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Performance Analysis of Multi Thread Polling Based DBA Algorithms for Long-Reach PONs

Shuvashis Saha[1], Monir Hossen[1], Md. Mostafizur Rahman[1], Noboru Yoshimura[2]

[1]*Department of Electronics and Communication Engineering, Khulna University of Engineering & Technology Khulna, Bangladesh*

[2]*Tohoku University of Community Service and Science, Yamagata, Japan*

Corresponding Author:** ***Monir Hossen *Department of Electronics and Communication Engineering, Khulna University of Engineering & Technology Khulna, Bangladesh*

Abstract: *Passive optical network (PON) technology has achieved a greater importance in the optical communication sector as it reduces the network deployment cost by introducing only passive components between the optical network units and an optical line terminal. Though the PON technology is an emerging solution for optical communication, the short reach PON (SR-PON) cannot support the heavy traffic and bandwidth necessities. Long reach PON (LR-PON) is introduced to support the huge bandwidth requirements as well as cover larger geographical areas. The LR-PON extended to more than ten times longer coverage area with enormous amount of end users compared to the SR-PON systems. However, the concerning issue is that it also increases the data transmission delay as the LR-PON systems enlarge the round trip time in the upstream channel. Furthermore, conventional dynamic bandwidth allocation (DBA) algorithms are not suitable for the LR-PON systems as these create longer idle time in the upstream data transmission. Multi thread polling (MTP) based upstream data scheduling is an effective solution to reduce the idle time. This paper specially focusses on both the conventional single thread polling (STP) and recently introduced MTP based DBA schemes for the LR-PON, i.e., MTP, adaptive multi gate polling with void filling (AMGAV), enhanced interleaved polling with adaptive cycle time (E-IPACT) and efficient multi thread polling (EMTP). We study and compare the performances of these schemes with different traffic loads, transmission distances, cycle times and also investigate the limitations and strengths in an LR-PON framework. The results indicate that though MTP and AMGAV schemes provide better upstream bandwidth utilization, these schemes suffer lower end-to-end packet delay and throughput performances in contrast with the E-IPACT and EMTP schemes.*

Keywords: *LR-PON, MTP, STP, E-IPACT, AMGAV, EMTP, DBA.*

1. Introduction

As the requirements of bandwidth and number of users increased tremendously, traditional communication system forcefully replaced with fiber to the home technologies. Passive optical networks (PONs) have been played an important role to implement a low cost, multiple services with higher data rates systems [1]. However, as the number of users and coverage are increased, short reach PON (SR-PON) technologies faced limitations by its services. Recent research progress has invented a growing number of modern equipment to enlarge the broadband excess network, i.e., SR-PON, from 20 km to 100 km or higher, known as long reach PON (LR-PON) [2]. Both the SR-PON and LR-PON systems are optical fiber based access networks. In the LR-PON architecture, diverse optical line terminals (OLTs) are converted into one central office (CO), which effectively reduces the network deployment cost. For enlarging the communication area, an extended optical fiber is used to connect the OLT and optical network units (ONUs) via optical passive splitter [3]. The LR-PON system uses either Ethernet PON (EPON) or Gigabit PON (GPON) standard to support the extended bandwidth requirement. Figure 1 shows a LR-PON architecture for ring and spur networks. In the Figure 1, each of the access networks are connected with the optical add drop amplifier (OADM) through passive splitter. The OADM amplifies the signal to ensure longer reach as well as more number of subscribers [4].

Dynamic bandwidth allocation (DBA) algorithms are used in the SR-PON systems to provide contention free upstream data transmission. In EPON system, multi-point control protocol (MPCP) was standardized to exchange Report and Gate messages between the OLT and ONUs. Usually, the ONUs send the Gate messages to the OLT for acknowledging the information of buffer status in form of time window size and OLT grants the time window size by comparing with a predefined window size. This mechanism successfully handles the contention free upstream data transmission [5, 6].When conventional DBA schemes are used in the LR-PON system, it creates idle period in the upstream channel. This idle period depends on the round trip time (RTT) and, in SR-PON system, it wastes only few micro seconds. However, in the LR-PON system the RTT increased for the longer OLT to ONUs distances. For this large RTT a significant amount of idle period remains in the LR-PON system, especially when traditional DBA algorithms are used [7]. To mitigate this longer transmission time, multi thread polling (MTP) based DBA scheme has been proposed in [8], which generates parallel request to the OLT in a time cycle. In the recent research, several schemes are proposed to reduce the transmission delay with better quality of services (QoSs) in the LR-PON system.

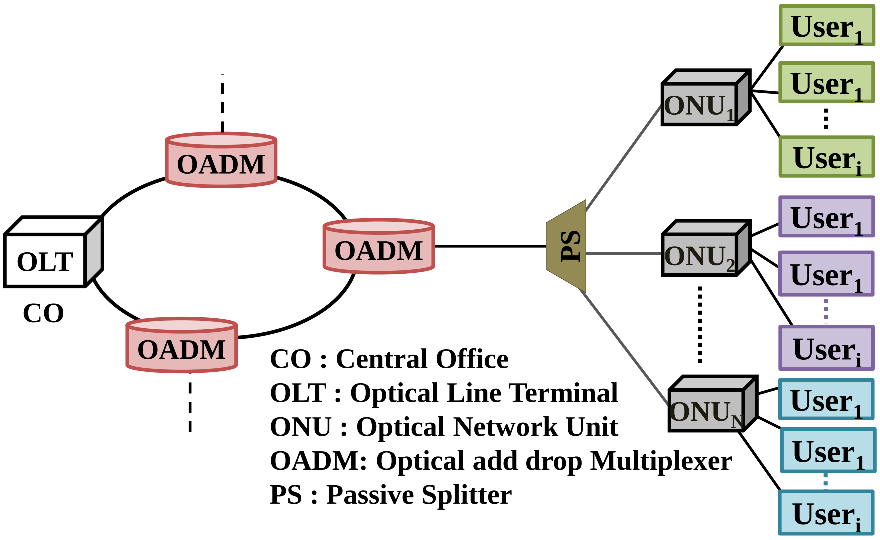


Figure 1. *LR-PON architecture for ring and spur network.*

In this paper, we studied and sort out some limitations of the MTP based DBA algorithms for the LR-PON systems. We also investigate the optimal time cycle length for individual schemes. Our comparative studies and result analyses show that, some of the MTP based DBA schemes offer lower end-to-end packet delay but these schemes are failed to achieve better throughput. Furthermore, duplicate Report messaging and unused time slots problem are serious issues that degrade the system performances. This paper shows the excess window size granted for double Report messaging effect on the different MTP based DBA schemes performances. Moreover, we investigate the bandwidth utilization in upstream channel for the different schemes in the LR-PON system.

The rest of this paper is organized as follows. Literature review on different MTP based DBA schemes are presented in the section II. In section III, we explain the end-to-end packet delay, bandwidth utilization, and throughput analyses. Section IV presents the simulation environment and results. Finally, the paper has been concluded in section V.

2. Related Works and System model on Different MTP based DBA Schemes

In this section, we explain about the traditional DBA schemes for the SR-PON systems and different MTP based DBA schemes for the LR-PON systems. The system model of different algorithms and their comparative differences will be discussed in this section.

2.1. Single Thread Polling (STP) Scheme

Interleaved polling with adaptive cycle time (IPACT) algorithm is the most well-known conventional DBA scheme for the SR-PON system [6]. In the IPACT scheme, the OLT issues the Gate messages and ONUs send the Report messages cyclically in an interleaved fashion. In polling cycle, the time interval between two successive Report messages transmitted from the same ONU to the OLT, no messages can be sent by the ONUs until the previous Gate messages are arrived. For this reason, an idle time is created between the two successive data packet. Usually this idle is same as the RTT and in PON system this is not significant limitation. Here, this is called STP scheme as it can send only one Report message from the ONU, in a time cycle. Figure 2 depicts the grant scheduling process in the conventional STP based DBA scheme. For the simplicity of the explanation, only two ONUs are shown in the Figure.

Every DBA algorithm contains three types of delays, namely granting delay T_{Grant}, polling delay T_{Poll}, and queuing delay T_{Queue}. In the LR-PON system, the STP based DBA scheme is not suitable as it creates larger end-to-end packet delay due to larger idle time that degrades the overall performances.

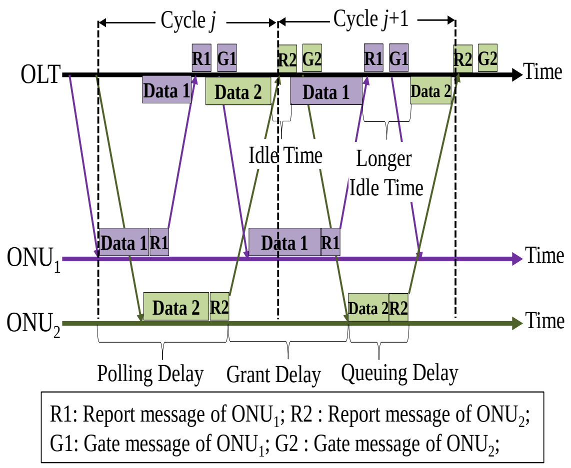


Figure 2. *Grant scheduling process in the STP based DBA scheme.*

2.2. Multi Thread Polling (MTP) Scheme

To mitigate the limitations of the conventional STP based DBA schemes for the LR-PON systems, MTP based DBA scheme has been proposed in [8]. According to the MTP based DBA scheme, in a time cycle, ONUs are able to send multiple Report messages to the OLT without waiting for the previous Gate messages. This scheme significantly reduces the end-to-end packet delay by allowing parallel transmission opportunities with a contention free upstream channel. Figure 3 explains the grant scheduling process of the MTP based DBA scheme. Here, we assume two ONUs and two threads for each ONU in the LR-PON system. Parallel thread operations reduce the idle time in the upstream channel as well as this scheme increases the data transmission rate.

However, executing multiple threads in same DBA cycle creates grant status information missing on the overlapped DBA cycles. For heavily loaded condition, MTP based DBA scheme suffers from request unbalancing problem, as it does not maintain the duplicate Report messages identification. These shortcomings may prevent the performances of the MTP based DBA scheme in the LR-PONs [9, 10]. Another important limitation of the MTP based DBA scheme has been investigated in [1] that is excess window granting problem. Due to parallel requesting approach, OLT can grant the same Report message twice in different DBA cycles. This creates excess granting in the upstream channel and degrades the bandwidth utilization.

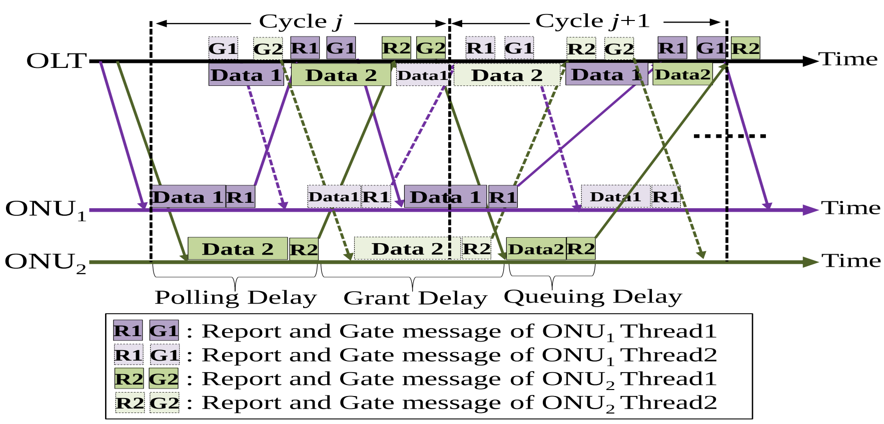


Figure 3. *Grant scheduling process in the existing MTP based DBA scheme.*

2.3. Adaptive Multi-Gate Polling with Void Filling (AMGAV) Scheme

An improvement version of the MTP based DBA scheme is proposed in [11], known as adaptive multi-gate polling with void filling (AMGAV), which specially focused on the load balancing issue and reduce the end-to-end packet delay for heavily loaded condition compared to the previous MTP based DBA schemes. According to the AMGAV scheme, the number of threads varied with traffic load instead of fixed number of threads. This scheme also makes the algorithm simpler by removing the separation between the two consecutive threads. In this paper, authors have investigated that due to the overlapping of the threads and load variation the MTP based DBA schemes suffer the thread convergence and thread spreading problems. When a thread in a time cycle becomes so large compared to the other threads, then thread convergence problem occurs. On the other hand, thread spread occurs when the data packet transmission period of all ONUs in one thread becomes enough larger than the RTT of the most distant ONU.
The AMGAV is a void filling scheme and it divides time cycle in several sub-cycles, which is fixed. As shown in Figure 4, three sub-cycles are initiated at time t_0, t_1, and t_2, respectively. The time t_0 denotes both the commencing of the new time cycle and the initial sub-cycle. At time interval t_1, the next sub-cycle will be distributed fairly according to the current demands of the respective ONUs. When there is no new data Request message between first two time slots, i.e., t_0 and t_1, the previous sub-cycle will be used as the distributed sub-cycle. This AMGAV scheme can prevents the void formation and utilizes the upstream channel bandwidth allocation effectively.

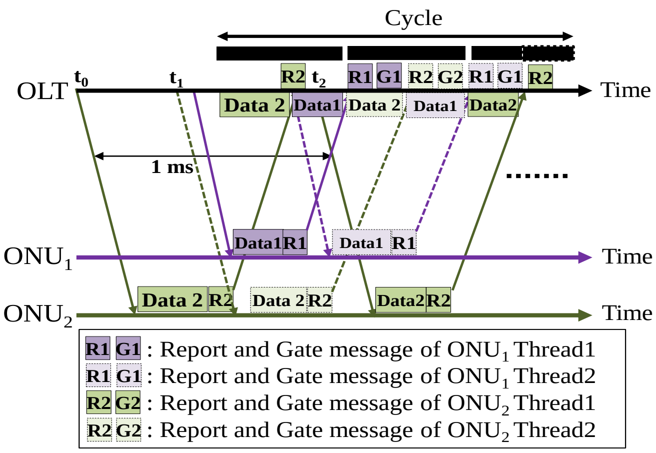


Figure 4. *Grant scheduling process in the AMGAV scheme.*

However, the AMGAV scheme selects the numbers of threads with respect to the offered load of an individual ONU as the numbers of threads are dynamic. Therefore, for heavily loaded condition it will be very difficult to manage the control messages. This scheme has not investigated any kind of fairness of bandwidth allocation for different ONUs for different classes of services. Overall, this scheme is not concerned about the over-granting problem that inherently occurs in the MTP based DBA schemes [9].

2.4. Enhance Interleaved Polling with Adaptive Cycle Time (E-IPACT) Scheme

The E-IPACT scheme is a promising solution for reducing the over-granting problems remains in the MTP based DBA schemes in the LR-PON systems [12].Over-granting can be defined as the excess bandwidth granted with respect to the actual bandwidth needs of an ONU. The MTP based DBA schemes that utilizes pre defined threshold in the scheduling process for granting the request messages is vulnerable to the over-granting problem. There are mainly two causes that emphasize the over-granting problem in the MTP based DBA schemes, i.e., lack of frame fragmentation and duplicated Report messages granting in a time cycle. According to the E-IPACT scheme, the ONU is acknowledged about the maximum timeslot threshold value by the OLT in each Gate message. This information is helpful for the ONUs that they can easily prepare their Report messages, which is fitted with the maximum timeslot threshold or integer number of frames. This mechanism ensures that there is no occurrence of fragmented frames in every thread. To ensure this condition the ONUs must need to actively participate in the DBA algorithm though it is not usual in existing DBA process. Figure 5provides information about how an ONU creates buffer status in the existing E-IPACT scheme to avoid the frame fragmentation problem. Here, F_{unR} is the unreported frame of the previous $(j\text{-}1)^{th}$ time cycle. For the next time cycle of *j*, frame *F3* is the unmatched frame with the maximum timeslot threshold W_{th}^{max} that will be preserved as F_{unR}in this current cycle and this unreported frame will be reported in the following $(j+1)^{th}$ time cycle. The E-IPACT scheme can mitigate the over-granting problem for the MTP based DBA schemes though Report and Gate messages require some overheads to control the contention free data packet transmission in the upstream channel.

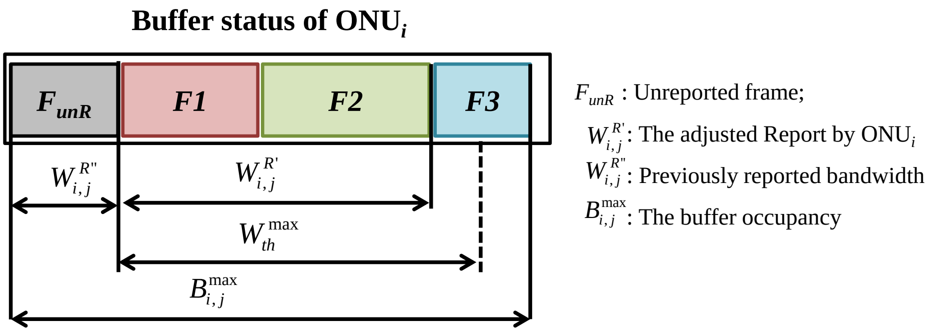


Figure 5. *Buffer status reporting process in the E-IPACT scheme.*

The existing E-IPACT scheme suffers from the following complexities reported on [13]:

1. The E-IPACT scheme increases the computational complexity of DBA processing as well as end-to-end packet delay as both the OLT and ONUs are involved in DBA processing.
2. The unreported frames that remain in the previous time cycle create ONU's buffer overflow.
3. The reserved fields in the Gate messages may reduce the bandwidth utilization in the upstream channel.

2.5. Efficient Multi Thread Polling (EMTP) Based DBA Scheme

An improved version of the conventional MTP based DBA schemes was proposed to enhance its performances, namely efficient multi thread polling [13]. This scheme specially focused on the over-granting problem and its solution with lower end-to-end packet delay. According to the EMTP scheme, the Report messages contain the required frame numbers serially instead of convey the information of total pending window size in the queues.Figure6 shows the grant scheduling process of the existing EMTP scheme. Here, F_i^k remarks the size of frame of ONU*i* of k^{th} frame. Not more than three frames are queued in the buffer of an ONU. It is assumed that in the second buffer status of the ONU$_1$, the maximum timeslot threshold is less than the Reported window size. After collecting the Report message which contains the sizes of different frames information, i.e., F_1^3, F_1^1, and F_1^2, the OLT grants the maximum number of frames which is upper bounded by the maximum timeslot threshold. If any frame is not granted by the OLT then this frame denoted as F_{unR} and this will not be reported again by the ONU$_1$and will be granted by the OLT in the following cycle with higher priority. The EMTP scheme mitigates over-grating problem, overlapping of timeslots, unused times slots, and bandwidth wastage with delay reduction approach.

3. System Model And Numerical Analysis

In this section, we explain the different performances parameter of the MTP based DBA schemes using numerical analysis. At first we briefly illustrate different delay components in the LR-PON system. Then the bandwidth utilization and throughput analysis are presented.

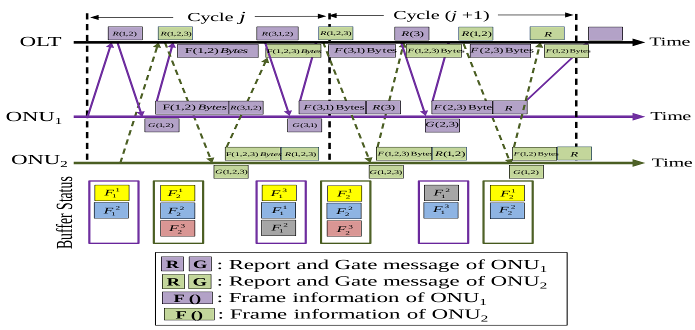


Figure 6. *Grant scheduling process in the EMTP scheme.*

3.1. Delay Model of the MTP based DBA Schemes

Figure 7 presents different types of transmission and processing delay exists in the MTP based DBA schemes. According to the MTP based DBA scheme, a transmitted packet from ONUs to the OLT may experience three types of transmission delay, i.e., T_{Poll}, T_{Grant}, and T_{Queue}, and three types of processing delays in the upstream channel, i.e., DBA processing delay (T_{DBA}),guard interval(T_G), and idle period(T_{Idle}) [14].

- *Polling delay: As packet in the buffer does not Reported immediately and it may have waited for a whole cycle, polling delay can be varied from 0 to the maximum cycle time length Tcycle. Usually, the average polling delay is half of the cycle time (Tcycle/2).*
- *Grant delay: ONU sends the Report message and a time is needed to get the corresponding Gate message, which is fully dependent on the RTT as well as on the distances between OLT to ONUs.*
- *Queuing delay: Queuing delay is fully dependent on the granted window size and during this time queued packet waits while other packets are transmitted from the buffer of an ONU.*
- *DBA Processing Delay: As the complexity of the algorithm increases, the DBA processing delay also increases. Since M rounds of grant allocations are made for every ONU in a time cycle, the complexity of the MTP based DBA scheme is considered by O(M×n) for n number of threads.*
- *Guard interval: A very small amount of time interval is placed between two successive upstream packets to make contention free transmission.*
- *Idle period: MTP based DBA schemes also introduce idle periods in the upstream channel as the exchange of MPCP messages needs at least one RTT.*

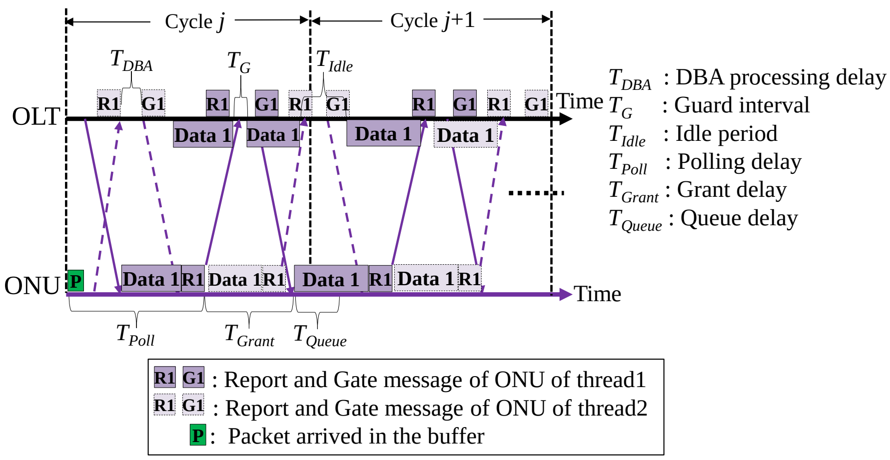


Figure 7. *Delay model of the MTP based DBA schemes.*

Total end-to-end packet delay is the summation of packet transmission and processing delays. Packet transmission delay depends on the network structure, distance, and network offered load, whereas processing delay relies on the DBA algorithm complexity and performances. Equations (1) and (2) are used to calculate the packet transmission T_{Trans} and processing $T_{Process}$ delays.

$$T_{Trans} = T_{Poll} + T_{Grant} + T_{Queue} \quad (1)$$

$$T_{Process} = T_{DBA} + T_G + T_{Idle} \quad (2)$$

The total end-to-end packet delay T_{E2E}^{Total} for the MTP based DBA scheme is calculated using following formula:

$$T_{E2E}^{Total} = T_{Trans} + T_{Process} \quad (3)$$

3.2. Grant Scheduling and Bandwidth Allocation Process

In the online MTP based DBA scheme, OLT is responded immediately after receiving the Report messages. Online scheduling can reduce delays, which are introduced because of waiting for the all other ONU reports [15]. By considering the traffic condition the ONUs are classified into two individual groups, i. e., lightly loaded ONUs and heavily loaded ONUs. The lightly loaded ONUs are those whose requested window size W_{th}^{R} is lower than the $W_{th}^{\max}$. If W_{th}^{R} is larger than the $W_{th}^{\max}$, then this is known as heavily loaded condition. The OLT allocate the granted window size W_{th}^{G} of a thread based on these two conditions.

$$W_{th}^{G} = \begin{cases} W_{th}^{R} \text{for } W_{th}^{R} < W_{th}^{max} \\ W_{th}^{max} \text{ for} W_{th}^{R} > W_{th}^{max} \end{cases} \tag{4}$$

However, this formula cannot distribute the data packets fairly among the ONUs. To ensure the faire bandwidth distribution, excess window sizes from the lightly loaded ONUs are necessary and this surplus bandwidth is distributed to the heavily loaded ONUs. For *N* number of ONUs and each ONU has *n*number of threads, we can determine the W_{th}^{max} by the equation (5);

$$W_{th}^{max} \quad = \frac{T_{cycle}^{max} - (N-1)\times T_G}{n\times N} \tag{5}$$

For heavily loaded condition, $\text{i.e.}, W_{th}^{R} > W_{th}^{max}$, OLT grants the un-granted request to the immediate next thread and give extra window size obtained from the lightly loaded ONUs.

$$W_{i,th}^{Ex} = \begin{cases} (W_{th}^{max} - W_{th}^{R}) & \text{for } W_{th}^{R} < W_{th}^{max} \\ 0 & \text{for} W_{th}^{R} > W_{th}^{max} \\ & W_{th}^{max} \text{ for} W_{th}^{R} = 0 \end{cases} \tag{6}$$

where,$W_{i,th}^{Ex}$ is the excess window size for the heavily loaded ONU *i* of a thread. Total excess window sizeW_{Total}^{Ex} from the *X* number of lightly loaded ONUs in a time cycle is;

$$W_{Total}^{Ex} = \textstyle\sum_{j\in X} W_{j,th}^{Ex} \tag{7}$$

where *j* indicates the group of lightly loaded ONUs in a time cycle. The W_{Total}^{Ex} is equally allocated to the heavily loaded ONUs. Therefore, excess window size for individual heavily loaded ONUs is;

$$W_{th}^{Ex} = \frac{W_{Total}^{Ex}}{N-X} \tag{8}$$

Therefore, fair bandwidth assignment in the MTP based DBA schemes can be obtained by the equation (9);

$$W_{th}^{G}(MTP) = \begin{cases} W_{th}^{R} \text{if } W_{th}^{R} < W_{th}^{max} \\ W_{th}^{max} + W_{k,th}^{Ex} \text{if} W_{th}^{R} > W_{th}^{max} \end{cases} \tag{9}$$

However, the SMGP scheme proposed in [16] used an utilization factor U_F to distribute the bandwidth among the ONUs in a demand on basis manner. This scheme reduces the polling delay by splitting the time cycle into multiple DBA processing units. The U_F^{i} of an ONU *I* can be defined as the;

$$U_F^{i} = \frac{\sum_{i=1}^{N}\sum_{th=1}^{n} W_{i,th}^{R}}{T_{Cycle}^{max}} \tag{10}$$

Following formula is used for bandwidth allocation in a thread among both the lightly and heavily loaded ONUs according to the SMGP and EMTP scheme;

$$W_{th}^{G}(EMTP) = \begin{cases} W_{th}^{R} \text{if } W_{th}^{R} < W_{th}^{max} \\ \frac{W_{th}^{R}}{U_F} \quad \text{if } W_{th}^{max} \le W_{th}^{R} \le (W_{th}^{max} + W_{k,th}^{Ex}) \\ \frac{W_{th}^{R}}{U_F} + W_{k,th}^{Ex} \text{if} W_{th}^{R} > \left(W_{th}^{max} + W_{k,th}^{Ex}\right) \end{cases} \tag{11}$$

3.3. Analysis of Throughput and Bandwidth Utilization

Throughput: Throughput is the average rate of successful message delivery in a communication channel, which is used to illustrate the performance of the system. Throughput is the ratio of total granted window size to the total requested window size in a time cycle for *N* number of ONUs;

$$Throughput = \frac{\sum_{i-1}^{N} W_i^G}{\sum_{i-1}^{N} W_i^R} \qquad (12)$$

Bandwidth Utilization (BWU):Bandwidth is the bit rate of available or consumed information capacity expressed typically in bits per second. In the EPON system, when DBA scheme is applied to the upstream channel, the performance of the BWU is degraded due to the excess Ethernet overhead used in the algorithm. Therefore, if the overhead is reduced, then the BWU will be increased. The BWU is defined as the ratio of granted window size by the OLT to the actual transmitted window size from the ONUs. Overhead is the summation of Ethernet overhead (E_{Oh}), guard interval T_G, and length of Report messages L_R. Overhead can obtained by the following equation (13) [17];

$$OH_{Total} = \sum_{i=1}^{N} [T_G + L_R + E_{OH} \times \left(\frac{W_{i-}^G T_G - L_R}{P_i}\right)] \qquad (13)$$

Where ,P_i is the length of packet for an ONU i. And equation (14) is used for calculating the BWU;

$$BWU = \frac{\sum_{i-1}^{N} W_i^G - OH_{Total}}{\sum_{i-1}^{N} W_i^G} \qquad (14)$$

4. PERFORMANCES ANALYSIS AND SIMULATION RESULTS

In this section, we first compare the end-to-end packet delay for different offer loads and time cycles of the discussed MTP based DBA algorithms with network extension effects. Next, we show their throughput performances for different loads and time cycles. Finally, we show the performance of the BUW for different schemes.

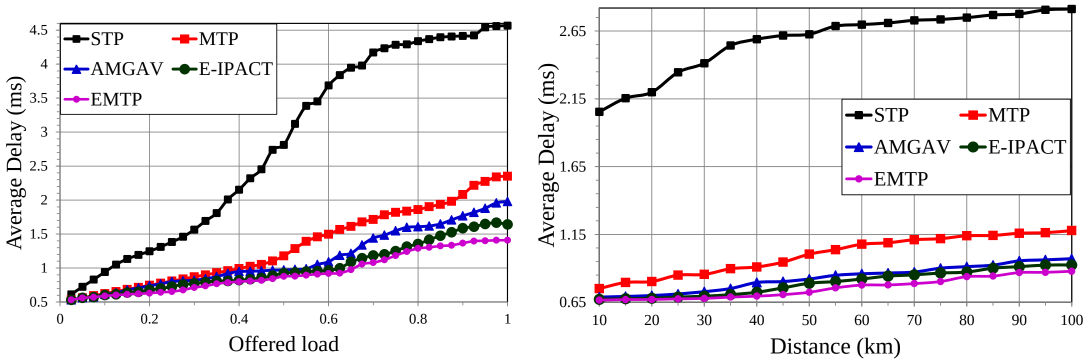
In the numerical analysis, we consider the LR-PON access network framework with a 100 km expansion of the OLT to ONUs separation and 16 ONUs each with two threads are considered. The upstream channel transmission speed is 1 Gbps shared by the entire ONUs. The system throughput is therefore less than the peak-aggregated load from all ONUs. Self-similar traffic was generated by the ONUs to distribute the random data in the upstream channel [18].The numerical analyses were done by using non-uniform offered loads in the range from 0 to1.0. The maximum cycle time T_{Cycle}^{max} is varied from 1 to 5ms in order to compare effects of time cycle in different schemes.MATLAB and C++ based simulation programswere generated to evaluate the performances of all the MTP based DBA schemes. Table I shows the entire summarization of the simulation parameters and their range of values [19].

Table1. *Simulation Parameters.*

Symbol	Description	Value
N	Total Number of ONUs in the LR-PON	16
n	Number of threads	2
T_{cycle}^{max}	Maximum length of a time cycle	1–5 ms
L_{OH}	Length of Ethernet overhead	576 bits
L_R	Length of Report message	304 bits
L_P	Maximum packet length	1500 bytes
P	Number of generated packets	10
T_{Guard}	Guard interval	5 µs
R_{UP}	Upstream speed	1 Gbps
$T_{Process}$	Data processing time	10 s

4.1. End-to-End Delay

Figures 8(a) and 8(b)show the end-to-end packet delay with respect to the offered load in the range of 0 to 1.0 and different distances from the OLT to ONUs for different DBA schemes in LR-PON framework. It is clear from the Figure 8(a) that the conventional STP based DBA scheme performs worst in the case of the LR-PON system; whereas the MTP based DBA schemes have significant improvement in the delay performance. In comparison among the MTP based DBA schemes, E-IPACT and EMTP have lower end-to-end packet delay than the MTP and AMGAV schemes. At the maximum offered load of 1.0, the EMTP, E-IPACT and AMGAV schemes offer almost 40%, 30%, and 16% lower end-to-end packet delay compared to the MTP scheme, respectively. In the Figure 8 (b), the end-to-end packet delay of different DBA schemes is compared with respect to the different distances from 10 to 100 km. The AMGAV, E-IPACT, and EMTP schemes provide similar type of performance. Only a little delay variation is observed between the E-IPACT and EMTP schemes which is the effect of RTT.



(a) Offered Load *(b) Distance (OLT to ONUs)*

Figure 8. *Comparison of average end-to-end packet delay for different DBA schemes.*

4.2. Bandwidth Utilization

In the Figure 9, we show how the upstream channel bandwidth utilization varies with different offered loads for different MTP based DBA schemes. As the delay performance of STP scheme for the LR-PON system is not acceptable, we exclude this scheme from the BWU analysis. It can be seen that BWU is little flat when the offered load is above 0.5; while it decreases when the offered loads move towards the minimum value. This can be explained by that for lower offered load the size of transmitted window size is small compared to the higher offered load, and hence, the E_{OH} is significant for the granted window size as explained in the section 3. From the Figure 9, it can be found that the MTP and AMGAV schemes have

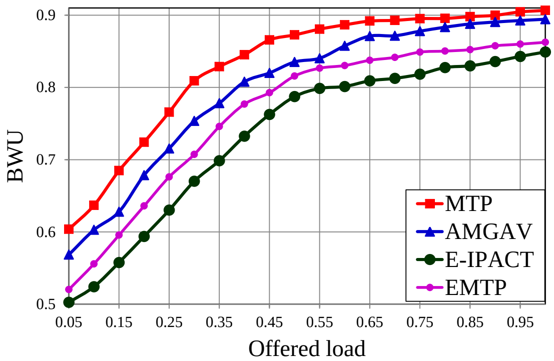


Figure 9. *BWU vs. offered load for different DBA schemes.*

better BWU than the E-IPACT and EMTP schemes. Furthermore, the E-IPACT scheme has the limited BWU 85% for the maximum offered load of 1.0, while the MTP and AMGAV schemes offer 91% and 89% BWU, respectively. As the E-IPACT and EMTP schemes use extra E_{OH} to ensure lower over-granting condition and packet loss rate, which affect the BWU performance.

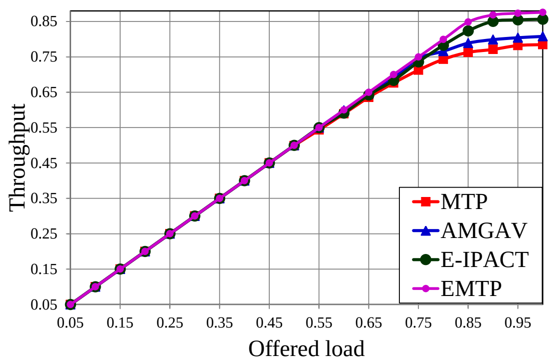
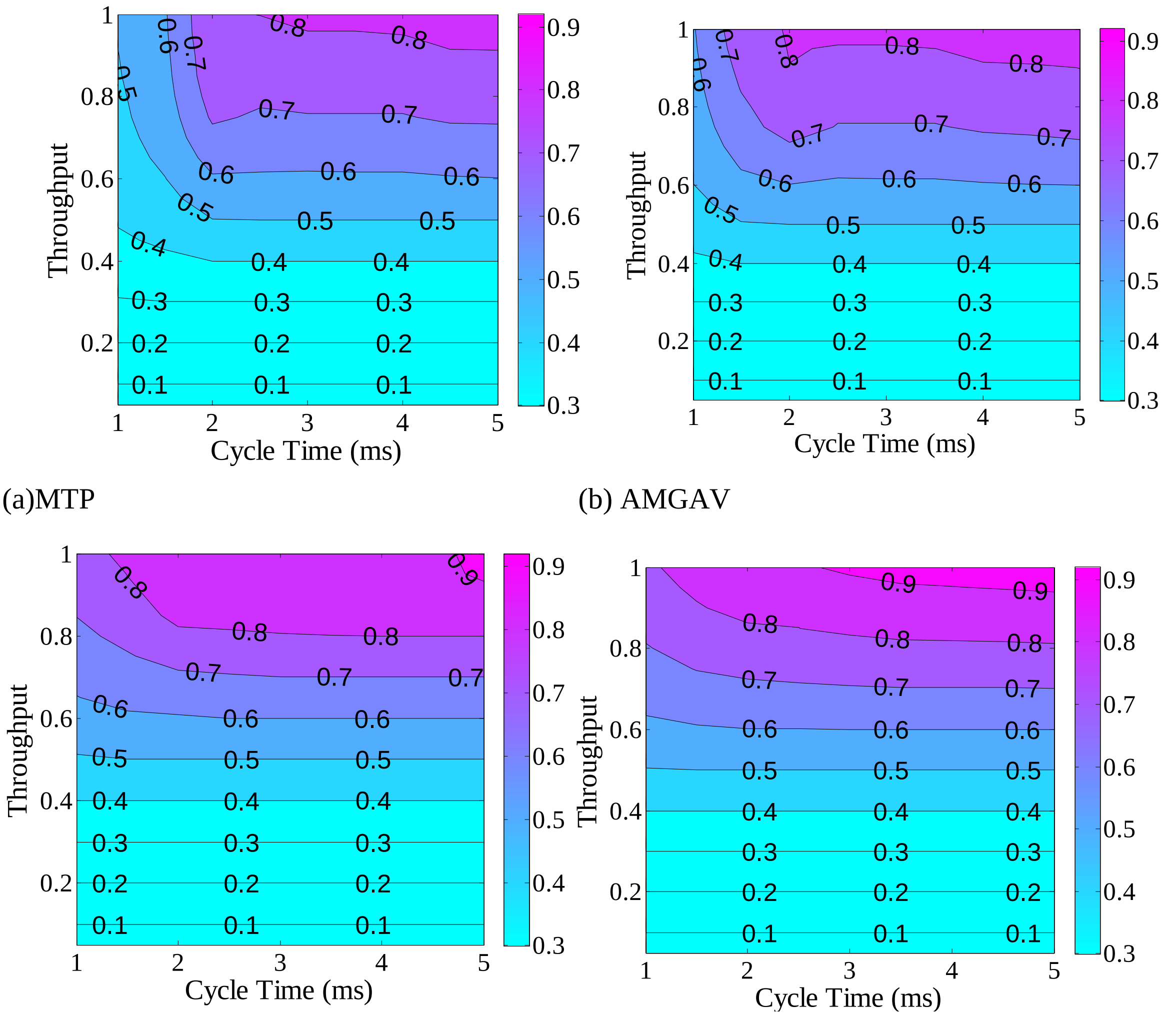


Figure 10. *Throughput vs. offered load*



(a)MTP (b) AMGAV

(c) E-IPACT (d) EMTP

Figure 11. *Throughput in the upstream channel for different offered loads and cycle times.*

4.3. Throughput

Due to the duplicate Report messages, unused timeslots and excess granted window size, a packet may be dropped or lost in the upstream channel. The E-IPACT and EMTP schemes offer over reporting free that ensure better utilization of the upstream timeslots. Therefore, a higher throughput can be achieved in the entire range of the offered loads. Figure 10 verifies the property and shows that for maximum offered load the EMTP and E-IPACT schemes provide almost 88% and 85% of throughput, respectively, while the MTP and AMGAV schemes offer only 78% and 80% of throughput, respectively.

For the MTP based DBA schemes in the LR-PON system, the throughput depends on the cycle time. Figures 11 (a), (b), (c) and (d) show the throughput performance of the MTP, AMGAV, E-IPACT and EMTP schemes for different cycle times of 1 to 5 ms and offered loads of 0 to 1.0, respectively. In these figures, brighter magenta color indicates the better throughput performance. According to the Figures 11 (a) and (b), the MTP and AMGAV schemes have limited throughput area in the cycle times range from 2 to 5 ms. Whereas, the E-IPACT and EMTP schemes provide higher throughput area in that range and the EMTP scheme has more than 90% of throughput in different cycle times coverage than the E-IPCAT scheme. For 2 ms or higher cycle time all the schemes provide better throughput.

5. Conclusions

In this paper, we studied several MTP based DBA schemes and their related performances, i.e., end-to-end delay, throughput, and BWU for the LR-PON system. We described all schemes in computational way and investigated their shortcomings. Although the MTP based DBA scheme is a promising solution for the LR-PON system, it performs worst compared to the conventional STP based DBA scheme if proper grant scheduling and over-granting condition is not considered. From the numerical analysis we observed that the end-to-end delay and BWU of the MTP and AMGAV schemes are far better than the conventional STP scheme, whereas these two schemes have limited throughput performance compared to the existing E-IPACT and E-MTP schemes. As the E-IPACT and EMTP schemes reduce the unused timeslots issue and duplicate Report messaging, they significantly increase their throughput performance with lower end-to-end packet delays. However, the MTP and AMGAV schemes use smaller Ethernet overhead, which increase the BWU performance compared to the E-IPACT and EMTP schemes. The result analysis shows that the MTP and AMGAV schemes have better BWU compared to the E-IPACT and EMTP schemes. However, the E-IPACT and EMTP schemes ensure lower end-to-end packet delay as well as better throughput performance than the MTP and AMGAV schemes.

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