CHAPTER 2

BACKGROUND AND RELATED WORKS

MPCP defined in IEEE 802.3ah only constructs a protocol frame but does not propose specific bandwidth allocation method. Therefore, dynamic bandwidth allocation algorithm is one of focuses of the research into the current EPON technology. This section provides a survey of the state-of-the-art DBA algorithms that have been proposed for EPONs. The classification of the bandwidth allocation algorithms for EPON system is provided in Figure 2.1.

![Classification of DBA algorithms](image)

**Figure 2.1 Classification of DBA algorithms**

The research community has unfolded different aspects of the Dynamic Bandwidth Allocation (DBA) process and here are a few worth
mentioning. Interleaved Polling with Adaptive Cycle Time (IPACT) (Kramer et al 2002a) is one of the earliest and most effective attempt in providing an improved DBA algorithm and hence solving the inadequacy of SBA algorithm. IPACT algorithm does not provide specific bandwidth allocation algorithm and only provides an interleaved polling mechanism. Research community has put forward a lot of polling-based DBA algorithms based on IPACT, optimizing the algorithm in certain performance aspect but at the cost of other performances. In polling-based bandwidth allocation algorithms, the OLT sends a GATE message to an ONU for its bandwidth request and then waits till the data and REPORT message from that ONU is received before sending GATE message to the next ONU. The bandwidth request reports the data queue length at the time of REPORT generation and does not include the data packets that might arrive at the ONU from the time the REQUEST is generated and GATE is received. This period is called waiting time and the data that arrives during this period need to wait until the next cycle for it to get reported and transmitted, and this increases the average packet delay of the service. A way to solve this problem is to increase the bandwidth request with an estimate of the waiting data length and the granted bandwidth includes the waiting data length as well allowing the waiting data also to get transmitted in the current cycle, and thus reducing the average packet delay. In this context, there are many prediction mechanisms used in the literature like constant credit, linear credit and elastic credit for estimating the waiting time bandwidth length (Luo & Ansari 2005) (Zheng & Mouftah 2005b) (Banerjee et al 2006).

Since EPON supports triple-play services, EPON is required to support multi service QoS and hence scheduling based on service’s priority gained momentum. (Sherif et al 2004) (Kim et al 2005) classifies services into three types: Expedited Forwarding (EF), Assured Forwarding (AF) and BE forwarding. The order of servicing is EF, AF and then BE services. With the
allocated bandwidth EF service requests are processed before any of the other requests. AF service requests and BE service requests are then processed with the remaining available bandwidth. Even though QoS is guaranteed for high priority services, packet loss rate is high for lower priority services under heavy network load resulting in unfair bandwidth allocation. When network is busy with higher priority services for a longer time, then the lower priority services might even face rejection of service provision. When the ONU underutilize the guaranteed bandwidth due to less load, there might be unused residual bandwidth in the system. This remaining bandwidth could be split between the heavy load ONUs by a secondary allocation in order to improve the upstream bandwidth utilization. The secondary allocation follows its own scheme, and traditionally the bandwidth is divided between the heavy-load ONUs in proportionate to their bandwidth request. This results in heavy-load ONUs monopolizing the bandwidth and to achieve fairness in this scheme, priority of the requesting services need to be considered as well (Banerjee et al 2006).

2.1 IPACT AND CLASSIC DBA ALGORITHMS BASED ON IPACT

IPACT facilitates queue report and bandwidth allocation by employing resource negotiation process using GATE and REPORT messages. The OLT polls ONUs and the ONUs report about their data queue length. On receiving bandwidth requests from each ONU, the OLT calculates the dynamic data load of each ONU and grants timeslot to each ONU in the upstream bandwidth in accordance with their demand. The allocated bandwidth to each ONU is limited by the SLA of the end users connected to that ONU. In IPACT, all ONUs are polled in a round-robin fashion and (i+1)th ONU is sent grant information when i\textsuperscript{th} ONU is transmitting. The major disadvantage of the IPACT algorithm is that when an ONU gets the token it
will release the token only after it has transmitted all its data. This may prove costly for other ONUs which are waiting to send data. Another distinct disadvantage of the IPACT algorithm is that even though the OLT has more bandwidth to support a particular ONU it only grants what is requested by the ONU. Both OLT and ONU do not have any provisions to utilize the unused bandwidth in a cycle. Following are the bandwidth allocation schemes discussed in IPACT:

- Limited allocation,
- Constant credit,
- Linear credit, and
- Elastic allocation.

Limited allocation scheme sets an upper limit to the transmission window size of each ONU and the ONUs are granted bandwidth not more than this value. This scheme avoids the bandwidth monopolizing by the heavy load ONU. Bandwidth allocated to each ONU is either the requested bandwidth or the limited transmission window size, whichever is smaller. The bandwidth request assuming no packets will arrive after the ONU sends its request, reports only the data queue length at the time of REPORT generation. Practically, data packets might arrive at the ONU between the time an ONU generates the REQUEST and the time the ONU receives the GATE. This period is called waiting time and the data that arrives during this period need to wait until the next cycle for it to get reported and transmitted, and this increases the average packet delay of the service. The credit scheme handles the waiting time data problem by adding an addendum to the requested bandwidth.

Constant-credit allocation adds a fixed credit to the requested bandwidth and is included in the granted timeslots. The credit value is the estimated value of the data arriving during the waiting time interval in the
ONU. It should be noted that the bandwidth allocated to each ONU should not exceed the maximum transmission window. The size of the credit is independent of the requested bandwidth and the choice of the size has an impact on the network performance. The granted window size for an ONU includes not only the requested window size but also the credit size and the ONU can send packets up to the requested window size plus the constant credit. This reduces the average packet delay since the waiting time packets get transmitted in the current cycle itself. Constant credit is based on service prediction and is applicable to CBR services and fixed waiting time interval, but cannot be adapted to high-burst data service. Larger credit size will reduce the upstream bandwidth utilization and smaller credit size will not help much to improve packet delay. Hence there should be a well-defined formula for choosing the credit size and should be based on the traffic characteristics or some empirical data.

In practical network, a certain degree of predictability is found in the network traffic in that traffic flow belonging to burst type has long-range dependence (Zheng & Mouftah 2005a). Constant credit prediction method results in bigger errors in that the waiting time interval data need not refer to certain constant value. In this context, a better approach is to use the linear proportion of the request window size for estimation of the credit size. Linear-credit allocation is similar to constant-credit allocation in that it adds a credit to the requested window size, but the size of the credit is proportional to the requested window size. Here again, the bandwidth allocated to ONU should not exceed the maximum transmission window. Compared to constant credit, the prediction accuracy of linear credit is improved. But due to complex non-linear characteristics such as data’s intrinsic high-burst and self-similarity, linear prediction still results in errors in that some ONU underutilize the bandwidth while the granted bandwidth of other ONUs is insufficient and this results in reduced network performance.
Elastic allocation scheme does not impose any restriction on the maximum transmission window size and the granted window size could be the maximum polling cycle time. The maximum window size $W_{\text{max}}$ is granted in such a way that the accumulated bandwidth of $I$ x ONU does not exceed $I$ x $W_{\text{max}}$, where $I$ is the number of ONUs. In this way, if only one ONU has data to send, it may get a granted window size up to $I$ x $W_{\text{max}}$.

Among all the above bandwidth allocation schemes, limited allocation exhibits the best performance (Kramer & Pesavento 2002).

There are many polling algorithms based on IPACT and here are a few worth mentioning.

2.1.1 IPACT with Grant Estimation

IPACT with Grant Estimation (IPACT-GE) (Zhu & Ma 2008) attempts to improve the efficiency of IPACT in sharing the upstream bandwidth among the ONUs by estimating the early arriving packets in a polling cycle and include them in the requested bandwidth size. This helps in reducing the packets waiting delay. The size of waiting time interval data arriving at an ONU is estimated based on the self-similar nature of network traffic. Transmission window size granted for an ONU is based both on the estimated early arriving packet size and the bandwidth requested in the previous polling cycle. By this, the grant size to the ONU is expected to be close to the real network traffic arriving at the ONU. Under light traffic load, the early arriving data packets get transmitted in the same polling cycle without having to wait until the next polling cycle, and thus reduces the average packet delay without affecting other performances like average packet loss and upstream channel utilization. IPACT-GE is highly suitable for light load ONUs.
2.1.2 IPACT with Smallest Available Report First

IPACT with Smallest Available Report First (SARF) (Bhatia & Bartos 2007) is yet another attempt to improve the performance of IPACT in the aspect of reduced packet delay. OLT in this algorithm arranges all pending ONUs in ascending order according to their queue length and grants bandwidth to ONUs with smallest reported queue length first. The heuristic is independent of the policy used for deciding the grant size. Although the SARF heuristic chooses the ONU with the smallest queue length for service, it treats ONUs with zero queue lengths differently. An ONU with a zero queue length has no data to transmit. Under low loads, without special exception, such ONUs will always be served first. While such data less grants do not contribute to lowering the packet delay at the source ONUs which has no packets to send, they do increase the delay faced by the succeeding ONUs. Hence, when choosing an ONU to serve next, ONUs with zero-length queues are treated as if they have a queue length that is equal to the average queue length taken over all ONUs. Moreover, this average is weighed by the number of times an ONU reports a zero length queue, consecutively. Thus, an ONU which has reported a zero length queue many times consecutively will likely be served at the end of the cycle. If the OLT chooses to serve the smallest request, it will increase the Scheduling Endpoint Indicator (SEI) by the smallest possible value, where SEI signifies the earliest time at which a new transmission can be scheduled on the upstream. Thus, the SARF heuristic minimizes the grant delay faced by packets. In turn, the average cycle length may also be reduced thus leading to a reduction in the reporting delay.

2.2 DBA WITHOUT QoS SUPPORT

Even though IPACT and IPACT-based DBA algorithms attempt to reduce the average packet delay, supporting differentiated services is not
considered in these algorithms. There are several DBA algorithms proposed for EPON which do not support differentiated services, and a few are discussed here.

2.2.1 Estimation-based DBA

Byun et al (2003) proposed a control theoretic extension which is again an estimation-based DBA algorithm to overcome the waiting time delay. The heuristic estimates the amount of traffic arriving at the ONU between two successive requests and this estimate is incorporated into the grant to the ONU. The difference between the grant for cycle n and the amount of traffic backlogged in the ONU when the grant arrives is approximately $X(n) = G(n) - [Z(n - 1) + T(n - 1)]$, where $G(n)$ is the grant generated by OLT for cycle n, $Z(n - 1)$ is the amount of backlogged traffic in the ONU at the instant when the request for cycle $n - 1$ is generated, $T(n - 1)$ is the amount of traffic arriving at the ONU between generating the request for cycle $n - 1$ and receiving the grant for cycle n. The OLT allocates bandwidth based on the size of the previous grant and the scaled version of the difference reported by the ONUs. More specifically, the grant for cycle $n + 1$ is calculated as $G(n + 1) = G(n) - f^*X(n)$, where $f$ is the gain factor. The derivations and simulation results of Byun et al (2003) show that the system is asymptotically stable for $0 < f < 2$. The best part of the algorithm is that the grant size is typically closer to the size of the backlog at the instant of receiving the grant at the ONU which in turn results in lower waiting delays. On the downside this creates problems when the traffic load is highly variable since the algorithm needs better fine tuning in responding to changes in the traffic load without disrupting the functioning of the system.
2.2.2 Bandwidth Guaranteed Polling

Bandwidth Guaranteed Polling (BGP) (Ma et al 2003) divides ONU's into two disjoint sets:

- Bandwidth guaranteed (bandwidth allotted determined by the SLA) and
- Best-effort or Bandwidth non-guaranteed.

The total upstream bandwidth is divided into equivalent bandwidth units such that the count of bandwidth units is larger than the number of ONU's. The OLT maintains a couple of Polling Tables, table 1 for bandwidth guaranteed ONU's and table 2 for best effort ONU's. Number of entries in table 1 is equal to the count of bandwidth units. Entry size for table 2 is not fixed. Table 1 entries are established for each bandwidth guaranteed ONU based on its SLA. Entries for ONU's requiring more than one bandwidth unit are evenly spread through the table 1. Since the ONU is polled more frequently, this reduces the average queuing delay. Unoccupied table 1 entries are dynamically assigned by the OLT when processing these entries to best-effort nodes in the order they are listed in the best effort table. Both the tables are used by the OLT to poll the ONU's. The OLT initially grants an ONU in table 1 with one bandwidth unit. The ONU responds back to the OLT about the amount of the granted transmission window it intends to utilize and then transmits this amount of data. If the ONU do not have any data and the intended utilization is zero, then OLT immediately polls the next ONU in the table. This waste the bandwidth involved with the round-trip time to the ONU. If the utilization is between zero and the minimum bandwidth unit that can be effectively shared between ONU's, the OLT polls the next best-effort ONU ready for transmission and grants it the rest of the transmission window. If utilization is larger than the minimum bandwidth that could be effectively shared, the OLT will not poll the next ONU. The simulation results show that smaller queuing delay is enjoyed by ONU's with more entries in the polling
table, but the throughput tends to be lower at heavy loads. Overall, the advantage of this approach is that it ensures that an ONU receives its SLA bandwidth. The approach includes unreserved bandwidth units and unused portions of a guaranteed bandwidth unit allowing statistical multiplexing of the traffic. One drawback of the scheme is that the upstream transmission tends to become fragmented with more grants in a cycle and thus requires more guard time between grants, which tends to reduce the throughput and channel utilization.

2.2.3 Multi Thread Polling

In an attempt to have better utilization and fair distribution of the upstream channel in long-reach PONs, the Multi-thread Polling (Song et al 2009) algorithm was proposed by Song et al. In this scheme, the ONUs are allowed to send its REQUEST message even before the arrival of the GATE message from the OLT for its previous REQUEST and there is a REPORT message generated for every GATE message received. GATE allocations for an ONU are done before the OLT receives the REPORT message from the ONU for the previous allocation. The cyclic execution of GATE allocation and then waiting for reception of corresponding REPORTs to proceed with the next allocation constitutes a thread. Many such allocation threads run in parallel, and the OLT can make use of not only the information in the current thread’s REQUEST message, but also that in subsequent threads before performing bandwidth allocation. Thus, this scheme reduces the packet delay far better than rest of the algorithms since their REPORT gets processed faster. The worst case delay is found when a packet gets reported in the next thread missing the current thread. This scheme definitely improves the performance of a single-thread polling algorithm under high traffic load in terms of average packet delay and throughput.
2.3 DBA WITH QoS SUPPORT

EPON delivers triple-play services which includes data, voice and video. Hence EPON system should not only deliver BE data traffic, but also real-time data traffic that have strict bandwidth, packet delay, and delay jitter requirements. Differentiated QoS provisioning should be enforced in EPON system to support this and this subsection discusses some of the DBA algorithms that provide differentiated QoS support for different types of data traffic in EPON.

2.3.1 Fair Sharing with Dual SLAs

In an attempt to provide fair and balanced sharing of bandwidth for end-users and in the process satisfying service-providers, Banerjee et al (2006) proposed a double SLA algorithm which uses two SLAs values. The primary SLA specifies the minimum requirements for high priority services and the secondary SLA specifies the service requirements for low priority services. Services with primary SLA values are allotted with timeslots before granting bandwidth to secondary SLA services. This means, higher priority services have higher privilege for bandwidth allocation than lower priority services and thus ensures differentiated QoS. Both excess and insufficient availability of bandwidth results in following max-min fair policy for allocation of bandwidth. Also, some packets may arrive without predefined SLA value for which SLA will be allocated according to max-min fair policy.

2.3.2 A Joint-ONU Interval-Based Dynamic Scheduling

Naser & Mouftah (2006) supports differentiated services by proposing a Class of Service (CoS) oriented packet scheduling algorithm. The algorithm uses two groups of leaky bucket credit pools in the OLT and is used to regulate the allocation of upstream bandwidth to the ONUs.
The average rate of CoS traffic transmitted from the ONU's is controlled by having a group of m credit pools where m refers to the number of different CoSs in the system. The other group contains n credit pools where n refers to the number of ONU's in the system and this group is used to control an ONU’s upstream bandwidth utilization. Higher CoS value services are granted with bandwidth before any of the lower CoS services are granted. This is accomplished with two rounds of allocation. First round grants each ONU’s traffic of the current CoS with the number of credits available for that ONU, and if the ONU’s request is granted completely the corresponding credit pool for that ONU gets reduced by the amount of granted credits. The unused credits at the end of first round are pooled together and distributed to the ONU's with unfulfilled requests. Requests get granted till the availability of credits in the pools. The algorithm, in the process of favoring higher priority services is not fair to the lower priority services even though the simulation results show that the algorithm has a lower average packet delay for all CoS.

2.3.3 Hybrid Granting Protocol

Hybrid Granting Protocol (HGP) by Shami et al (2005) proposed a dynamic scheduling algorithm to minimize packet delay and jitter for delay and delay-variation sensitive traffic by allocating bandwidth in a grant-before-report fashion. HGP classifies the traffic into three categories: EF with the highest priority for strictly delay sensitive CBR services, AF with medium priority for services of non-delay sensitive Variable Bit Rate (VBR) services, and BE with the lowest priority for delay tolerable services. HGP applies a two-cycle allocation scheme for EF and AF / BE services. First cycle applies grant-before-report allocation for EF services followed by grant-after-report allocation for AF and BE services in the second cycle. EF traffic being fully-deterministic, the bandwidth allocation need not rely on the REPORT message for bandwidth estimation but uses a queue prediction mechanism to
estimate the EF traffic that will arrive before the next transmission start time. This preallocation scheme guarantees a maximum packet queuing delay for EF services. For the AF and BE traffic, the grant size is solely based on the REPORT message from that ONU for the cycle.

Grant-before-report and grant-after-report allocations cannot be implemented simultaneously due to the fact that the prospective transmission start time of an ONU cannot be decided before bandwidth is allocated to all ONUs with earlier transmission times. In this context to achieve feasibility, an EF subcycle and an AF subcycle is built to transmit EF data and AF/BE aggregated data respectively. Now, EF bandwidth allocation for one ONU and transmission start time for the next ONU can be decided sequentially in the EF subcycle. The length of the EF sub-cycle is predetermined while that of the AF/BE sub-cycle depends on the traffic load of each ONU.

 Accordingly, a GATE message to an ONU has two grant sections – one for AF subcycle of the current transmission cycle and other for EF subcycle of the next transmission cycle. The status of the AF and BE queues in an ONU is not reported until the end of the EF grant for that ONU, which allows the ONU to report up-to-date queue status to the OLT. The AF transmission window granted to an ONU is an aggregated value for both AF and BE services. In order to prevent AF services from inadvertently monopolizing this granted window allocation, intra-ONU scheduling is employed in that only reported packets are eligible to access the link in accordance with their service priorities.

In this way, HGP guarantees the bandwidth to the EF traffic and thus minimizes the jitter experienced by the EF traffic, while keeping QoS support for the AF and BE traffic with flexible bandwidth allocation. The simulation results show that HGP has smaller queuing delay under higher traffic load as compared to a regular EPON scheduler. Under lower traffic
load, the regular EPON scheduler has smaller queuing delay because of the increased length of guard time per cycle.

2.3.4 Bandwidth Allocation for Multiservice Access on EPONs

Luo & Ansari (2005) proposed an algorithm for dynamic bandwidth allocation that employs bursty traffic prediction with service differentiation. Bandwidth Allocation for Multiservice Access on EPONs (DBAM) combines the provisioning of multiple services among ONUs and among end users within a single ONU by a combination of queuing, scheduling, and class based bandwidth allocation at the ONU. DBAM applies priority queuing to enqueue EF, AF, and BE frames with preference to higher priority traffic. The frames are scheduled using priority-based scheduling mechanism. Also, limited bandwidth allocation is adopted to arbitrate bandwidth allocation among ONUs, thus prohibiting aggressive bandwidth scrambling.

Added to that, DBAM employs class-based traffic prediction to accommodate the traffic that arrives during the waiting time to reduce packet delay and queue length. The ONUs in the system are served in a round-robin fashion to facilitate traffic prediction. Multiservice access at an ONU is based on the traffic classification. EF traffic gets allocated first, followed by AF traffic. Left out bandwidth is used for BE traffic. To avoid monopolizing of the network by EF and AF traffic, their grants are upper bounded by their maximum bandwidth parameter. The simulation results show that the fixed service order among ONUs in DBAM enhances the accuracy of traffic estimation, and the improved traffic estimation thus contributes to the reduction of frame delay, queue length, and frame loss.
2.3.5 Limited Allocation with Excess Distribution

Assi et al (2003) proposed a dynamic bandwidth allocation algorithm with QoS support to accommodate different types of traffic in EPONs. This scheme combines gated transmission mechanism and DBA scheme with priority scheduling and queue management to implement a cost-effective EPON network with differentiated services support. Ethernet traffic’s bursty nature results in some ONUs with lighter load and may have less data to transmit, while other ONUs are heavily loaded with more data to transmit. The lightly-loaded ONUs require less than the minimum guaranteed bandwidth or SLA bandwidth, while the heavily-loaded ONUs require more than their SLA bandwidth. The lightly-loaded ONUs end up in unused bandwidth and this unused left out bandwidth is shared between the heavily-loaded ONUs to satisfy their excess demand. The heavily-loaded ONUs are allocated excess bandwidth in proportional to their bandwidth demands. For this process, the OLT collects the REPORT messages from all ONUs, computes the bandwidth to be allocated to each ONU and schedules them. The algorithm requires certain time to do the DBA computation and grant table generation, this results in some idle time during which the upstream channel is not utilized. To account for this shortcoming, an early allocation mechanism was proposed. Here, the lightly-loaded ONUs are scheduled instantaneously without waiting, whereas the heavily-loaded ONUs are scheduled only after the OLT receives REPORT messages from all ONUs and their bandwidth allocation is computed. This mechanism significantly improves bandwidth utilization only under low and medium traffic load but fails to utilize the idle time in a better way under high traffic load. Zheng (2006) proposed a new scheduling control mechanism to address this idle time problem under high traffic load and to further improve bandwidth utilization. In this improvement, the OLT still employs an early allocation mechanism for lightly-loaded ONUs and service them instantaneously, and
accumulates the excessive bandwidth contributed by each lightly-loaded ONU. Normally, heavily-loaded ONUs are serviced only after receiving the REPORT messages from all such ONUs. To ensure that the idle period is not wasted, the OLT maintains a tracker that records the last scheduled ONU’s ending time of its timeslot and updates the tracker every time the next ONU is scheduled. The OLT will schedule a heavily-loaded ONU under some special conditions depending on the value of the tracker. The simulation results show that the DBA algorithm proposed in Zheng (2006) can effectively improve the network performance in terms of packet delay and throughput under high traffic load compared with the algorithm proposed in Assi et al (2003).

### 2.3.6 Queue-based DBA

Choudhury & Saengudomlert (2007) in their work proposed an OLT-centric DBA scheme for a QoS-aware EPON. The DBA scheme is based on individual requests from the service queues in each ONU. In order to avoid resource starvation for lower-priority traffic when the higher-priority services are preferred to be scheduled more than lower-priority services, the proposed DBA scheme employs queue scheduling. The scheme also makes use of the excess bandwidth of lightly-loaded queues that is left out due to their underutilization, to meet the bandwidth demand of heavily-loaded queues. Also, the scheme incorporates an efficient polling mechanism to solve the idle period problem. A novel different-cycle policy is employed to reduce the scheduling overhead by selectively allocating bandwidth to different service classes based on their delay bounds. The simulation results show that the scheme performs better in terms of average packet delay and bandwidth utilization than using a strict priority policy.
2.3.7 Fine Scheduling

Chen et al (2006) proposed a fine scheduling algorithm with an inter-ONU scheduler at the OLT and an intra-ONU scheduler at each ONU. A novel DBA algorithm runs as the inter-ONU scheduler to allocate the upstream channel among the ONU's in a fair manner and optimizes the upstream bandwidth utilization. Generally, the ONU's report only its data queue length at the instant of REPORT generation as request to the OLT. Whereas, in the proposed DBA algorithm each ONU sends two requests in its REPORT messages: a guaranteed or minimum window size and a maximum window size. The OLT waits till the REPORT messages from all ONU's are received and then performs bandwidth allocation. The following fairness criteria are considered in allocating bandwidth to each ONU:

- Bandwidth granted to an ONU does not exceed its maximum window size;
- Bandwidth granted to an ONU always meets its guaranteed or minimum window size;
- Excess bandwidth allocated to an ONU is in accordance to its weight.

Additionally, the unused bandwidth leftovers are eliminated by sending the REPORT message ahead of the data stream. Also, the OLT is informed of the total bandwidth of each ONU for this cycle and the maximum and minimum requested bandwidths of each ONU for the next cycle. In addition to the inter-ONU scheduler, a novel hierarchical intra-ONU scheduler is also proposed to realize fine granularity scheduling to support QoS for traffic of each individual user by combining the M-TB algorithm for inter-class (Chen et al 2005) and the modified start-time fair queuing for intra-class (Ghani et al 2004). The simulation results show that the proposed
overall scheduling algorithm can meet the performance requirements in terms of packet delay and throughput for the transmission of multimedia traffic of each end user.

2.3.8 Priority-based DBA for Emergency Handling

The network activity is broadly classified into two states: normal and emergency. Moon (2008) analyzed the DBA scheme in network emergency state and concluded that priority-based DBA should only be used for emergency state. Modified version of Son (2004) is adopted for the normal state DBA, and the modification includes considering the weight of each ONU for allocation. For the emergency state, three priority-based DBA algorithms are proposed. These algorithms differ in how they protect the network from being monopolized by the high-priority services paving way for protecting the low-priority services from starving. In the first algorithm, high-priority service requests are served before any of the low-priority services request and hence do not avoid the bandwidth being over utilized by high-priority services and end up being unfair to low-priority services. The second algorithm overcomes this drawback by serving each priority-level services requests only for a certain count and then starts serving the next priority-level services requests, say, the high-priority services requests are serviced only upto a certain count and then low- priority services requests are served. To achieve this, a counter is maintained that counts the requests being served. It should be noted when low-priority services requests are served for a certain count, the service is handed over to high-priority services requests. In the third algorithm, the OLT maintains a polling sequence table to avoid the high-priority services requests from monopolizing the bandwidth. The simulation and analytical results show that the proposed DBA algorithms perform efficiently in terms of packet delay and bandwidth utilization, and can meet more stringent QoS requirements than the conventional weighted round-robin based algorithms.
2.3.9 Predictive QoS based DBA

Peng et al (2010) proposed a PRNN/ERLS-based predictive QoS-promoted dynamic bandwidth allocation (PQ-DBA) scheme. The scheme not only commits the QoS requirements for real time services, but also promotes the fairness for non-real time packets. The incoming packets of voice, video, data service traffic are divided into six priorities. Packets in starvation situation will be dynamically promoted to high priority cycle-by-cycle. It predicts packets arriving at prediction interval for ONUs using pipeline recurrent neural network (PRNN)/extended recursive least squares (ERLS) so that the bandwidth allocation can be more up-to-date and accurate. Simulation results show that the scheme achieves higher system utilization and lower average voice, video, data packet delay time than the DBAM scheme (Luo & Ansari 2005).

2.3.10 Intelligent DBA Algorithm

Radzi et al (2010) proposed an intelligent fuzzy-logic-based dynamic bandwidth allocation algorithm (IFLDBA) for EPONs, and uses fuzzy logic to improve the bandwidth allocation within each ONU. The algorithm does both inter and intra ONU scheduling using fuzzy logic.

2.3.11 Generic QoS-Aware Interleaved DBA

Hwang et al (2012) proposed a generic QoS-aware interleaved dynamic bandwidth allocation (QA-IDBA) mechanism, where ONUs are divided into two groups and the mechanism operates in coordination with adaptively bi-partitioned interleaved scheduling. When one group is sending data to the OLT, the bandwidth for another group is simultaneously calculated and reserved. By this, the mechanism attempts to resolve the jitter problem.
with non-interruption transmission. Moreover, a linear estimation credit is incorporated to predict the arrival of traffic during the waiting time. Also, strict priority allocation is used to reduce the high-priority traffic delay to support QoS and the excess bandwidth of light-load ONU’s are reallocated for extra demand to heavy-load ONU’s. In addition, any remaining available bandwidth is adjusted between the two groups.

2.3.12 A Distributed Dynamic Scheduling for EPON

Most of the proposed DBA algorithms discussed so far are centralized wherein the OLT takes the sole responsibility of estimating and allocating the bandwidth to ONU’s based on their queue length. From the best knowledge of the literature survey, the work by Andrade et al (2007) - A Distributed Dynamic Scheduling for EPON (DDSPON) is the only decentralized approach, where the estimation and allocation of bandwidth is done at the ONU’s and not at OLT. Garfias et al (2012) is an extension of DDSPON to realize it in 10G EPONs. The work by Sherif et al (2004) also proposes a decentralized approach but through distributed EPON architectures. The work proposes ethernet over star coupler-based PON architecture that uses a fully distributed TDMA arbitration scheme, which requires a hardware change in the topology realization. The algorithm proposed by Andrade et al (2007) is as follows: Each ONU on registration is assigned a weight based on SLA. The OLT also sends each ONU the list of weight values of all currently active ONU’s. The unused fields (Pad / Reserved) in the REPORT and GATE messages are used for the purpose. Each ONU will send its weight value in the REPORT message and the OLT on receiving the message adds / updates the value in its list which it sends back to ONU along with GATE message. The ONU’s estimate its upstream window size for the next grant based on values in this list. Unfortunately, the authors of Andrade et al (2007) have failed to address the fact that the ONU’s
bandwidth request for the current cycle is solely based on the previous cycle’s data and any new add / delete / modify of the bandwidth request by the rest of the ONUs for the current cycle doesn’t get reflected in an ONU’s estimation.

The research community has however put maximum effort in proposing and improving centralized DBA algorithms with different viewpoints and the one in Andrade et al (2007), which attempts to do it in de-centralized way, has multiple drawbacks as stated earlier. Also from the literature survey, it could be concluded that most of the DBA algorithms act to increase their throughput and performance at the cost of other performance aspects and the fact that most of the algorithms suffer from some drawbacks has motivated this research. Hence an attempt is made in this research work to fine tune the both the centralized and distributed DBA process in a different perspective to maximize bandwidth utilization and minimize packet delay, which are the objectives of a good DBA algorithm.