

Figure 9. Grant utilization of M-IPACT, FF-DWBA and proposed EBMA.

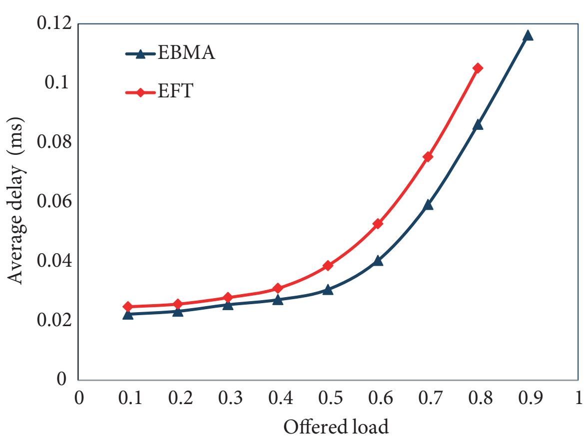

Figure 10. Average packet delay comparison between EFT and EBMA.

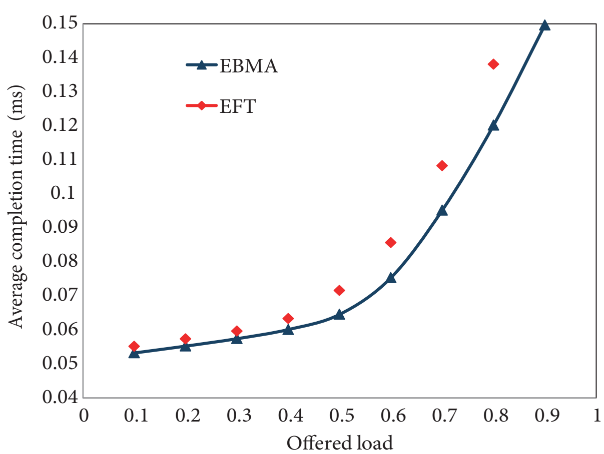

Figure 11. Average completion time comparison between EFT and EBMA.

One of the reasons for decrease in delay of EBMA would be the fact that two ONUs are allocated a single wavelength channel for transmission one after the other. Report-to-schedule delay is reduced to quite an extent for EBMA as compared to the other existing solutions. EBMA also avoids the denial of packet transmission and packet size mismatching problems; thus causes reduction in bandwidth wastage as compared to the other existing DWBA algorithms. Moreover, EBMA also avoids frame sequencing issue and thus no frame sequencing delay would be induced in the NG-EPON execution.

6. Conclusion

NG-EPON is the future optical access network that can meet bandwidth demands of subscribers and latest modern applications in access networks. To address bandwidth utilization problem for NG-EPON, we have proposed a DWBA algorithm; named as EBMA. Our proposed EBMA reduces delay and avoids bandwidth wastage, and thus improves bandwidth utilization comparatively. In EBMA, overall delay would be decreased due to the reduction in report-to-schedule delay and avoidance of frame resequencing delay. Wavelength allocation of HL and LL classes is proved to be quite amicable as far as performance improvement suggests. Our simulation results verify that our EBMA performs better as compared to M-IPACT and FF-DWBA on the basis of packet drop ratio, grant utilization and packet delay in NG-EPON. EBMA is scalable but not very flexible, because we have segregated the ONUs in HL and LL classes. If demand of ONUs changes, we have to change their class according to their traffic requirements. As future directions, studies could be done on the designing of new DWBA algorithms than can handle the frame out-of-order problem. Subscribers demand oriented algorithms should also be worked on to meet modern traffic demands of consumers.

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