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### RESEARCH ARTICLE

#### A DYNAMIC BANDWIDTH ALLOCATION SYSTEM IN XG-PONS BASED ON STATISTICAL ESTIMATION OF BUFFER INPUTS AND OUTPUTS

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#### Abstract

The exchanges in the New Generation Optical Access Network (NG-PON), are mainly based on the bandwidth request by the Optical Network Units (ONU) and its granting by the Optical Line Termination (OLT). This process (request-grant) not being synchronized, will create in the ONU buffer a long delay and the loss of sensitive packets. Many authors, from signaling to prediction, have proposed models to control these parameters, however only those based on prediction reduce the delay in the queues but also waste bandwidth by over- or under-allocating. Our goal is to propose a model that accurately allocates bandwidth to ONU while minimizing their queue delay. As such, we propose a Statistical Queue Estimation model based on ONU Buffer Inputs and Outputs (ESTEST). In its execution ESTEST memorizes the ONU bandwidth requirements and the bandwidth used to transmit their data in the  $i$ th upstream frames. With these two parameters (requirements and bandwidth used), our algorithm computes the traffic intensity ( $\rho$ ) and predicts the queue size of the ONU. On 100 observations we compute the mean and standard deviation of the  $p$ th values and with the reduced centered normal distribution, find the confidence interval of size estimation.

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#### Introduction:-

The rapid evolution of the Internet has favored the integration of numerous real-time web services that are quite resource-intensive, making bandwidth an issue [1]. Indeed, the access network or distribution network was essentially made of copper on which the XDSL technology was deployed [2]. However, new bandwidth-hungry Internet services (Cloud, Internet television, distance learning...) are putting a strain on this copper network, which can no longer meet the ever-increasing demand of customers [3]. Faced with these limitations, operators are considering a new low-cost infrastructure with flexible maintenance and an acceptable quality/price ratio for all types of customer services [4], [5]. Their choice is the New Generation Passive Gigabit Optical Network (NG-PON) with a throughput of 2.5 Gbt/s up and 10 Gbt/s down [6], [7]. This single-mode, point-to-multipoint technology pools part of the infrastructure for all customers and divides the output signal power into N ports (1: N) reflecting the sharing of the system bandwidth among N users [8]. The basis of the exchanges on this network is based on a "request-grant" method, i.e., the ONU request bandwidth upon presentation of their buffer contents to the OLT, which allocates it to them. In addition, given the request processing time and the propagation time estimated at 0.6 ms (round trip) between the two terminals, the report signaling allocation algorithms, regardless of their robustness,

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cannot execute before this threshold [9]. This delay will cause a queue and loss of sensitive data in the ONU buffer. This paper presents a new dynamic bandwidth allocation (DBA) algorithm for XG-PON architectures. Unlike other proposed predictive DBA, this one observes the flows input and output of the ONU buffer to predict the queue size using a normal distribution.

The rest of paper is organized as follows: The state of the art is the first section, the second presents methodology and model: ESTEST (Statistical Estimation of the Queue based on Buffer Inputs and Outputs). The third is dedicated to the simulation, and the last to the analysis of the obtained results and the last part the conclusion and the perspectives.

### **State of the art:-**

Faced with the delay and packet loss caused by signaling in [7], some authors have favored prediction for bandwidth allocation to control these factors. Thus, in [10], some propose a prediction model based on the high moving average method to estimate the high priority traffic in the ONU buffer. This model relies on the observation of data received by the OLT during the previous  $J$  cycles to predict the buffer size. The moving average method provides verification of the estimated traffic, however at low load, the redistribution of excess bandwidth collected with this method creates waste. For efficient bandwidth redistribution, the authors in [11] suggest that OLT probe the network to detect ONUs that have not transmitted buffer content and estimate them, either based on their previous grants (MMBoG) or on their previous reports (MMBoR). However, this method could be a source of wasted bandwidth, since ONU waiting for an allocation also send empty frames as if they had no data to transmit. The authors in [12] to overcome the lack of DBA that are cognitive enough to allocate bandwidth introduce learning automate (LA), a simple but powerful tool to isolate idle ONU and integrate them when they become active in order to address the bandwidth wastage observed in [10] and [11]. This model is able to decide when to use signaling or network monitoring to make the allocation efficient, however results in the inability of the system to adjust the bandwidth of ONU to traffic variations for high priority services. To allocate bandwidth to ONU in an efficient and reactive manner, without requiring signaling of their buffers, the authors in [13] propose a first approach that consists of estimating the ONU buffer and sequential bandwidth update by a stochastic approximation, then a second approach that is a closed-form solution to maximize the weighted throughput and finally an aggregation of the first two approaches into an ensemble learning model. Sequential bandwidth updating minimizes latency and packet jitter in the buffer but does not guarantee its efficient use. In [14], the authors pose the problem of customizing dynamic allocation algorithms, they state that the classical model that integrates the dynamic allocation algorithm (DBA) with the optical line termination (OLT) makes it difficult to quickly modify the model to fit specific cases of Optical Network Units (ONU). Therefore, they propose a DBA as a module disassociated from the OLT hardware platform to predict the packet size in the buffer and the average delay  $\rho$  experienced by a given ONU, however the modularization also leads to data transfer delays due to additional propagation time on the new interface. The authors in [15] to solve the linear performance instability between the Optical Network Unit (ONU) loads and the Optical Line Termination (OLT), propose the polynomial regression method to estimate the queue size in the ONU buffer during the channel idle period, unfortunately this model ran with a small sample of 20 iterations at the risk of having a high computational complexity. In [16] following a traffic prediction in the channel idle period, the OLT makes time slot reservations to reduce the delay in the queues, however the bursty traffic faces a prolonged delay with this model. The authors in [17] present a DBA that predicts the arrivals in the buffer proportionally to the waiting time of the ONU, the set of arrivals in a few cycles and the current traffic. These parameters make the prediction cumbersome and may bias the results. Still using prediction to determine the queue, the authors of [18], use the high-order moving average filter model, with weights assigned to previous traffic to predict the arrival time in the buffer. The statistics are proven in [19] to be reliable as a DBA and could increase the performance of the QOS. In [20] the basis of the first dynamic allocation algorithm of the GPON standards is defined.

### **Methodology and Model:-**

#### **Methodology**

According to the state of the art, signaling causes a long delay as mentioned in [9], so we propose a prediction-based model to better evaluate the two exchange modes between the OLT and the ONU (signaling and prediction).

In this mode, we use a model based on propability laws to predict the queue in order to limit the imprecision in bandwidth allocation.

Finally a comparison test is done with the NS3 simulator on three models as follows:

- signaling model
- the model of the reference article
- our proposed model

**Estest model**

The authors in [9] introduce statistical prediction in DBAs. They propose with a normal distribution a model that predicts the size of the ONU queue following the observation of the rate of data arrivals in their buffer  $\lambda(QTCONT)$ . Despite the results obtained: packet loss -14%; delay -50%; the allocated bandwidth still remains imprecise and high packet loss of type 2 and 4 according to the authors in [21]. The inaccuracy of the bandwidth could be due to not taking into account the flow out of the buffer (service rate). Indeed, according to the authors in [22], the queue delay depends on the data arrival rate in the buffer ( $\lambda$ ) and the service rate ( $\mu$ ) of the bandwidth. This is because the input stream (arrival rate) only leaves the ONU buffer when it obtains the required bandwidth (service rate) from the OLT. For this purpose, our algorithm (ESTEST) uses the input and output flows of the buffer (Traffic Intensity) to predict the data size using a normal distribution. The bandwidth allocation (service rate) will be done according to the priority of service and to correct the loss of some data types.

**Diagram associated with the estest model**

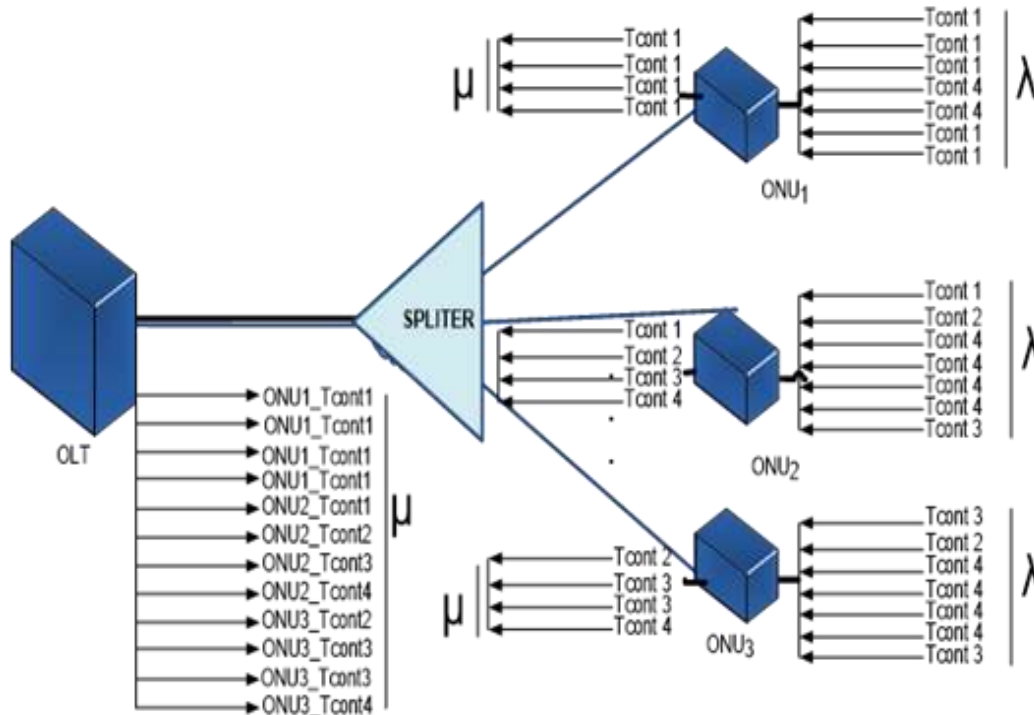


Fig.1:- Input ( $\lambda$ ) and output ( $\mu$ ) rates of the ONU buffer.

**Formulation of the mathematical model**

Let  $\lambda$  be the rate of arrival of data in the ONU buffer at a time  $\Delta$  data

$$\lambda = \frac{(R_i + G_i - R_{i-1})}{\Delta}$$

Let  $\mu$  be the service rate which is the bandwidth ( $BP_k$ ) required to transmit a service of type (k) during a service interval ( $SI$ ).

$$\mu = \frac{BP_k}{SI} \tag{2}$$

Let us determine the traffic intensity( $\rho$ ), which is the proportion of bandwidth ( $\mu$ ) that ONU must be allocated to transmit a data buffer ( $\lambda$ ).

$$\rho = \frac{\text{Arrival rate}(\lambda)}{\text{Service rate}(\mu)} = \frac{\lambda}{\mu}$$

$$(1) \text{ and } (2) \rho = \frac{(R_i + G_i - R_{i-1})}{\Delta} * \frac{SI}{BP_k} \tag{3}$$

Let us estimate with the normal distribution the average size of a queue T(TCONT) by its mean ( $\theta$ ) and standard deviation ( $\delta$ ) :

$$T(\text{TCONT}) = N(\theta, \delta) \tag{4}$$

The OLT, without receiving reports from the ONU, will use this model to predict the size of the data in their queue and allocate bandwidth proportionally to it.

Where

$\lambda$  : Arrival rate

$\mu$ : Service rate

$\rho$  : Traffic Intensity

$BP_k$ : Bandwidth for type k service

SI: Service interval

$\theta$ : Average

n : Sample size

$\delta$ : Standard deviation

T(TCONT) : Buffer size

$\Delta$ : Time to transmit a data buffer

**Algorithm of the mathematical model**

1 //Let  $\lambda$  be the data arrival rate at a time  $\Delta$  in the ONU buffer.

$$\lambda = \frac{(R_i + G_i - R_{i-1})}{\Delta} \tag{1}$$

2 //The ONU sends the Report from its buffer ( $\lambda$ ) to the OLT in the ith authorized frame

3 //Upon receipt of the report, the OLT calculates the bandwidth rate ( $\mu$ ) required to transfer the report data type (k) during the service interval (SI)

$$\mu = \frac{BP_k}{SI} \tag{2}$$

4 //Let us then determine, ( $\rho$ ) the traffic intensity of the ONU.

$$\rho = \frac{\text{Arrival rate}(\lambda)}{\text{Service rate}(\mu)}$$

$$(1) \text{ and } (2) \rho = \frac{(R_i + G_i - R_{i-1})}{\Delta} * \frac{SI}{BP_k}$$

5 //At the reception of each upstream frame (i) the OLT memorizes the report( $R_i$ )the transmitted data ( $G_i$ ) and deduces the corresponding traffic intensity ( $\rho_i$ )

$$\rho_i = \frac{SI}{BP_k} \sum_1^n \frac{(R_i + G_i - R_{i-1})}{\Delta}$$

6 //Compute the mean ( $\theta$ ) of the  $\rho_i$  followed by the standard deviation ( $\delta$ )

$$\theta = \frac{\sum_{i=1}^n \rho_i}{n}$$

7 //Let's calculate the standard deviation

$$\delta = \sqrt{\frac{\sum_{i=1}^n (\rho_i - \rho)(\rho_i - \rho)}{n}}$$

8 //Estimation of the buffer size with the normal distribution

$$T(\text{TCONT}) = N(\theta, \delta)$$

$$\text{Let } T(\text{TCONT}) = X$$

$$X \sim N(\theta, \delta)$$

9. //Let's determine the confidence interval by the transformation of the centered reduced normal distribution

$$X_i \sim N(\theta, \delta) \text{ we note } \bar{X}_n = \frac{1}{n} \sum_{i=1}^n X_i$$

We obtain  $\frac{\sqrt{n}(\bar{X}_n - \theta)}{\delta} \sim N(0, 1)$

$$P\left[\bar{X}_n - \frac{\delta}{\sqrt{n}}\varepsilon \leq \theta \leq \bar{X}_n + \frac{\delta}{\sqrt{n}}\varepsilon\right] = 1 - \frac{\alpha}{2}$$

Where

$\varepsilon$  Quantile of order  $1 - \frac{\alpha}{2}$  of the normal distribution

$\bar{X}_n$  : Estimator of the mean ( $\theta$ )

n : Sample size

**Simulation:-**

The simulator chosen for the test of our model is NS3 (Network Simulator 3). This choice is explained by the fact that the XG-PON module developed by researchers to simulate the passive optical network in accordance with the ITU-T (International Telecommunication Union Telecommunication) standards runs on the ns3.21 version of NS3 [23]. It should also be noted that the simulator does not include models for the simulation of optical networks. The XG-PON module, once integrated into NS3, simulates a queue report signaling environment with the GigaPON Access Network (GIANT) model, the first Dynamic Bandwidth Allocation (DBA). The architecture of the simulation network is as follows:

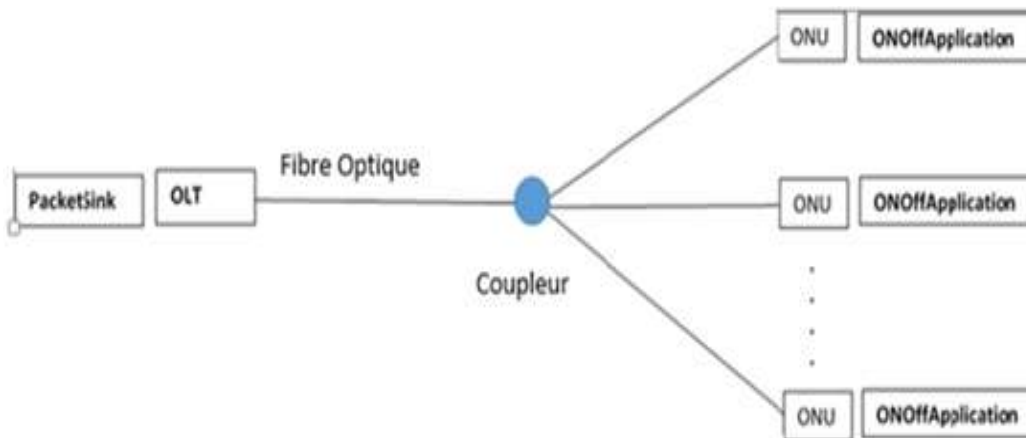


Fig.2:- Architecture of the Siulation Network.

- OLT: Bandwidth provider server, runs the DBA
- PacketSink: Receiving application of transmitted packets
- ONU : Optical equipment at the customer's place receives the waiting lines
- OnOffApplication: Application generating packets to be transmitted or queue
- Optical fiber: Optical link between OLT and ONU

- Coupler: Passive filter, optical link branching

**Simulation parameters**

Parameters	Quantities
OLT	1
Debit amount	2.5 Gbps
Downlink rate	10 Gbs
ONU	16
Package size	1472 bytes
Simulation time	5s
Traffic loads	80-90-100-110-120-130-140-150
Type TCONT	5
Sample (n)	100 observations

**Table 1:-** simulation parameters of the xg-pon module.

Operating system : Linux distribution Ubuntu 14.04 LTS

Simulator: NS3 version ns3.21

XG-PON module: version xgpon4ns3 v2.1

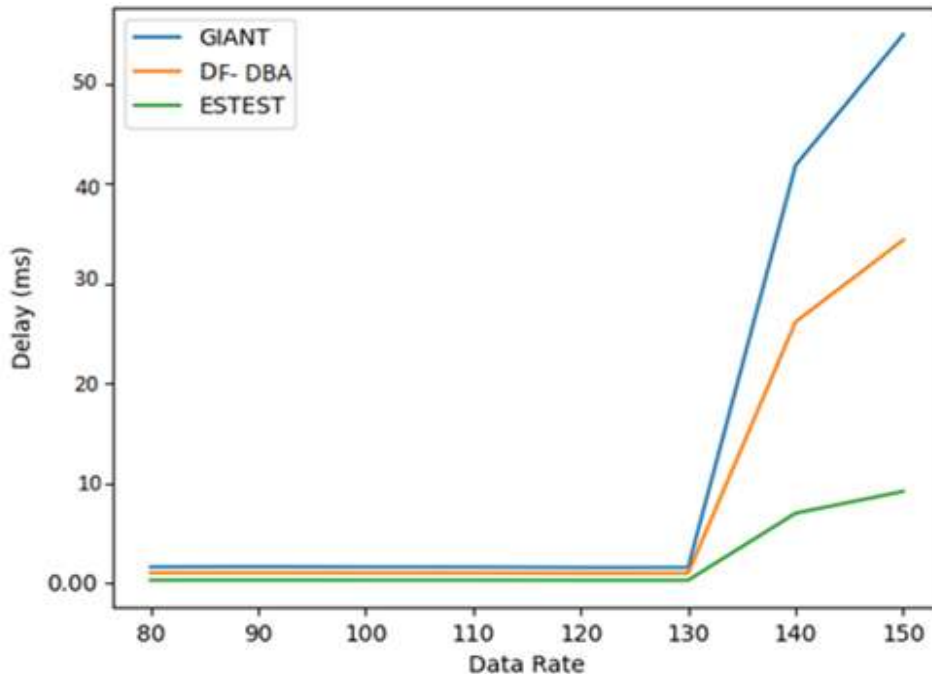
The objectives of the simulation are to:

- ✓ Highlight the delay in the ONU queues.
- ✓ Dress the lost packages.

It is assumed that there are no disturbances of some factors (ranging, signal propagation, signal attenuation ...) on the flows and that the downstream and upstream signal flow without impact. To do this, we compare the delay and the lost packets of three algorithms:

- 1- GIANT (GigaPON Access Network)
- 2- DF-DBA (Demand Forecasting-DBA)
- 3- ESTEST our algorithm

**Results of the simulation**



**Fig 3:-** Delay according to traffic loads.

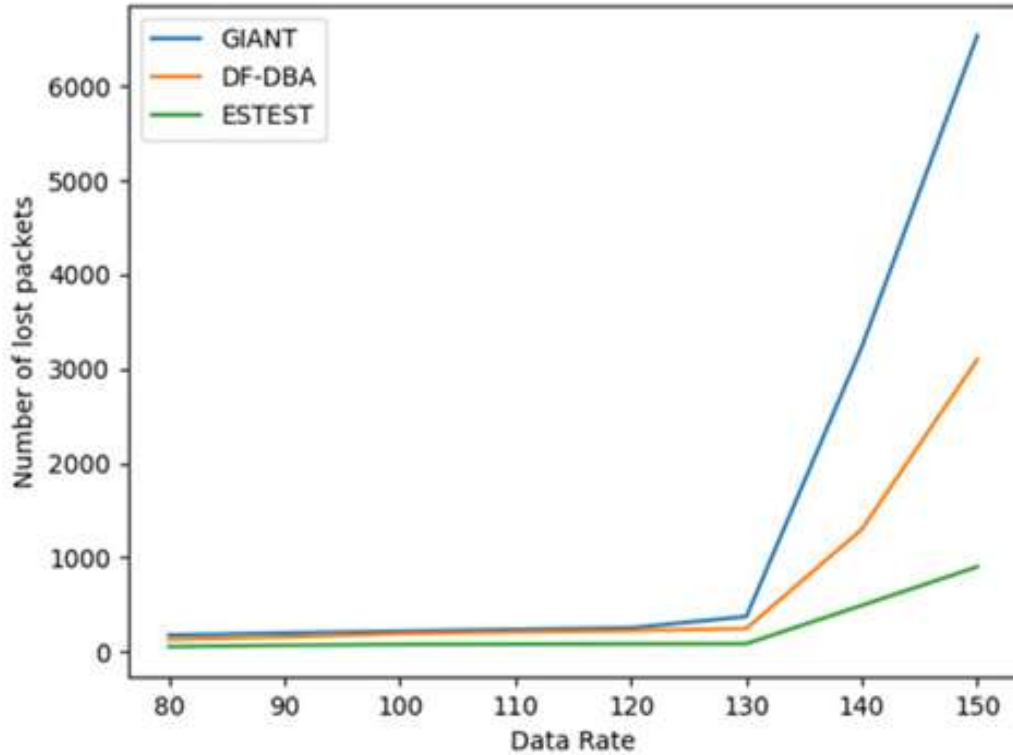


Fig.4:- Lost packages as a function of traffic loads.

**Performance analysis:-**

The GIANT algorithm, despite its heavy execution due to the report generation and the existence of a down counter before the bandwidth allocation, generates like DF-DBA and ESTEST a recommended delay (< 1.5 ms) with loads of 80 to 130 Mbps. Fig. 3. This is due to a large fixed bandwidth from the first allocation to satisfy the queues. Beyond 130 Mbps, the increasing bandwidth requirements and the long allocation process of GIANT will cause a delay in the queue. On the other hand, ESTEST and DF-DBA, which anticipate the bandwidth to be allocated by predicting the size of the queues with a normal distribution, have a lower delay than GIANT. On the other hand, ESTEST which takes into account in its prediction the arrivals (arrival rate) and the services (service rate) in the queues, has a better planning of the bandwidth and thus succeeds in satisfying more frames and keeping the delay below 10 ms (<10 ms) beyond 130 Mbps of loads fig.3.

**Loss of packages**

Packet loss, a delay-related phenomenon, occurs when the packet does not reach its destination at the OLT. The simulator has a traffic generator (OnOffApplication) that randomly creates all types of packet priorities (TCONT5). The loss of a packet depends on two parameters: the priority of the packet and its delay. A low priority packet can withstand a certain amount of delay and be transmitted to the OLT, which is not the case for high priority packets.

Table 2:- Lost packets by traffic load.

DBA	Traffic loads								
	80	90	100	110	120	130	140	150	
Giant	176	198	217	236	253	373	3224	6537	
Dfdbba	98	120	154	192	223	245	1299	3010	
Estest	54	68	77	80	83	85	491	901	

The packet loss is the evidence of the queue formation between the different XGPON cycles (125 μs).

Indeed, despite the coverage of the ONU bandwidth needs with the first allocation Fig. 3, we observe packet losses in proportions related to each DBA as shown in Table 2. This observation can be explained by the existence of a rather long DBA time or an imprecision in the bandwidth allocation. Giant to a packet loss that increases as the loads evolve (Fig. 4). This is one of the reasons why the scientific community has proposed solutions to improve this basic reporting algorithm. The prediction-based DF-DBA and ESTEST models also generate packet losses (Fig. 4), (Table 2).

We explain this by the dissatisfaction of some queues that have packets of certain priorities but do not receive adequate bandwidth. Although ESTEST gives better proportions than DF-DBA (Table 2), the instability of packet losses in general (Fig. 4) can degrade the quality of services offered in the long run following the integration of new subscribers on the network

### Conclusion And Perspectives:-

In order to correct the inaccuracies of linear regression based prediction algorithms, we introduce ESTEST the algorithm on statistical predictions to estimate the size of data in the buffer. Compared to the model of some authors who have worked in the statistical field, we find that our model which uses the input data in the ONU buffer ( $\lambda$ ) and the provided bandwidth as output data ( $\mu$ ), gives significantly lower delay and packet loss (Fig. 3), (Fig. 4). We can claim to have a good concentration of the estimated values. We believe that other laws or other prediction models can further reduce the packet losses, one of the signs of a good accuracy of the bandwidth allocated in the prediction..

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