Performance Evaluation of DBA Algorithms with QoS in Protected Super-EPON Access Networks using a Dedicated Protection Ring Architecture

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I. INTRODUCTION

The use of new Web applications, such as IPTV, VoIP, or online gaming, is propelling the growth of bandwidth demand in the access network. Passive optical networks (PONs) are seen as the best solution to deliver higher bit rates to the end-user in these networks. With the widespread use of Ethernet technology in local area networks (LANs), the E-PON technology is viewed as a compatible and cost-effective solution to provide the required access network upgrade.

Since each E-PON only supports a limited number of optical network units (ONUs) in a short distance, the Super-EPON structure\([1,2]\) permits to extend the optical network reach to provide quality of service (QoS) guarantees to high priority control (MAC) level to manage the upstream transmission and to provide quality of service (QoS) guarantees to high priority traffic.

The results obtained are expressed in packet delays, mean bit rate per ONU, time-slot occupation efficiency, and mean cycle duration. The network behavior when working in service or protection mode is also evaluated. The traffic distinction inside the ONUs is achieved by using two different queues. One will receive high priority packets (e.g. voice packets) and the other is used for low priority packets (e.g. data packets).

The time arrivals of the packet streams are generated by different probability distributions, namely a Poisson distribution for voice packets and a Pareto distribution for data packets. The evaluation of the DBA algorithms is performed in a Super-EPON with 4 E-PONs, each with 16 ONUs and 20 km long, connected by remote nodes (RNs) to a ring that has a perimeter of 50 km. It is assumed that the RNs are equally spaced along the ring and the total upstream bit rate available is 1 Gbps in compliance with the E-PON standard (IEEE 802.3ah)\([5]\).

The rest of the paper is organized as follows. Section II describes the Super-EPON structure and the transmission pattern used in both service and protection modes. Section III describes the DBA algorithms studied. Section IV describes the general simulation conditions. Section V presents and compares the simulation results of the MAC DBA algorithms. Finally, the main conclusions are given in Section VI.

II. THE SUPER-PON ARCHITECTURE

The structure of the Super-PON considered in this study is depicted in Fig. 1. As seen, it is based on a double-fiber ring with the transmission in each of the fibers done in different directions. In the outer fiber, the signals are transported clockwise and in the inner fiber the signals travel counterclockwise.

![Ring-shaped Super-EPON structure](image)

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Fig. 1. Ring-shaped Super-EPON structure

In the outer fiber the wavelengths used are the service downstream (\(\lambda_{D,S}\)) and the protection upstream (\(\lambda_{D,P}\)). In the inner fiber, the service upstream (\(\lambda_{U,S}\)) and the protection downstream (\(\lambda_{D,P}\)) wavelengths are used. The protection and
service wavelengths, for the same stream are identical, i.e., \( \lambda_{D,S} = \lambda_{D,P} \) and \( \lambda_{U,S} = \lambda_{U,P} \). To assure the redundancy path, the OLT simultaneously sends the downstream signals \( \lambda_{D,S} \) and \( \lambda_{D,P} \) to both fibers and receives the upstream signals \( \lambda_{U,S} \) and \( \lambda_{U,P} \). The RNs are key elements in this network, since they are responsible for amplification, signal extraction/insertion from/to the ONUs, as well as protection switching in the case of fiber breaks in the ring plant.

As shown in Fig. 2(a), in the service state the RNs extract the downstream from the outer fiber and place the upstream in the inner fiber. When a break in the ring occurs, as exemplified in Fig. 2(b), only the RNs located after the fault are affected and as a consequence they must switch to the protection mode. In this situation the downstream signal is obtained from the inner fiber and the upstream is sent in the outer fiber. The switching process in the RNs takes place in an autonomous way, and these network elements only need to send an alarm message to the OLT. After receiving this message the OLT must readjust the round trip time (RTT) of all the ONUs connected to the RNs that entered the protection mode. This action is essential to assure an accurate synchronisation of the upstream time-slots and is needed because, as one can see, for example, in the RN #2 of Fig. 2(a) and Fig. 2(b), the service mode distance between an ONU and the OLT is usually different than the protection mode distance. In fact, the RTT is obtained by \( \frac{2 \times d}{c} \), where \( d \) is the fiber extension that connects the ONUs to the OLT, \( c \) is the light speed in the vacuum \( (3 \times 10^8 \text{ m/s}) \), and \( k \) is the propagation constant in the fiber \( (=1.5 \text{ for single mode fiber}) \).

\[ B_{MIN} = D_o \left( \frac{T_{cycle} - N_{ONU} G}{N_{ONU}} \right) \]  

where \( T_{cycle} \) is the maximum cycle duration, \( G \) is the guard band between time-slots, and \( D_o \) is the total upstream bit rate. As mentioned, the excess bandwidth is obtained by \( B_{\text{excess}} = \sum_{i} (B_{\text{MIN}} - R_i) \), for \( R_i \leq B_{\text{MIN}} \), where \( R_i \) is the request size of each of the \( L_{ONU} \) light-loaded ONUs. The ONUs that request \( B_{MIN} \) or less, are attributed \( R_c \). Thus, the time-slot size of the \( M_{ONU} \) heavy-loaded ONUs is given by \( B_i = B_{MIN} + B_{\text{excess}} \) and the excess bandwidth fraction \( B_i^{\text{excess}} \) is weighted by the size of their requests [4]:

\[ B_i^{\text{excess}} = B_i^{\text{excess}} \frac{R_i}{\sum_{i} R_i} \], for \( R_i > B_{MIN} \)  

Additionally, the ONUs with the highest number of voice packets waiting are provided the first time-slots of the cycle, as exemplified in Fig. 4.
The total network load can be obtained by
\[ L = \frac{B_{\text{MIN}}}{T_{\text{cycle}} + T_{\text{sch}} + \text{RTT}} \]

where \( T_{\text{sch}} \) is the scheduling time needed for the EDBA to perform the next cycle organization, and the RTT is referred to the ONU that was assigned the first time-slot of the cycle.

**B. Intra-ONU Scheduling**

This scheduling task is applied by each ONU in order to establish a QoS distinction between the high real-time traffic and low priority data queues by choosing which packets should occupy the available time-slot. This discipline provides two different algorithms:

1. **Priority Queuing (PQ):** This algorithm only allows the transmission of data packets if the voice queue is empty.
2. **Deficit Round Robin (DRR):** This algorithm [7] provides a weighted share between the waiting queues at the ONU. To service the queues, it uses round-robin servicing with a quantum of service assigned to each queue. The only difference from traditional round-robin is that if a queue was not able to send a packet in the previous round because its packet size was too large, the remainder of the previous quantum is added to the quantum for the next round. Thus, deficits are kept track off, i.e., queues that were shortchanged in a round are compensated in the next round. For the voice and data queues a quantum of 900 bits and 100 bits is used.

**IV. SIMULATION CONDITIONS**

The upstream performance evaluation of the Super-EPON MAC management is done by combining the Inter-ONU EDBA with the two Intra-ONU algorithms described. For this purpose, a network simulator was developed using C programming language.

In compliance with the E-PON standard [5] the 64-byte REPORT message and the queue packets sent in each time-slot are encapsulated in an Ethernet frame. This means that they must include an 8 byte preamble and be separated by a 12 byte inter-frame gap (IFG) from each other. The maximum cycle duration is limited to 2 ms and the time-slots are separated by a 5 \( \mu \)s guard band.

The simulation is performed considering a Super-EPON with a 50 km ring perimeter and 4 RNs. Each RNs connects the ring to an E-PON of 20 km that supports 16 ONUs, which means that the OLT is shared by a total of 64 ONUs. The RNs are equally spaced through the ring. For this reason, the fiber links \( L_1, L_2, L_3 \) and \( L_4 \) (see Fig. 2) are 10 km long. Each ONU receives traffic with the same mean bit rate \( D_{\text{PACKET}} \), and the high and the low priority queues receive packets with a bit rate of \( D_{\text{PACKET}} / 2 \). The total network load can be obtained by
\[ D_{\text{TOTAL}} = \sum_{j=1}^{N_{\text{ONU}}} D_{\text{PACKET}} = D_{\text{TOTAL}} / (64 \times D_{\text{PACKET}}) \]

V. SIMULATION RESULTS

One of the most relevant values obtained from the simulation is the packet delay. This quantity expresses to the time elapsed since the packet arrival to the ONU’s queue until it is received at the OLT. Fig. 5 presents the mean packet delay for the DBA algorithms. As depicted, the Intra-ONU tasks obtain very similar results in both queues. The voice mean delay is kept close to 1 ms, while the low priority queue delay is deteriorated as expected.

Since the PQ task blocks the data packets until the voice queue packets are all transmitted, the voice delay is lower than the obtained by the DRR but the data delay is slightly worse. In Fig. 6, the maximum packet delay is also shown.
the mean cycle length variation. Fig. 7 (a) shows that the weighted share of the available bandwidth between the two queues of the ONUs provides a higher time-slot occupation efficiency for the DRR. In Fig. 7(b) we can observe that the maximum usage of the cycle is achieved for a total load of 0.7. This earlier occupation of the network capacity can be explained by taking into account the 64 time-slot guard-bands per cycle, plus the $T_{sch}$ and the RTT, that reduce the available network bit rate $D_n$ shared by all the ONUs.

![Occupation efficiency and Mean cycle length](image)

(a) Occupation efficiency (b) Mean cycle length

Fig. 7. (a) Time-slot occupation efficiency and (b) mean cycle length

Fig. 8 illustrates the mean bit rate provided to the ONUs by the OLT and we confirm that the network full capacity use is reached at a total load of 0.7.

![Mean bit rate of the ONUs](image)

Fig. 8. Mean bit rate of the ONUs

In order to evaluate the performance of the network operating in protection state the analysis of the influence of the distance between the OLT and the ONUs in the maximum bit rate available per ONU, when the network operates in the protection state, for different fault locations. The theoretical results are obtained using (3) and (4).

![Comparison between simulated and theoretical results](image)

<table>
<thead>
<tr>
<th>Fault Location</th>
<th>Simulated $D_{max}^{sim}$ (Mbps)</th>
<th>RTT (ms)</th>
<th>Theoretical $D_{max}^{theo}$ (Mbps)</th>
<th>RTT (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link $L_1$ (Service)</td>
<td>10.581</td>
<td>0.444</td>
<td>10.606</td>
<td>0.450</td>
</tr>
<tr>
<td>Link $L_2$ and $L_4$</td>
<td>10.854</td>
<td>0.378</td>
<td>10.938</td>
<td>0.375</td>
</tr>
<tr>
<td>Link $L_3$</td>
<td>10.931</td>
<td>0.349</td>
<td>11.053</td>
<td>0.350</td>
</tr>
</tbody>
</table>

As can be seen, the fault in link $L_2$ (or $L_4$) provides an increase in $D_{max}^{theo}$ of 332 kbps (theoretical) and 273 kbps (simulated) in comparison with the service mode. If the break occurs in the link $L_1$, this improvement is of 447 kbps (theoretical) and 350 kbps (simulated). We verify that the reduction of $\overline{d}$, due to a fiber fault, provides a smaller $\overline{RTT}$ which provides an increase of $D_{max}^{theo}$.

VI. CONCLUSION

This work has evaluated the performance of DBA algorithms with QoS in the upstream channel management of a ring-shaped Super-EPON. We conclude that the use of shorter distances between the OLT and the ONUs provides the improvement of the maximum bit rate allowed per ONU with the EDBA scheduling algorithm. We also confirmed that both the priority queuing (PQ) and the weighted queuing (DRR) tasks can accomplish QoS requisites.

REFERENCES


