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# APPLICATION OF DYNAMIC BANDWIDTH ALLOCATION (DBA) ALGORITHMS IN XG-PON NETWORKS

Almardanov Mukhriddin Xurram ugli

Teacher of Institute ISFT

almardanovmail.com@gmail.com

### Abstract

As a result of the rapid advancement in telecommunication technologies, user demand for higher data transfer speeds is increasing year by year. Today, providing high-speed internet services, accessing cloud computing platforms, and supporting modern applications such as video conferencing and 4K/8K video streaming require a fast and reliable network infrastructure. To meet these demands, Passive Optical Network (PON) technology is recognized as the most promising solution. This chapter provides a detailed examination of the evolutionary history of passive optical networks, the architecture and operating principles of XG-PON technology, the concept and necessity of Dynamic Bandwidth Allocation (DBA), as well as the various types and classifications of existing DBA algorithms.

**Keywords:** XG-PON, Dynamic Bandwidth Allocation (DBA), Passive Optical Networks, Quality of Service (QoS), Resource Allocation.

### Introduction

Dynamic Bandwidth Allocation (DBA) is a mechanism in XG-PON networks that distributes upstream bandwidth to Optical Network Units (ONUs) in real-time, based on actual traffic demand. The DBA algorithm is executed by the Optical Line Terminal (OLT) and determines the number of time slots allocated

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to each ONU during every transmission cycle. To fully grasp the significance of DBA, it is appropriate to compare it with Static Bandwidth Allocation (SBA). In SBA, a fixed and constant amount of bandwidth is assigned to each ONU. Although this approach is straightforward, it leads to inefficient use of network resources: slots allocated to idle ONUs remain unused, while heavily loaded ONUs cannot obtain additional resources when needed.

The ITU-T G.9807 standard defines T-CONT (Transmission Container) service classes for DBA. These include:

T-CONT 1: Guaranteed, constant bandwidth (for voice services and video conferencing);

T-CONT 2: Guaranteed bandwidth with a variable rate;

T-CONT 3: Assured bandwidth with a guaranteed minimum;

T-CONT 4: Non-assured, utilizing available best-effort capacity;

T-CONT 5: A combination of the aforementioned types [1].

The fundamental operational cycle of DBA is carried out in the following sequence: The ONU reports its buffer status (the volume of queued data) to the OLT; The OLT calculates the required bandwidth for each ONU using the DBA algorithm; The OLT issues a Grant message to notify each ONU of its allocated transmission window and data volume; The ONU transmits its data during the designated time slot.

### Literature Review: Analysis of Previous Research

The development and optimization of **Dynamic Bandwidth Allocation (DBA)** algorithms have been extensively studied across various generations of Passive Optical Networks. A foundational comparative study by **Skubic et al. [1]** evaluates the performance of DBA mechanisms within **EPON** and **GPON** standards, highlighting how architectural differences influence bandwidth efficiency and latency. Their research underscores that while both standards aim to optimize resource distribution, the framing and reporting mechanisms inherent

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to each require distinct algorithmic approaches to maintain **Quality of Service (QoS)**.

Furthering the focus on higher-speed systems, **Neto et al. [2]** provide a comprehensive performance analysis specifically tailored to **XG-PON** environments. Their work explores how DBA algorithms manage the increased capacity of 10-Gigabit systems and addresses the complexities of maintaining fairness and efficiency among multiple **Optical Network Units (ONUs)**. This analysis is crucial for understanding the transition from legacy PON systems to next-generation high-speed access networks.

In addition to specific algorithmic evaluations, the theoretical framework for medium access in optical networks is well-documented. **Zheng and Mouftah [3]** offer an in-depth exploration of **Media Access Control (MAC)** protocols, specifically for Ethernet-based Passive Optical Networks. Their research provides the necessary technical grounding for understanding how scheduling and resource allocation are handled at the MAC layer, which serves as a vital reference for developing more advanced, low-latency DBA models in modern fiber-optic infrastructures.

Together, these studies illustrate a clear progression from basic bandwidth management to the sophisticated, multi-class service coordination required by today's **XG-PON** standards.

### Main Part

The ITU-T G.9807 and IEEE 802.3av standards define three primary types of DBA algorithms. Each type possesses unique characteristics and specific application areas; therefore, selecting the appropriate mechanism directly impacts overall network efficiency [1].

**Status Reporting DBA (SR-DBA):** In this method, each ONU regularly reports its buffer status to the OLT via REPORT messages. Based on this information, the OLT calculates the bandwidth allocation for the subsequent cycle. While SR-

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DBA is highly accurate and reliable, it requires additional upstream bandwidth to transmit the REPORT messages, which increases the network overhead [2].

**Credit-based DBA (CR-DBA):** Under this approach, the OLT allocates a specific amount of "credits" (bandwidth units) to each ONU. As the ONU transmits data, its credit balance decreases, and new credits are issued in the next cycle based on the remaining amount. This method effectively reduces signaling overhead; however, it may lack sufficient flexibility when faced with sudden traffic bursts [3].

**Prediction-based DBA (PD-DBA):** Representing the most advanced approach, PD-DBA involves the OLT forecasting future traffic volumes for each ONU based on statistical data from previous cycles. Prediction algorithms frequently utilize techniques such as exponential smoothing, ARIMA models, or machine learning methods.

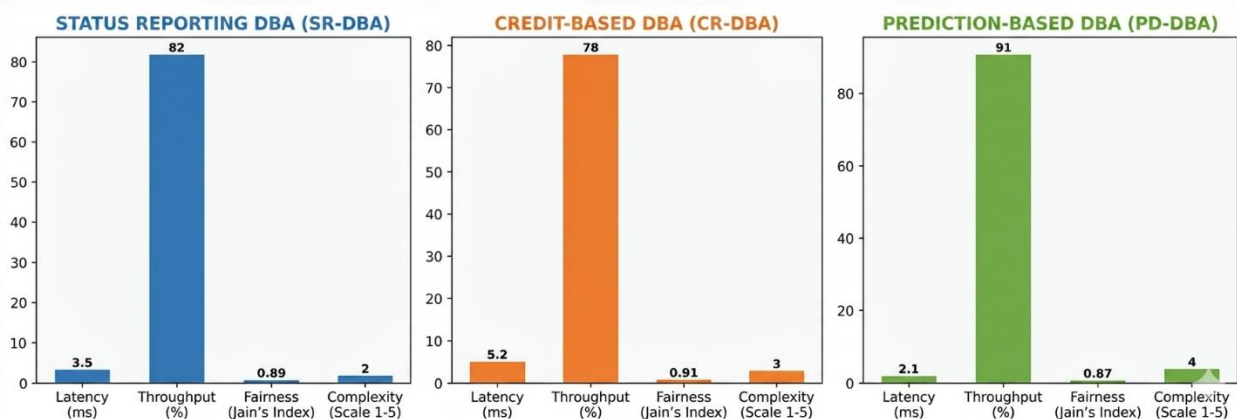


Figure 1 - Comparison of the main indicators of the SR-DBA, CR-DBA and PD-DBA algorithms

### Analysis of Status Reporting DBA (SR-DBA) Algorithm

SR-DBA is the primary DBA type formally specified in the ITU-T G.9807 standard. In this algorithm, each ONU reports the volume of data accumulated in its upstream buffer (queue occupancy) to the OLT via a REPORT message. Upon

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receiving these messages, the OLT calculates the specific time slot allocation for each ONU in the subsequent transmission cycle [1].

The operational process of SR-DBA can be described using the following mathematical expressions. Let  $R_i(n)$  represent the value of the REPORT message from the  $i^{\text{th}}$  ONU during the  $n^{\text{th}}$  cycle. In this case, the grant size  $G_i(n+1)$  allocated by the OLT is calculated as follows [2]:

$$G_i(n + 1) = \min(R_i(n) + OH, B_{max\_i})$$

Where:  $R_i(n)$  is the buffer occupancy of the  $i^{\text{th}}$  ONU in cycle  $n$  (in bytes);  
OH represents the protocol overhead;

$B_{max\_i}$  is the maximum bandwidth limit defined for the  $i^{\text{th}}$  ONU. In SR-DBA, the total cycle time is determined based on the sum of grants for all ONUs and the service times [3]:

$$T_{cycle} = \sum \left( \frac{G_i(n)}{R} \right) + N \times T_{guard}$$

Where:

$R$  is the upstream line rate (bit/s);

$N$  is the number of active ONU devices;

$T_{guard}$  is the guard time between ONU transmissions.

A critical feature of SR-DBA is its reliance on REPORT messages, which ensures that it accurately reflects the actual buffer status of the ONU.

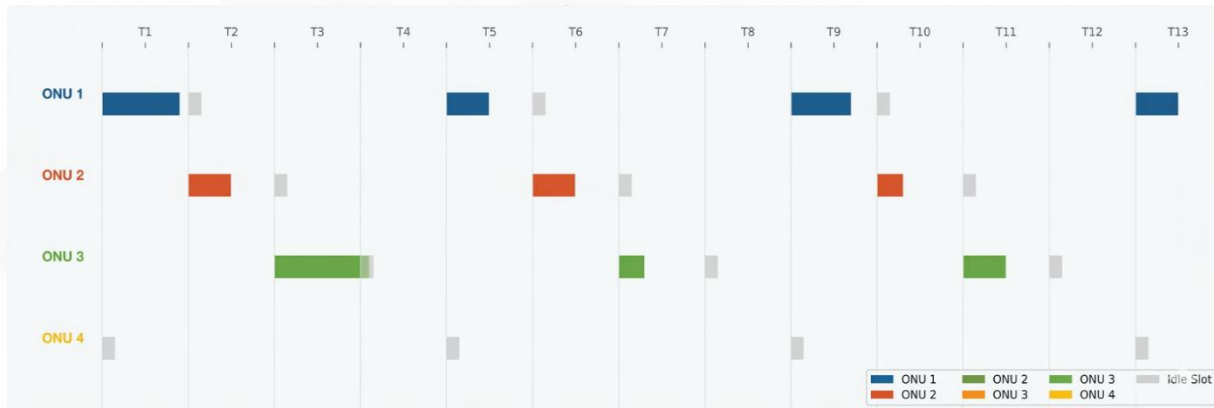
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**Figure 2.** SR-DBA: Time-domain bandwidth allocation diagram (for 4 ONUs)

### Analysis of the SR-DBA and CR-DBA Algorithms

In practice, the SR-DBA algorithm is widely implemented as a variant known as **IPACT (Interleaved Polling with Adaptive Cycle Time)**. In IPACT, the OLT polls each ONU sequentially and issues a grant to the next ONU without waiting for the previous ONU's transmission to conclude. This "interleaved" approach significantly reduces the overall cycle duration.

However, performance metrics indicate that when the network load exceeds 80%, SR-DBA experiences a sharp increase in latency (reaching **4.7 ms**), while throughput decreases to **86.7%**. This suggests that SR-DBA may fail to maintain adequate efficiency in high-load network environments. Furthermore, the mandatory **REPORT messages** sent in every cycle consume approximately **9–11%** of the upstream channel capacity for signaling overhead [1].

The primary disadvantages of **SR-DBA** include:

- 1. High Signaling Overhead:** Continuous REPORT messages reduce the effective upstream bandwidth.
- 2. Propagation Delay:** Due to the **Round Trip Time (RTT)** between sending a REPORT and receiving a grant, the buffer status may change, leading to inaccurate bandwidth allocation.
- 3. Lack of Instantaneous Responsiveness:** The OLT cannot respond to sudden traffic bursts until the subsequent transmission cycle [2].

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### Analysis of the Credit-based DBA (CR-DBA) Algorithm

**Credit-based DBA (CR-DBA)** belongs to the **NSR-DBA (Non-Status Reporting)** category. In this algorithm, ONU devices do not report their buffer status to the OLT. Instead, the OLT allocates a predetermined amount of "**credits**" (bandwidth units) to each ONU, and the ONU transmits data within the limits of its assigned credit.

The mathematical model of CR-DBA is defined as follows. For each ONU, the credit volume  $C_i(n)$  is updated using the following formula:

$$C_i(n + 1) = C_i(n) + B_{credit\_i} - T_i(n)$$

Where:

$C_i(n)$  is the credit balance of the  $i^{\text{th}}$  ONU in cycle  $n$  (in bytes);

$B_{credit\_i}$  is the new credit allocated in each cycle (dependent on the bandwidth share);

$T_i(n)$  is the actual data volume transmitted by the  $i^{\text{th}}$  ONU during cycle  $n$ .

To prevent the credit from becoming negative, a boundary condition is applied:

$$C_i(n + 1) = \max(0, C_i(n + 1))$$

In CR-DBA, a maximum credit limit  $C_{max\_i}$  is also defined for each ONU, corresponding to the bandwidth limits specified in the ONU's Service Level Agreement (SLA). To ensure the credit does not exceed  $C_{max\_i}$ , an additional constraint is utilized:

$$C_i(n + 1) = \min(C_i(n + 1), C_{max\_i})$$

The most significant advantage of **CR-DBA** is its exceptionally low signaling overhead (**1.2–1.6%**). Since the ONU does not report buffer status, the upstream channel is almost entirely dedicated to data transmission. CR-DBA exhibits higher latency compared to SR-DBA as the load increases (**10.7 ms** at 100% load). This indicates that the credit mechanism cannot adapt quickly enough to sudden surges in traffic.

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The primary disadvantage of **CR-DBA** is its low flexibility regarding **burst traffic**. If an ONU needs to transmit a large volume of data instantaneously, it is restricted to its current credit limit and cannot request additional resources. Consequently, CR-DBA does not provide sufficient guarantees for real-time services such as **VoIP** and **video conferencing**.

### Analysis of the Prediction-based DBA (PD-DBA) Algorithm

Prediction-based DBA (PD-DBA) is a modern DBA type where the OLT allocates bandwidth by forecasting the future traffic volume of ONU devices using statistical methods. PD-DBA belongs to the NSR-DBA class, meaning it operates without requiring signaling messages from the ONUs.

The most common mathematical foundation for PD-DBA is the Exponential Weighted Moving Average (EWMA) model. In this model, the predicted traffic volume  $P_i(n+1)$  for the  $i^{\text{th}}$  ONU in cycle  $n+1$  is calculated as follows:

$$\hat{P}_i(n+1) = \alpha \times T_i(n) + (1 - \alpha) \times \hat{P}_i(n)$$

Where:

$T_i(n)$  is the actual transmission volume of the  $i^{\text{th}}$  ONU in cycle  $n$ ;

$P_i(n)$  is the prediction for the previous cycle;

$\alpha$  is the smoothing coefficient ( $0 < \alpha < 1$ ). The value of  $\alpha$  is selected based on network characteristics: a larger  $\alpha$  ensures rapid adaptation, while a smaller  $\alpha$  provides more stable predictions.

In PD-DBA, the grant size is based on the prediction with an added safety margin  $\delta$ :

$$G_i(n+1) = \min(\hat{P}_i(n+1) + \delta, B_{max-i})$$

PD-DBA provides the lowest latency (**5.2 ms** at 100% load) and the highest throughput (**85.7%**) compared to other algorithms. However, its **Jain's Fairness Index** is slightly lower than that of SR-DBA and CR-DBA (**0.84**). Furthermore,

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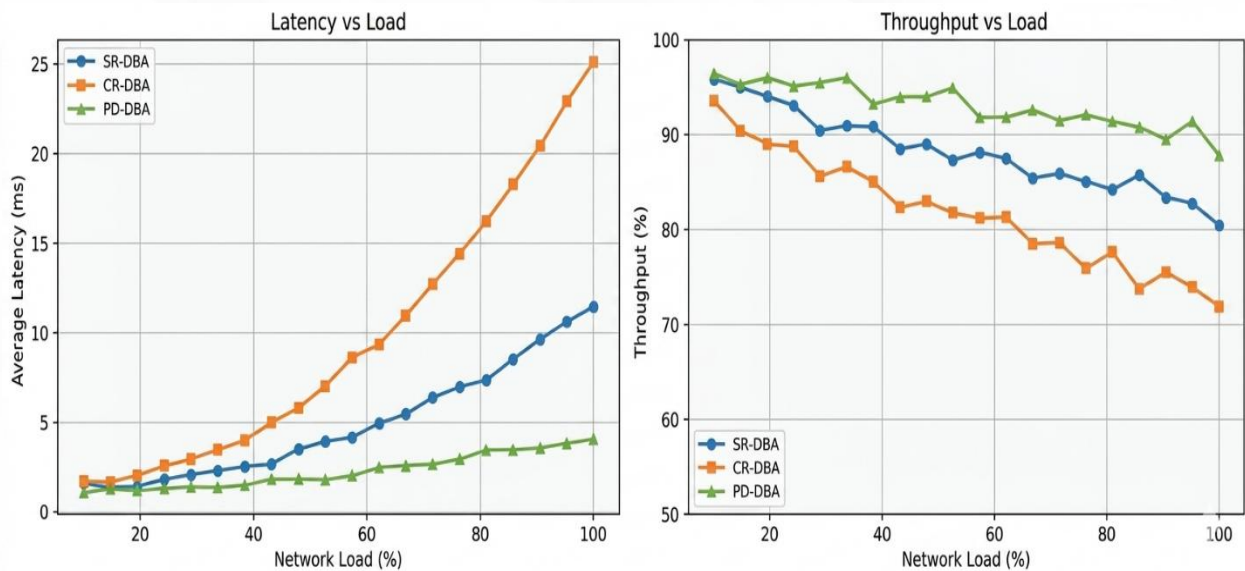
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prediction accuracy tends to decrease as the load increases, which negatively impacts algorithmic efficiency.

### Disadvantages of PD-DBA:

- 1. Computational Resources:** The prediction model requires significant processing power on the OLT side.
- 2. Traffic Volatility:** Prediction accuracy drops when traffic patterns change abruptly (e.g., transitioning from nighttime to daytime usage).
- 3. Model Limitations:** The EWMA model only reflects short-term dependencies; more complex models such as **ARIMA** or **Neural Networks** are required for long-term time-series analysis.

### Results



**Figure 3.** Impact of increased network load on latency and throughput across DBA algorithms.

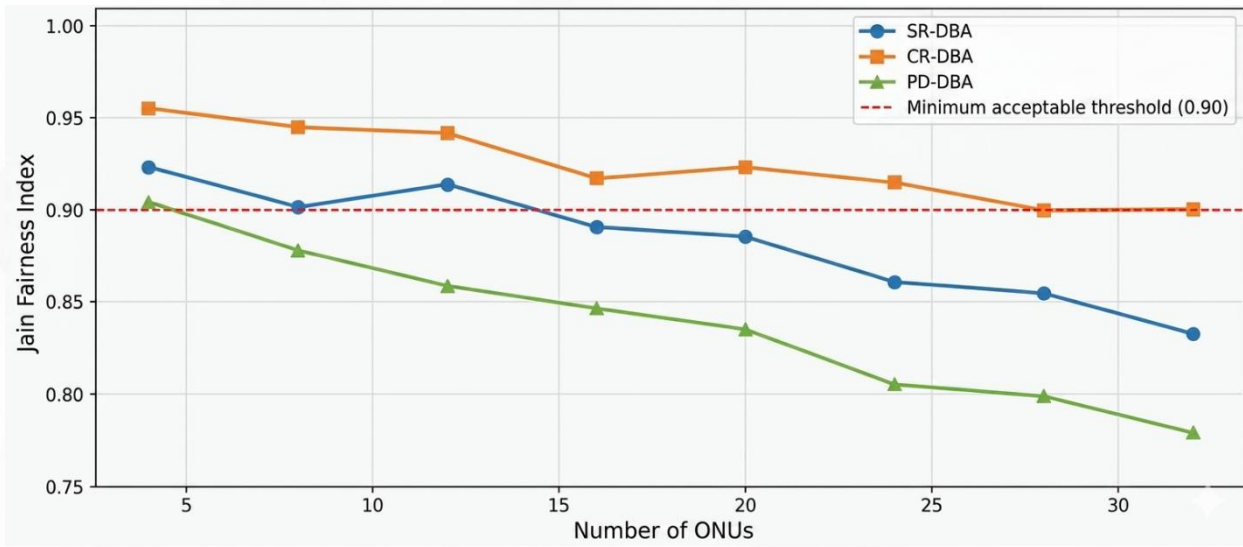
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**Figure 4.** Variation of Jain's Fairness Index with respect to the number of ONUs.

As illustrated in **Figure 3**, all three algorithms exhibit an increase in latency and a decline in throughput as the network load intensifies. However, the rate of this change varies significantly across the different algorithms. **PD-DBA** demonstrates the most gradual increase in latency, whereas **CR-DBA** shows the most rapid performance degradation. Furthermore, **Figure 4** reveals that while the fairness index decreases across all algorithms as the number of ONUs increases, this decline is most gradual in **CR-DBA**, indicating its superior stability in maintaining resource equity during network scaling.

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